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Long-term energy transition assessments for islands

The case of Mayotte

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Long-term energy transition assessments for islands

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DEM	Websites, patents filing, press & media actions, videos, etc.	
O	Software, technical diagram, etc.	

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

LIST OF ABBREVIATIONS

Abbreviation	Definition
ADEME	Agence de l'environnement et de la maîtrise de l'énergie
aFRR	automatic Frequency Restoration Reserve
BEV	Battery Electric Vehicle
boe	barrel of oil equivalent
BRGM	Bureau de Recherches Géologiques et Minières
CCS	Carbon Capture and Storage
CGE	Computable General Equilibrium
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRE	Commission de régulation de l'énergie
CSPE	Contribution to the public electricity service
EC	European Commission
EDM	Electricité de Mayotte
EEA	European Economic Area
EED	Energy Efficiency Directive
EU ETS	European Union Emission Trading Scheme
EV	Electric Vehicle
FCR	Frequency Containment Reserves
FiT	Feed in Tariff
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GECO	Global Energy and Climate Outlook
GHG	Greenhouse Gases
GVA	Gross Value Added
HH	Household
ICE	Internal Combustion Engine
IMF	International Monetary Fund
INSEE	Institut national de la statistique et des études économiques/National Institute of Statistics and Economic Studies
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Center
KPI	Key Performance Indicator
LCOE	Levelized Cost Of Electricity
LPG	Liquified Petroleum Gas
LULUCF	Land Use, Land Use Change and Forestry
MSR	Market Stability Reserve
O&M	Operation & Maintenance
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
RES	Renewable Energy Sources
RR	Replacement Reserves
R&D	Research & Development
UN	United Nations
VAT	Value Added Tax
V2G	Vehicle-to-Grid
WACC	Weighted Average Cost of Capital

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EXECUTIVE SUMMARY

Mayotte is a geographically isolated island and an integral part of the European Union (one of the EU Outermost regions[1]), as an overseas department of France. The island is densely populated, and its economy is highly service-oriented. Market and non-market services as well as agriculture and fishing account for 95% of the GDP[2]. The energy sector of the island is carbon intensive as it relies mainly on imported oil products, with diesel-fired power plants accounting for 95% of total electricity production in Mayotte. The decarbonization of the energy sector of such an emerging, isolated economy, presenting sustained activity growth rates and rising population, implies several technical, economic, and regulatory challenges.

The need for clean energy transition and energy impact assessments for Mayotte

The local population is currently heavily burdened by the energy sector as the share of income that people spend on energy is much higher compared to the mainland France driven by the high dependency on imported fossil fuels and the lack of energy interconnections[3]. Given the need to align with the EU ambition regarding climate change policy targets, the energy transition seems therefore a one-way street for Mayotte. This study discusses and assesses 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. To this end, the horizon of the study has been set to 2050, and the analysis covers all economic sectors, including the energy, transport, and residential sector, as well as the supply of electricity and, steam for industrial processes. Special attention has been also given to the horizon of 2030 as a time checkpoint of the transformation pace until reaching net zero emissions by 2050. The following scenarios have been co-designed in a participatory approach and with the contribution of MAESHA partners – especially EDM, the Distribution System Operator of Mayotte –, capturing the local specificities, circumstances, and priorities for the future development of the energy and economic sectors of Mayotte:

- A ***Baseline*** scenario (Base) that accounts for the existing energy and climate policies adopted by the end of 2020 (Business-As-Usual scenario).
- A ***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.
- A ***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.
- An ***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.
- A ***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-

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[1] https://ec.europa.eu/regional_policy/en/policy/themes/outermost-regions/

[2] https://ec.europa.eu/regional_policy/sources/policy/themes/outermost-regions/pdf/rup-2022/comm-rup-2022-glance_en.pdf

[3] https://ec.europa.eu/regional_policy/sources/policy/themes/outermost-regions/rup-2022/comm-rup-2022_en.pdf

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. A large set of indicators/metrics across the energy and economy are applied for this assessment based on the three criteria identified above. These indicators and metrics range from economy-wide to sectoral and end-use level. The Table 1 includes the categorization of the indicators based on the three criteria described above as well as the key indicators of each category used to analyze energy transition pathways for Mayotte.

Table 1: Assessment criteria and key indicators for alternative transition scenarios

Energy & Climate Transition	Economy & Society	Energy security
Energy and carbon intensity of GDP	Structure of the economy, Trade, Employment, GDP	Import dependence (Net imports/Gross Inland Consumption
Power generation and energy mix	Energy system costs by sector	Operating reserves (FCR, aFRR, RR)[4]
RES deployment rates (RES-E share, RES-T share)	Investment expenditures by sector	Diversity of primary energy supply, Diversity of electricity generation
Market uptake of clean technologies and flexibility solutions	Investment Cost to GDP ratio/System cost to GDP ratio	
Sectoral CO_2 emission reduction rates, CO_2 emission per unit electricity generated	Evolution of electricity prices by consumer type	

Scenario variants have also been developed to further analyze the dynamics of the energy system transformation regarding high reliance on clean e-fuels or biofuels for decarbonization, as well as to stress and evaluate the boundaries and the potential of the system, assuming different levels of use of domestic energy resources.

The energy-economy modelling framework designed and built within MAESHA Tasks 2.1 and 2.2 has been used to quantify the impacts of the alternative transition pathways. This framework is developed in GAMS and puts together the energy system planning model E3-ISL and the macroeconomic CGE tool GEM-E3-ISL, aiming to design and develop integrated impact assessments of different configurations of the energy system towards deep decarbonization. More specifically, the island-scale modelling framework E3-ISL/GEM-E3-ISL represents adequately the complex interlinkages of the energy system with the entire economy. On the one hand, E3-ISL is developed on optimization grounds and covers in detail specificities of the energy sector of the island-scale demonstration site, i.e. existing and candidate power plants, RES potentials, load seasonality, capital and operation costs of assets, energy efficiency potential, flexibility services (i.e. demand response, rooftop solar PV, V2G, batteries, Power-to-X), transportation, ancillary services and storage requirements as a result of the deployment of variable RES coupled with load uncertainty and seasonality. The model 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 behaviors towards cleaner and environment-friendly choices, considering the impact of energy communities. On the other hand, the GEM-E3-ISL model complements the modeling framework by providing details on the macro-economy and its interactions with the environment and the energy system and is used to quantify the socio-economic impacts of decarbonization pathways for the local economy and society.

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[4] To ensure the reliable provision of on-demand electricity, the system requires some reserve capacity to compensate for unforeseen events, imbalances as well as normal variations in supply and demand. In E3-ISL, minimum levels of reserves (primary, secondary and tertiary reserves) are secured by default in all scenarios, while increased balancing services are considered when variable RES are in operation (wind, solar). ICE and geothermal plants as well as batteries are among the plants that can provide ancillary services, reserving part of their capacity.

Key framework conditions for the analysis

The evolution of the energy sector strongly depends on the future development of population, GDP, and sectoral production of Mayotte. The economic projections and demographic dynamics are underpinned by econometric projections, official economic development plans and international prospects. 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, Mayotte's population is expected to continue growing in the next decades, reaching 495 thousand inhabitants by 2050. It is noteworthy that the economy did not contract due to the COVID crisis but had a modest growth of 1.72% in 2020 and recovered fast in 2021. This momentum 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.

Passenger transport activity is expected to grow significantly, owing primarily to the private road transport, accounting for over 60% of total passenger activity. This assumption considers the rising population and income, as well as the trend of increasing car ownership in the medium and long run, which is currently rather low in Mayotte (less than 100 cars per 1000 inhabitants). 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.

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.

The baseline scenario

The Baseline Scenario assumes the continuation (but not strengthening) of currently implemented energy and climate policies 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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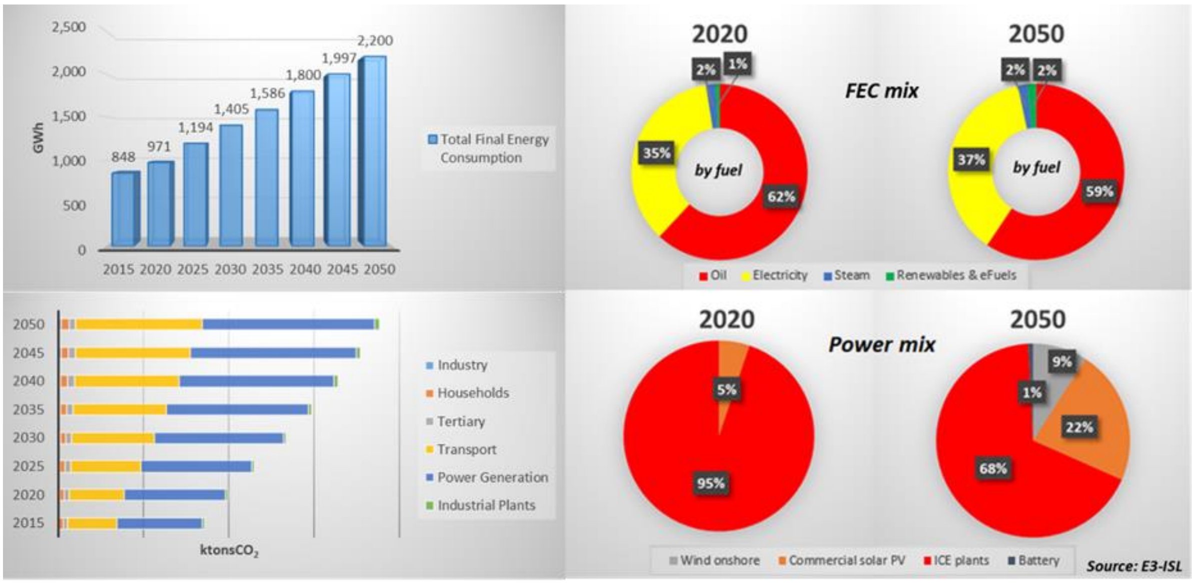
[5] https://data.europa.eu/doi/10.2833/35750

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

In the Baseline scenario, an increase of 110% in gross inland energy consumption of Mayotte is projected in the period 2020 – 2050, which is lower than the increase in economic activity illustrating a relative decoupling of energy demand growth from GDP due to the reduction in energy intensity. Oil products are envisaged to continue to dominate 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 assuming limited decoupling of activity from energy consumption and a low electrification rate. Limited energy efficiency improvements are anticipated in buildings and manufacturing following historical trends and technology advancement. The power mix is expected to differentiate from the current one, with investments in new solar PV and wind capacities driven by the decreasing costs of solar panels and wind turbines. Nevertheless, diesel oil continues to play a significant role in the power supply sector until 2050. As expected, CO_2 emissions present a constantly rising trend by 2050, when they are projected to amount to 750 ktons in total, due to the continuously wide use of fossil-based liquids in power generation and transport. 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 1: Key figures of Baseline scenario

The alternative clean energy transition pathways

The E3-ISL integrated energy-economy modelling framework is then used to develop alternative pathways towards deep decarbonization of Mayotte, building on the Baseline scenario, but assuming strong emission reduction efforts guided by the EU's flagship strategy Green Deal and the EU "Clean Planet for all" long-term mitigation strategy. Several decarbonization pathways aiming to achieve CO_2 emissions reductions larger than 95% in 2050 from 2015 levels are developed and evaluated. A range of scenario narratives and related variants, differentiated by time horizon, climate policy, and technology uptake scope, allows for a comprehensive assessment of the various impacts, challenges and opportunities that can arise from the clean energy transition in the island.

The assumptions for the development of population, economic growth, sectoral activity, and oil import prices are the same as used in the Baseline scenario, to ensure comparability among them. Energy and climate policies vary by scenario, affecting the speed of the transition, the technologies and mitigation options used, the energy import dependency and the socio-economic outcomes. All decarbonization scenarios include an economy-wide CO_2 price trajectory (similar to the one used in EC decarbonization scenarios) that drives mainly the low-carbon transition of power supply and industrial sectors, carbon standards for new vehicles, technology and efficiency standards, and blending mandates with conventional and advanced biofuels, as well as green hydrogen and clean e-fuels. The challenges and opportunities that emerge from the clean energy transition of the various sectors of the island are explored in terms of emission reduction, fuel mix, energy costs, and socio-economic implications.

Transformation of the Buildings – Agriculture – Industry sectors

Energy efficiency improvements and fuel switching in the buildings and agricultural sectors are found to be among the most cost-efficient mitigation actions. Investments on highly efficient appliances and emerging technologies and equipment drive the reduction of end-use energy consumption by 2050 in the building sector. Since this sector is already highly electrified, no significant differentiation in the fuel mix is observed across the decarbonization scenarios – oil phase-out entails a higher electrification rate and further uptake of solar thermal applications, given that space-heating use is very limited in Mayotte due to climatic conditions. In agriculture and the limited industrial processes, diesel is substituted by electricity and biofuels to a great extent.

Apart from the direct electrification, that by default leads to higher efficiency, the energy savings on the demand side helps ease pressure on the energy supply side. This means that less electricity demand infers less investments in the power production sector. This can be observed with clarity in the consumer-driven decarbonization scenario, that considers the awareness and empowerment of the consumers and the emergence of local energy communities giving them a more active role in managing their energy consumption that helps reduce the investment requirements and costs on the supply side.

Transformation of Transportation

Transport accounts for most of the energy system costs and CO2 emissions in the island. For some transport segments (i.e., private road transport), the uptake of electric vehicles is the preferred option to drive decarbonization. However, there are transport segments with hard-to-abate emissions, e.g., freight transport, aviation, and navigation, where direct electrification is very challenging and there are limited available mitigation options. The role of green hydrogen and e-fuels such as ammonia and synthetic kerosene as well as extensive use of biofuels via blending mandates and emission standards, is significant for decarbonizing such transport segments, taking advantage of the existing infrastructure to some extent. A strict regulatory framework that imposes declining emission performance standards and ambitious blending mandates would results in large-scale uptake of low-carbon fuels and reduced emissions in the road transport sector.

In all sectors, demand for electricity is projected to increase compared to 2020. The increase of the electricity share in transport is prominent – ranging from 25% to 38% in 2050 compared to 0% in 2020 or 4% in 2050 according to the Baseline scenario. The gross domestic electricity demand increases even more due to the increasing needs to produce green hydrogen in various forms, either for direct fuel consumption or for the production of synthetic e-fuels, which represents a considerable share of energy consumption in the long run, especially for navigation and aviation sectors.

Power sector decarbonization

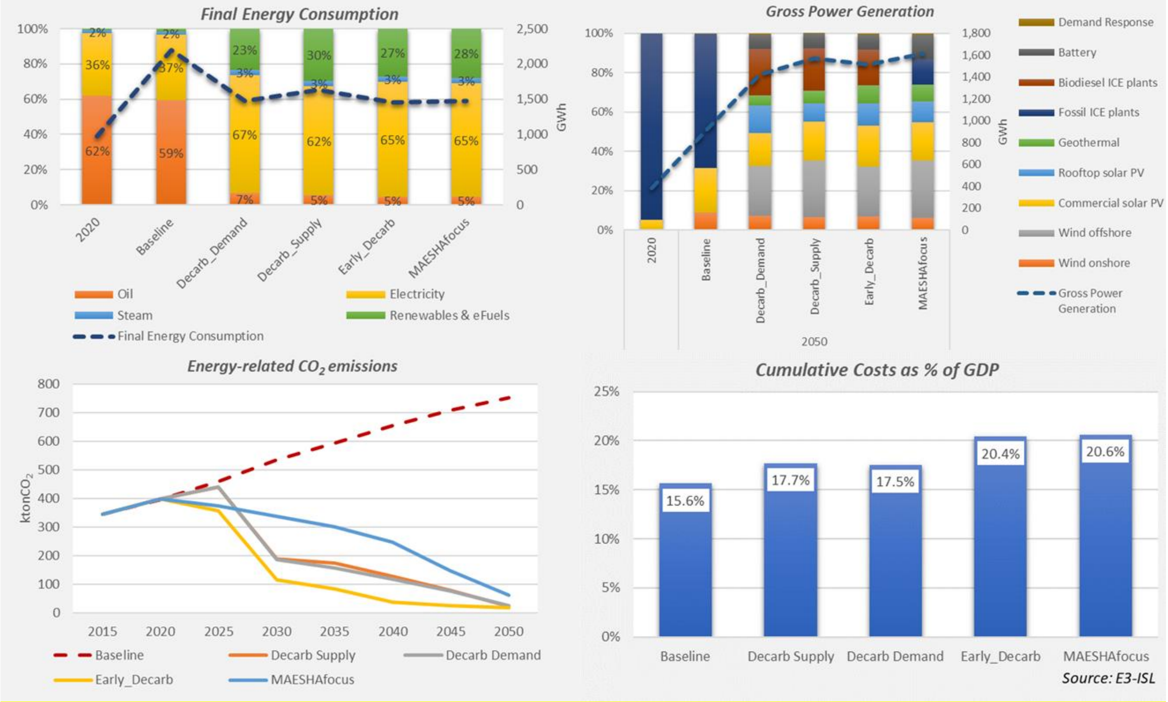
In all scenarios, apart from Baseline and MAESHAfocus, EDM plans for fuel-switching of the Longoni and Badamiers ICE plants from diesel to biodiesel by 2030, have been considered. Oil phase-out is assumed to materialize within the period 2026-2029. Existing ICE plants are envisaged to participate as firm capacity in the provision of ancillary services to support the large-scale deployment of variable renewable sources like solar PV and wind. The power supply mix that serves the rapidly increasing electricity consumption is based on variable RES, accounting for 65% of the gross power generation by 2050 coupled with storage (mostly with batteries), ICE plants (using biodiesel) and geothermal plants; therefore, in all decarbonization scenarios the share of renewable energy in power generation increases to 100% after 2030. This means that emissions from electricity production decline rapidly to zero, allowing the carbon-free electricity to be used for the decarbonization of energy demand sectors, which commonly face higher transformational challenges and have limited emission reduction options. In this context, green electricity is increasingly used to electrify energy demand across sectors, both directly and indirectly through the production of green hydrogen and e-fuels. Indicatively, the gross power generation almost triples compared to 2020 levels in all decarbonization scenarios. The necessary flexibility services are secured with battery storage and demand response. From the demand-side, higher contribution in balancing is assumed in the Decarb_Demand scenario with wide demand-response by consumers and V2G practices.

Early decarbonization

The Early Decarbonization scenario considers that the transition to a net zero economy for Mayotte starts early in 2025 so carbon taxation and other relevant climate policies intensify gradually after 2025. This scenario entails certain trade-offs: energy transition accelerates as all mitigation options are deployed more rapidly, and cumulative emissions in the projection period decline more than other decarbonization scenarios, albeit with higher energy system costs.

Full implementation of MAESHA solutions

The MAESHA project aims to achieve concrete milestones and KPIs related to the island decarbonization in the short-, medium and longer term. In this respect, the MAESHAfocus scenario incorporates these project KPIs and MAESHA solutions but does not consider the fuel switching of Longoni and Badamiers in 2030, since the MAESHA KPIs did not account for this possible development. A variant of MAESHAfocus scenario (MAESHAfocus+) is also developed assuming the fuel switching of the existing oil-fired plants by 2030. Scrutinizing the results of the scenarios, it is evident that the ambition (in terms of projected emission reductions) of MAESHAfocus+ is similar to the Early_Decarb scenario, but the former entails higher energy system costs for Mayotte. This is stipulated by the fact that MAESHAfocus+ sets the clean transition of the transport sector very early in the decarbonization agenda, around 2040. The decarbonization of transport entails high costs to purchase low- and zero-emission vehicles for road, water, and air transport, as well as to build the required infrastructure (recharging stations, clean fuel production, etc.). The technology learning incorporated in the modelling implies that if these clean transport solutions are implemented early in the transition process (as in MAESHAfocus), they will lead to higher costs as their learning potential will not have been fully materialized by then.



Source: E3-ISL

Figure 2: Key figures of the Decarbonization scenarios

The decarbonization effort requires a complete restructuring of the energy sector, rapid commercialization and cost improvement of clean energy technologies and ambitious investments plans for all the sectors of the economy. This should be also coupled with targeted and ambitious energy and climate policies and regulatory frameworks that encourage investments in energy efficiency, renewable power generation, green hydrogen, advanced biofuels, clean e-fuels, and disruptive technologies in all sectors.

Socio-economic impacts of Mayotte's transition to carbon neutrality

Through a detailed soft link between the E3-ISL energy system model and the macro-economic model GEM-E3-ISL, the socio-economic impacts of deep decarbonization pathways for Mayotte are assessed. The transition to carbon neutrality is a complex and lengthy process that requires high uptake of low- and zero-emission energy technologies, low-carbon innovation, sufficient financial resources, and coordination of market players, including consumers, policy makers, technology developers, R&D providers, and industries. In Mayotte, energy system decarbonization involves the substitution of imported fossil fuels (mostly oil products) by services and products related to low and zero-carbon technologies and energy-efficient equipment, vehicles, 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 is an investment-intensive and technology-intensive process that requires economic restructuring away from fossil fuels and towards a more capital-intensive structure. The large-scale deployment of renewables in the power supply sector will reduce the average cost of electricity production, 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 (as businesses would incur reduced production costs), and the transition to carbon neutrality would provide clear socio-economic benefits in the form of increased GDP, 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 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 decarbonisation, as the rapid energy transformation poses stresses in capital markets influencing the 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 sector), 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 decarbonisation related to avoided climate impacts and improved air quality.

1. INTRODUCTION

1.1. PURPOSE OF THE ANALYSIS

The scenario analysis is 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. The projection horizon of this analysis is 2015 up to 2050. As part of the deliverable D2.3, several scenarios have been co-designed in a participatory approach and with the contribution of MAESHA partners, especially EDM located in Mayotte. In this way, the scenarios capture the local specificities, circumstances, and priorities for the future development of Mayotte and incorporate realistic assumptions about how the economic and energy system of the island will develop in the future. 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 alternative policy scenarios are introduced in section 6.3, while the modelling tools are described in section 7. Section 8 describes the general framework conditions, while model-based projections for alternative scenarios are included in Sections 9 and 10.

The island-scale modelling framework E3-ISL/GEM-E3-ISL represents adequately the complex interlinkages of the energy system with the economy. It covers in detail specific issues for the demonstration site, i.e. the 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), transportation, ancillary services and storage requirements as a result of the deployment of variable RES coupled with load uncertainty and seasonality. The model 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 behaviors, habits and practices towards cleaner and environment-friendly choices paving the way for a clean energy transition, considering the impact of energy communities.

The modelling suite quantified the impacts of clean energy transition plans on RES investments, power generation mix, energy security, electricity prices, energy demand by fuel and sectors, interlinkages between electricity, transport and industrial systems, investment requirements and energy system planning. The model-based quantitative results were synthetized in the medium and long-term energy and economic assessment of the island considering in detail the impacts of alternative energy system configurations and exploring the challenges, barriers and opportunities arising from the development of RES and other clean energy solutions.

These scenarios account for a series of assumptions for the future development of the energy-economic system of the island up to 2050, including:

- socio-economic baseline evolution (in terms of population, GDP, employment, international fuel prices, etc.),
- energy, economic and climate policies,
- Renewable Energy Sources (RES) potential and local resources,
- technology costs for energy equipment and power generation technologies.

The scenarios explore both energy demand and supply trends and the potential for sectoral integration (i.e., facilitated by power storage, demand response and power-to-X technologies) and demonstrate the positive impacts and economic, environmental, and societal benefits of the MAESHA's solutions, providing a deep understanding into the transformation barriers, challenges and opportunities in all energy demand and supply sectors on islands.

1.2. CURRENT STATUS OF ENERGY SECTOR IN MAYOTTE

Mayotte is one of the overseas departments of France, a geographically isolated island, approximately about 8000 km away from France. Mayotte is also part of the Eurozone as a department of France. The population of Mayotte in 2020 reached about 279 thousand, having an increase of about 24% from 2014 where its population stood at 224 thousand. The department of Mayotte has very high population density and it is the most densely populated department outside metropolitan France.

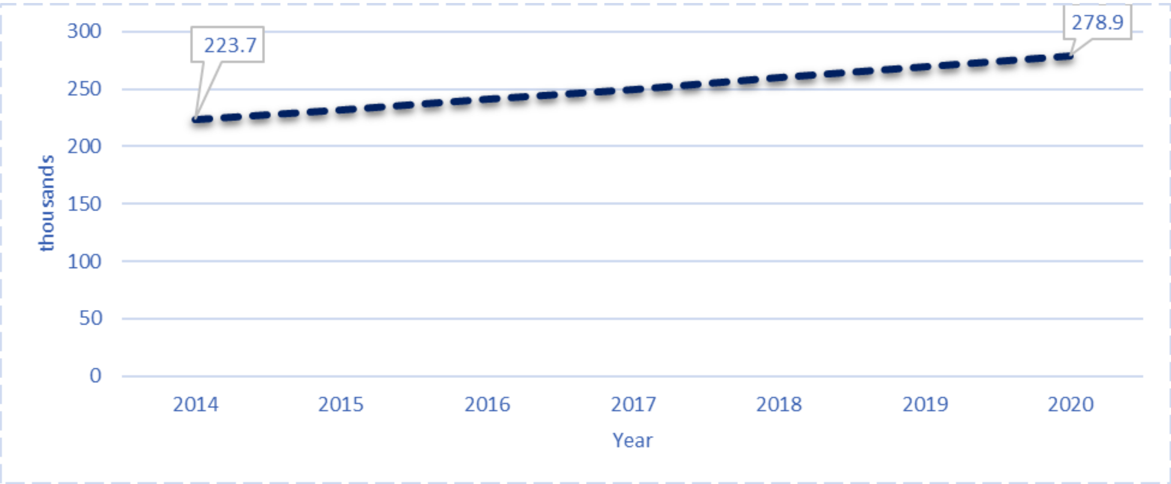


Figure 3: Population of Mayotte from 2014-2020, Edited by E3M

Mayotte is the least economically prosperous French department. Its economy is based primarily on the tertiary services sector, including non-market services, trade, retail, and basic services, accounting for about 85% of Mayotte's GDP. The agriculture sector including fishing and livestock has a smaller economic contribution. Mayotte's economy is heavily depending on French financial assistance.

The economy of Mayotte grew on average by 6.9% per year during the years 2010-2017. Its economic growth slowed down in 2018, as its GDP growth rate was 8% in 2017 and fell to only 3% in 2018. This deceleration of GDP growth is due to the massive civil unrest experienced by the territory in 2018 followed by weeks of demonstrations, roadblocks and work stoppages negatively influencing Mayotte's economy. Mayotte's GDP growth rate increased by 8% in 2019, but its growth slowed down in 2020 due to COVID-19 and general lockdowns before rebounding again to a 6.3% growth in 2021.

Mayotte's economic activity is largely based on the services sector, which accounts for about 85% of its GDP over 2015-2020 (Figure 4). The energy and industry sectors jointly account for 6% of Mayotte's GDP, having a relatively small contribution to overall economic activity in the island. The construction sector accounts for about 5% of the GDP of Mayotte, while the share of agriculture stands at 3% in 2015. The island's remote location remains an obstacle in expanding the development of tourism. The development of Mayotte's economy largely depends on French financial assistance, which is an important supplement to the island's GDP. Like other small island economies, Mayotte is highly dependent on imported goods and raw materials, and its trade balance is structurally in deficit.

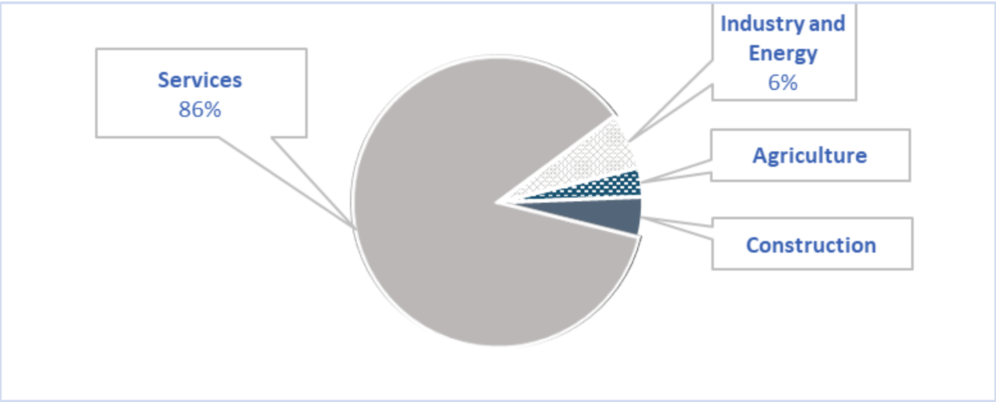


Figure 4: GDP by sector composition in percentage for 2015

The energy sector of Mayotte is mainly oriented towards the consumption of oil products and electricity to meet the growing energy requirements in the transport, industry, and residential sectors. About 95% of the electricity is produced using oil products, while renewable energies are currently under-developed in Mayotte. Mayotte does not produce fossil fuels, so it must import all oil products it needs. The island's oil imports are used to meet its growing energy requirements, mostly for the consumption of vehicles (for passenger and freight transport) and thermal power stations.

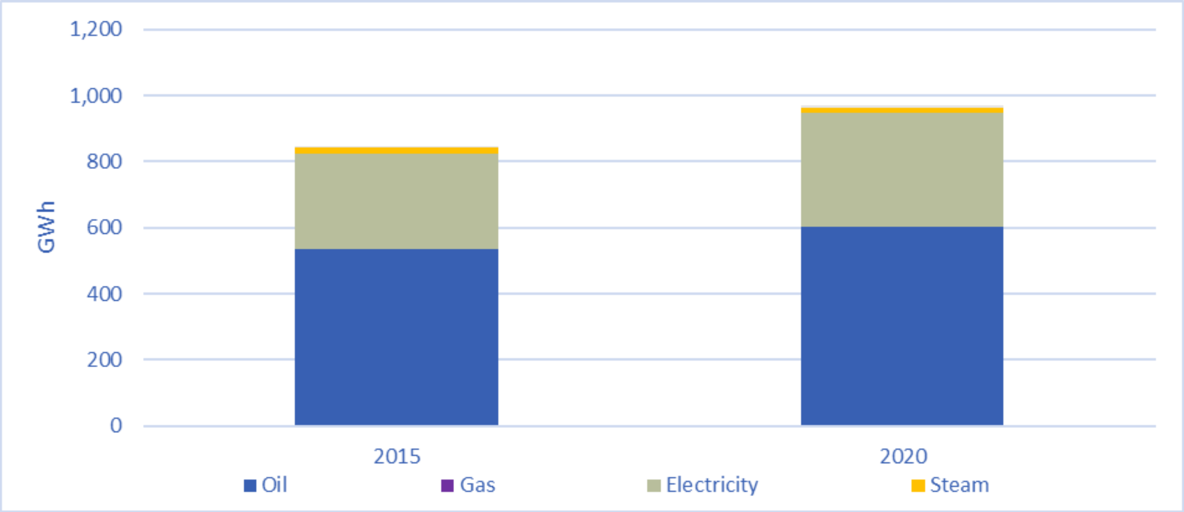


Figure 5: Total final energy consumption in Mayotte by fuel in 2015 and 2020, Edited by E3M

Electricity needs are growing strongly due to the growth of Mayotte and its population, driven by both the residential/commercial and the industrial sectors. Air conditioners have been installed on a wide scale, which leads to peaks in consumption in summer. The electricity consumption increased by 14.5% per year during the years 1995 and 2010. In 2015, electricity production reached 315.9GWh and it then increased to about 381GWh in 2020, with an increase of 20.5% in the 2015-2020 period, as a result of continued economic development and rapid demographic expansion. Electricity production using fossil fuel resources (diesel) increased rapidly in recent years, reinforcing the island’s dependence on imported hydrocarbons, despite the growth in solar PV installations in the last decade.

In the industrial sector, electricity is by far the most used fuel, as it accounted for 72% of the final energy consumption in 2020. The rest was covered mostly by steam (20%) and fossil-based liquid fuels (8%). In the residential sector, there was an increase of about 24% in final energy consumption between 2015 and 2020 due to increased population, GDP, and higher standards of living for the local population. Electricity accounts for about 75% of the final energy consumption in the residential sector, followed by liquids (oil products/LPG) with a share of 17% and solar accounting for 8% of energy consumption.

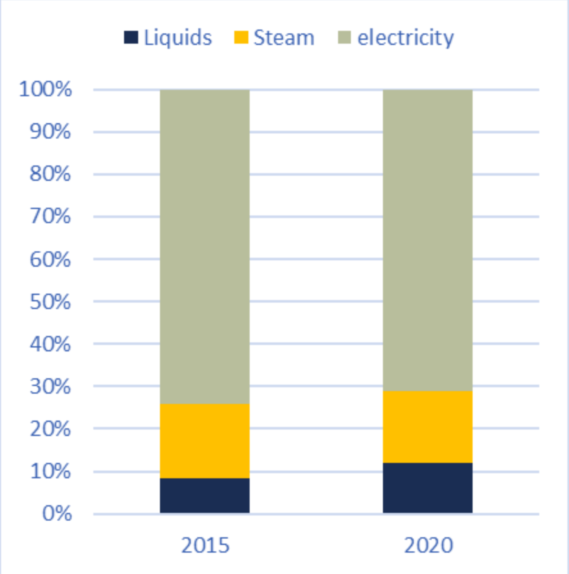


Figure 6: Final energy consumption of industrial sector by fuel type for 2015 and 2020, Edited by E3M

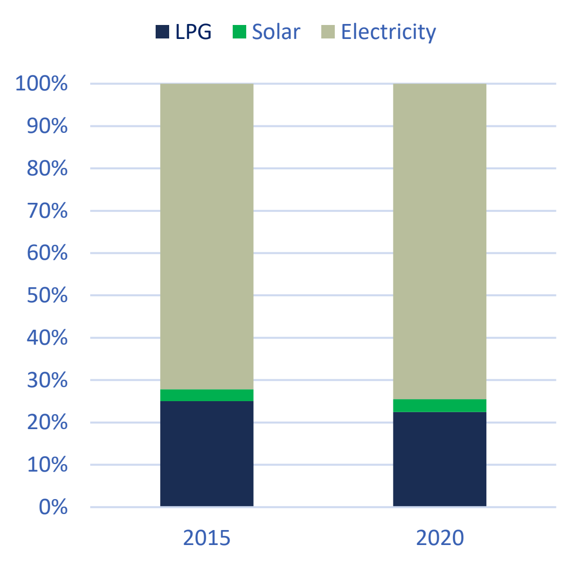


Figure 8: Final Energy Consumption of residential sector by fuel type for 2015 and 2020, Edited by E3M

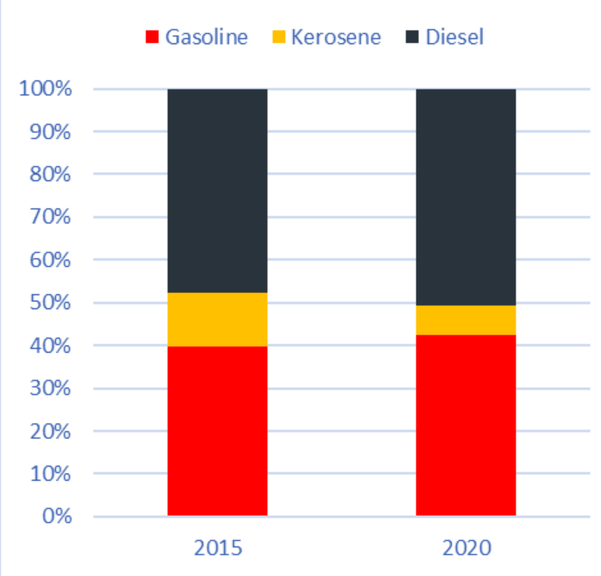


Figure 7: Final Energy Consumption of transport sector by fuel type for 2015 and 2020, Edit by E3M

The energy consumption in the transport sector in Mayotte is dominated by the use of oil products (e.g., diesel, gasoline, kerosene), as low-emission fuels, such as biofuels and electricity, have so far failed to spread in the island. In 2015, the most consumed fuel type was diesel with a share of about 48%, followed by gasoline (39%) with kerosene (used for aviation) accounting for 13%. During the 2015-2020 period, there was an increase in total transport consumption due to rising passenger and freight transport activity. Both gasoline and diesel consumption have increased by 19% over 2015-2020, but kerosene use dropped substantially, negatively impacted by the COVID-19 pandemic and the lockdowns.

In Mayotte the electricity production is dominated by fossil-fired combustion plants, which account for 95% of the total power generation. The remaining 5% comes from renewables, primarily solar plants. Solar energy is the only renewable energy with significant development on the island so far. Although the production of solar energy has gradually increased, its contribution to the energy mix of

Mayotte remains very low. The first solar panels were installed in 2009 and are not associated with storage. The capacity of solar PV plants stood at 13 MW in 2015 and increased to 17MW in 2020.

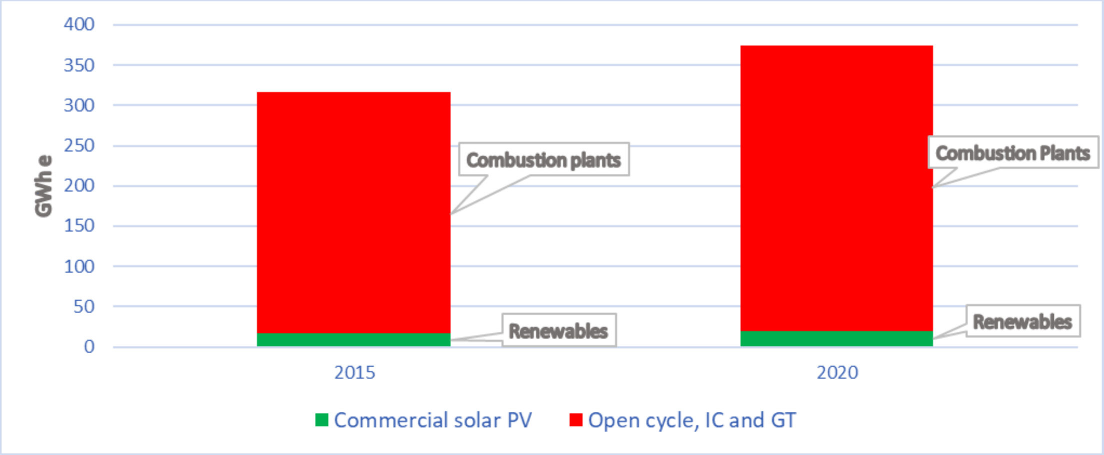


Figure 9: Electricity production in Mayotte for 2015 and 2020, Edited by E3M

In Mayotte there are two thermal power stations, consisting of 17 diesel engines in all. The capacity of their units ranges between 750kW and 8MW. This makes it possible to adjust as needed. In 1987 on Petite-Terre Island, the Badamiers power station was commissioned having a capacity of 38,1MW. In 2015 this plant provided 38% of total electricity production of Mayotte. However, this plant does not comply with the industrial standards for air pollution and noise but operates with a temporary exemption from the DEAL. EDM plans to operate the plant until 2023, when it would be at the end of its life, as the potential plant upgrading would be very costly.

The Longoni power station, on the island of Grande-Terre, was commissioned in 2009, with a capacity of 40 MW, and provided 57% of total Mayotte's electricity production in 2015. This plant has been extended to add 3 new Wartsila 12V46 engines of 12 MW capacity each, adding 36 MW of capacity. The Kawéni power station, with a capacity of 11 MW, was opened in 1978, but it has been dismantled since. Several solar PV power plants have already been commissioned, with a total capacity of 17.7 MW. These PV plants generate about 20 GWh annually, covering more than 5% of domestic electricity requirements.

The only electricity supplier on the island is Électricité de Mayotte, a société anonyme d'économie mixte owned by the General Council of Mayotte (50.01%), Électricité de France (24,99%), SAUR International (24,99%), and the State (0,01%). The inhabitants of Mayotte benefit from regulated tariffs in the same way as the metropolis, even if the electricity production costs are five times higher than the energy share of these tariffs. The additional costs are covered by the contribution to the public electricity service (CSPE), paid by all French consumers.

1.3. SCENARIO DESCRIPTION

Long-term energy scenarios can serve to guide the transition to a clean, sustainable, low-emissions and increasingly renewable-based energy system. Based on a participatory co-design approach, the MAESHA partners involved in Work Package 2 and other Work Packages such as WP9, whose work is based on scenarios underpinning different future configurations of the energy system of Mayotte, co-designed five (5) scenarios. In particular, the local partner EDM played an important role in the design of these scenarios aiming to capture local context, specificities and priorities and providing a reality-check for key scenario assumptions and model-based results. In this respect, dedicated workshops as well as special sessions in already established meetings (consortium meetings, etc.) have been organized with the participation of local stakeholders and EDM with the following objectives:

- to present the framework conditions, the policies, and the input assumptions regarding investments already in the pipeline, as those were to be included in the scenario analysis,

- to discuss on the scenario design to increase the relevance of our research for local decision makers and stakeholders in Mayotte,
- to present and receive feedback on the initial/draft baseline results and discuss their plausibility (and make any changes required) with MAESHA partners and EDM.

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. The scenario assumptions are integrated in the E3-ISL modelling framework, which was then used to estimate their impacts on energy consumption, fuel mix, technology uptake, CO_2 energy-related emissions, required investment, energy system costs and prices. The impacts of alternative scenarios are compared with a scenario simulating Business-As-Usual developments (the Baseline scenario) and are 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 island transition pathways start from a vision and spell out options that exist for the island's clean energy future, with the aim of considering holistic energy scenarios. (…) The transition pathways describe possible storylines, including goals and interventions, in the short-, mid- and long-term to make the bridge between the island's envisioned clean energy future and the present."*
>
> Source: **Islands Transition Handbook (available at: https://clean-energy-islands.ec.europa.eu/insights/publications/islands-transition-handbook**

There are multiple perspectives to define energy transition scenarios/pathways depending on the technology and policy focus, the horizon of policy action (early vs late), the climate ambition towards emissions reduction, the boundaries of the analysis, etc.

In the current study, the scenarios were co-designed based on the following objectives:

1. Explore ambitious energy transition pathways for the island of Mayotte towards carbon neutrality by 2050 or sooner
2. Explore island dynamics regarding different mitigation options, energy consumption trends, level of activation of local communities, policy focus and technologies to reach carbon neutrality
3. Cover medium- and long-term vision of the energy system and the following sectors: Electricity, Heating & Cooling, Transport on, to and from the island
4. Assess the energy and electricity costs and socio-economic impacts of the different pathways
5. Assess the impacts of higher RES deployment and proposed flexibility solutions on the island energy system if MAESHA solutions are implemented
6. Quantify the MAESHA KPIs that go beyond the duration of the project

The Table 2 contains an overview of the co-developed scenarios and summarizes their key characteristics. Further information on the narrative and assumptions of each scenario is provided in section 5.1 of this report.

Table 2: Scenario overview

Identifier	Name	Policy focus	Decarbonization horizon
Base	Baseline	No significant change in attitudes, activities and policies with regard to the energy system. Currently implemented energy and climate policies continue by	No long-term target Used as benchmark/business-as-usual case

		2050 but do not intensify, including reduction in low-carbon technology costs	
Decarb_Demand	Consumer-driven Decarbonization	Active involvement of communities in the transition (energy savings, demand response, V2G, car sharing, high rooftop PVs, etc.), high electrification in demand side. Policies: economy-wide carbon pricing, enabling conditions[7], emission and technology standards	Decarbonization of Mayotte's energy system by 2050
Decarb_Supply	Supply-side Decarbonization	Moderate communities' response, moderate electrification, extensive utilization of hydrogen, e-fuels and biofuels to decarbonise the Mayotte's energy system 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 Decarbonization	Early policy action and high ambition both in demand and supply side	Decarbonization of Mayotte's energy system by 2040-45
MAESHAfocus	MAESHA-focused	Full implementation of MAESHA proposed solutions by 2030 Achievement of MAESHA's relevant KPIs	Intermediate targets by 2030-2040 as set out in MAESHA Decarbonization of Mayotte's energy system by 2050

Assumptions about policies and measures are critical and stipulate the differences in outcomes across the scenarios. The implementation of ambitious climate policies steers the energy system to carbon neutrality. 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 both price-related (or market-driven) and non-price related policy instruments as well as regulatory standards. The policy drivers are presented in the next Table.

The most significant policy instrument is the carbon price. The carbon price represents either a carbon tax or the price of the EU emission allowance in EU-ETS. This is an important driver for the reduction of fossil fuels' consumption and RES deployment both on the demand and supply side. Also, policies related to fuel blending mandates play a key role for the decarbonization of the "hard-to-abate" sectors such as manufacturing and transport. More specifically, technologies that operate directly fueled with green hydrogen such as fuel cell vehicles in transport or with biofuel and/or e-fuel blends are accounted for in the modelling.

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[7] 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.

Table 3: Key policy drivers by sector as included in E3-ISL

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

The scenario narratives were simulated and quantified with the use of the energy model E3-ISL, while the implications on the island economy were evaluated by the macroeconomic tool GEM-E3-ISL.

Those scenarios were assessed against a series of criteria, including: 1) mid- and long-term energy transition and climate targets, 2) energy security, 3) energy system costs and socio-economic implications. A large set of indicators/metrics across energy and economy, computed by the models E3-ISL and GEM-E3-ISL, were applied for this assessment based on the three criteria identified above. These indicators and metrics range from economy-wide to sectoral and end-use level and, for instance, they include energy and carbon intensity of GDP, carbon intensity per unit of fuel consumed, residential energy consumption, CO_2 emission per unit electricity generated, CO_2 emissions per tonne-kilometer in freight transport etc.

The Table below includes the categorization of the indicators based on the three criteria described above as well as the key indicators of each category.

Table 4: Assessment criteria and key indicators for alternative transition scenarios

Energy & Climate Transition	Economy & Society	Energy security
Energy and carbon intensity of GDP	Structure of the economy, Trade, Employment, GDP	Import dependence (Net imports/Gross Inland Consumption

Power generation and energy mix	Energy system costs by sector	Operating reserves (FCR, aFRR, RR)[8]
RES deployment rates (RES-E share, RES-T share)	Investment expenditures by sector	Diversity of primary energy supply, Diversity of electricity generation
Market uptake of clean technologies and flexibility solutions	Investment Cost to GDP ratio/System cost to GDP ratio	
Sectoral CO_2 emission reduction rates, CO_2 emission per unit electricity generated	Evolution of electricity prices by consumer type	

Several variants of the decarbonization scenarios have also been developed with the E3-ISL model in order to analyze the dynamics of the energy system transformation regarding high reliance on clean e-fuels or biofuels for decarbonization, as well as to stress and evaluate the boundaries and the potential of the system, assuming different levels of use of domestic energy resources.

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[8] To ensure the reliable provision of on-demand electricity, the system requires some reserve capacity to compensate for unforeseen events, imbalances as well as normal variations in supply and demand. In E3-ISL, minimum levels of reserves (primary, secondary and tertiary reserves) are secured by default in all scenarios, while increased balancing services are considered when variable RES are in operation (wind, solar). ICE and geothermal plants as well as batteries are among the plants that can provide ancillary services, reserving part of their capacity.

2. MODELLING APPROACH

The energy-economy modelling framework designed and built within Tasks 2.1 and 2.2 of the MAESHA project has been used for the development of the present analysis. An energy system planning model (E3-ISL) and a macroeconomic CGE tool (GEM-E3-ISL) have been soft-linked into a unified modelling suite. This suite is purposed for:

- Designing and assessing sectoral pathways for decarbonization with optimal utilization of the available resources.
- Ensuring integration of sectoral decarbonization trajectories into an economy wide model.
- Formulating a set of quantified policy scenario alternatives considering stakeholder feedback achieving concrete targets in terms of emission reductions.
- Impact assessment of alternative policies and objectives.

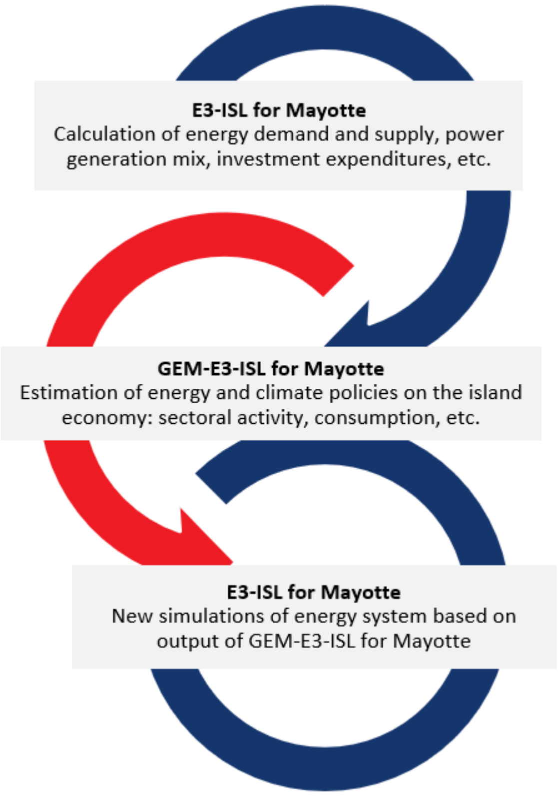

Figure 10: Energy-economy modelling framework for island systems

2.1. THE ENERGY SYSTEM MODEL E3-ISL

The E3-ISL energy system planning model was developed using the General Algebraic Modelling System (GAMS)[9]. It is as a fully-fledged energy demand and supply model for detailed energy system projections[10], energy demand forecasting, power sector planning, as well as for impact assessment of national and local climate and energy policies with a horizon up to 2050.

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[9] https://www.gams.com/

[10] 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.

Methodologically, 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. The model is executed in 5-year time steps from the base year (2015) up to 2050 and comprises two main components: **i)** the Demand module, **ii)** the Supply module. The Modules run sequentially, performing user-induced iterations. The Balancing and Reporting Modules produce the results of the E3-ISL tool and report them in user-friendly Excel-based files, which can be customized to include additional energy indicators relevant for Mayotte.

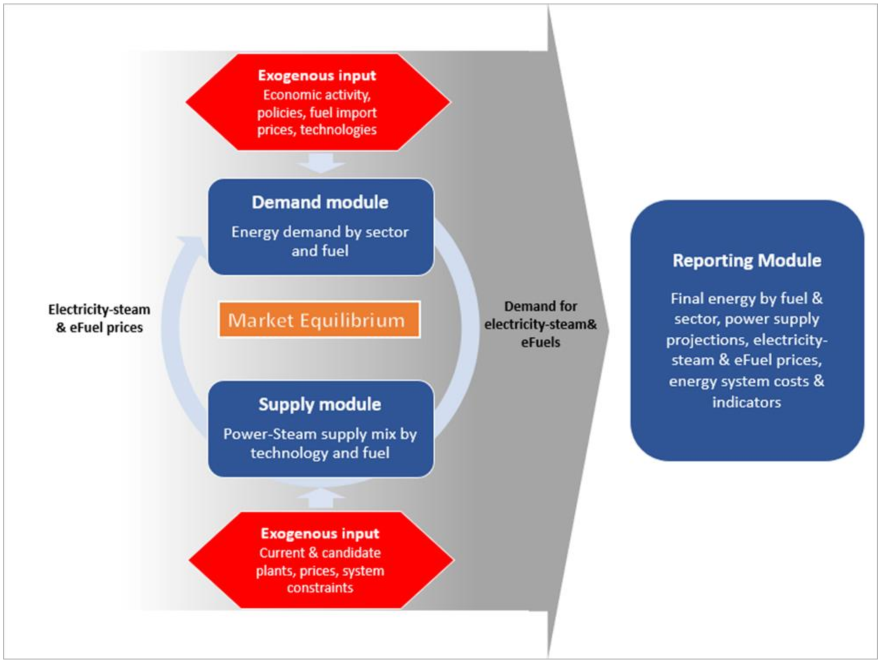


Figure 11: E3-ISL structure

2.1.1. The Demand Module

The **Demand** Module projects the demand for energy commodities and investments in the end-use sectors to satisfy the sectors' activity. The unit of measurement of activity differs from one sector to another (e.g., passenger-km, tonne-km, industrial activity), or between the uses of a sector.

The Demand Module depicts all energy demand sectors and processes in a high level of detail.

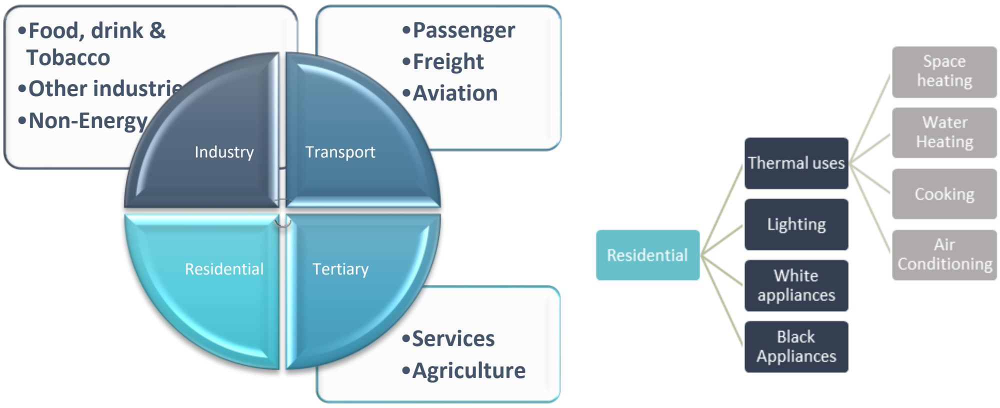


Figure 12: Sectoral coverage of E3-ISL energy system model & disaggregation of the residential sector in uses

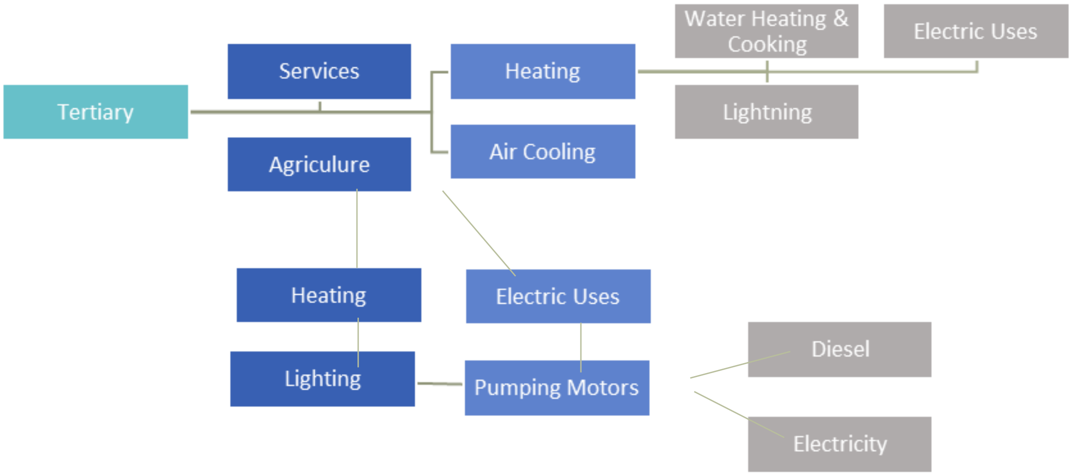


Figure 13: Disaggregation of the tertiary sector

A representative decision-making agent is considered to operate in each energy demand sector implying that different decision makers within a sector act in a way that the sum of their choices is mathematically equivalent to the decision of one individual. The **Demand** Module considers a representative agent (who represents the entire population), except for the choice on private cars, cooking and water heaters where 3 different consumer types are represented. In **E3-ISL**, the choice of consumers among different technologies and energy forms is modeled through a logit function, where the decisive variable is the ***cost*** of competing technologies. These costs include capital expenditures, Operation and Maintenance costs, and fuel costs and incorporate both price-related (actual costs) and non-price related elements (perceived costs). The problem that the Demand Module ought to solve can be summarized in Table 2.

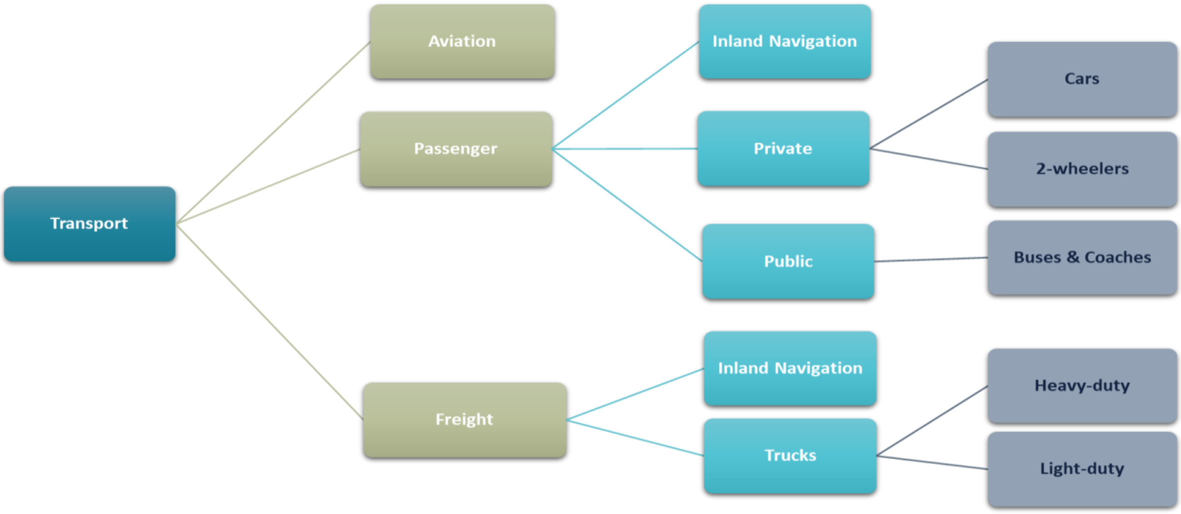


Figure 14: Disaggregation of the transport sector

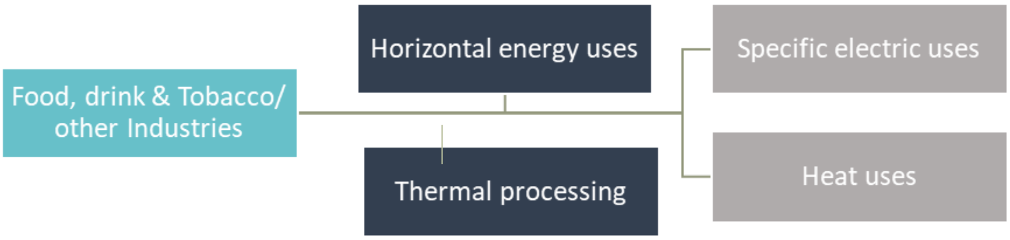
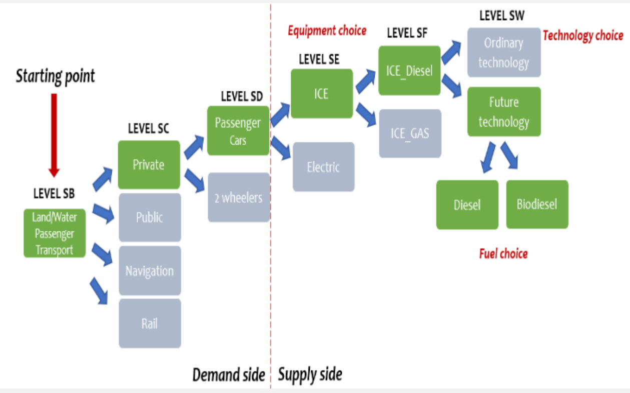


Figure 15: Disaggregation of the Industrial sectors

Table 5: Summarization of the problem that the Demand model ought to solve

1st step: Nesting Decision Tree by sector Each sector is decomposed in subsectors and processes following the structure of a nesting tree.  	**2nd step: Exogenous introduction of sectoral activity in the first level sectors** The first-level branches of the tree accommodate the projections for the sectoral activities, defined exogenously by the user. This level includes non-substitutable activities with each other sectors of the economy.
3rd step: Allocation of activity across the nesting levels, equipment investment and operation Having defined the decomposition of demand sectors in subsectors, the model calculates the percentages of each process/equipment or subsector to meet the demand for activity of the corresponding upper-level process/equipment or subsector. The model solves the short-term and long-term problems simultaneously by 2050**.**	**4th step: Calculation of final energy consumption** The final level of the nesting tree accounts for the most detailed equipment and fuel categorization. All technical characteristics of equipment, including specific energy consumption, utilization rates, investment, and fixed costs, etc. are defined for each equipment type, while fuel switching is also calculated.

The Demand Module includes a variety of policy instruments and measures that can be modified by the user: i) Emission trading – emission taxation, ii) Fuel taxation, iii) Implicit RES and energy efficiency targets, iv) Subsidies for new efficient technologies, v) Regulatory instruments – Fuel or equipment restrictions, vi) Biofuel mandates and carbon/efficiency standards, vii) Enabling conditions – removal of behavioral barriers in the residential and transport sector.

2.1.2. The Supply Module

The **Supply** Module runs right after the Demand Module and projects energy supply, including power, steam, hydrogen, and clean fuel production. For the sake of speedy execution of E3-ISL, small existing plants like solar PVs have been grouped according to their characteristics (hereinafter Plant Groupings). Plant Groupings have been developed for small plants by fuel type, technology and use (utility or industrial). The E3-ISL model considers a wide range of power generating technologies that may be installed in Mayotte to cover increasing electricity requirements in the future.

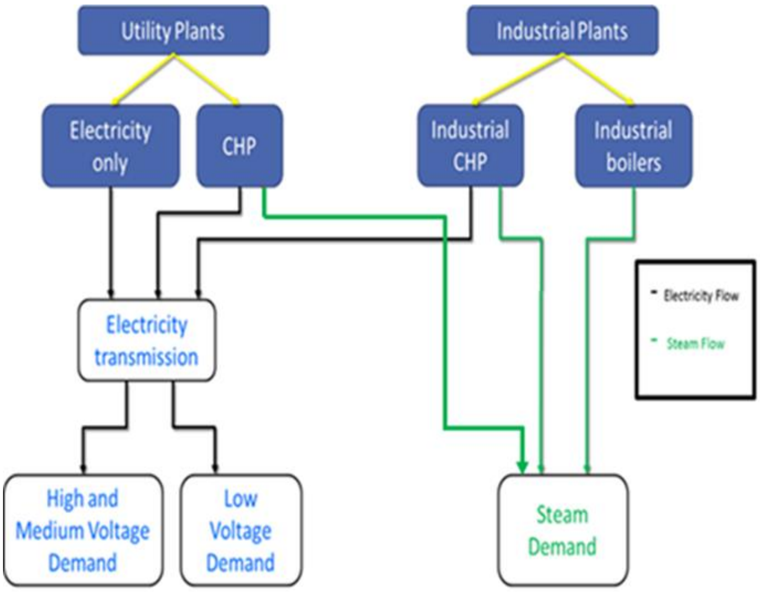


Figure 16: Representation of Power and Steam Supply system

The E3-ISL model simulates the annual hourly load curve by using representative daily and hourly load curves with a specific frequency/occurrence which varies according to season (winter, summer) and/or type of day (working day, holiday, peak, off-peak). The operation of power plants is calculated on an hourly basis for each typical day to meet demand in each time segment.

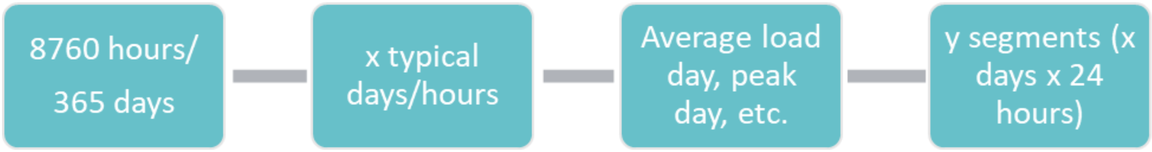


Figure 17: Time resolution of the Supply Module

The production pattern of variable renewable energy and the consumption patern of each sector can be adjusted according to the chosen time resolution. Although there are multiple load curve versions and possibilities for different time resolutions, the chosen ones to be integrated in E3-ISL should serve three purposes: i) adequately capture the load variability in Mayotte, ii) simulate the peak load demand, iii) achieve short running time of the E3-ISL model. The user of the tool may choose to simulate extreme days in terms of demand load (peak) and low renewables generation to test the robustness of the electricity system and calculate the reserve requirements in extreme cases. The E3-ISL model currently includes two different versions of time resolution. The first includes one typical 24-hour day with average load and frequency of 365 days for the facilitation of the user. The second version includes 8 typical days and differentiates between the months of the year to capture the high load variability between the seasons.

The E3-ISL model currently includes three (3) different versions of time resolution. A relevant switch is included in the source code of E3-ISL to enable the user of the tool to easily switch to the different versions.

- ✓ The first version of time resolution includes one typical 24-hour day with average load and frequency of 365 days for the facilitation of the user.
- ✓ The second version includes 8 typical days and differentiates between the months of the year to capture the high load variability between the seasons, based on the findings of the MAESHA Deliverable 2.4, including two “extreme” typical days representing the days of the year with peak load and those with low solar irradiance (low solar PV generation).

- ✓ The third version includes 9 typical days with the same differentiation as the previous 8-day version plus an additional typical day corresponding to the days with high solar PV generation, that require increased flexibility services by the system.

The power plants incorporated in the Supply Module are classified into: utility plants, industrial plants, storage facilities, and power-to-X plants (including hydrogen production facilities). The utility plants are divided into power only plants (generating only electricity) and cogeneration utility plants, i.e., CHP plants producing both electricity and steam. The model includes several power generating technologies for Mayotte, including ICE diesel or gas, gas turbines, gas open cycle, biogas, biomass/waste, combined cycle gas turbines, solar PV, solar thermal, wind onshore and offshore and geothermal power. However other power technologies like coal-based, hydro-electric, or nuclear power plants are also included in E3-ISL with the possibility to be activated for follower islands. The industrial plants are located in industrial sites and are divided into steam only plants (boilers producing only steam) and cogeneration plants with the main purpose to generate steam to serve the industry. No industrial CHP units (auto-producers) are currently reported in Mayotte, but CHP can be a candidate technology for the industrial sectors

The types of storage plants included in E3-ISL are: i) Pure pumped storage plants, ii) Batteries, iii) Power-to-X plants, including the production of hydrogen. E3-ISL determines the investment and operation of the various power storage options simultaneously with the capacity expansion and operation of power plants. The operation of storage plants is determined by the charging times, when the storage unit consumes electricity (usually in times of high production from variable RES) and discharging times when the storage unit provides electricity to the grid, usually in times of low power production from solar and wind.

In the Supply module the types of Power-to-X plants are: i) Power-to-Hydrogen, ii) Power-to-Clean Gas, iii) Power-to-Liquids. Demand Response[11] acts as demand shifting and not as demand shedding. It is treated as a daily balancing storage and is included in a simplified manner in E3-ISL model. One of the modelling enhancements specifically realized for the MAESHA project is the bi-directional EV charging – where 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.

The Power **Supply** Module assumes that each utility power plant may use as input one or more fuels. For the existing plants, the possibility of fuel switch or fuel blend exists (e.g., blending of diesel with biofuels). The user may choose whether an existing plant will switch its fuel or whether this plant blends more than one fuels and to what extent (co-blending rates). These two mechanisms have been designed so that users can assess the economics of potential fuel switching policies.

The model can account for policies allowing for the lifetime extension of power plants and retrofitting. Individual parameters allow the users to exogenously define the final decommissioning date, a retrofitting scheme, or the limitation of the operating hours for a specific plant. The model considers two types of power grids, the transmission and the distribution grid. Each demand sector is connected to the high or/and medium/low voltage either fully or partially. For each type of power grid, a grid loss rate is applied aiming to represent the electricity losses. The user may change these loss rates by accessing the relevant parameters in the supply-related input file.

The model simulates a well-functioning market, where the tariffs of electricity are calculated assuming that total costs are recovered by agents, including also possible stranded investment costs. The tariffs distinguish between electricity generation and the provision of grid services. The price of electricity is calculated by type of voltage (base, medium, high) and consumer (households, industries, transport). Total production costs of electricity must be recovered including the annualized capital investment

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[11] Demand response is modelled as a battery with low capital cost that is charged for 1 hour and discharged in 1 hour.

costs, fixed Operation and Maintenance (O&M) costs, variable O&M costs, fuel costs, emission taxation, etc.

The policy drivers of the **Supply** Module can be modified by the user and include: Fuel taxation, Feed-in-Tariff (FiT) and other forms of RES support, Carbon Price (EU-ETS), Environmental Policies for emissions and permitting policies (e.g., limits in the operating hours of any plant, due to environmental issues, policies regarding the permission of investments in certain power plant technologies etc.), Policies related to lifetime extension of plants, retrofitting and early retirement, Technology progress and market failures.

2.2. GEM-E3-ISL MODEL FEATURES

GEM-E3 is a multi-sectoral, recursive dynamic computable general equilibrium (CGE) model 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, labor 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 model has been very widely used by the European Commission for several studies, including the Single Market Act Climate Action policies, Energy policies, Transport policies, and Employment policies.

In the MAESHA project, the GEM-E3-ISL version has been developed, which 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, 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; it can handle current account or public budget constraints endogenously by readjusting taxes and interest rates. 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.

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).

GEM-E3-ISL includes a detailed representation of energy system and technologies, thus enhancing the credibility of CGE modeling 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.

Table 6: Energy system representation in GEM-E3-ISL

-Electricity production GEM-E3-ISL adopts a bottom-up approach for electricity sector with power producing technologies treated as separate production sectors.	**-Energy use in households** Energy demand for households is divided into Heating and cooking demand and Electric Appliances and separated into different fuels.
-Transport 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** 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.

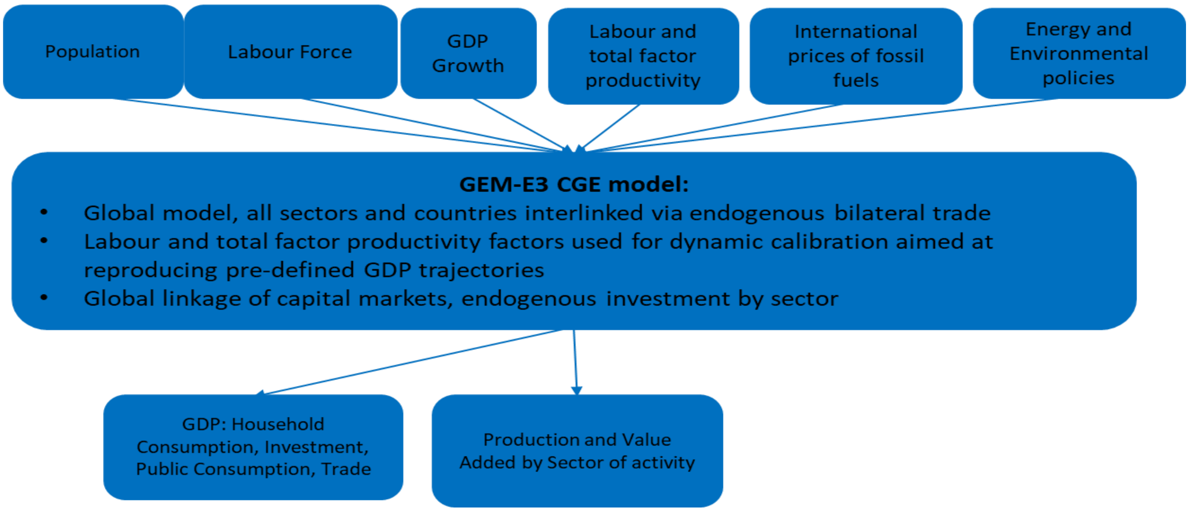

Figure 18: Main inputs and outputs to create scenarios in GEM-E3-ISL model

In GEM-E3-ISL, the installation of low-emission and energy efficient technologies is considered as an intermediate input. Climate policy can be implemented either through the imposition of an exogenous carbon tax, or through an exogenous emission cap. GEM-E3-ISL represents different options to recycle carbon revenues, e.g., through lump-sum transfers to households, or tax rate reduction. GEM-E3-ISL can assess the impacts of market-oriented instruments, such as carbon taxes and investigates market-driven structural changes, as well as the re-structuring of economic sectors, income and re-location of industrial activities induced by climate policies (Paroussos et al., 2015). The model can support the analysis of social and distributional effects of climate, energy and economic policies, both among countries and among income classes within each country (Fragkos et al., 2021).

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.

2.3. LINKS BETWEEN ENERGY AND ECONOMY MODELS

In the MAESHA project, GEM-E3-ISL is soft-linked to the E3-ISL energy system model through exchanges of model parameters and variables, as illustrated in the Figure 19 below. The process has been evaluated in several test scenarios.

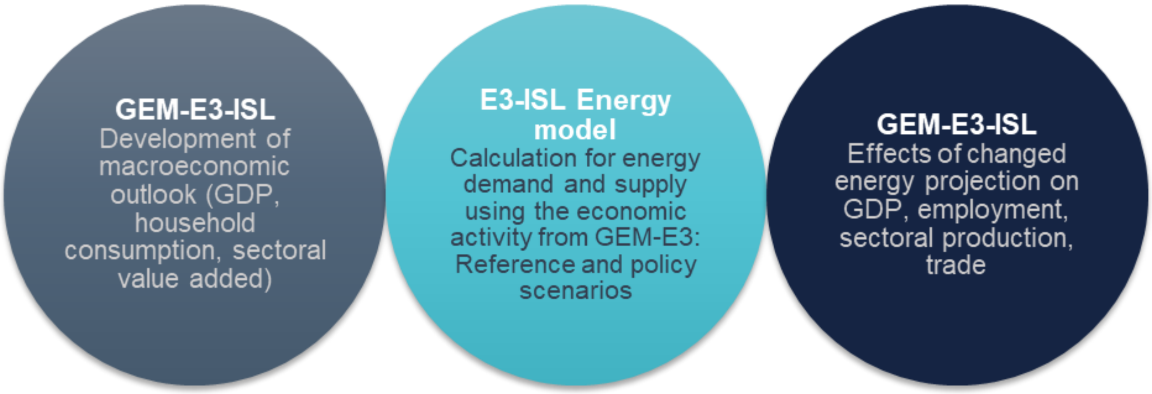

Figure 19: Soft-link between the energy and the macro-economic island-scale models

The development of the two modeling tools was guided by our attempt to harmonize their sectoral and technology representation and granularity as much as possible. For example, the detailed, bottom-up representation of the transport sector in both models allows to project mobility and to simulate the choice of transport modes, the choice of transport technologies and the way of using transport equipment. In particular, the road passenger transport sector in GEM-E3-ISL is dynamically calibrated to reproduce the same car-type mix and fuel consumption as E3-ISL scenario results for Mayotte, while costs are also synchronized in the two models. The same process is followed for the energy use in households, where GEM-E3-ISL parameters are re-adjusted so that the model reproduces the same technology and fuel mix as the E3-ISL model. Finally, GEM-E3-ISL adopts a bottom-up approach for the electricity sector with power producing technologies treated as separate production sectors, with their shares in power production dynamically adjusted to reproduce the power generation mix from the E3-ISL model in each scenario.

Table 7: Linking energy & economy models for Mayotte

-GEM-E3-ISL results incorporated into the energy system planning model E3-ISL	**-Energy system results integrated into GEM-E3-ISL**
In the Baseline scenario the process starts with a first run of the GEM-E3-ISL model which provides the development of a "Baseline" macro-economic outlook for Mayotte. This outlook is used by the E3-ISL energy model, as the energy demand by sector is driven by relevant activity indicators. The E3-ISL model takes as exogenous input the variables: i) GDP growth and population development, ii) Sectoral production for services, industrial and agriculture sectors.	A specific methodology based on the soft-link approach has been developed for the calibration of the relevant parameters of GEM-E3-ISL to the energy and technology-related projections of the E3-ISL model. The methodology is based on examining and synchronizing different sets of energy-related variables, including among others, power generation mix, energy demand and fuel mix, transport by fuel, mode and technology, and energy efficiency measures. This process is implemented until the 2 models converge to a common solution, which is commonly obtained with 2-3 iterations. The process is repeated for all scenarios analyzed in MAESHA.

3. FRAMEWORK CONDITIONS

The scenario analysis is based on a series of assumptions regarding the evolution of the main drivers for the future development of the energy-economic system of the island up to 2050. These assumptions are provided as exogenous inputs to the E3-ISL energy-economy modelling tool. The main exogenous drivers are:

- Socio-economic indicators: population, GDP, sectoral value added, international fuel prices (e.g., for oil products)
- Technology costs for energy-related technologies, including different power plant technologies and car types
- Renewable Energy (RE) potentials

The scenario assumptions are consistently integrated in the island-scale E3-ISL model that will explore in detail the impacts of the energy transition on the energy - economy system of Mayotte up to 2050.

3.1. SOCIO-ECONOMIC ASSUMPTIONS

The macroeconomic assumptions used in the study build on the demographic and economic projections for Mayotte mainly provided by international organizations such as the United Nations (UN) and the International Monetary Fund (IMF).

3.1.1. Population

The medium- and long-term population projections derive from the population trajectory of Mayotte of the medium-variant scenario of the “UN World Population Prospects: The 2019 Revision”[12]. In recent years, the population of Mayotte has increased at an average annual growth rate of 3.77% based on INSEE[13] statistics. The UN Population Prospects project that this growth rate will gradually slow down to 2.1% by 2035 and further to 1.75% by 2050, in line with trends observed in European and African countries. In the MAESHA Baseline scenario, the population of Mayotte is expected to increase from about 279 000 in 2020 to 495 000 in 2050.

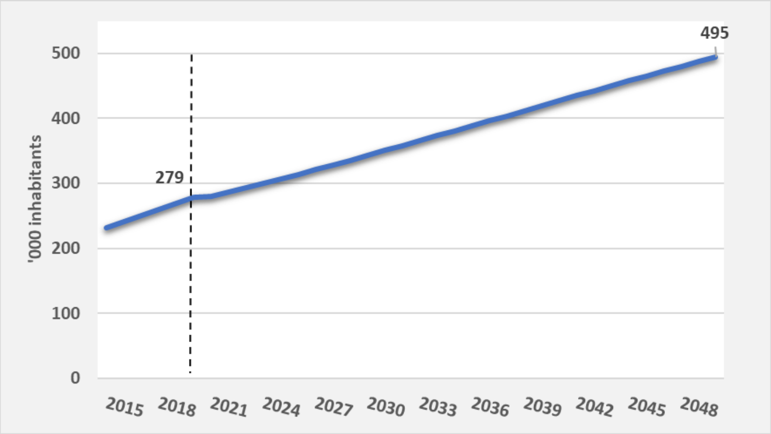

Figure 20 Population projections in thousand inhabitants (UN World Population Prospects- Revision 2019)

3.1.2. Gross Domestic Product

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[12] https://population.un.org/wpp/Publications/

[13] The National Institute of Statistics and Economic Studies, abbreviated INSEE, is the national statistics bureau of France.

The economic system projections required for the Reference scenario include projections for Gross Domestic Product (GDP) in constant monetary terms, the value added by sector and activity (structure of Mayotte's economy) and GDP per capita. The GDP of Mayotte has shown a rapid increasing trend in the period 2015-2019, with an average annual growth rate of 5.3% based on data from INSEE[14] and EUROSTAT[15]. This momentum was halted in 2020 due to the COVID-19 repercussions for Mayotte's economy, which presented a growth of 1.72% compared to 2019 according to recent EUROSTAT[16] data. Region-specific GDP projections for Mayotte are not available in official reports or international organizations, as most projections are often provided at national level. Hence, short-term GDP projections (until 2026) follow the recent International Monetary Fund forecasts[17] for Comoros[18] (as Mayotte and Comoros have a similar economic structure and development priorities), with an average annual GDP growth rate of 4.4%. Nevertheless, the GDP per capita of Comoros is far lower than that of Mayotte. On the other hand, the average growth rate of GDP in France, as forecasted by IMF and the European Commission, is 2% on average, corresponding to a more mature economy, as the metropolitan France has a much higher GDP per capita relative to Mayotte. Comparing the two trajectories for GDP growth, that of Comoros seems quite closer to the recent historical GDP trend of Mayotte.

For mid-term (until 2035) and long-term projections (till 2050), the rate of economic growth is projected to stabilize and slightly decelerate in the long-term approaching a potential growth which is driven by the evolution of the island population and labor productivity. Table 7 presents our assumptions for the average annual GDP growth rates in Mayotte over 2020-2050. The evolution of the island's economic activity (in terms of GDP and GDP per capita) is shown in Figure 21, illustrating a more than tripling of GDP in the period 2020 to 2050. Projections on GDP growth are characterized by very large uncertainty in the wake of the COVID-19 pandemic and the current energy crisis since the macro-economic impacts are highly complex and widely varied by sector and region.

Table 8 Average GDP growth rates across the time horizon of the study

2020	2021	2022-2026	2027 – 2035	2036 – 2050
1.72%	**6.29%**	**4.01%**	**4.95%**	**3.99%**

Accordingly, the GDP per capita in Mayotte increases from about 9,500 EUR/capita in 2019 to 18,870 EUR/capita in 2050, increasing with an average annual growth of 2.3% per annum over 2020-2050.

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[14] https://www.insee.fr/en/statistiques/serie/010751764

[15] Regional economic accounts, at: https://ec.europa.eu/eurostat/web/national-accounts/data/main-tables

[16] Regional economic accounts, at: https://ec.europa.eu/eurostat/web/national-accounts/data/main-tables

[17] https://www.imf.org/en/Publications/WEO/weo-database/2021/October

[18] We used the GDP growth rate of France for 2021 according to IMF, to reflect the recovery from COVID crisis, as this rate coincided with the GDP growth rate of 2019 for Mayotte. According to the short-term IMF forecasts, the GDP growth rates of France were low as France is already a highly developed economy, thus they could not be used as representative figures for Mayotte. On the other hand, based on the available historical time-series data on GDP for Mayotte, the growth rates were similar of those envisaged by IMF for Comoros, a nearby block of islands.

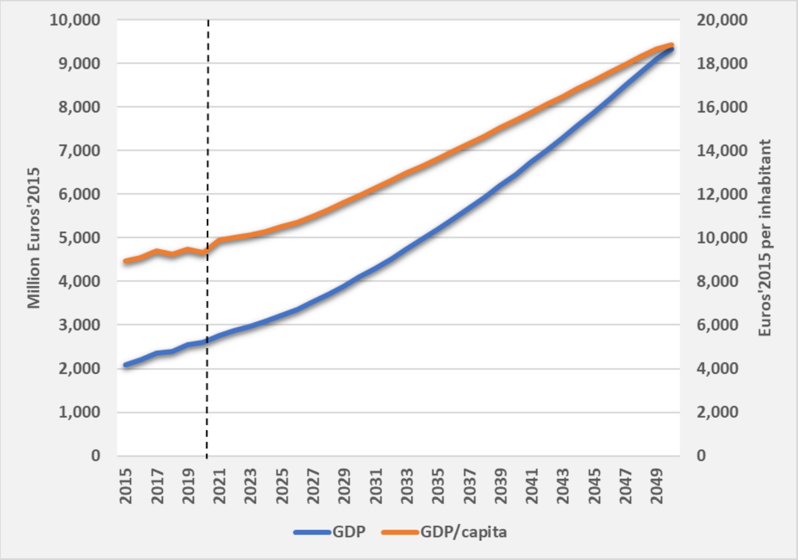

Figure 21 Evolution of GDP (in million Euros) and GDP per capita (in Euros)

3.1.3. Gross Value Added by economic activity

The contribution of each sector to the overall economy of Mayotte for 2020 is shown in Figure 22 and is derived from Eurostat statistics[19]. The major contributor 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. Non-market services account for the major share of the services sector (63.6%[20]), in contrast to European economies where market services contribute more to economic development.

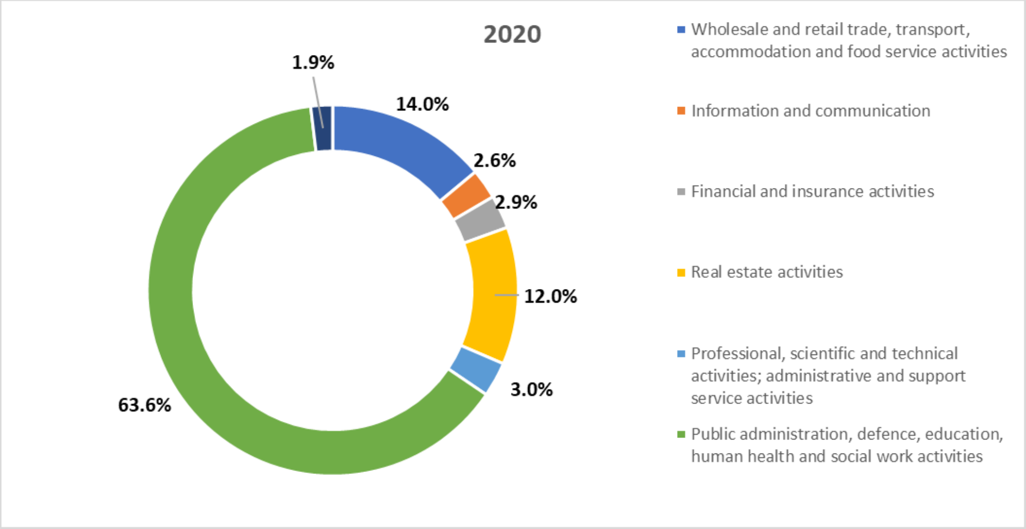

Figure 22: Structure of the services sector in Mayotte in 2020, EUROSTAT

The industry sector (including the energy sector and excluding construction) accounts for only 6.5% of the island GDP in 2020. The manufacturing branch accounts for 43% of the industry Gross Value Added, while energy accounts for the remaining 57%. There are no available data regarding the further disaggregation of the manufacturing sector, given its small size in Mayotte. According to IEDOM's

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[19] https://ec.europa.eu/eurostat/web/national-accounts/data/database (table nama_10r_3gva)

[20] https://ec.europa.eu/eurostat/web/national-accounts/data/database (table nama_10r_3gva)

recent annual economic report[21], the manufacturing sector is considered 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. Hence, the manufacturing sector in E3-ISL has been disaggregated into two major sub-sectors – Food, Drink and Tobacco (37% of GVA in Manufacturing) and Other industries (63% of GVA in Manufacturing).

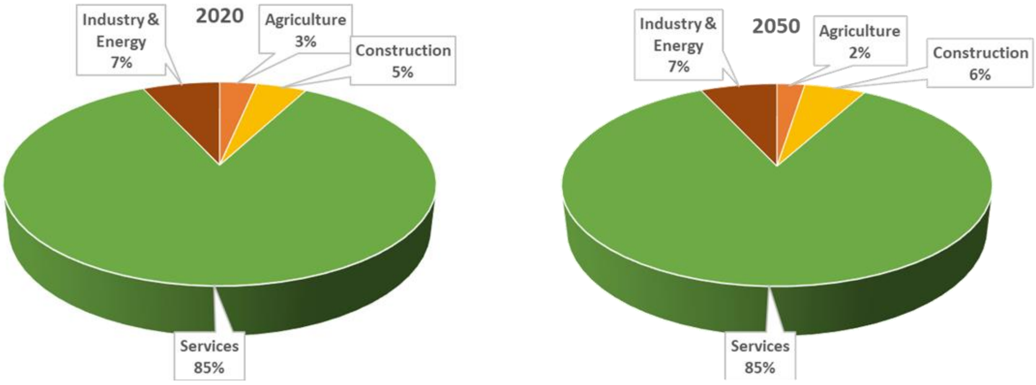

Figure 23: Structure of Mayotte's economy in 2020 and 2050

The Reference macro-economic assumptions for Mayotte for the period 2020-2050 are developed based on the below considerations:

- Traditionally the GDP is strongly correlated to energy demand, meaning that the growth of GDP is typically followed by an equivalent growth in energy consumption, at least for regions that have not reached demand saturation yet. At least, this has been the trend in past decades in developed as well as in developing countries. The recent trend however, in the EU and in other developed, mature economies is that energy consumption gradually decouples from GDP due to the use of more energy efficient equipment and technologies and the implementation of ambitious energy efficiency policies and standards. However, in less developed regions like Mayotte, energy consumption is expected to continue following GDP growth trends in the future.
- No major structural changes in the economy are assumed to be materialized in the long term, apart from a slight increase in the share of construction sector (1%), based on the population rise and the current living standards, and the respective reduction in the share of agriculture following international trends.
- The economy of Mayotte is expected to continue to be dominated by the services sector, which accounts for more than 85% of the island's GDP. The energy and manufacturing sectors maintain their shares in gross value added over time.

An internal shift inside the services sector from non-market services to market services and trade could be assumed following global trends and the emergence of the tourism sector in Mayotte. However, the respective impacts cannot be measured since the E3-ISL model does not provide such kind of granularity due to the lack of relevant data, such as the number of hotels, the number of public offices, energy consumption for specific service-related activities, etc.

3.1.4. International fuel prices

The trajectories of the international fossil fuel prices are derived from the "EU Reference Scenario 2020, Energy, transport and GHG emissions – Trends to 2050"[22]. The long-term estimates of the

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[21] https://www.iedom.fr/mayotte/publications/rapports-annuels-economiques/rapports-annuels-economiques/article/rapport-annuel-economique-2020-de-l-iedom-mayotte

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

international fuel prices are derived from the Global Energy and Climate Outlook (GECO[23]) JRC report, also considering the recent increase in oil and gas prices, that is assumed to continue in the midterm. The COVID-19 pandemic has had a major impact on international fuel prices especially in the years 2020-2021. The global economic slowdown in 2020 led to the reduction of demand for fossil fuels, and given the oversupply in international markets, the prices of energy products had drop. The import price assumptions for Mayotte used in E3-ISL have been agreed with EDM.

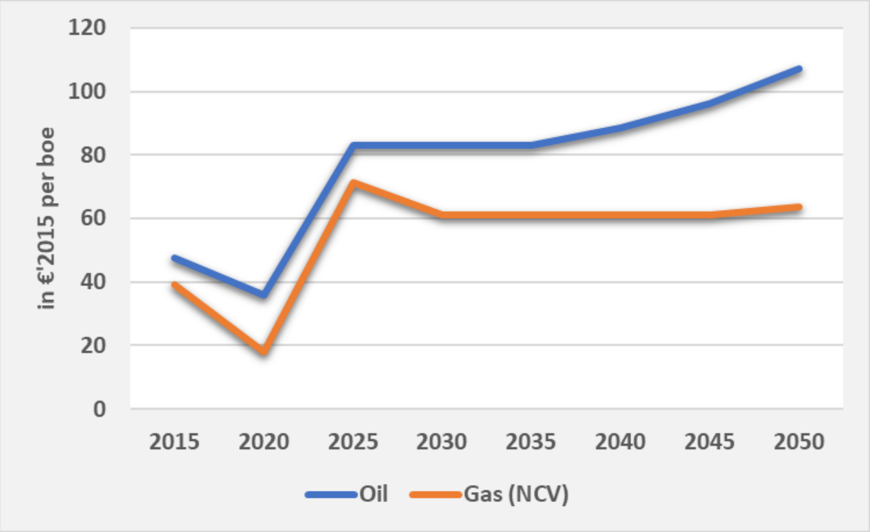

Figure 24: Evolution of international fuel prices in Euros per boe[24]

The price of imported crude oil will affect the domestic prices of the various petroleum products used in Mayotte (e.g., diesel, gasoline, LPG). Currently, there is no gas consumption on the island, so Mayotte will not be heavily impacted by the recent high increase in imported gas prices.

3.2. TECHNOLOGY ASSUMPTIONS

The E3-ISL energy-economy model includes a large variety of technology options both in energy demand and supply sectors. The assumptions on the technological developments both in terms of performance and costs by 2050 used in E3-ISL should be based on rigorous analysis and reflect recent market trends (IRENA, 2020[25]). The costs of renewable energy technologies are adequately captured and integrated into E3-ISL model to consistently estimate the cost of the potential energy transition of islands. Therefore, we decided to use the technology cost estimates provided by the most recent and official source available, i.e., the European Commission in its assessments for Fit for 55 package[26] as well as the ASSET study - Technology pathways in decarbonization scenarios [27].

The technologies considered in E3-ISL model concern the following categories: a) power generation, b) appliances and equipment used in Buildings, c) industry, d) transport vehicles. The costs of RES technologies for power generation have sharply declined in the last decade (IRENA, 2020) because of accelerated diffusion, deployment, and innovation dynamics. Furthermore, the appliances and equipment goods in the buildings and transport sectors are provided with higher energy efficiency.

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

[24] Barrel of oil equivalent

[25] https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

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

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

Regarding the power sector technologies, the Table below includes the various types of power plants incorporated in the E3-ISL model and the assumed evolution of their overnight capital costs[28] by 2050.

Table 9 Overnight capital costs of power technologies in Euros'2015/kW (or otherwise specified)

Power sector technologies	2015	2020	2025	2030	2035	2040	2045	2050
Wind Power Onshore	1078	1050	1025	1000	975	950	938	925
Wind Power - Offshore	2214	1750	1672	1593	1553	1513	1472	1432
Solar PV Commercial Medium	951	529	496	463	456	449	442	435
Geothermal PPs	4066	3131	3042	2952	2933	2914	2895	2875
Internal Combustion Engine Diesel	925	900	900	900	900	900	900	900
Internal Combustion Engine Gas	850	800	790	780	765	750	735	720
Internal Combustion Engine Hydrogen	2350	2200	2175	2150	2000	1850	1825	1800
Gas Turbine Combined Cycle Gas Conventional	650	550	543	536	535	533	532	530
Small waste/biogas burning plant	1650	1650	1633	1615	1611	1608	1604	1600
Steam turbine biomass	2000	2000	1900	1800	1750	1700	1700	1700
Small battery storage costs in Euros/kWh	1500	700	550	400	400	400	400	400
Industrial boiler - Oil/Gas	162	170	175	186	186	186	186	186
Industrial boiler - Biomass	702	737	760	807	807	807	807	807
Industrial boiler - Electricity	350	344	340	333	333	333	333	333
Power-to-Hydrogen	1552	1438	1248	670	646	622	598	418
Power-to-Gas	1450	1200	1097	733	678	623	468	316
Power-to-Liquids	1113	1000	865	720	611	519	466	413

For stationary energy uses, technologies are distinguished by vintages (ordinary, improved, advanced and best-available technologies), which have increasing capital costs and efficiency. The features of the ordinary technology change over time accounting for the expected technological progress. These costs are reported below.

Table 10 Technology cost assumptions in stationary energy uses in Euros'2015/kW

Demand-side technologies	Ordinary	Improved	Advanced	Future
Food, Drink and Tobacco				
Electric uses	167	355	512	668
Heat uses	408	534	718	902
Thermal processing	408	1054	1479	1903
Other Industries				
Electric uses	167	369	526	684
Heat uses	135	278	428	578
Thermal processing	550	915	1166	1418
Domestic sectors				
Lighting	34	45	77	89
Black appliances	163	205	260	424
White appliances	550	641	724	807
Electric stoves - cooking	183	171	187	260

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[28] "Overnight capital cost" is defined as the sum of engineering, procurement, and construction costs, and excluding financing of construction, site work, transmission upgrades and other "owner's cost - https://acee.princeton.edu/wp-content/uploads/2015/06/Andlinger-Nuclear-Distillate-Article-6.pdf

Gas stoves - cooking	191	179	195	258
Biomass stoves - cooking	232	239	255	293
Boilers oil/gas	174	205	228	250
Wood stoves	410	471	540	610
Heat pumps	1172	1248	1431	1614
Electric resistance/convectors, etc.	60	76	78	80
Solar collector - water heating	254	290	317	343
Electric water heater	110	122	136	149
Water heating boiler - diesel/gas	265	308	340	371
Water heating stove	556	604	706	767
Air-conditioning	315	423	496	570

Table 11 Technology cost assumptions in transport sectors in Euros'2015/vehicle[29]

Transport	Ordinary	Improved	Advanced	Future
Private cars - Diesel	21,914	23,496	26,423	39,645
Private cars - Gasoline	19,114	19,786	23,214	53,740
Private cars - Gas	20,628	22,023	25,984	55,253
Private cars - Plugin Hybrid Diesel	29,171	29,437	30,855	103,823
Private cars - Plugin Hybrid Gasoline	26,539	26,797	27,401	73,087
Private cars - Pure electric	25,739	32,132	36,673	43,533
Fuel cell cars	51,200	52,925	54,708	55,286
2-wheelers - gasoline	6,161	6,665	7,628	9,965
2-wheelers - electric	9,142	9,474	9,797	10,070
Light-duty trucks - Diesel	21,231	24,695	36,867	111,419
Light-duty trucks - Gasoline	17,408	18,561	28,551	99,590
Light-duty trucks - Gas	18,929	22,004	34,296	101,111
Light-duty trucks - Plugin Hybrid Diesel	29,286	29,852	34,743	110,253
Light-duty trucks - Plugin Hybrid Gasoline	25,953	37,090	61,369	99,214
Light-duty trucks - Pure electric	24,873	31,835	36,793	44,277
Light-duty trucks - Fuel cell	46,087	48,359	50,979	52,016
Heavy-duty trucks - Diesel	91,547	97,638	107,763	182,622
Heavy-duty trucks - Gas	100,963	103,899	114,493	192,038
Heavy-duty trucks - Electric	169,673	185,546	222,496	241,577
Heavy-duty trucks - Fuel cell	321,760	328,789	336,559	338,250
Buses - Diesel	285,454	290,851	324,190	397,390
Buses - Gas	303,534	308,931	342,270	415,470
Buses - Electric	425,521	436,980	482,466	502,852
Buses - Fuel cell	622,539	624,863	626,412	627,187
Passenger Water - Oil	7,580,514	10,245,149	15,981,727	20,957,265
Passenger Water - Gas	8,640,878	11,305,513	17,042,091	22,017,629
Passenger Water - Electric	9,081,146	9,950,940	13,342,954	16,734,969
Passenger Water - Fuel cell	12,668,152	13,629,829	14,472,698	15,034,610

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[29] These costs correspond to 2015 levels. The costs are diminishing across the projection years based on a learning-by-doing rate.

Freight Water - Oil	8,555,775	12,980,771	16,461,830	18,782,536
Freight Water - Gas	10,553,001	16,010,952	20,304,615	23,167,057
Freight Water - Electric	15,889,616	16,965,719	19,589,004	23,133,960
Freight Water - Fuel cell	16,627,321	17,486,215	18,230,102	19,345,931

3.3. RES POTENTIAL

Data on the potential for Renewable Energy Sources in Mayotte has been obtained by the report “Vers l'autonomie énergétique en zone non interconnectée (ZNI) à Mayotte à l'horizon 2030” of ADEME[30] and CRE's guidelines on multi-annual energy programme of Mayotte[31].

Table 12 RES potential in MW in Mayotte

RES type	Potential in MW
Wind Power Onshore	43
Wind Power Offshore	200
Solar PV	250-300
Geothermal	40

Judging from other similar islands in terms of size such as Malta and taking into account the favorable weather conditions with high solar irradiation in Mayotte, we consider that the reported solar PV potential is underestimated. According to the recommendations of CRE France, the French Energy Regulatory Commission, an in-depth study on photovoltaic potential should be performed on the island of Mayotte, listing among others the area of the roofs of public buildings, car parks and warehouses and the land with no conflicts of use that can be utilized now and in the future. Furthermore, based on their study, 100% of solar PV in the power mix of Mayotte implies the installation of more than 300 MW[32] of solar PV, considering the time horizon of 2024. This corresponds to the coverage of an area of 2.9 square kilometers[33]. For these reasons, the current study assumes higher solar PV potential than that reported by ADEME, reaching 250-350MW.

Currently, in addition to solar PV and wind turbines, longer-term solutions are being explored to decarbonize Mayotte, such as the deep high-temperature geothermal potential in Petite Terre by BRGM (French Geological Survey) with support from the Mayotte branch of the French Agency for the Ecological Transition (ADEME)[34]. Reaching the end of the second study phase (2021-2022), depending on the results, exploratory drilling may be considered in order to confirm the presence and quantify the level of exploitable geothermal resources. This information will initiate the next phase of exploitation of the geothermal resource of Petite Terre to produce electricity, “*and thus potentially significantly increase the share of renewable energy in Mayotte's energy mix (several tens of percent of total production)*”.

In addition, the current scenario analysis considers the plan of French authorities and EDM to convert existing diesel power plants into biofuel-fueled plants. A relevant study has been conducted back in 2016 to convert the Longoni and Badamiers engines to consume imported biodiesel, derived from palm oil and other vegetable oils (rapeseed, sunflower). Regarding biomass, although ADEME acknowledges the potential of 12 MW for biomass plants in their studies, there are major risks

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[30] https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/4172-vers-l-autonomie-energetique-en-zone-non-interconnectee-zni-a-mayotte-a-l-horizon-2030.html

[31] https://www.cre.fr/content/download/22000/file/RAPPORT_MAYOTTE_2020.pdf

[32] Assuming average capacity factor of 17%.

[33] The total area of Mayotte is 374 km^2.

[34] https://www.brgm.fr/en/current-project/exploring-deep-geothermal-potential-petite-terre-mayotte

regarding the sustainable supply and imports of biomass in Mayotte. A representative example is the Dzoumogne biomass plant, that counts only few hours of operation and is currently not operational due to biomass supply restrictions. These point to strong limitations in the development of biomass-fired power plants in Mayotte, while the potential to convert existing diesel-fired plants to consume imported biodiesel is fully considered in the study.

4. BASELINE SCENARIO

The Baseline Scenario projects how macro-economic, world fuel prices, technology and market trends will shape the evolution of the energy and transport systems and the associated CO_2 emissions on the island of Mayotte until 2050. It offers a detailed outlook of the energy demand by sector and fuel, energy supply, power generation mix, investment, energy prices, costs, and emissions, based on the legislation that is already in force. The Baseline scenario does not represent a forecast but projects the future state of the energy system of Mayotte in the horizon to 2050, assuming no additional energy and climate policy and legislation is introduced.

In essence, the Baseline Scenario is an informed, internally consistent, and policy relevant projection on the future developments of Mayotte's socio-economic developments, energy system, transport system and CO_2 emissions that acts as a benchmark for new policy initiatives. It reflects already legislated and currently implemented policies and market trends. This scenario can be used by policymakers as a reference for the design of more ambitious policies that can bridge the gap between where energy and climate policy stand today and where it aims to be in the medium- and long-term, notably in 2030 and 2050, in particular towards the net-zero transition. The Baseline scenario is therefore not an ambitious policy case but serves as a benchmark upon which the alternative decarbonization scenarios have been developed and assessed.

4.1. POLICY ASSUMPTIONS

The Baseline scenario depicts a future state of the energy-economy system of Mayotte in which no new, additional energy and climate policies are implemented apart from those already in legislation today. Hence, the Baseline scenario assumes a continuation – but not further strengthening – of energy and climate policies entered into force by the end of 2021. The adopted policies are those derived from the French legislation and the relevant EU Directives. EU level policies cover those adopted in the fields of energy, transport, and climate until December 2019 (cut-off date). These include (among others) the directives and regulations included in the "Clean Energy for All Europeans" package, the revised EU ETS Directive, the energy efficiency and renewable energy directives, and key transport policies such as the CO_2 standards for vehicles, the Directive on alternative fuels infrastructure, the Clean Vehicles Directive, etc.

The Baseline Scenario builds on historical trends, based on the available time-series data that cover the period 2013-2020 and reflects the continuation of current tendencies of the energy and economic system given the projections about a set of framework conditions presented in the previous section, including socio-economic development, international fuel prices and technology costs. The Baseline scenario also incorporates the feedback from the extensive and thorough discussions with the DSO of Mayotte – EDM – on the future energy system evolution of Mayotte, in particular on the commissioning/decommissioning of power plants, as well as current emerging technology, policy, and market trends. In addition, draft model-based projections for the Baseline scenario were presented and extensively discussed in an online workshop organized with EDM, and the feedback from local stakeholders has been incorporated in the Baseline scenario.

The current energy and climate policies and measures implemented on the island of Mayotte are basically those related to the policy framework of the EU and France (included those adopted as part of its National Energy and Climate Plan). We assume that EU-wide energy, climate, and transport policies that are recently legislated are implemented in Mayotte but with some delay to take into account the island's specificities and implementation barriers (e.g., lack of energy interconnections, electricity access, lower GDP per capita than EU).

Table 13 Baseline – Key policy drivers

Policy Driver	Unit	Sector/End-use	2015	2020	2025	2030	2035	2040	2045	2050
Carbon price	**€/tonCO₂**	**Industry-Power - Aviation**	25.0	25.0	80.0	80.0	85.0	120.0	135.0	150.0
Carbon standards	**% reduction vs 2020**	**Passenger cars**	-	-	-15%	-28%	-44%	-44%	-47%	-50%
		LDVs	-	-	-15%	-28%	-40%	-40%	-40%	-40%

The key policy instrument of the EU to reduce its greenhouse gas emissions is the emission trading scheme EU-ETS. Mayotte as part of the EU, participates 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 suggested carbon price trajectory for 2020-2050 can be seen in Table 13 and is derived from the official Reference scenario 2020[35] of the European Commission. In phase IV (2021-2030) of the EU ETS, the Market Stability Reserve (MSR)[36] is reinforced. The cap on EU ETS allowances is subject to an annual linear reduction factor of 2.2%. The modelling accounts for the different allowance allocation rules foreseen in the legislation for different sectors, including the provisions for sectors at risk of carbon leakage[37]. The EU ETS legislation is assumed to continue in its current scope (phase IV) throughout the projection period to 2050, leading to a continuous increase of ETS carbon prices; also, the rules relating to the MSR, and carbon leakage are assumed to remain unchanged in the character of “current policies” of the Baseline scenario. Following the recent upward trends of the EU Allowance price market (2021-2022) that range between 60 to over 90€/tonCO2, the carbon price trajectory has been aligned accordingly in the medium term (2025-2030), reaching the levels of EU Reference in the longer term.

Aviation emissions are partly covered by the EU ETS, yet the geographic scope is limited to intra-EEA (European Economic Area) flights from 2017 until the end of 2023. The EU ETS for aviation is subject to a review in light of the international developments related to the operationalization of CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation)[38]. Regarding the free allocation of emission allowances, E3-ISL allows the user to denote the proportion of CO_2 emissions from a sector or activity that is not included in the ETS. For instance, all flights from/to Paris are considered domestic flights for Mayotte which fall under the EU-ETS, while there are also international flights from/to Kenya and Madagascar that are not charged by the carbon price. In this case, based on information[39],

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

[36] The market stability reserve began operating in January 2019. The reserve addresses the current surplus of allowances and improves the system's resilience to major shocks by adjusting the supply of allowances to be auctioned (https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/market-stability-reserve_en#market-stability-reserve).

[37] What is Carbon Leakage? - Carbon leakage refers to the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints. This could lead to an increase in their total emissions.

[38] CORSIA is the first global market-based measure for any sector and represents a cooperative approach that moves away from a “patchwork” of national or regional regulatory initiatives (https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx).

[39] There are 50 flights per week from France to Mayotte, 24 flights per week from/to Madagascar and 4 flights per week. We considered also the distance that is greater in case of France, leading to higher passenger-kms. https://www.liligo.fr/vols/mayotte,https://www.skyscanner.fr/itineraires/yt/mg/mayotte-a-madagascar.html,

we assume that most flights are from/to France, and that 75% of emissions from aviation is allocated for free. Regarding the end-use sectors, only civil aviation falls under EU-ETS, since the industrial sector in Mayotte comprises light industries such as food and beverages, and not energy-intensive enterprises[40], such as steel and cement producing facilities. Regarding the energy supply-side sectors, steam generation by industrial boilers as well as the diesel power plants are charged by the carbon price. Especially for the industrial boilers, we assumed the allocation of 30%[41] of free allowances (in line with the current legislative provisions) for the whole projection period.

With regards to energy efficiency, the Baseline Scenario reflects policies at EU and Member State level, including the Ecodesign Directive[42] and the Energy Labelling Regulation[43] as well as the implementing measures, the revised Energy Efficiency Directive[44] (EED) and the revised Energy Performance of Buildings Directive[45](EPBD). E3-ISL can simulate energy efficiency policies with different modelling techniques and instruments affecting the context and conditions under which individuals, represented by stylized agents per sector, take decisions about energy consumption and the related equipment. To represent such policy instruments, model parameters are modified to mirror the effects of improved technology performance, i.e., improved equipment and appliances become available to consumers as future choices. In addition, specific modelling instruments are used to capture the impacts of efficiency performance standards ranging from ordinary technologies i.e., the currently available and common technologies, to advanced and best available technologies. Eco-design standards have been considered for the entire spectrum of energy technologies, particularly to define the standard or ordinary technologies. The Baseline Scenario considers the most recent available data on RES potentials for Mayotte (section above). The enabling conditions for the penetration of RES improve significantly, since the Baseline scenario incorporates known direct RES aids (e.g., feed-in tariffs, feed in premium schemes) and other RES supporting policies, such as priority access, grid development and streamlining of authorization procedures. E3-ISL provides a detailed modelling of RES-support incentives representing a variety of economic support schemes differentiated by sector (e.g., for power generation, transport). Beyond 2030, no additional RES targets are set in the Baseline scenario and therefore no additional specific RES policy support is modelled[46]. Although direct incentives are phased out in power generation, investment in renewable energy continue to 2050 due to: (i) the increasing ETS carbon price , (ii) the cost competitiveness of solar PV and wind power vis-à-vis diesel-based power plants, (iii) the learning-by-doing assumed in the techno-economic assumptions (section above) which increases the economic competitiveness of RES technologies; and (iv) extensions in the grid and improvement in market-based balancing of RES as well as maintaining priority dispatch for RES technologies.

In the transport sector, the Baseline Scenario reflects various policy measures, which drive: (i) the uptake of low-emission vehicles and the roll-out of the recharging/refueling infrastructure (e.g. the post-2020 CO_2 standards for new light duty and heavy-duty vehicles, the Clean Vehicles Directive, and the Directive on the deployment of alternative fuels infrastructure); (ii) the uptake of renewable and low carbon fuels (through the Renewable Energy Directive, Fuel Quality Directive, and the Directive

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https://www.aeroports-voyages.fr/fr/vols/nairobi-mamoudzou/NBO-DZA#:~:text=La%20compagnie%20Kenya%20Airways%20propose,1%20404%20%E2%82%AC%20aller%20retour.

[40] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

[41] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/free-allocation/allocation-industrial-installations_en

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

[43] Regulation (EU) 2017/1369

[44] Directive (EU) 2018/2002

[45] Directive (EU) 2018/844

[46] No relevant policies are currently in place that go beyond 2030 and can be assumed for the business-as-usual case.

on the deployment of alternative fuels infrastructure); (iii) improvements in transport system efficiency, and further encouraging multi-modal integration. 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[47]. E3-ISL considers such fleet-wide emission targets in the decision process regarding new investments for cars and vans. Hence, from 2020 onwards the Regulation (EU) 2019/631 is considered, setting the following EU fleet-wide CO_2 emission targets:

- For the period 2020-2024
  - Cars: 95 gr CO_2/km[48]
  - Vans: 147 gr CO_2/km
- For the period 2025 and 2030, the target is defined as a % reduction from 2021 levels
  - Cars: 15% reduction in 2025 & 37.5% reduction in 2030
  - Vans: 15% reduction in 2025 & 31% reduction in 2030

Emissions in cars and vans are measured using a standardized test cycle that is designed to simulate real driving[49]; thus, these figures correspond to benchmark values. As the model is calibrated in 2015 and 2020 data for Mayotte, no standards are imposed for cars and vans in these years, while for the years 2025 onwards, the emission targets decline gradually based on the latest EU regulation 2019/631.

Although biofuel mandates[50] are currently implemented in France, no information is available for Mayotte. Hence, biofuel blending in transport fuels is applied only in decarbonization scenarios.

We assume no change regarding fuel taxation in the Baseline scenario. Currently, no VAT is applied on energy commodities in Mayotte, while excise taxes are imposed only on diesel and gasoline in the transport sector. The maximum prices of oil products are published[51] every year and are set pursuant to the provisions of the Energy Code (Articles R. 671-23 to R. 671-37). Excise taxes (Tax on Final Electricity Consumption, etc.) and 2.5% regional sea fees continue to be applied on electricity tariffs[52]. The end-user electricity tariffs in Mayotte, as in other Outermost Regions, are not cost-reflective – they resemble those in their corresponding mainland (France), despite much higher real production costs[53] due to the very high costs to produce electricity with oil-fired power plants. This distortion is represented in E3-ISL with the introduction of negative profit rates for power producers in Mayotte. These negative profit rates are assumed to gradually bounce back (become less negative) in the Baseline scenario, albeit to a small extent, reflecting a continuation of the current paradigm.

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

[48] For manufacturers of passenger cars 2020 is a phase-in year: the specific emission targets will apply only to the 95% least emitting new cars in their fleet.

[49] https://www.airclim.org/sites/default/files/documents/Factsheet-emission-standards.pdf

[50] 8.2% biofuel blending in gasoline/petrol (inc. 0.7% advanced biofuel) and 8% biofuel blending in diesel (https://www.epure.org/wp-content/uploads/2021/01/201104-DEF-REP-Overview-of-biofuels-policies-and-markets-across-the-EU-Nov.-2020.pdf).

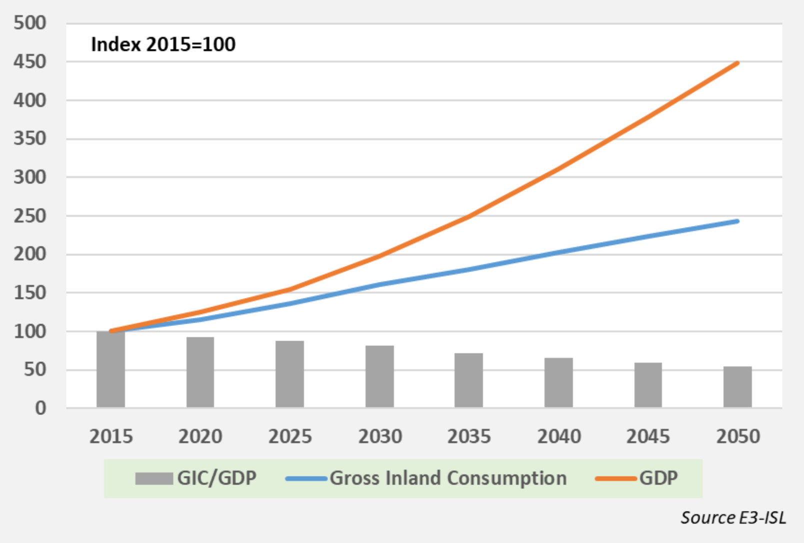
[51] https://www.mayotte.gouv.fr/Actualites

[52] https://www.electricitedemayotte.com/collectivite/nos-tarifs-services/

[53] https://ec.europa.eu/regional_policy/sources/policy/themes/outermost-regions/pdf/energy_report_en.pdf

4.2. ENERGY CONSUMPTION

In the period 2020 – 2050, the Baseline scenario projection points to an increase of 110% in gross inland energy consumption (GIC), while GDP of Mayotte grows by 259% in the same period[54]. The ratio of gross inland energy consumption to GDP indicates the energy intensity of an economy. Traditionally, economic growth goes hand in hand with increasing energy consumption. In the Baseline scenario, energy intensity is projected to decline by 1.8% percentage points on average over 2020-2050. This shows that the inland's energy consumption is projected to gradually decouple from the GDP growth, as energy consumption grows in Mayotte, albeit more slowly than the economic activity measured in terms of GDP. This is triggered by the promotion of energy efficiency in all sectors through various measures, most importantly the increased adoption of more efficient technologies, equipment, appliances and vehicles and the transition towards more efficient energy forms (e.g., renewable energy instead of diesel in power generation, electricity instead of petroleum products in transport).



Source E3-ISL

Figure 25: Baseline – GIC and GDP evolution over 2015-2050

The transport sector accounted for about 51% of total final energy consumption in Mayotte in 2020, while buildings (including both households and services) account for 37% and industrial sectors for 12% reflecting the relatively limited industrial development of the island.

Transport is projected to remain the biggest energy consumer in Mayotte by 2050 as the decoupling of transportation activity from energy consumption is limited, mainly owing to the population growth and the increasing income, leading to rising standards of living and higher car ownership rates. The tertiary and residential sectors show a moderate increase in energy consumption thanks to technology progress, the adoption of efficient appliances and equipment, and the already high electrification rate in Mayotte. The share of manufacturing in the energy consumption is slightly rising, mainly driven by the growth of construction business and the limited room for further decoupling of industrial activity.

The fuel mix of the demand sectors is generally preserved throughout the projection period., with oil products projected to continue their dominance in energy consumption with a small decline in their share from the current 62% to 59% in 2050. The Baseline scenario leads to a slight shift in the fuel mix from oil to electricity (covering 37% of energy needs in 2050) and RES, which refers to the use of solar water heaters in buildings, the wide application of which is included in Mayotte plans for sustainability

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[54] This projection is in line with the "*Reference scenario*" of the 2018 EDM study "Mayotte Bilan Previsionnel Horizon 2040" (https://fr.readkong.com/page/mayotte-bilan-previsionnel-horizon-2040-6182888) that goes up to 2040. In the "Reference Scenario" the average annual growth rate of GDP is 5% between 2019 and 2040, whereas in the present study, GDP grows by 4.4% annually on average in the period 2021-2040.

(multi-annual energy plan of Mayotte)[55]. The share of electricity rises by 2050, stimulated by the moderate market uptake of PHEVs and BEVs which allows for substituting (to a limited extent) oil products in transport. To a much smaller extent, the growth of electricity share is attributed to the growing electric uses in the residential and tertiary sectors. Oil products – namely diesel, gasoline, LPG, paraffin oil and kerosene – continue to be used in transport, industry, agriculture, and cooking; thus, oil retains the largest share of total final energy demand accounting for 59% by 2050.

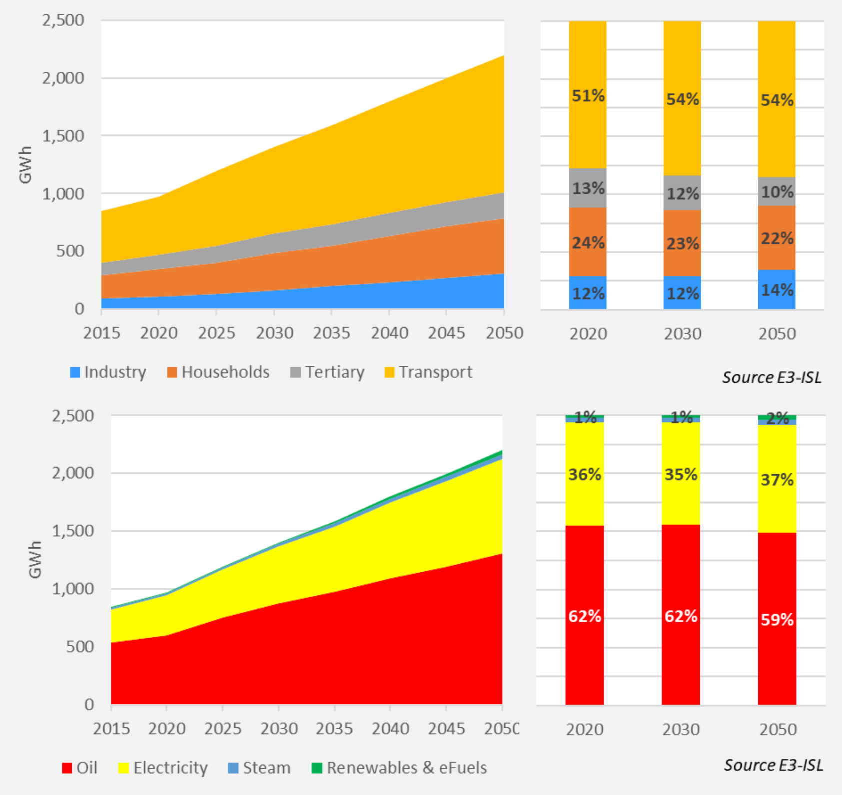

Figure 26: Baseline – Final energy consumption by main sector and main fuel

This is also shown in the Figure 27, that depicts the average growth of energy demand by sector. Transport is by far the fastest growing sector in terms of final energy consumption, albeit decelerating in the longer term. Overall, the average increase of energy consumption is slowing down in the last decade of the projection period, mainly due to efficiency improvements, indicated by the higher electrification rate, as electricity is less energy intensive than oil products.

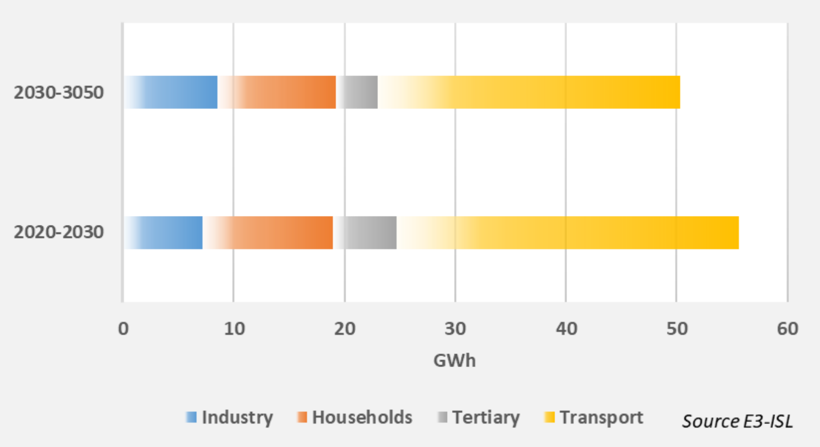

Figure 27: Baseline – Average growth of energy demand by sector in the period 2020-30 & 2030-50

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[55] https://ec.europa.eu/regional_policy/sources/policy/themes/outermost-regions/pdf/energy_report_en.pdf

The Manufacturing sector

The fuel consumption in the manufacturing sector shows a slight decoupling trend in the long run, driven by technology progress and moderate energy efficiency improvements. The manufacturing sector of Mayotte consists of light non-energy-intensive industries that leaves small room for decoupling of energy consumption from activity growth. With regard to the fuel mix, further electrification of the industrial sector is favored by the relatively low electricity prices, with the share of electricity projected to increase from 74% in 2020 to 78% in 2050, while the contribution of petroleum products and heat is found to decline in the longer term.

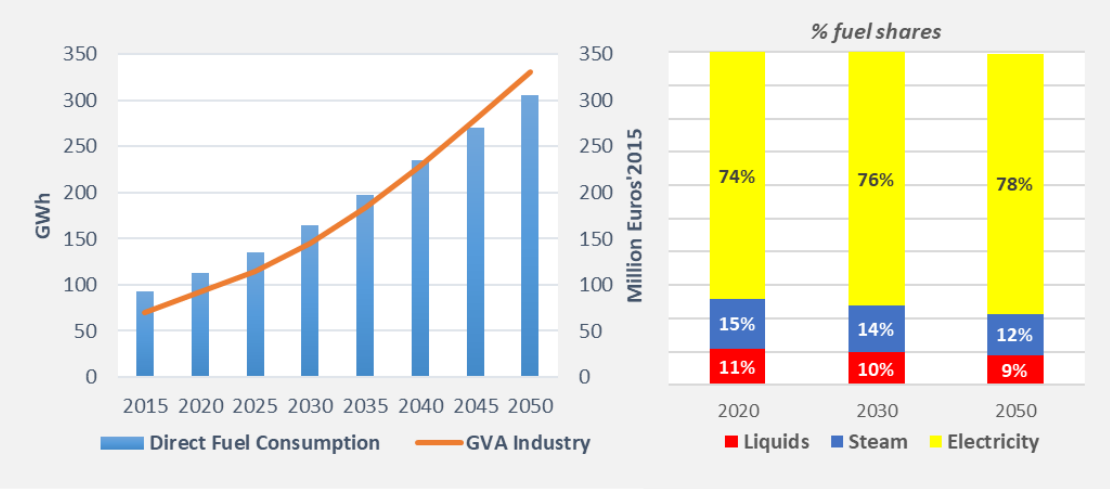
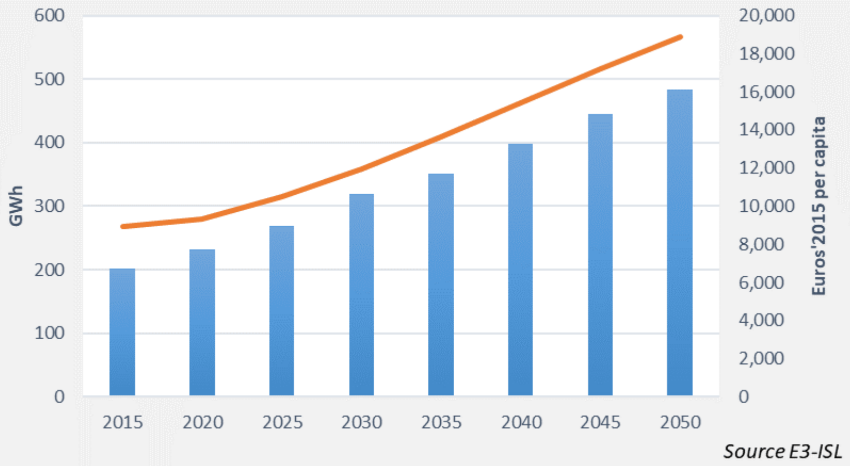


Figure 28: Baseline – Fuel consumption in Manufacturing vs GVA and evolution of fuel mix

The Residential sector

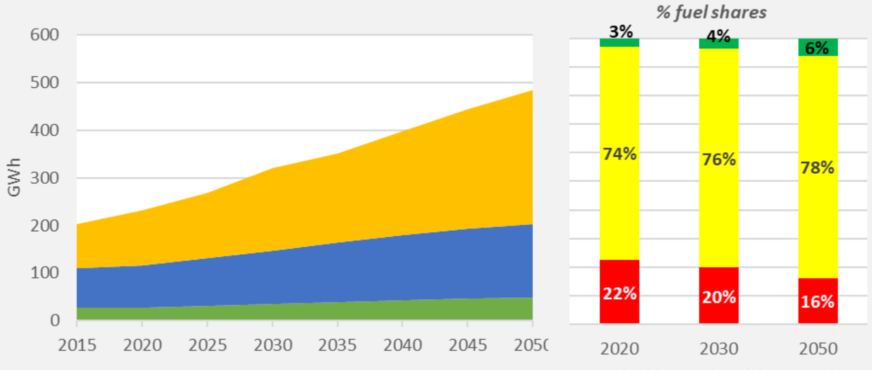
The final energy consumption in the residential sector is more than doubled by 2050 compared to 2020 levels following the growth of economic activity. Projections show a limited decoupling of energy demand from income growth, which intensifies after 2040. This is driven by 1) the purchase and use of more efficient equipment and appliances and 2) the gradual saturation of demand for useful services commonly observed above a certain income threshold (virtual decoupling). The part of the decoupling driven by technology progress shows a steady pattern across the projection period, while the virtual decoupling intensifies in the longer term, since at some point the demand for useful services tends to reach a plateau despite the continuous growth of the income.

Final energy demand in households is split to electric uses, heating and cooling uses and other heat uses, including water heating and cooking. Due to climatic conditions, space heating requirements are low in Mayotte, so electric uses and "other" heat uses account for about 90% of the sectoral final energy consumption by 2050. The energy demand for other heat uses and electric uses increases significantly over 2020-2050. Lighting and household appliances, shown as electric uses in the graph, are the fastest growing end use in terms of energy consumption. The share of electricity and solar is projected to increase in the Baseline scenario (Figure 30), stimulated by the wide use of solar thermal water heaters, electric cookers - to the detriment of LPG-fired stoves – as well as the increasing use of electric appliances. In contrast, the share of liquids (oil-based fuels) is projected to gradually decline from 22% in 2020 to 20% in 2030 and further to 16% in 2050. Efficient space cooling systems retain the share of the cooling in the energy mix of households.



Source E3-ISL

Figure 29: Baseline – Final energy consumption in residential sector vs GDP per capita



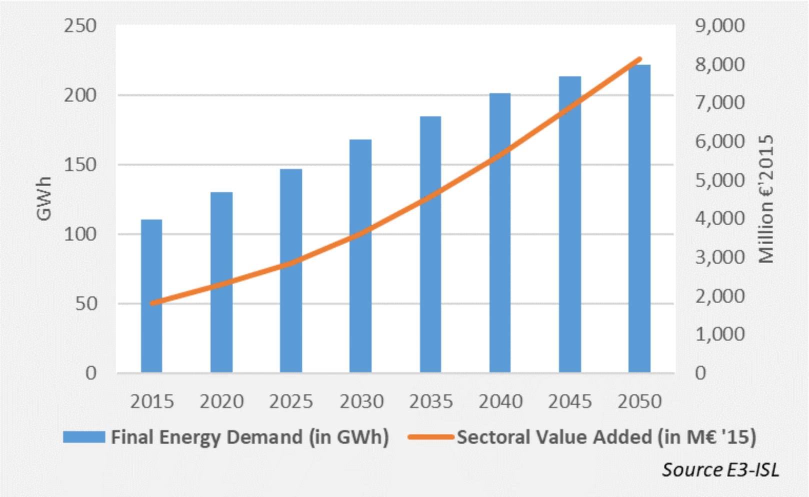
Source E3-ISL

Figure 30: Baseline – Final energy consumption in residential sector by end-use and fuel mix

The Tertiary sector

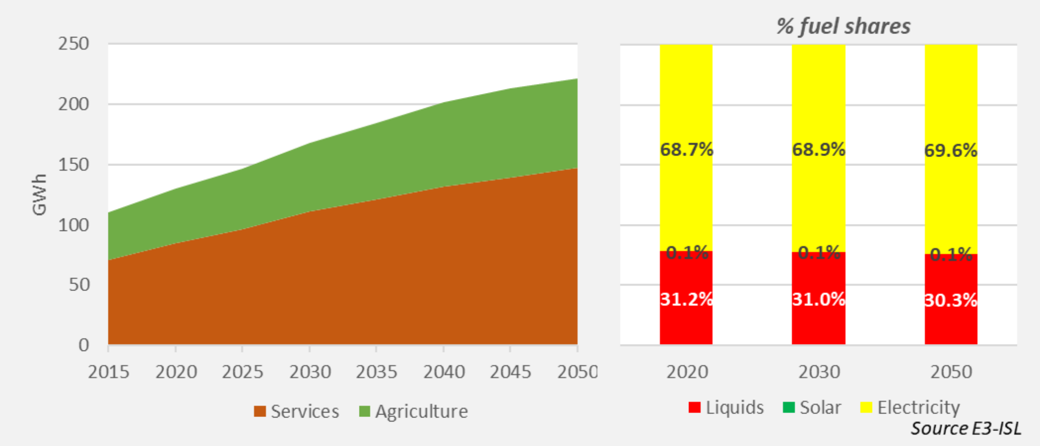
The final energy demand in the tertiary sector increases, following the growth of sectoral value added, but after a certain point in time (2035 onwards) a gradual decoupling from economic activity is projected. This is manifested in the delivery of less energy intensive, high value-added activities and the deployment of more efficient appliances, technologies and fuels.

Services consume two thirds of the energy demand in the tertiary sector, while the remaining part is used in agriculture. The fuel mix in the tertiary sector presents no major differences, except for a slight increase of the electricity share to the detriment of liquids. This is attributed to the agricultural sector, since services already consume only electricity, no oil products, and, to a limited extent, solar.



Source E3-ISL

Figure 31: Baseline – Final energy consumption in tertiary sector vs GVA Services-Agriculture



Source E3-ISL

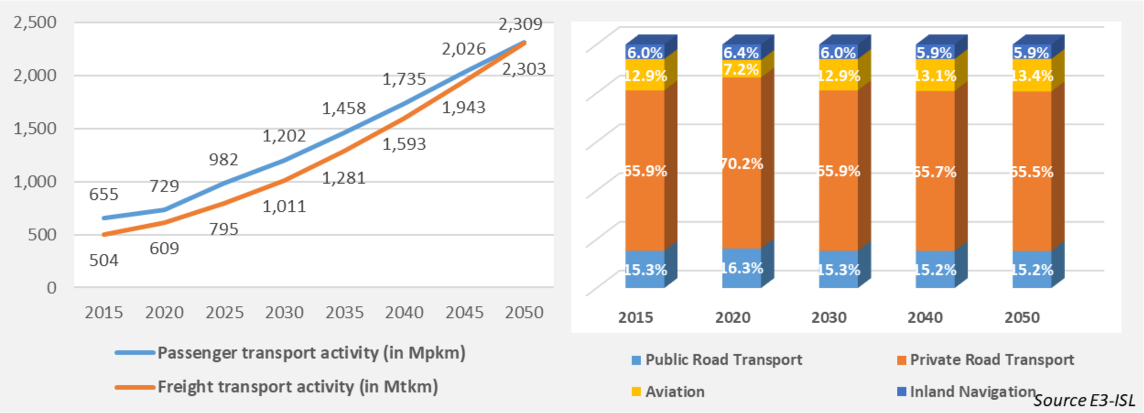
Figure 32: Baseline – Final energy consumption in tertiary sector by sub-sector and fuel mix

The Transport sector

Passenger transport activity is expected to grow significantly, driven by the population and income growth as well as the increasing rate of car ownership and the rising standards of living in the medium and long term. Private road transport drives the overall increase, as it accounts for about two thirds of total passenger activity in the 2020-2050 period.

Public road transport activity is currently limited to school buses and private coaches; there is no public transportation on the island. Since there are no concrete plans regarding the development of this sector, the share of public road transport is assumed to be the same across the projection horizon. The share of aviation is growing, albeit modestly in the long-term, driven mostly by the increasing standards of living and the higher touristic activity.

Likewise, freight transport activity is projected to grow until 2050, owing to the high economic activity and demand for transportation of goods. Navigation and road remain the dominant modes.

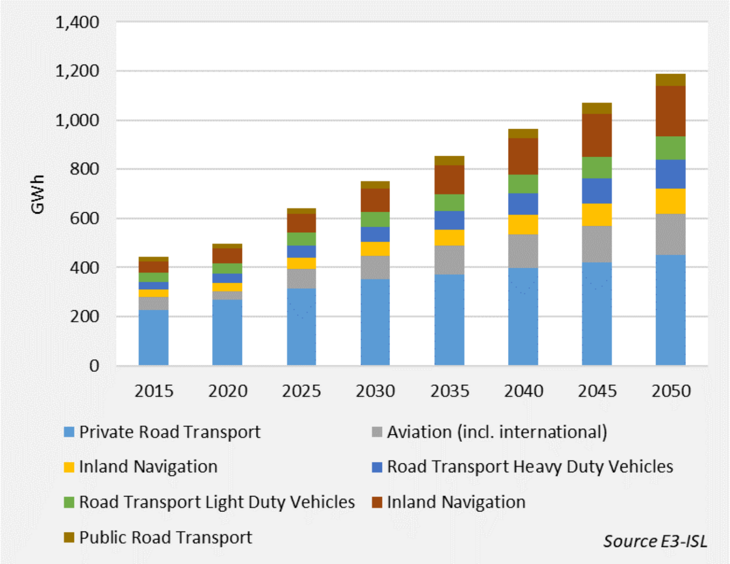


Source E3-ISL

Figure 33: Baseline – Evolution of passenger and freight transport activity and split of passenger activity by mode

Energy consumption from passenger transport is projected to increase by 82% by 2040 and 114% by 2050 compared to 2020 levels in the Baseline scenario. Increasing passenger activity is covered mainly by private cars, inland passenger navigation and aviation, driven by the growth in tourism sector. This partially explains the high growth rate of energy demand in the sector. On the contrary, the share of public road transport remains relatively stable reflecting the limited school and staff transportation. Energy consumption from aviation is projected to increase both in absolute and relative terms, reaching 21.6% share in passenger transport by 2050, gaining 5 percentage points compared to 2015 levels[56].

It is estimated that Heavy Duty Vehicles (HDVs) account for approximately 27% of the total energy demand from freight transport in 2015, while LDVs account for 30% and inland navigation for 42%, highlighting the importance of the sector in transporting goods among the islands in Mayotte. The Baseline scenario projections show that the share of LDVs decreases by 2050 (from 30% in 2015 to 23% in 2050), with freight activity shifting to HDVs and most importantly navigation, which accounts for about half of freight transport activity by 2050. This is linked to the higher energy efficiency achieved by LDVs, stimulated by the increasing uptake of low-carbon vehicles, while progress in the navigation sector is more limited.



Source E3-ISL

Figure 34: Baseline – Final energy consumption in transport by mode

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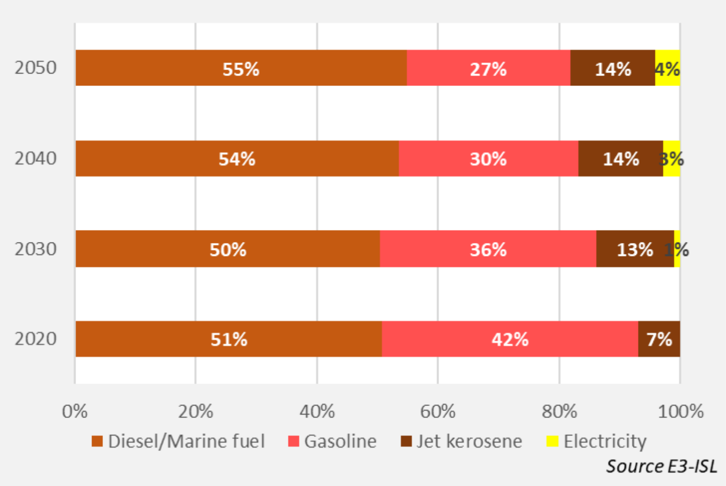
[56] 2020 level of energy demand in aviation is not representative of the sector due to pandemic crisis.

The total energy consumption of the transport sector rises from 596GWh to 1188GWh. Transport is heavily dependent on fossil fuels, since oil-based liquids, i.e., gasoline, diesel and jet kerosene account for 100% of sectoral energy consumption in 2020. In the long run, following a limited electrification trend, the share of liquids slightly declines in the Baseline scenario; From 100% in 2020, it declines to 97% in 2040 and 96% in 2050. This development is mostly the result of low-carbon vehicle penetration (PHEVs and BEVs) in passenger road transport and freight light duty vehicles. Electric vehicles are mostly deployed in the road passenger sector accounting for about 33% of total car stock by 2050. However, their high energy efficiency compared to conventional ICE cars and their low uptake in other transport segments means that the share of electricity in the transport fuel mix is only 4% in 2050. Diesel (both automotive and marine fuel) continues to be the dominant fuel, while the share of jet kerosene is increasing due to the slight shift to aviation in the passenger transport activity.



Source E3-ISL

Figure 35: Baseline – Evolution of fuel mix in transport

The current stock of private cars in Mayotte consists of ICE vehicles, while only few electric cars have been purchased so far. Electric vehicles are the key technology to decarbonize road transport driven by ambitious policies and emission standards. In the Baseline scenario, electrified cars make significant inroads in private passenger car fleet of Mayotte, with their share increasing to 10% in 2030 and further to 33% in 2050, with plug-in hybrids accounting to 21% and pure electric cars accounting for 12%. Electrified cars and vans are surging in popularity, driven mainly by the improved range and performance of these vehicles as well as the gradually more stringent technology performance standards. Market sales in developing and emerging regions have been slow until now due to high purchase costs and the lack of charging infrastructure[57]. As shown in the Figure 36 below, BEVs and PHEVs are projected to gradually displace ICE cars in the longer term.

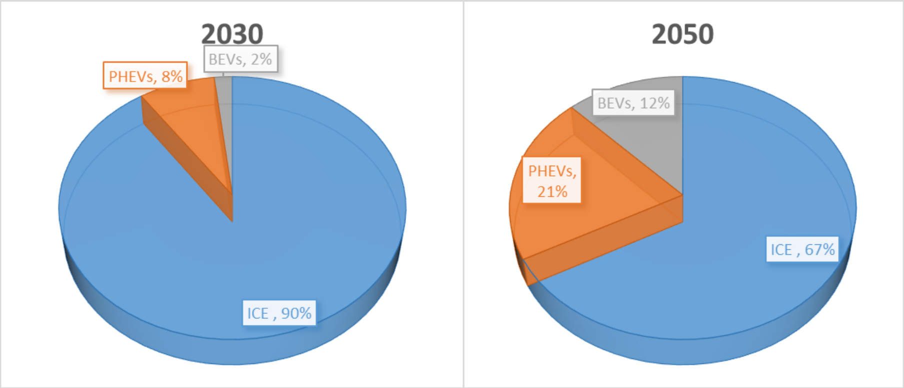


Figure 36: Baseline – Penetration of low-carbon vehicles in 2030 and 2050 in Mayotte

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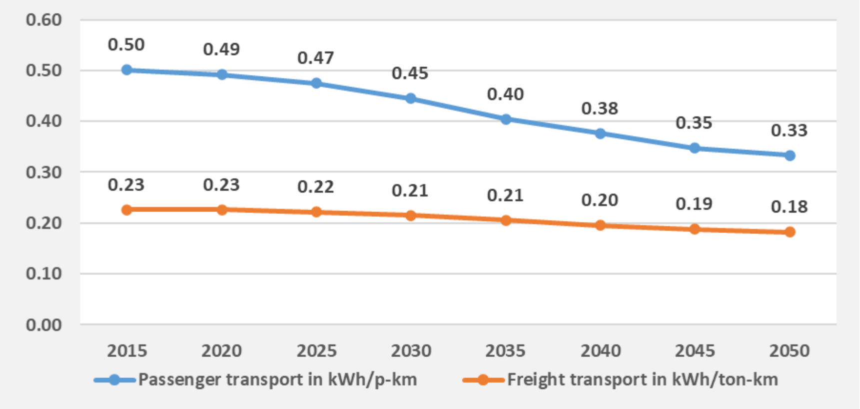
[57] https://www.iea.org/reports/electric-vehicles

The efficiency improvements are more visible in the passenger transport sector, driven by the market uptake of electric vehicles and the technology progress. No car sharing or modal shift practices are taken into account in the Baseline scenario. Regarding freight transport, the unit consumption is declining, albeit by a lower rate, driven by technology progress and efficiency improvements.



Source E3-ISL

Figure 37: Baseline – Efficiency improvement in transport by mode

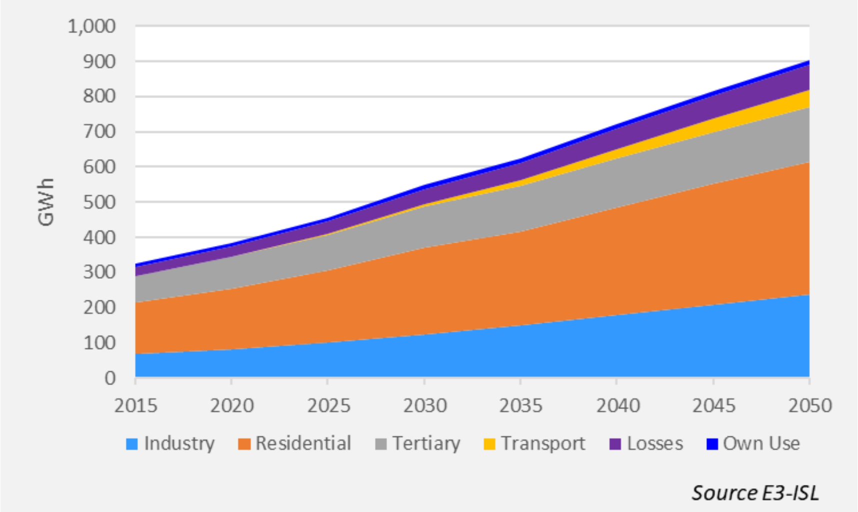
4.3. ENERGY SUPPLY

Regarding the power generation sector, E3-ISL accounts for all current and candidate power plants in Mayotte. In the Baseline scenario, the following assumptions are considered (based on the input provided by local stakeholders and EDM):

- The four (4) older units G01-G04 of Badamiers plant are decommissioned before 2020.
- 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.
- The utilization of Longoni and Badamiers is assumed to be rationalized in the future. Currently, according to the electricity balance data, the units are operating for 2000-3000 hours per year.
- The installation of 11.5 MW of battery storage is an ongoing project and is assumed to be completed by 2025.

Regarding the planned solar PV capacities, we assume that the PV plants that have already acquired a license to operate and reach the total capacity of 36.6 MW, will be connected to the grid by 2030. Although the expected date of commissioning for most of these plants does not go beyond 2023, small delays are inserted in the Baseline scenario based on the current EDM experience of how PV projects are developed in Mayotte. The further penetration of RES is stimulated by the market trends, the decreasing capital costs, and the increasing carbon price.

Electricity consumption is stipulated to increase by 134% between 2020 and 2050 in Mayotte, with an average annual growth rate of 2.9%, a surge largely driven by higher economic activity, increasing standards of living, and EV market uptake. The surging gross electricity demand is mainly driven by the residential sector and the manufacturing. The grid losses sustain their share in the gross electricity demand and as the utilization rate of thermal ICE plants Longoni and Badamiers increases, the self-consumption of these plants increases at the same rate.



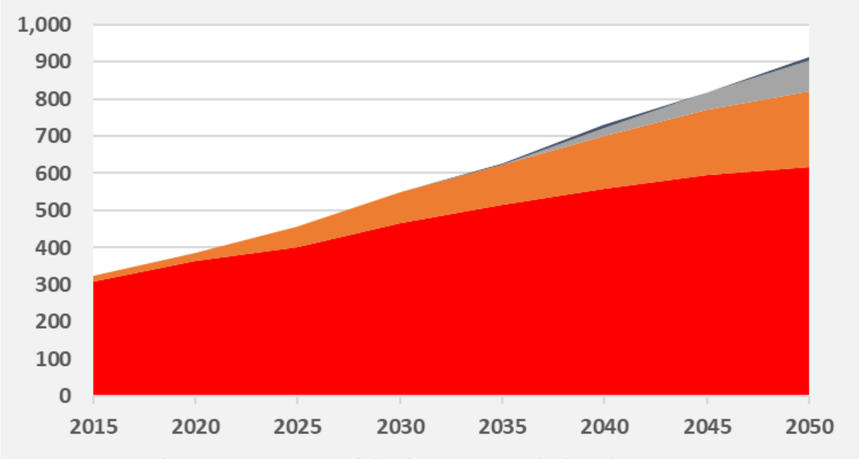
Source E3-ISL

Figure 38: Baseline – Evolution of gross electricity demand by sector

The Lifetime extension of existing ICE plants, Longoni and Badamiers, has been assumed by the end of the projection period. Diesel plants gradually reduce their share in power supply mix of Mayotte, gradually substituted by variable RES (commercial solar PVs and wind onshore); but diesel plants still account for the larger part of the power generation (67.6% in 2050).

At the same time, technology and investment trends confirm the cost-competitiveness of solar and wind power, whose share is projected to grow gradually, driven by the increasing EU-ETS carbon price and their cost reduction through learning. By 2050, almost 33% of power generation comes from solar PV (23%) and wind (9%). Batteries complement the power mix, albeit to a limited extent, to balance the intermittency of variable RES.

Additionally, the model accounts also for the ancillary services applied in the power system, in terms of primary, secondary, and tertiary reserves[58]. These requirements have been sustained for the whole projection period. Due to the increased penetration of variable RES, additional constraints regarding the provision of balancing services from diesel plants and batteries during the power generation of variable RES have been inserted.



Source E3-ISL

Figure 39: Baseline – Gross electricity generation by plant type

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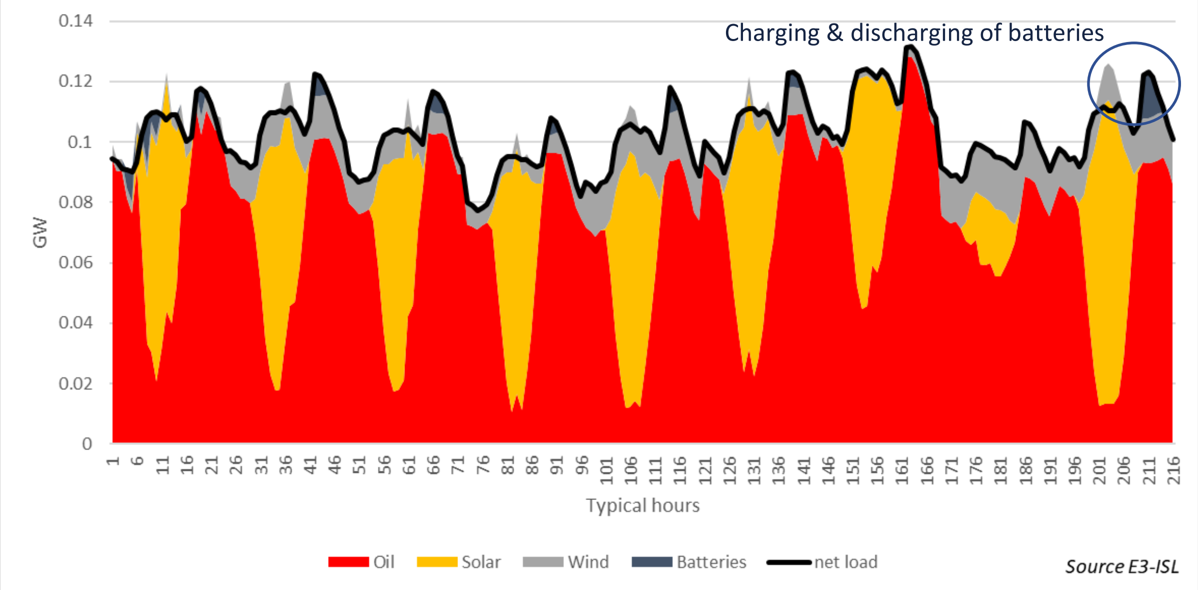
[58] The E3-ISL Supply Module includes all three types of reserves, as defined by the pan-European harmonized terminology of ENTSO-E: FCR: Frequency Containment Reserve – Primary Reserve, aFRR: automatic Frequency Restoration Reserve (upwards and downwards) – Secondary Reserve, mFRR/RR: manual Frequency Restoration Reserve and Replacement Reserve – Tertiary Reserve

The following Figure 40 represents how the different plant types serve the load in each typical representative hour modelled in E3-ISL. Nine (9) typical days of 24 hours are selected to account for the load variability in Mayotte.



Source E3-ISL

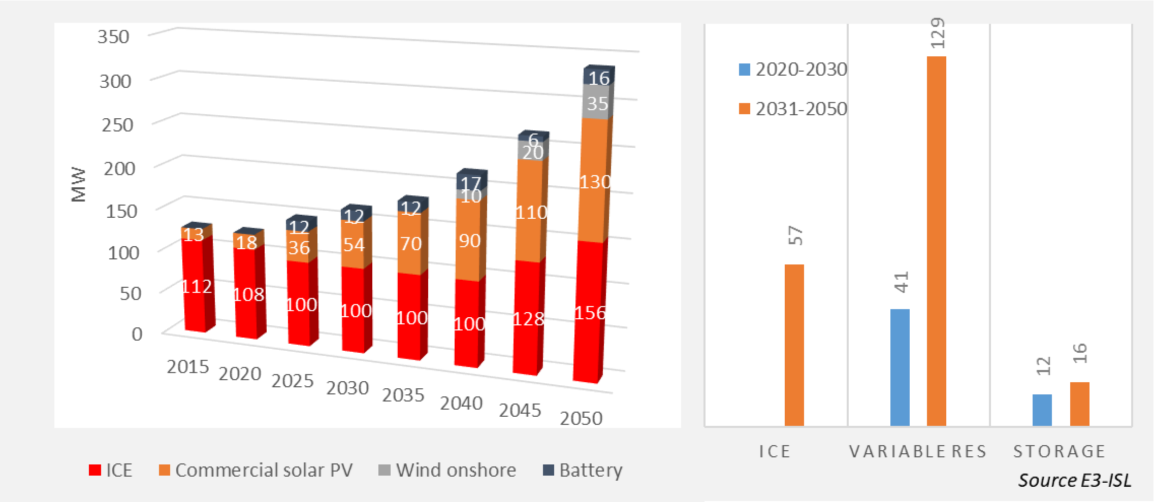
Figure 40: Baseline – Gross power generation by plant type and typical hour plus net load in 2050

The Baseline scenario envisages the gradual deployment of variable RES, and in particular solar PV. This is incentivized by the decreasing capital costs and the increasing carbon price. Although the optimization process of the model would dictate even higher RES penetration as they are cheaper than diesel-fired power plants, technical and regulatory barriers such as grid constraints, as well as investment barriers (e.g., high risk premiums, lack of access to capital) are represented in the model and impede such investments. This mechanism simulates the inertia of the island's power system to endorse high variable RES deployment. These pitfalls are reflected in the model in the form of non-linear cost supply curves for each renewable energy source.

The installed capacity of solar PV is projected to increase from 18 MW in 2020 to 54 MW in 2030, 90 MW in 2040 and 130 MW in 2050. Investment in new solar PV capacity is driven by the decreasing costs of solar panels and high sector competitiveness. Wind enters the power mix from 2040 onwards. Onshore wind capacities are also growing, albeit not as fast as solar PV due to the limited potential – wind capacities amount to 10 MW in 2040 rising to 35 MW in 2050.

Diesel continues to be the dominant fuel in power generation throughout the projection period, serving the base load as well as providing the necessary balancing services that allow the uptake of variable RES. Increased needs for battery storage lead to growing capacity from 11.5 MW in 2025 to 16 MW by 2050. Demand response practices are not stipulated in this scenario, as the activation and the engagement of the local community towards clean energy transition is assumed to be conservative.

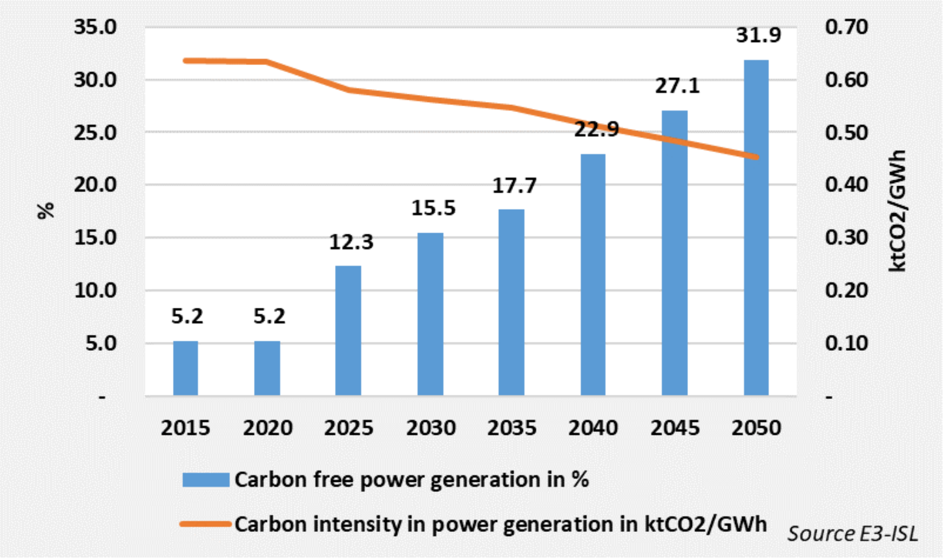
The existing thermal plant capacities are currently underutilized. This is assumed to change in the future. In this respect, the capacity of thermal diesel-fired plants remains constant by 2040 and the surging electricity demand is adequately served by Longoni and Badamiers as well as the new RES capacities. From 2041 onwards, new investments on diesel plants are required, accounting for 57 MW.



Source E3-ISL

Figure 41: Baseline – Operating power capacities and investment in new capacities by plant type

The following Figure 42 depicts the key indicators of the power sector in Mayotte in the Baseline scenario. The carbon-free power generation rises from 5.2% in 2020 to 22.9% in 2040 and further to 31.9% in 2050, driven by the variable RES deployment (solar PVs and wind onshore plants). RES uptake coupled with new investments on more efficient thermal plants especially in the last decade of the projection horizon also leads to the gradual reduction of carbon intensity in the power sector (30% less in 2050 compared to 2020 levels).



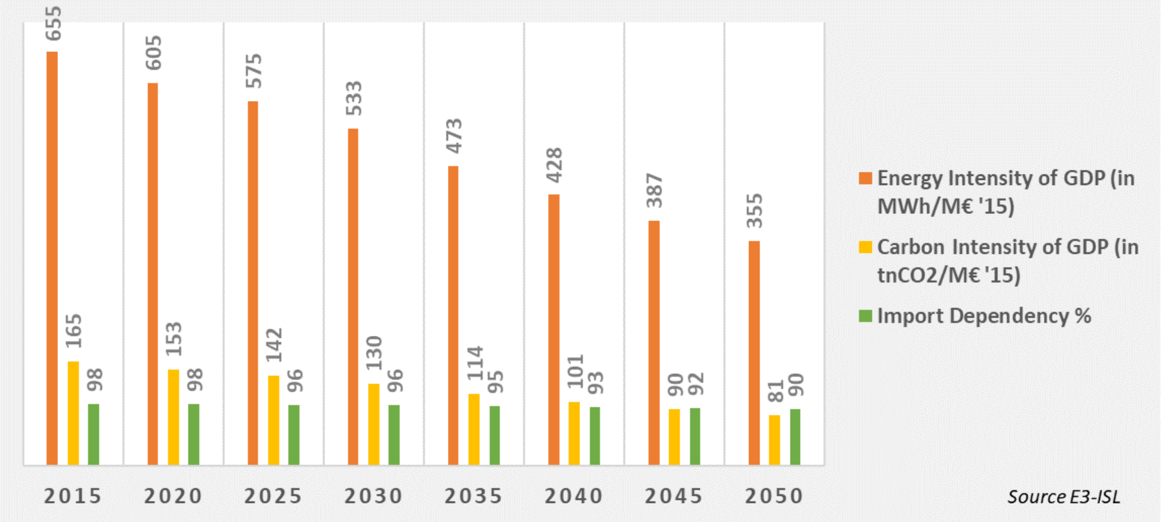
Source E3-ISL

Figure 42: Baseline – Power sector key indicators

4.4. EMISSIONS AND POLICY INDICATORS

Although the Baseline scenario reflects only the current policy settings, without any further climate action, the energy and carbon intensity of Mayotte's economy declines by 42% and 48% over 2020-2050 respectively. The energy, transport, and climate policies already in place, the technology maturity as well as the cost competitiveness of clean energy technologies are adequate factors to steer Mayotte's energy system to a less energy- and carbon-intensive pathway.

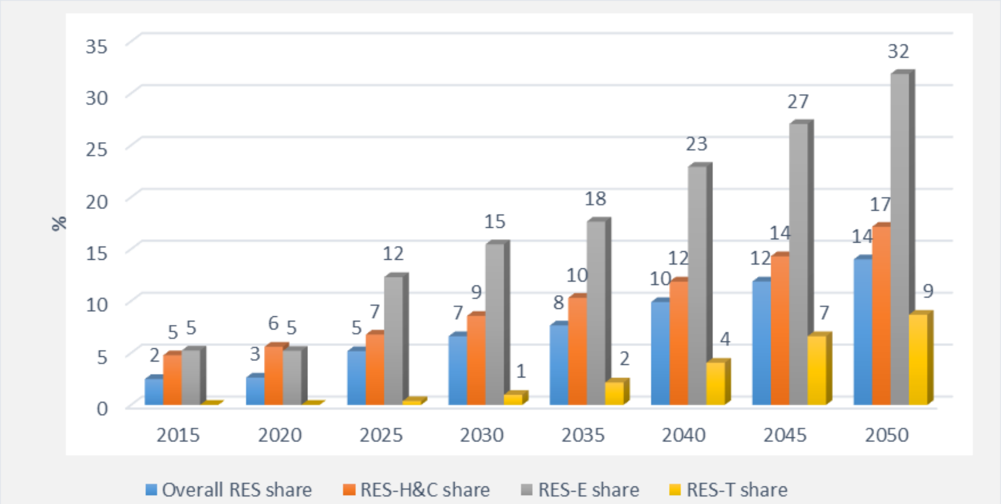
Import dependence is defined as the net imports of energy commodities divided by the gross inland consumption. Mayotte currently imports almost all its energy requirements with a dependency ratio of 98% in 2020. In the Baseline scenario, the import dependence is projected to decline gradually to 96% in 2030 and further to 90% in 2050, mainly driven by the decreasing share of imported fossil fuels (oil products) and the parallel modest increasing electrification in the end-use sectors, as well as the emergence of RES power investments. Hence, Mayotte is projected to rely less on imported liquids and more on domestic renewable energy resources by 2050.



Source E3-ISL

Figure 43: Baseline – Key climate and energy security indicators

The overall RES share of primary energy consumptions of Mayotte is growing from 2% in 2015 to 14% in 2050, stimulated by the wider use of solar PV installations and the introduction of wind power in the electricity supply, as well as the increasing use of solar thermal water heaters in buildings. This can be also observed in the relevant sector-specific indicators, for electricity (RES-E) – which increases to 32% in 2050-, heating and cooling (RES-H&C) and transport (RES-T), as calculated based on the Eurostat methodology[59].



Source E3-ISL

Figure 44: Baseline – RES shares by main sector

CO_2 emissions are projected to increase until 2050 driven by the increasing energy requirements (to fuel rapid GDP growth and rising standards of living) and the continued dominance of fossil fuels (oil products). The extensive use of oil in power generation and transport renders the two sectors as the most carbon emitting throughout the projection period, jointly accounting for 94% of CO_2 emissions of Mayotte in 2020 (Figure 45). Electricity production remains the highest carbon emitting sector in the island, but its share in CO_2 emissions is projected to decline from 58% in 2015 to 54% in 2050, due

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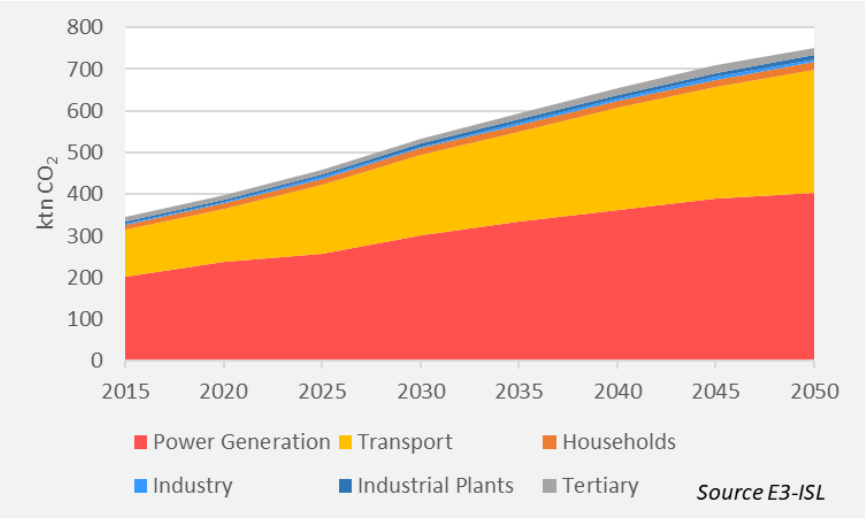
[59] https://ec.europa.eu/eurostat/documents/38154/4956088/SHARES+Manual+2018/37909ab2-8c1f-907b-2e97-3111d0691b9f

to the commissioning of new RES capacities. On the other hand, the emissions of transport are growing both in absolute and relative terms, driven by the large increases in passenger and freight transport activity and the limited uptake of low-carbon vehicles in all transport segments (with the exception of private cars). The emissions of the other sectors are very low compared to power supply and transport, since electricity -which does not emit CO_2 at the point of end-use - is the dominant energy carrier used for providing energy services to the residential, tertiary, and manufacturing sectors.



Source E3-ISL

Figure 45: Baseline – Energy related CO_2 emissions by source

As EDM is investigating the possibility of switching Longoni and Badamiers from diesel to biodiesel, a variant of the Baseline scenario has been developed in order to assess the impacts from a possible fuel blending of 10% biodiesel in the diesel plants from 2030 onwards. The Figure 46 presents the trajectories of CO_2 emissions in the two scenarios – the scenario assuming biodiesel blending in diesel plants would lead to a 5.3% reduction of CO_2 emissions by 2050.

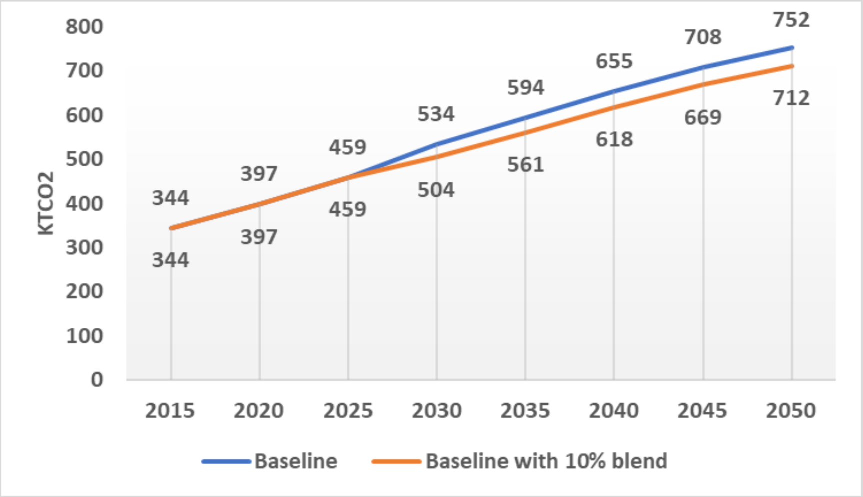


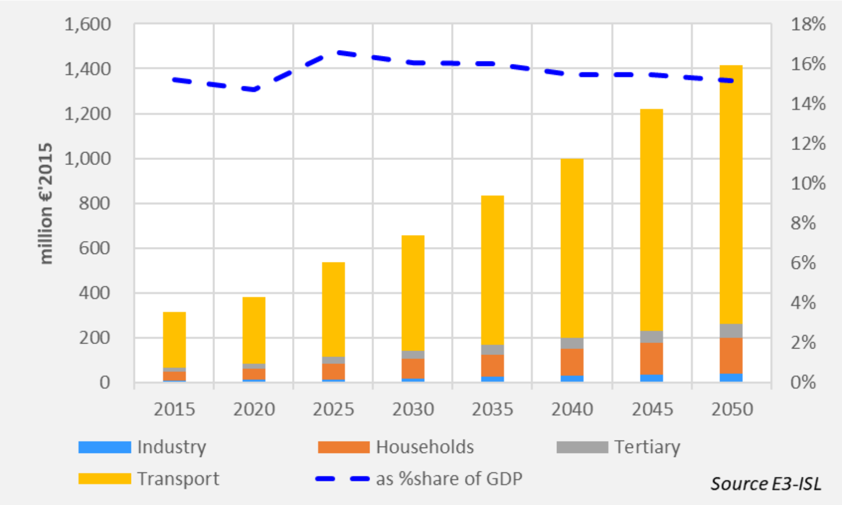
Figure 46: Baseline – Energy related CO_2 emissions vs Baseline with 10% fuel blending of diesel plants

4.5. ENERGY SYSTEM COSTS

In E3-ISL, energy system costs include: 1) fuel and other variable costs, 2) Capital costs of the energy related equipment, 3) Operation and maintenance costs of the energy related equipment, and 4) Emission and energy taxation costs. The latter component is incorporated in the prices of the energy carriers (oil products, electricity, steam).

In the Baseline scenario, oil products continue to dominate in the energy mix of the island. Overall energy system costs are estimated to amount to 15% of GDP in 2020, including annual capital payments for energy technologies and equipment; this is a high share relative to EU but it's common in emerging, low-income economies that tend to spend higher shares of income in energy products, especially in case they are energy importers. This figure is increasing in the short term (to about 16.2% of Mayotte's GDP in 2025) due to the high oil import prices and the high carbon price that followed the COVID-19 and the Russia-Ukraine crisis. However, in the long run, this share is projected to modestly decrease based on the gradual decoupling of energy demand and GDP and the declining technology costs for RES.

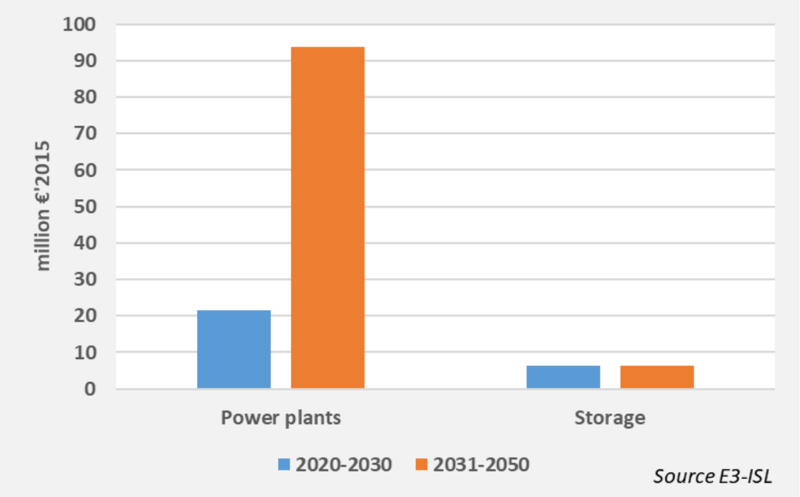
Transport and households account for most of the energy consumption, as well as the energy-related system costs. This is stimulated by the low decoupling of the social and economic activity with the energy consumption driven by the rising income and standards of living. Growth of private vehicle ownership in low-income and emerging economies is a dominant factor in forecasts of global oil demand and greenhouse gas emissions[60].



Source E3-ISL

Figure 47: Baseline – Energy system costs by sector in million €'2015 and total costs as % share of GDP

Regarding the supply side, the greatest volume of investment expenditures is projected to materialize after 2030, due to the surging electricity demand and the need to renew the power plant stock. In this period, new investments are assumed to be materialized on wind onshore, solar PV and diesel ICE plants, while before 2030, solar PV installations (already in pipeline) dominate power investment.



Source E3-ISL

Figure 48: Baseline – Cumulative investment expenditures in power sector

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[60] https://media.rff.org/documents/VehicleDemandWorkingPaper.pdf

In Mayotte, the electricity prices are not cost-reflective and thus, not sufficient to recover the overall generation, transmission, and distribution costs. The power sector is heavily subsidized by the mainland (France). In the Baseline scenario, we assume that this situation will be largely sustained in the future. The pre-tax electricity price paid by the consumers is projected to recover in the short term from 2020 low levels, propelled by the rapid economic recovery, then gradually increase in the midterm, and tending to stabilize in the long term due to the accelerated deployment of RES combined with their decreasing RES technology costs. The latter eases the effect of a high carbon price towards the end of the projection period. The electricity tariff is projected to increase by 15% in 2050 compared to 2015 levels.

By examining the cost components of the electricity tariff, it can be noticed that while in the short- and medium term, the fuel-related cost accounts for a significant part of the tariff, this declines in the long term (from 73% in 2030 to 63% in 2050). On the other hand, the share of the capital investment and the energy taxation increases driven by the new investments on capacity (mostly for solar PV and wind) and grid expansion and the rise of the carbon price, but do not outweigh the fuel cost component. Afterall, the power system of Mayotte is assumed to remain fossil-based in the Baseline scenario.

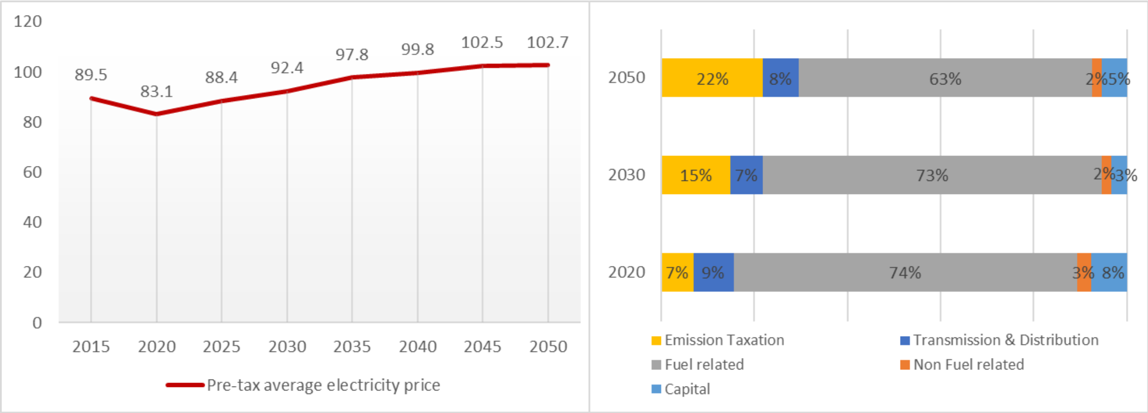
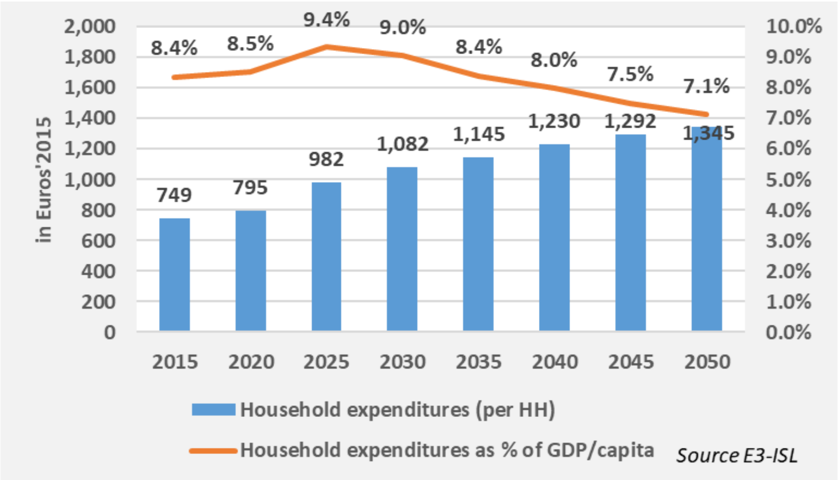


Figure 49: Baseline – Projection of electricity tariff and its components

The household energy-related expenditures are projected to rise by 80% in 2050 compared to 2020 levels, nevertheless the growth tends to slow down at the end of the period. It is evident that GDP per capita, which can be considered as a proxy for household income, grows faster than the energy-related expenditures in the longer term pointing to energy efficiency improvements in the island. Hence, the share of energy-related costs of households is projected to decline in the future from 8.5% in 2020 to 7.1% in 2050.



Source E3-ISL

Figure 50: Baseline – Estimation of household energy expenditures per household by 2050 and as %share of GDP/capita

5. DECARBONIZATION SCENARIOS

This section presents the model-based results of the decarbonization scenarios for Mayotte, as described in the section 1.3. A decarbonization scenario sets out a pathway for the energy sector to achieve net zero CO_2 emissions within a predetermined horizon. Mayotte, as part of France and consequently the EU, is engaged to endorse and adopt EU climate policy actions, paving the way towards the overarching climate neutrality goal by mid-century.

At the end of 2019, the European Commission announced the European Green Deal[61], Europe's flagship strategy to become a "modern, resource-efficient and competitive economy" by 2050. The European Green Deal is a package of policy initiatives which sets the EU path to a green transition, with the binding target of climate neutrality by 2050. Against this background, the EU introduced the "Fit-for-55"[62] package and, later the "Repower EU" plan[63], which establish initiatives for the upward revision of the EU climate, energy, and transport legislation for 2030 and 2050 with stronger action to combat climate change. These policy initiatives aim to achieve at least 55% emission reduction in 2030[64], applying existing policy instruments such as the EU Emissions trading system (EU ETS) with higher ambition, but also introducing new policy measures with the aim of strengthening Europe's competitiveness and protecting the most vulnerable consumers in the climate-neutral transition.

In this respect, E3-ISL is used to explore various decarbonization scenarios, each of which is built on a different set of underlying assumptions about how the energy system of Mayotte might evolve in the future. All scenarios have been co-designed with the active participation of various project partners, EDM and local stakeholders from Mayotte (through participatory workshops) to increase the relevance of the scenario analysis and its uptake by local decision makers. Comparing and contrasting these scenarios enables the assessment of what drives the various outcomes, and the opportunities and pitfalls that lie in a pathway towards decarbonization. It should be highlighted that these scenarios are not predictions, but rather they enable the comparison of different possible versions of the future energy system of Mayotte, the levers and policy actions that generate them, as well as the respective impacts on the entire energy system, emissions, and economy of the island.

To this end, local reports and strategies such as the multi-annual energy plan of Mayotte were studied and fed in the scenario narratives. The multi-annual energy plan of Mayotte is a key strategic document that goes up to 2023 and aims at establishing the priority actions for all energy sources with respect to supply control, supply diversification, supply security, development of storage facilities and networks. It covers the 5-year period from 2019 to 2023 and supports the long-term transition towards an energy system which is more efficient, less wasteful, more diverse, and therefore more resilient. This document reaffirms France's commitment to reducing energy consumption, particularly energy from fossil fuels, and associated CO_2 emissions.

The transition to carbon neutrality requires the adoption of ambitious energy and climate policy measures and the accelerated uptake of low- and zero-carbon technologies both in the demand and supply side of the energy system. Decarbonization of the energy system needs to go hand in hand with the introduction of efficient technologies, rapid electrification of numerous end-users in transport and industry, the uptake of renewables in both demand and power sectors as well as considerable use of biofuels, clean e-fuels, and hydrogen in the demand side, especially in sectors with

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[61] https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF.

[62] https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/#:~:text=The%20Fit%20for%2055%20package%20is%20a%20set%20of%20proposals,Council%20and%20the%20European%20Parliament.

[63] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

[64] Compared to 1990 levels

hard-to-abate emissions. These is a challenging task for all emerging economies, and especially the geographical islands like Mayotte that should also consider the lack of interconnections and the limitations of the local energy resources.

The incremental costs associated with the decarbonization of the energy system are significant in the short- and medium-term and concern basically high capital expenditures for renewable energy technologies and low-emission vehicles. However, in the longer term, the cost impacts of decarbonization may be limited because of the decreasing cost of low- and zero-carbon technologies. Still, the investments needed on capital-intensive emerging and early-stage clean technologies to replace the existing fossil fuel incumbents are large, while barriers exist related with access to financing, building infrastructure, territorial management, and regulation.

The analysis presents four (4) decarbonization scenarios, co-designed with EDM. They achieve close to net zero emissions by 2050. The assumptions of population, economic growth, sectoral activity and import oil prices are kept the same across the scenarios (and in the Baseline), as presented earlier in the document. Thus, the further reduction of energy intensity is not the outcome of structural changes in the economy, but of energy savings through technological advancements, heat recovery, emergence of efficient fuels, electrification, and behavioral changes. Assuming the same economic structure ensures comparability between the decarbonization scenarios and the Baseline scenario.

Energy and climate policies vary by scenario, affecting the speed of the transition, the technologies and mitigation options used, the energy import dependency and the socio-economic outcomes. All decarbonization scenarios include an economy-wide CO_2 price trajectory (similar to the one used in EC decarbonization scenarios) that drives mainly the low-carbon transition of power and industrial sectors, carbon standards for new vehicles, technology and efficiency standards, and blending mandates with conventional and advanced biofuels, as well as green hydrogen and e-fuels. Aviation is a “hard-to-abate” sector, thus it is partly decarbonized even by 2050. The current study focuses on the transformation of the energy, industrial and transport sectors of Mayotte towards carbon neutrality, while assuming that the EU also follows a path towards climate neutrality by 2050.

The scenarios being studied as well as their underlying policy assumptions are presented in the following section.

5.1. SCENARIO DESCRIPTION AND RELEVANT POLICY ASSUMPTIONS

The policies assessed cover a broad spectrum, including energy and carbon taxation, efficiency standards, electrification programs, support for the uptake of low- and zero-carbon technologies and vehicles etc. E3-ISL allows for sectoral modelling accounting for sector-specific policies such as technology performance standards in transport as well as economy-wide policies such as carbon pricing. The scenarios analyzed in this study differ in terms of policy focus and intensity.

A common methodology for the development of the scenarios has been followed implying the following concrete principles:

1. *Identification of the sectors with the highest share in energy-related emissions*: The share of residential, tertiary, and industrial sectors in total energy-related emissions of Mayotte is only 8% in 2020, while power generation accounts for 60% and the transport sector for 32% of Mayotte’s emissions in 2020, being the highest carbon emitting sectors.
2. *Identification of the sectors accounting for the highest shares of the total system costs:* The sector that contributes the most to the total energy system costs is transport. It presents a high share of the overall expenses, driven by the higher capital costs of electric/fuel cell vehicles. According to our data assumptions, learning by doing drives the competitiveness of these technologies in the long run, reducing their capital costs. Nevertheless, their purchase cannot be postponed later than 2040, as this will entail massive early retirement of conventional vehicles (stranded assets).

3. *Prioritize cost-efficient mitigation measures over the expensive ones:* as identified by the U.N.'s Intergovernmental Panel on Climate Change (IPCC) as low hanging fruit[65], these are the ramping up of solar and wind technology in the power sector and economy-wide energy efficiency improvements, especially for buildings (no-regret policies). For Mayotte, this is linked primarily with the installation of heat pumps for space cooling and the use of energy efficient appliances.
4. *Push costly measures towards the end of the projection period*: As aforementioned, costly measures are associated with applications in hard to decarbonize sectors such as industry and specific transport segments (aviation, navigation, trucks). The emission reduction in these sectors, especially for processes hard to electrify, requires the use of expensive energy carriers such as sustainable biofuels, clean fuels such as hydrogen and synthetic liquids, which can be either produced domestically or imported. Nevertheless, it has been proved by the modelling exercise that the effort in transport and industrial sectors cannot be pushed to the last decade, as this risks compliance with the net zero emissions target due to the slow stock turnover, leading to high risks for premature replacement and stranded assets. This principle is reinforced by the fact that low-carbon technology costs tend to decrease over time mainly due to technology progress (learning-by-doing effect). This has been also evidenced by the significant reduction of capital costs for technologies such as solar PV, wind turbines, and batteries in the recent years.

The MAESHAfocus scenario has deviated from the aforementioned process, as it entails a pathway with concrete milestones and KPIs, already set by the project.

Table 14: Scenario overview

Identifier	Name	Policy focus	Decarbonization horizon
Base	Baseline	No significant change in attitudes, activities, and policies with regard to the energy system. Currently implemented energy and climate policies continue by 2050 but do not intensify, including reduction in low-carbon technology costs	No long-term target Used as benchmark/business-as-usual case against which decarbonisation scenarios are compared
Decarb_Demand	Consumer-driven Decarbonization	Active involvement of communities in the transition (energy savings, demand response, V2G, car sharing, high rooftop PVs, etc.), high electrification in demand side. Policies: economy-wide carbon pricing, enabling conditions[66], emission and technology standards	Decarbonization of Mayotte's energy system by 2050, close to net zero CO_2 emissions by 2050
Decarb_Supply	Supply-side Decarbonization	Moderate communities' response, moderate electrification, extensive utilization of hydrogen, e-fuels	Decarbonization of Mayotte's energy system by 2050, close to net zero CO_2 emissions by

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[65] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

[66] 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.

		and biofuels to decarbonize the Mayotte's energy system Policies: economy-wide high carbon pricing, emission and technology standards, blending mandates in transport, uptake of clean e-fuels	2050
Early_Decarb	Early Decarbonization	Early policy action and high ambition both in demand and supply side	Decarbonization of Mayotte's energy system by 2040-45
MAESHAfocus	MAESHA-focused	Full implementation of MAESHA proposed solutions by 2030 Achievement of MAESHA's relevant KPIs	Intermediate targets by 2030-2040 as set out in MAESHA Decarbonization of Mayotte's energy system by 2050

5.1.1. Consumer-driven Decarbonization (Decarb_Demand)

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

Thus, this scenario considers:

- High energy savings in all end-use sectors (buildings, agriculture, manufacturing, transport) via the use of energy efficient technologies
- Maximum heat recovery in manufacturing sectors
- High demand response potential, V2G[67] 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
- Wide use of biofuels in all transport modes

The decarbonization of the electricity system requires a rapid ramping up of low- to zero-CO_2 electricity generation capacity. For a large-scale transition, significant levels of new investments are needed on commercial and rooftop solar PV as well as onshore and offshore wind plants. This scenario also considers the fuel switching of Longoni and Badamiers from diesel to biodiesel in 2030 onwards and a small-scale use of geothermal power potential from 2045 onwards.

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[67] Batteries in the electricity system can be used in two forms: stationary and electric vehicle (EV) batteries. Stationary batteries can be used to reduce the total system cost by storing electricity from hours of low net-load [i.e., electricity generation from variable RES minus demand] to hours with high net-load. EV batteries can be used to power the EV when driving, as well as to store the electricity through vehicle-to-grid systems or to absorb electricity at low or negative net-load hours when the vehicles are parked.

Table 15 Decarb_Demand – Key policy drivers

Policy Driver	Unit	Sector/End-use/Fuel	2025	2030	2035	2040	2045	2050
Carbon price	**€/tonCO$_2$**	**Industry-Power - Aviation**	80	80	170	213	257	300
Carbon value[68]	**€/tonCO$_2$**	**Buildings-Industry**	80	80	170	213	257	300
Carbon standards	**% reduction vs 2020**	**Passenger cars**	-15%	-32%	-56%	-85%	-96%	-96%
		LDVs	-15%	-40%	-66%	-83%	-96%	-96%
		HDVs	-	-58%	-58%	-92%	-99%	-99%
		Buses/Coaches	-	-55%	-78%	-89%	-92%	-92%
		Marine vessels	-	-51%	-84%	-84%	-90%	-97%
Blending mandates in Transport	**% of sectoral energy consumption**	**Biogasoline**	9%	12%	15%	18%	22%	25%
		Biodiesel	8%	15%	20%	24%	28%	33%
		Ammonia (in navigation)	-	2%	5%	10%	30%	50%
		Biokerosene (in aviation)	-	4%	15%	24%	27%	35%
		Synthetic kerosene (aviation)	-	1%	5%	8%	11%	30%
Heat recovery incentive	**€/MWh saved**	**Industry**	-	-	8.3	29.1	36.6	51.6

From 2030 onwards, no free emission allowances are allocated to the industry or the power sector, while international aviation is assumed to continue to be exempted from the EU-ETS. A carbon price is imposed on the wide economy – nevertheless, it is not paid by the buildings or the light industrial processes, apart from the industrial plants that fall under EU-ETS.

Regarding the sectoral policies, transport constitutes the most energy-intensive end-use sector in Mayotte and is considered a "hard-to-abate" sector. Getting transport on track with a pathway to carbon neutrality requires implementing a wide range of policies, targeting both to the boosting of advanced efficient technologies, electrification, and clean fuels, and to encourage lifestyle changes such as modal shifts to less carbon-intensive travel options, application of soft mobility and car sharing practices. The electricity needs through direct electrification of transport or indirectly with the extensive use of hydrogen and e-fuels are significant for the decarbonization of the sector. Given the size of Mayotte and the availability of local resources, it is assumed that 50% of the needs for hydrogen, ammonia and synthetic liquids will be served by imports. This can be feasible without putting a risk to the energy security and self-sufficiency.

The industrial sector is of limited scale on the island and includes only light, low energy-consuming industries. The measures focus on waste heat recovery techniques exploiting the full potential, energy efficient industrial equipment and electrification of processes. The buildings use electricity as the main energy carrier. As fossil fuels, namely LPG, paraffin oil and diesel, are used only for cooking and

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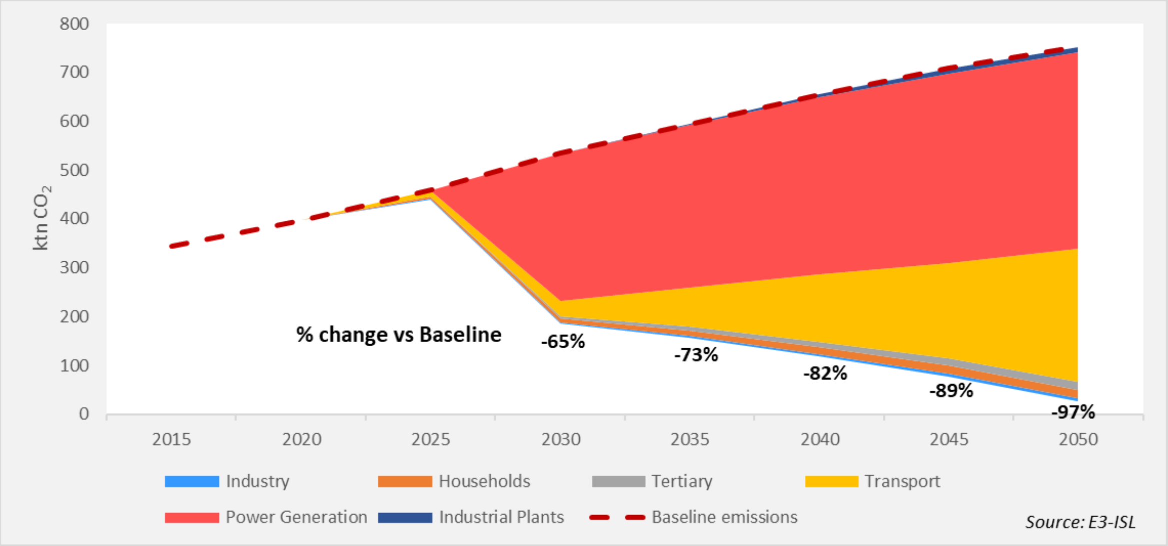
[68] A price signal that makes the carbon-intensive fuels unattractive. Carbon value is a driver that behaves as an implicit CO$_2$ reduction target and represents carbon emission taxation and other emissions reduction policies but is not finally paid. Carbon value applies to sectors not burdened with carbon price.

agricultural purposes, measures such as further electrification, the uptake of electric cookers and the wide application of solar thermal water heaters are being implemented. As this scenario relies on a considerable extent on the consumer's active involvement in the clean energy transition of the island, behavioral change and measures for removing non-price market barriers or consumers' reluctance towards sustainable practices and technologies, a shift is observed to best available appliances, lamps and air conditioning systems.

Assuming the elimination of market, institutional and regulatory barriers, the power sector is succumbed to a full transformation with high-RES penetration and availability of storage systems, such as batteries and chemical storage for the production of clean fuels. The establishment of energy communities allows the consumers to take control of their consumption but also provide flexibility and thus reduce the pressure on the power system in the energy transition. Practices such as wide application of demand response, vehicle-to-grid and the installation of solar rooftop PVs are assumed to be adopted in this scenario. Demand response is acknowledged as a key resource to balance supply and demand in a context of a significant amount of intermittent renewable generation. Demand-side flexibility in the timing and magnitude of energy consumption is expected to be provided by different sectors. V2G is introduced in the model via a different load profile of the private transport sector – vehicles are mainly charged during the peak production of solar PVs and discharge during the other typical hours.

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.

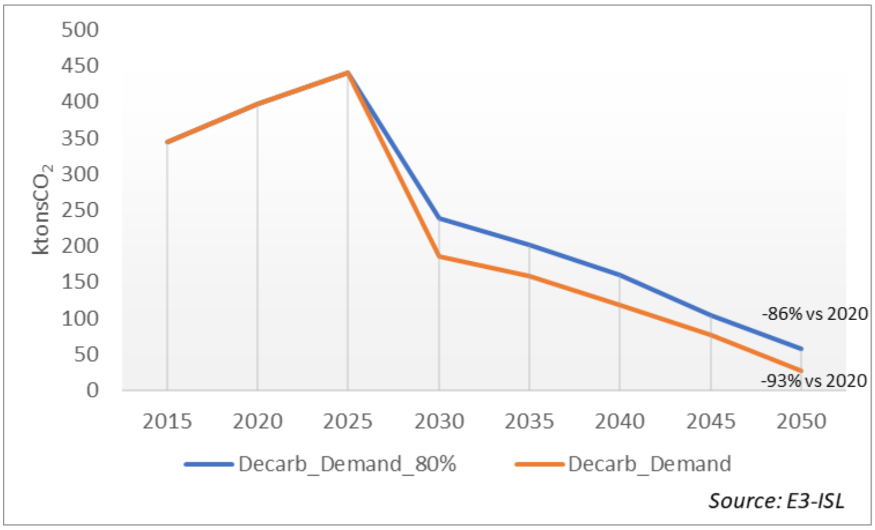
The Figure 51 presents the CO_2 emission reduction trajectory of this decarbonization scenario compared to the Baseline emissions. In 2030 a steep decrease is observed, stimulated by the fuel switching of the ICE plants from diesel to biodiesel.



Source: E3-ISL

Figure 51: Decarb_Demand - CO_2emission reduction by sector vs Baseline

A variant of Decarb_Demand scenario has been explored assuming 80% of fuel blending of ICE plants with biodiesel instead of fuel switching in 2030.



Source: E3-ISL

Figure 52: Decarb_Demand - CO_2 emission reduction vs variant with 80% biodiesel blending in ICE plants

5.1.2. Supply-side Decarbonization (Decarb_Supply)

This scenario sets also the decarbonization horizon by 2050, but it focuses on actions from the energy supply side, as a fully decarbonized electricity sector is the essential foundation of a net zero energy system. In this respect, this scenario is more supply-driven and explores the potentials of the local renewable energy resources in Mayotte, assuming:

- Fuel switching of Longoni and Badamiers from diesel to biodiesel from 2030 onwards
- Full exploitation of wind onshore and offshore potential of Mayotte
- Wide use of geothermal potential of Mayotte
- Wider use of commercial solar PVs and moderate installation of rooftop solar PVs
- Moderate heat recovery and energy efficiency in industry
- Limited energy savings in buildings
- Moderate demand response and absence of V2G practices
- Extensive biodiesel blending in transport
- High demand for e-fuels and hydrogen to decarbonize land and navigation transport sectors. Given the relatively limited domestic renewable energy potential, we assume that the demand for e-fuels and hydrogen is met both by imports (50%) and by domestic production

The complete transformation of the vehicle fleet accompanied by the development of supply infrastructure for alternative fuels is necessary. Consequently, this implies high gross electricity demand, stressing the potentials of solar and wind energy resources, and extensive investments on Power-to-X and hydrogen production facilities.

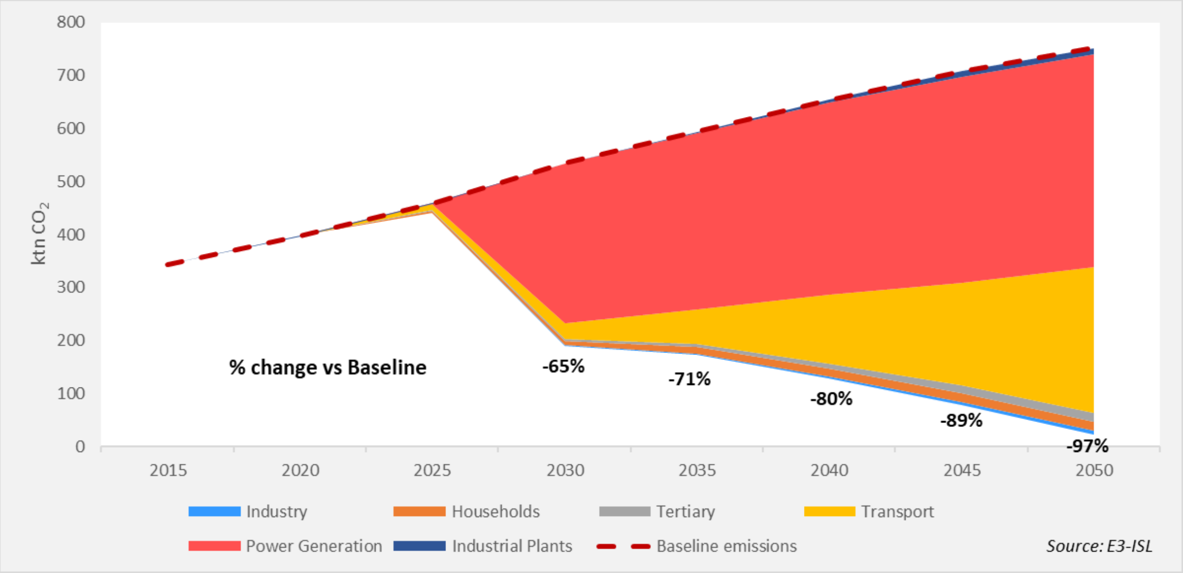
Table 16 Decarb_Supply – Key policy drivers

Policy Driver	Unit	Sector/End-use/Fuel	2025	2030	2035	2040	2045	2050
Carbon price	**€/tonCO₂**	**Industry-Power - Aviation**	80	80	170	213	257	300

Carbon value[69]	**€/tonCO₂**	**Buildings-Industry**	80	80	170	213	257	300
Carbon standards	**% reduction vs 2020**	**Passenger cars**	-15%	-32%	-56%	-85%	-96%	-96%
		LDVs	-15%	-40%	-66%	-83%	-96%	-96%
		HDVs	-	-58%	-58%	-92%	-99%	-99%
		Buses/Coaches	-	-55%	-78%	-89%	-92%	-92%
		Marine vessels	-	-51%	-84%	-84%	-90%	-97%
Blending mandates in Transport	**% of sectoral energy consumption**	**Biogasoline**	9%	12%	15%	18%	22%	25%
		Biodiesel	8%	15%	20%	24%	28%	40%
		Ammonia	-	2%	5%	10%	30%	50%
		Biokerosene	-	4%	15%	24%	27%	35%
		Synthetic kerosene	-	1%	5%	8%	11%	30%
Heat recovery incentive	**€/MWh saved**	**Industry**	-	-	4.1	7.3	9.1	11.5

The carbon price trajectory, the technology standards and the blending mandates are mostly the same as in the previously described scenario. The major differences of these scenarios lie in the limited energy savings from the demand side, the low capacity of the demand response, the extensive use of hydrogen and e-fuels as well as the almost complete exploitation of RES local resources (commercial solar PV, wind onshore and offshore plants, geothermal power plants).

The graph that follows presents the CO_2 emission reduction trajectory of this decarbonization scenario compared to the Baseline emissions. The emissions reduction in this scenario resembles that of the previously described scenario, albeit with a different policy and sectoral scope.



Source: E3-ISL

Figure 53: Decarb_Supply – CO_2 emission reduction by sector vs Baseline

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[69] 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.

We also developed variants of the Decarb_Supply scenario, assuming 80% and 100% imports of e-fuels and hydrogen in order to explore the impacts on the system costs, technology uptake, and energy import dependence.

5.1.3. Early Decarbonization

Both Decarb_Demand and Decarb_Supply scenarios consider that the transition to a net zero economy for Mayotte initiates roughly from 2030 onwards, so carbon taxation and other ambitious climate policies intensify gradually over this period. In contrast, the Early Decarbonization scenario assumes that the implementation of transition policies and measures initiates from 2025 onwards and is fully materialized by 2045, leading to a decarbonized energy system earlier than 2050. This scenario is a combination of Decarb_Supply and Decarb_Demand, albeit with a narrower decarbonization horizon. The clean energy transition by 2045 requires early and coordinated action in both the demand and supply sectors. The more rapid nature of the emissions reduction affects particularly the carbon-intensive sectors, such as transport, leading to accelerated transformation dynamics in the medium-term. The Early_Decarb scenario entails certain benefits and drawbacks:

- Shifting the ambition towards the initial stage of the transition horizon implies a lower carbon budget for the energy sector by 2050, since the policy effort starts 5 years earlier.
- This scenario may lead to higher energy system costs since the low-carbon technology costs are relatively higher at the beginning of the projection period. The rapid uptake of a certain clean energy technology over a short period of time may also imply larger financial, regulatory and implementation barriers.

Table 17 Early_Decarb – Key policy drivers

Policy Driver	Unit	Sector/End-use/Fuel	2025	2030	2035	2040	2045	2050
Carbon price	**€/tonCO_2**	**Industry-Power - Aviation**	80	170	211	252	293	375
Carbon value[70]	**€/tonCO_2**	**Buildings-Industry**	80	170	211	252	293	375
Carbon standards	**% reduction vs 2020**	**Passenger cars**	-56%	-96%	-100%	-100%	-100%	-100%
		LDVs	-61%	-96%	-100%	-100%	-100%	-100%
		HDVs	-75%	-95%	-100%	-100%	-100%	-100%
		Buses/Coaches	-55%	-78%	-99%	-100%	-100%	-100%
		Marine vessels	-51%	-67%	-90%	-98%	-98%	-98%
Blending mandates in Transport	**% of sectoral energy consumption**	**Biogasoline**	12%	15%	18%	25%	25%	25%
		Biodiesel	15%	20%	24%	32%	32%	32%
		Ammonia	-	2%	5%	10%	30%	50%
		Biokerosene	4%	15%	24%	35%	35%	38%
		Synthetic kerosene	1%	5%	8%	30%	30%	30%

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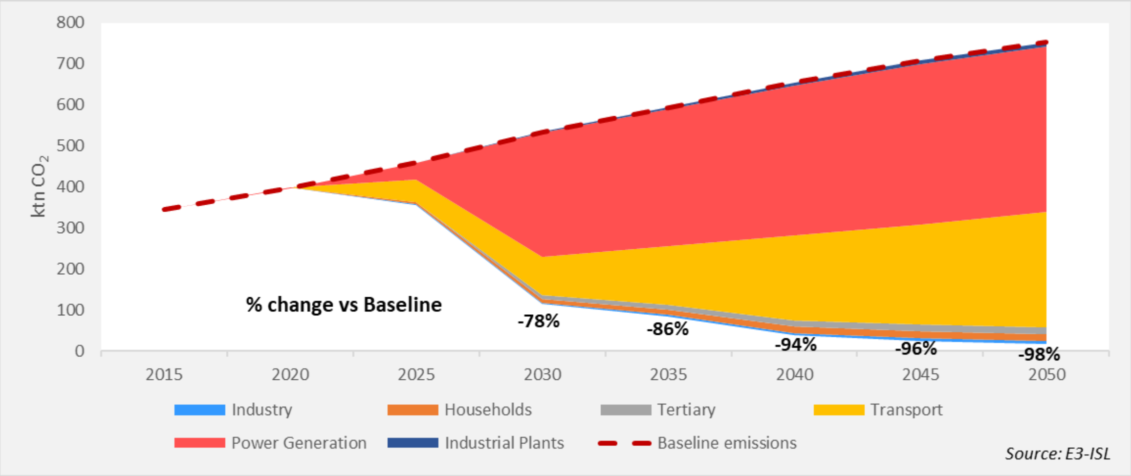
[70] A price signal that makes the carbon-intensive fuels unattractive. Carbon value is a driver that behaves as an implicit CO_2 reduction target and represents carbon emission taxation and other emissions reduction policies, but it is not finally paid. Carbon value applies to sectors not burdened with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

Heat recovery incentive	**€/MWh saved**	**Industry**	8.3	29.1	36.6	51.6	61.1	61.1

The graph that follows presents the CO_2 emission reduction trajectory of this decarbonization scenario compared to the Baseline emissions. Compared to the Decarb_Demand and Decarb_Supply scenarios, Mayotte is close to carbon neutrality 5-10 years earlier.



Source: E3-ISL

Figure 54: Early_Decarb – CO_2 emission reduction by sector vs Baseline

5.1.4. MAESHA-focused Decarbonization

This scenario explores the impacts of a full implementation of MAESHA solutions by 2025-2030 as well as the achievement of the relevant KPIs of the project. Decarbonization in Mayotte is assumed to be met by 2050, while intermediate targets for 2030 and 2040 are set. This scenario is characterized by high ambition in the period until 2035 and could result in early decarbonization of Mayotte, since one of the most carbon-intensive sectors, transport is envisaged to be decarbonized by 2040.

In this scenario, the overall targets set as KPIs in the MAESHA project have been met, while the achievement of several sectoral KPIs depend on the input assumptions of the analysis (Table 17). In the latter case, deviations from the initial KPIs may exist. Nevertheless, the policy directions and the level of climate ambition is sustained.

Table 18 MAESHAfocus – Scenario KPIs vs MAESHA KPIs

Horizon	KPIs	MAESHA	MAESHAfocus scenario
2025	Share of electricity production from fossil fuels	70%	75%
	Share of variable RES	30%	25%
	Additional installed capacity of RES	20 MW	35 MW (plus 18MW under construction or with license)
	Installed battery storage	1.4 MW/3 MWh	11.5MW planned
	Demand Response	2.6 MW/13 MWh	1 MW
	Total flexibility services	4 MW – 18 MWh	12.5 MW

	Self-consumption by Local Energy Communities	over 5MWh	4.3 MWh
	Reduction of CO_2 emissions in the power sector	30%	6% vs 2020 level 14% vs Baseline
	Reduction of CO_2 emissions in the transport sector	10%	10% vs 2015 level 23.4% vs Baseline
	Average LCOE variation before/after demonstration	-5%	-1% vs 2020 level -7% vs Baseline
2035	Share of electricity production from fossil fuels	40%	46%
	Share of variable RES	60%	54%
	Reduction of ICE car activity by 50%	50%	83% vs 2020 level 76% vs Baseline
	Reduction of CO_2 emissions in the power sector	60%	10% vs 2020 level 36% vs Baseline
	Reduction of CO_2 emissions in the transport sector	50%	40% 52% exc. aviation vs 2020 level
2040	Full decarbonization of the transport sector	√	√[71]
2050	Full decarbonization of the energy sector	√	√ (exc. aviation)

The policy focus in this scenario is front-loaded and resembles that of the early decarbonization scenario in order to achieve the KPIs of the MAESHA project in 2025, 2035 and 2040.

Table 19 MAESHAfocus – Key policy drivers

Policy Driver	Unit	Sector/End-use/Fuel	2025	2030	2035	2040	2045	2050
Carbon price	**€/tonCO_2**	**Industry-Power - Aviation**	80	170	211	252	293	375
Carbon value[72]	**€/tonCO_2**	**Buildings-Industry**	80	170	211	252	293	375
Carbon standards	**% reduction vs 2020**	**Passenger cars**	-56%	-96%	-100%	-100%	-100%	-100%
		LDVs	-61%	-96%	-100%	-100%	-100%	-100%

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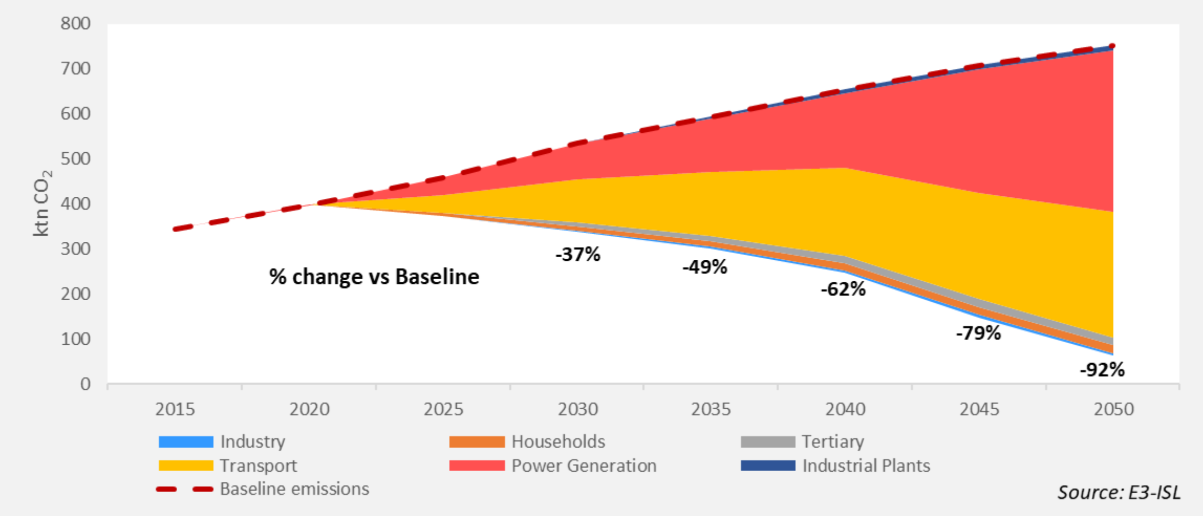
[71] The full decarbonization of transport sector (excluding aviation) in 2040 requires higher ambition than the one depicted in MAESHA KPIs for the years before 2040, i.e., more than 50% reduction of activity of ICE cars and further effort in 2025 (-15% reduction of emissions in transport by 2025 instead of -10%).

[72] 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 it is not finally paid. Carbon value applies to sectors not burdened with a carbon price.

		HDVs	-71%	-95%	-100%	-100%	-100%	-100%
		Buses/ Coaches	-55%	-78%	-99%	-100%	-100%	-100%
		Marine vessels	-51%	-67%	-90%	-98%	-98%	-98%
Blending mandates in Transport	**%**	**Biogasoline**	12%	15%	18%	25%	25%	25%
		Biodiesel	15%	20%	24%	32%	32%	32%
		Ammonia	-	2%	5%	10%	30%	50%
		Biokerosene	4%	15%	24%	35%	35%	38%
		Synthetic kerosene	1%	5%	8%	30%	30%	30%
Heat recovery incentive	**€/MWh saved**	**Industry**	8.3	29.1	36.6	51.6	61.1	61.1

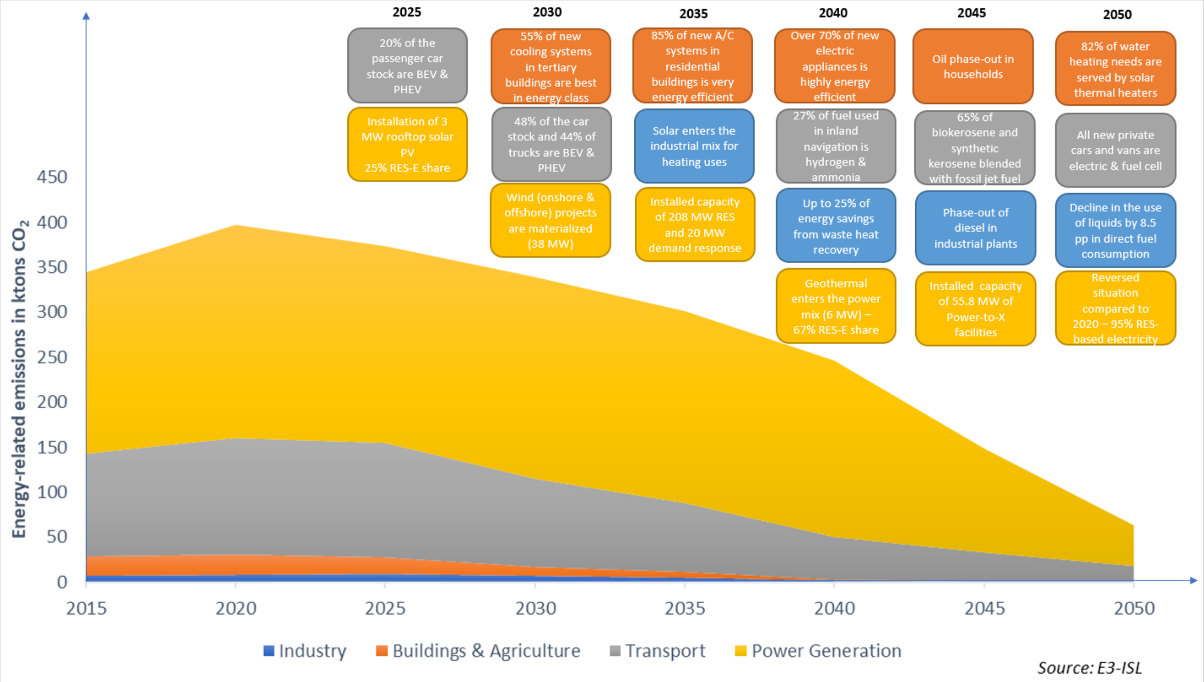
The Figure 55 presents the CO_2 emission reduction trajectory of this decarbonization scenario compared to the Baseline scenario. The transition to carbon neutrality is smoother in this scenario, even though it is characterized by high ambition in the medium-term. This is driven by the fact that the scenario does not consider the fuel switching of Longoni and Badamiers in 2030, since the MAESHA KPIs did not account for this possible development, strongly supported by EDM. It resembles the early decarbonization scenario, mainly because it sets the decarbonization of the transport sector – one of most carbon intensive sectors of the island – very early in the agenda.



Source: E3-ISL

Figure 55: MAESHAfocus – CO_2 emission reduction by sector vs Baseline

The key milestones of this pathway concern the rapid roll-out of cutting-edge technologies and fuels in critical sectors such as transport and power generation, as well as the exploitation of the still untapped energy saving potential in end-use sectors. The decarbonization of the transport sector is hard to be attained, first due to the "hard-to-abate" aviation and navigation transport segments and second, because that would entail the mandatory and thus abrupt withdrawal of conventional oil-fired vehicles in 2040 before the end of their lifetime, resulting in stranded assets.

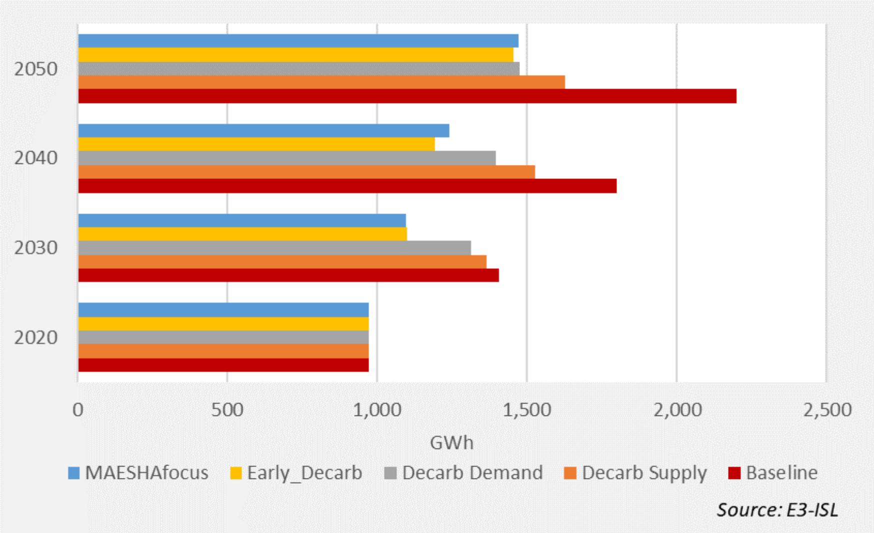


Source: E3-ISL

Figure 56: MAESHAfocus – CO_2 emission trajectory by sector & Key milestones

5.2. ENERGY CONSUMPTION

The introduction of stringent measures to reduce carbon emissions brings about a substantial reduction in the energy and carbon intensity of Mayotte. In all decarbonization scenarios, final energy consumption is at lower levels compared to the Baseline due to high electrification rates in the end-use sectors and energy efficiency improvements. In all decarbonization scenarios, the final energy consumption presents a continuously upward trend, driven by the rapid economic growth and rising standards of living in the island, but it stands more than 25% lower than in the Baseline scenario in 2050. The Decarb_Demand scenario is projected to lead to lower final energy consumption than the Decarb_Supply, as the latter is based on the emergence of clean e-fuels, which have a much higher energy intensity than electricity. On the other hand, Decarb_Demand is assumed to achieve significant energy savings from the demand side and accelerated electrification of energy and mobility end-uses.



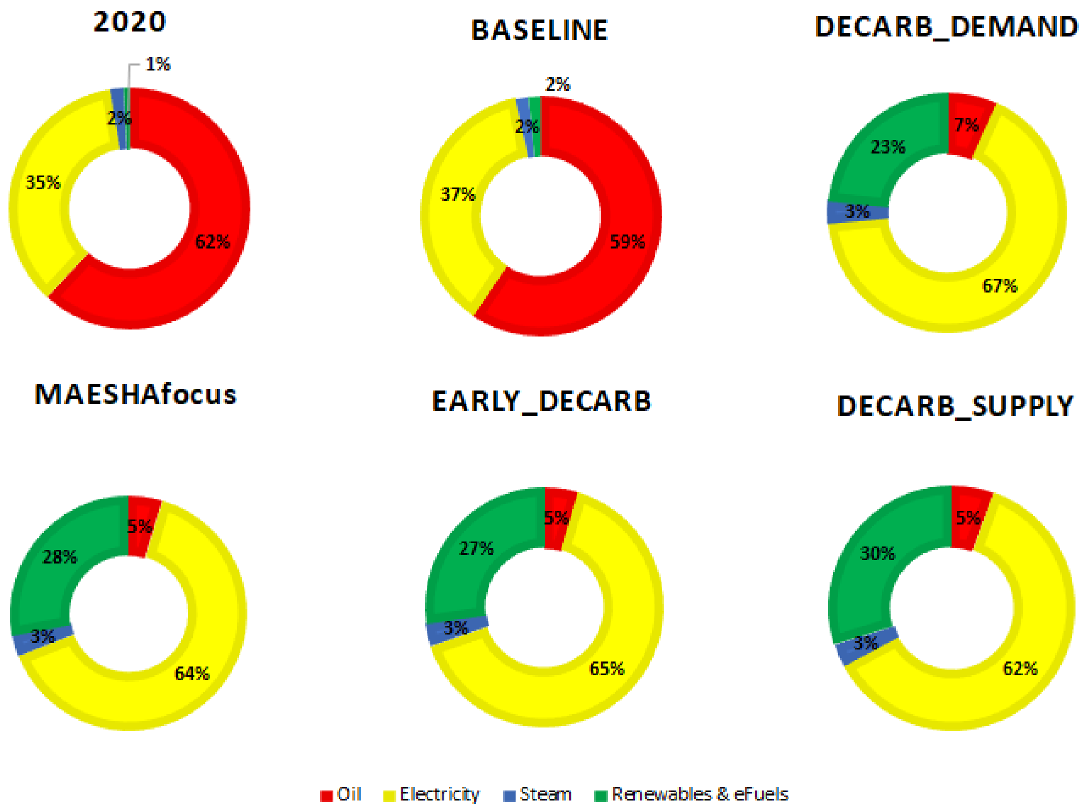
Source: E3-ISL

Figure 57: Evolution of Final Energy Consumption by scenario including the Baseline

The oil products currently represent 62% of the total end-use demand in Mayotte. Decarbonization scenarios would result in a large-scale reduction of fossil fuel use combined with the uptake of clean energy forms. However, the rate of substitution is limited in all demand sectors until 2030 in the scenarios Decarb_Demand and Decarb_Supply, with the share of oil standing at almost 52% in 2030; in contrast, the accelerated transformation assumed in the MAESHAfocus and Early_Decarb scenarios, implies that the share of oil declines to only 39% in 2030, due to its replacement by electricity in all demand sectors. Triggered by the rising CO_2 prices, the large-scale electrification, the use of e-fuels and hydrogen as well as other sectoral policies, the share of oil products is reduced substantially to only 5%-7% of by 2050 (mostly used for aviation), while in the Baseline scenario they accounted for 59%.

Final electricity consumption is projected to constantly increase in the long run, driven primarily by the electrification of the transport sector and secondarily by the industrial and building sectors. Electricity accounts for about 62%-67% of the total final energy consumption by 2050, mainly driven by the electrification of road transport.

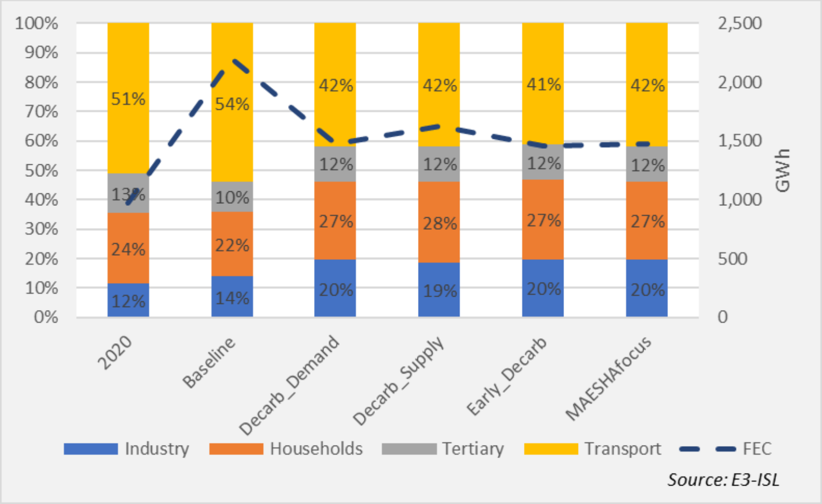
The consumption of RES in end uses concerns biofuels, solar thermal and clean fuels produced by electricity (hydrogen, ammonia, and synthetic liquids for transport). Currently, direct consumption of RES represents a small share in the island's final energy consumption, close to 1%. This comes mainly from the building sector. The imposition of high carbon price favors increased consumption of renewable fuels in transport, industry, and buildings. These fuels are projected to account for 23%-30% of final energy consumption in the series of decarbonization scenarios by 2050 and are mostly used in sectors that cannot be easily electrified, including navigation, aviation, freight transport, and manufacturing.



Source: E3-ISL

Figure 58: Fuel shares of Final Energy Consumption by scenario in 2050 and 2020

All sectors experience a significant reduction in energy demand as compared to the Baseline scenario. Over 60% of this reduction comes from the transport sector, followed by industrial and building sectors with much lower rates. Transport exhibits a high energy consumption reduction potential since electric vehicles are far more efficient than conventional vehicles. Moreover, the drop in energy demand is justified by the high shares of transport in final energy consumption (over 40% in the long run). Energy efficiency in the residential and tertiary sectors is driven by the use of energy efficient equipment and substitution of LPG stoves for cooking with the more efficient electric cookers.

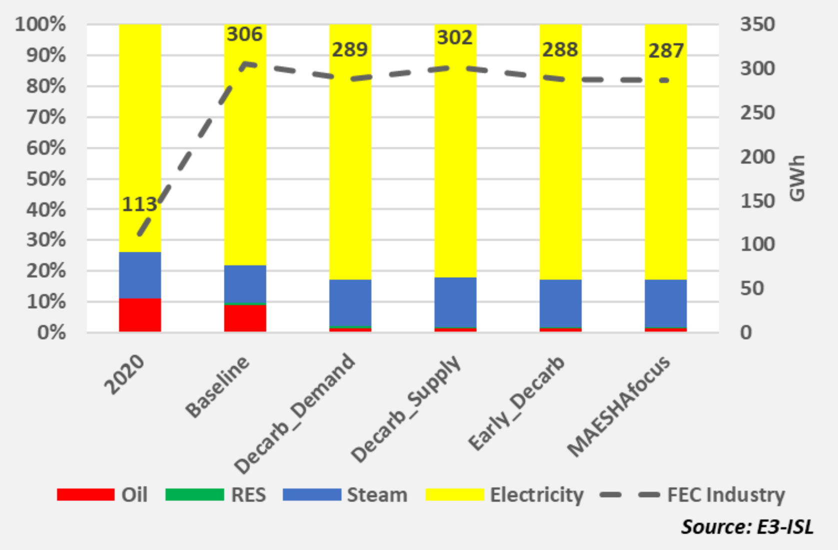


Source: E3-ISL

Figure 59: Final Energy Consumption by sector in % shares in 2050 vs 2020

The focus of industrial economic activity on the island of Mayotte lies on the food and beverage manufacturing, construction, wood enterprises and generally light industries to produce consumer goods[73]. Currently, the energy consumed by industry accounts for about 12% of the total energy consumption. The emissions from light industries are generally easier to abate from a technological point of view compared to heavy industry due to lower temperature requirements. At the same time, the energy saving potential is limited. Moreover, the light industry spreads over many different companies and products, adding to the complexity of deploying clean energy technologies at scale.

Compared to the Baseline scenario, energy demand in the industrial sector decreases slightly by almost 6% by 2050, mainly due to the limited energy saving potential in light industries. This is attributed to heat recovery investments, improvements in energy efficiency and electrification that drive the reduction of end-use consumption in industry.



Source: E3-ISL

Figure 60: Final Energy Consumption of Industry by fuel in 2050 vs 2020

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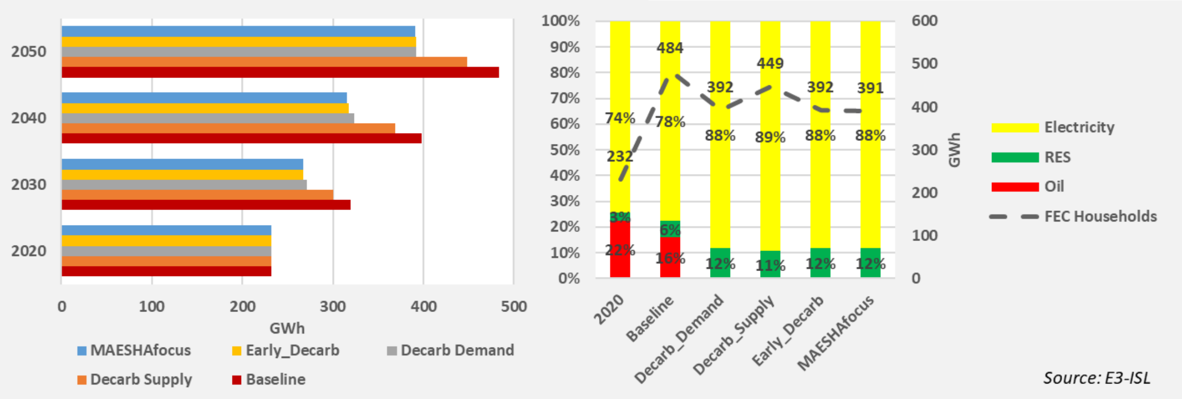
[73] https://www.iedom.fr/IMG/rapport_annuel_iedom_mayotte_2021/#page=1

Regarding the residential sector, the building stock in Mayotte is heterogenous regarding the building material and the status of construction. Due to the local climate conditions, there are no space-heating needs. In other regions of the world, heating of space is the most energy-consuming use in a household. This means that there are specific margins that allow for energy savings and fuel switching.

The Demand_Supply and Decarb_Demand scenarios assume the scale up of policies for the clean energy transition after 2030 and thus the final energy consumption in the residential sector follows roughly the Baseline scenario trend until 2025. This trend persists in the Demand_Supply scenario, as it considers no major energy saving effort from the demand side. In contrast, the Early_Decarb and MAESHAfocus scenarios that are characterized by accelerated transformation present a sharp decline in final energy consumption relative to the Baseline scenario even from the year 2025.

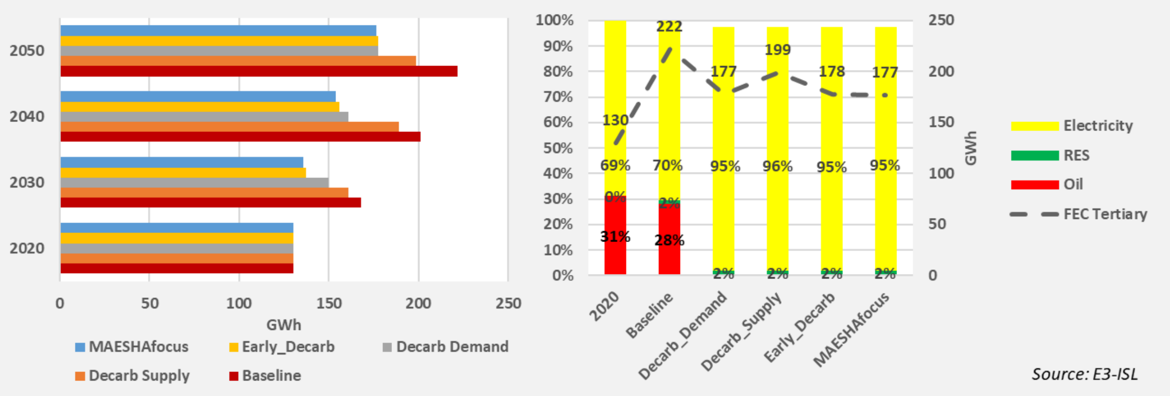
Currently, the residential sector is already highly electrified in Mayotte. The oil products – LPG and paraffin oil – used for cooking purposes are projected to be substituted by electricity, while high diffusion of solar thermal water heaters displace the electric ones. The current effort of EDM and the Departmental Council to promote the purchase of individual water heaters supplied by solar thermal energy through a financial assistance system is scaled up in the decarbonization scenarios.



Source: E3-ISL

Figure 61: Final Energy Consumption of Households by scenario & fuel in 2050 vs 2020

Currently, the services sector consumes only electricity and solar energy for water-heating purposes, while agriculture uses diesel for pumping and motors. Gradually, this sector becomes almost fully electrified, driven by the introduction of cost-efficient new technologies. Services and agriculture are the less energy consuming sectors in the island, and consequently their relative contribution in the decarbonization of the energy system in Mayotte is minimal.



Source: E3-ISL

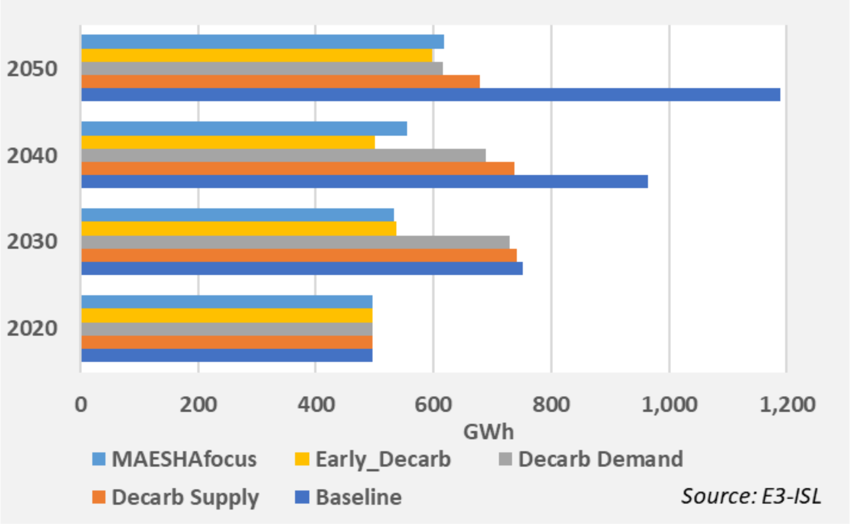
Figure 62: Final Energy Consumption of the Tertiary sector by scenario & fuel in 2050 vs 2020

Regarding transportation, the activity by mode is similar in all scenarios – no major modal shifts are assumed to be materialized for local transportation. The decarbonization scenarios accounted for the following facts derived from the multi-annual energy plan:

- The current public transport services in Mayotte are limited to a maritime barge link between Petite Terre and Grande Terre, collective taxis, as well as school transport services for students.
- The motorization rate in Mayotte remains very low: around 30% of households own a vehicle compared to more than 80% in mainland France. The territory also observes a modal shift from mopeds to private cars, which can be explained by the increase in GDP per capita.

These trends are reflected in the scenarios, that is why no significant shift is materialized towards public transport, and the motorization rate is increasing in all scenarios.

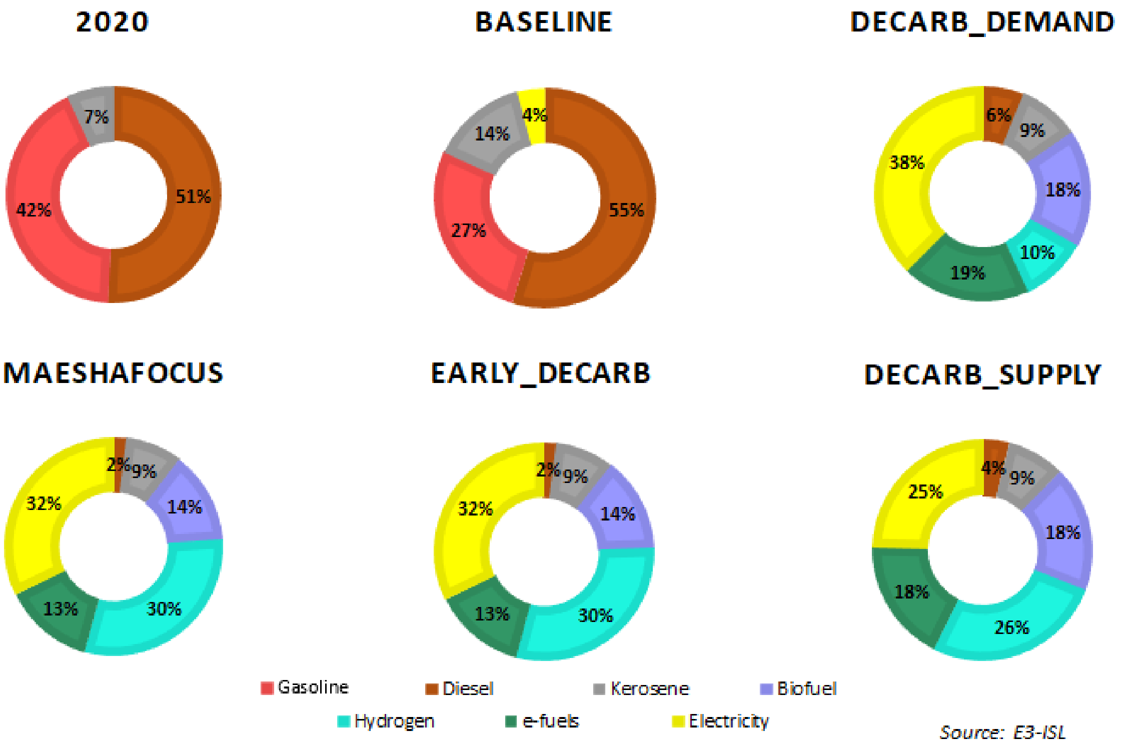
The decarbonization of the transport sector is a quite challenging task and requires considerable investments both in infrastructure (charging points, clean fuel production, etc.) and in equipment (BEVs, fuel cells, etc.). Apart from these challenges, vehicles are characterized by long lifetimes and hence their full replacement with zero-carbon technologies may be a long process. The Early_Decarb and MAESHAfocus scenarios show the best performance in terms of energy consumption for the transport sector, as they assume that the decarbonization of transport will be completed by 2040-2045. This implies that the ambitious policy action should be initiated even before 2025. The next best-performing scenario is Decarb_Demand which stipulates higher electrification rates compared to Decarb_Supply that considers wide use of hydrogen and e-fuels, which have much higher energy intensities compared to the direct use of electricity.



Source: E3-ISL

Figure 63: Final Energy Consumption of the Transport sector by scenario

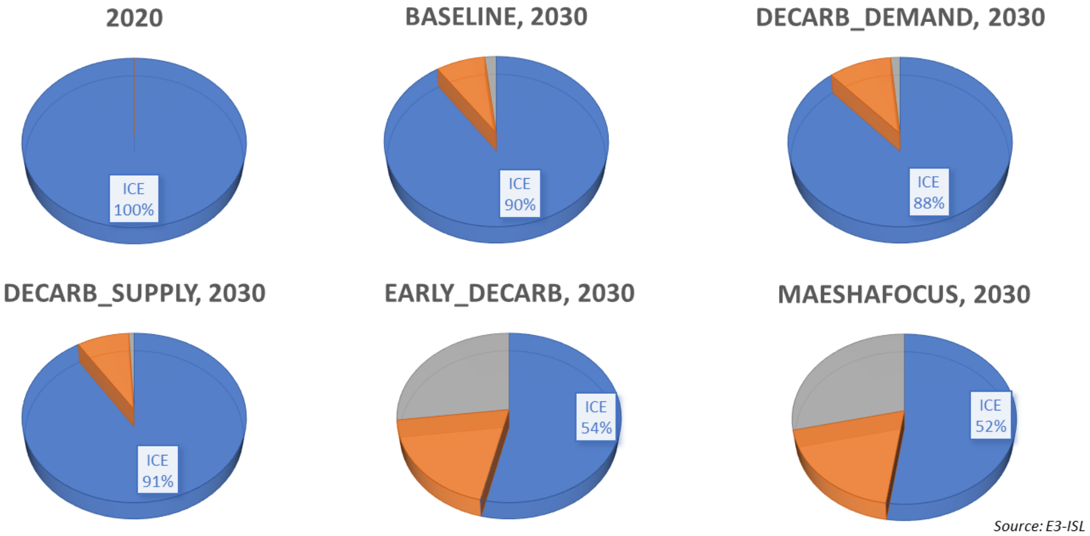
The stringent technology performance standards and the blending mandates are the main policy drivers that lead to a carbon-neutral transport system. The scenarios are differentiated in terms of the decarbonization horizon for the transport sector and in terms of the technology mix used for the clean transition. For instance, the Decarb_Supply scenario implies higher roll-out of fuel cell vehicles and wide use of e-fuels and biofuels such as ammonia for navigation, synthetic kerosene and biokerosene for aviation and conventional and advanced ethanol and methanol compared to Decarb_Demand. On the other hand, the Demand_Decarb scenario considers massive penetration of pure battery electric vehicles in the road transport sectors and in other transport segments. The residual shares of diesel (2%-6% in 2050) and kerosene (9% in 2050) corresponds to navigation and aviation respectively. Overall, decarbonization leads to a higher diversification of the transport fuel mix compared to the current absolute dominance of oil products. Several low-emission fuels emerge to replace the carbon-intensive use of oil products (diesel, gasoline and kerosene), each of them focusing on specific transports segments: electricity with a share of 25%-38% among the decarbonization scenarios in 2050 is mostly used in passenger cars, hydrogen (share of 10%-30%) is mostly used in freight transport, biofuels (14%-18%) and e-fuels (13%-19%) are mostly used to decarbonize aviation and navigation sectors. This illustrates the different options, choices and low-emission fuels to decarbonize the transport sectors, the deployment of which is highly influenced by specific scenario assumptions.



Source: E3-ISL

Figure 64: Final Energy Consumption of the Transport sector by fuel and scenario in 2050 vs 2020 fuel mix

Private passenger road transport accounts for over 50% of the total energy demand of the sector. Hence, the private car fleet is at the center of decarbonization efforts. All four decarbonization scenarios envisage a growing share of zero and low emission vehicles. Higher ambition is foreseen in the Early_Decarb and MAESHAfocus scenarios, driven by stricter carbon standards and the ambition for a full sectoral transformation before 2050.

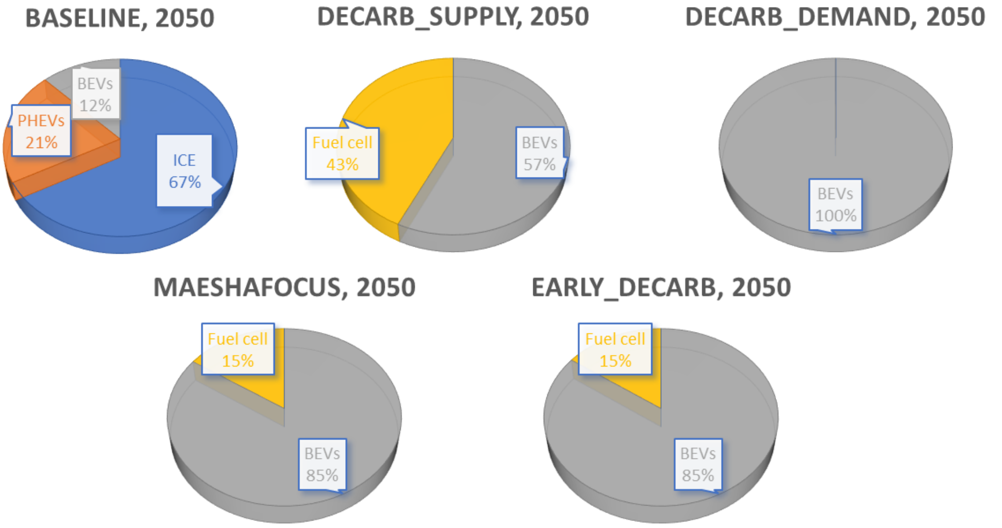


Source: E3-ISL

Figure 65: Stock of passenger cars by type as % share by scenario in 2030

As presented in the Figure 65-Figure 66, the private passenger road transport shifts away from fossil fuels. Two types of electric vehicles are assumed:

- Battery electric vehicle (BEV), powered solely by an electric motor, using electricity stored in an on-board battery which should be charged, typically by plugging the vehicle in to a recharging point connected to the local electricity grid.
- Fuel cell electric vehicle, entirely propelled by electricity, which is generated on board by a fuel cell stack that uses hydrogen, which should be carried in a tank. They can provide longer ranges than BEVs and the time of refueling is almost the same as that of internal combustion engine vehicles. The drawbacks are the high purchase costs, mainly due to the expensive fuel cells, and their lower efficiency than BEVs. Currently, few fuel cell cars are offered for sale on the EU market and the refueling infrastructure is less developed than that for electric cars[74].



Source: E3-ISL

Figure 66: Stock of passenger cars by type as % share by scenario in 2050

5.3. ENERGY SUPPLY

The decarbonization of the end-use sectors would increase electricity requirements either for direct use (electrification) or indirect use for the production of hydrogen and e-fuels. It is obvious that in all decarbonization scenarios, the gross electricity demand is projected to increase from Baseline levels, driven mainly by the transport sector. Demand for green hydrogen and for synthetic fuels represents a considerable share of electricity consumption in the long run, especially in the Decarb_Supply scenario. Electricity demand by electrolyzers is added to the electricity demand by end-users and the grid losses.

The rise of the gross electricity demand implies significant investments in the power sector and especially on RES and storage. This is more pronounced in the case of the Decarb_Supply scenario that entails high levels of production of hydrogen and clean e-fuels and relatively low energy savings and flexibility from the demand side. The Early_Decarb and MAESHAfocus scenarios have intermediate targets regarding the penetration of renewable energy and especially solar PV; thus in 2030 almost 40% of the electricity needs are served by variable RES, wind and solar PV. In the longer term, the picture is totally different, and the power sector is fully transformed towards a RES-based paradigm. More than 90% of the electricity is produced from variable RES coupled with storage, while Longoni and Badamiers still operate providing balancing services, albeit with low utilization rate. Both power plants are running with biodiesel from 2030 onwards in all decarbonization scenarios, thus having zero

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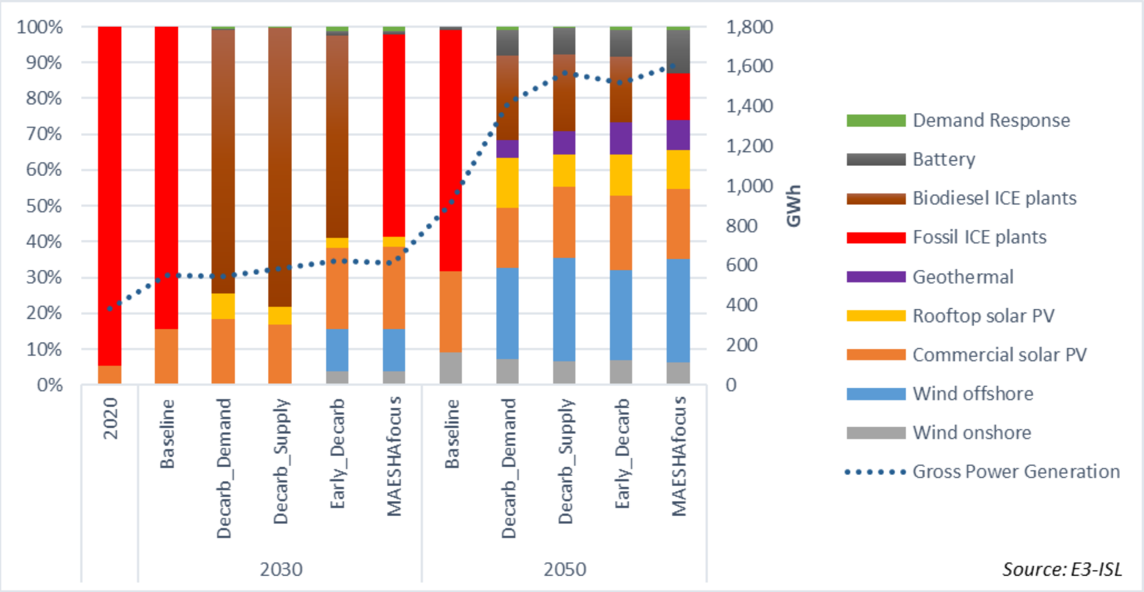
[74] https://www.eea.europa.eu/publications/transport-and-environment-report-2021/download

CO_2 emissions from an energy system perspective, without considering emissions relate to the Land Use, Land Use Change and Forestry (LULUCF) sector.

In order to respect the boundaries of the local energy resources of the island, we assume that 50% of the needs for hydrogen, ammonia and synthetic kerosene, will be served through imports, without compromising the energy security of the island.



Source: E3-ISL

Figure 67: Gross Power Generation by plant type & scenario in 2020, 2030, 2050

It is important to note that, due to the decreasing costs of variable RES and the increasing carbon price, the variable RES and especially solar PV is the most cost-efficient power generation technology in the mid- and long-term. Consequently, in the long run, the capacity mix is dominated by solar PV plants in all decarbonization scenarios. Solar PV plants are the primary source of renewable energy generation, but their capacity factor is lower compared to the wind plants. On-shore 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 2030 or 2035 depending on the scenario. According to the ADEME study[75], the local potential of wind offshore is 200 MW. The high capital cost of offshore wind is partially compensated by its high capacity factors, which boost its competitiveness at high CO_2 prices. It is assumed that the geothermal potential is partly utilized in the period after 2040. The use of variable RES and the demand for clean fuels leads to high investment in battery storage and Power-to-X facilities. Demand response practices are widely applied in the Decarb_Demand scenario and thus the need for battery storage is lower than in other scenarios.

Regarding the penetration of rooftop solar PV, this is pronounced in Decarb_Demand scenario reaching 140 MW, as compared to the other scenarios, driven by strong consumer willingness to embrace the transition and perform decentralized emission reduction actions. This technology is differentiated by the commercial solar PVs based on the different capacity factor and the capital costs per kW, as well as the “perceived/hidden” costs that are associated with the unclear regulatory framework and other barriers that often impede consumers on investing on this technology. In the case of MAESHAfocus scenario, the installed power capacity reaches the highest point compared to the other scenarios, driven basically by the high battery storage capacity. Unlike the other decarbonization scenarios, this scenario does not account for the fuel switching of the existing diesel plants to biodiesel, hence oil-fired plants are charged by the high levels of carbon price, rendering them totally uneconomical. This makes the deployment of variable RES a preferable cost-efficient

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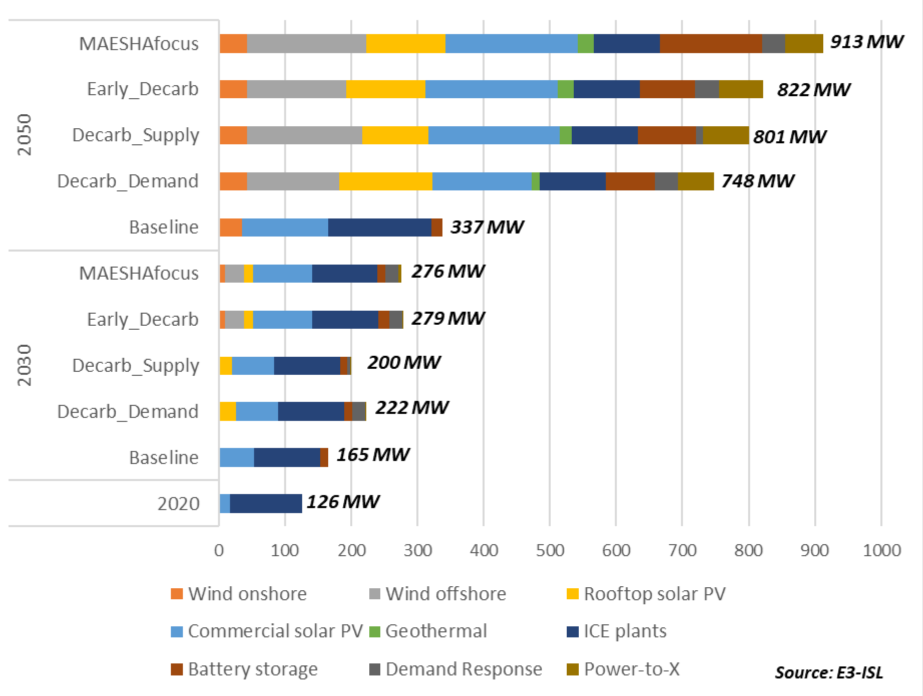
[75] https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/4172-vers-l-autonomie-energetique-en-zone-non-interconnectee-zni-a-mayotte-a-l-horizon-2030.html

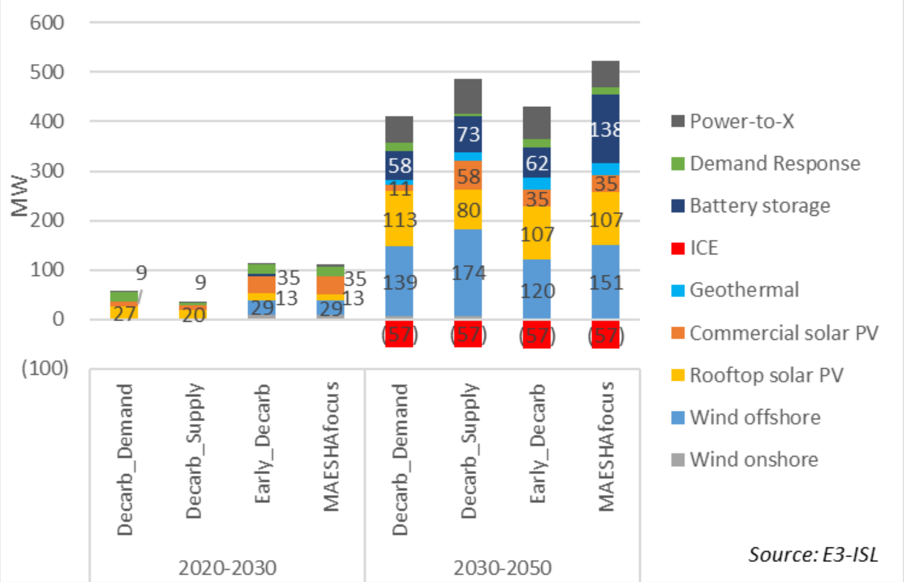
alternative. In this respect, higher investments are materialized on wind offshore plants, with still untapped potential, coupled with higher battery storage for balancing purposes, thus decreasing the operating hours of diesel-fired power plants. This is evident in the Figure 67.



Source: E3-ISL

Figure 68: Gross installed capacity by type and scenario in 2030 & 2050 vs 2020 level

Figure 69 presents the additional investment capacities in the alternative decarbonization scenarios compared to the Baseline scenario. It should be highlighted that the investment of 57 MW on new diesel plants is avoided in the decarbonization scenarios.



Source: E3-ISL

Figure 69: Investment capacities by type and scenario in 2020-30 & 2030-50 (difference from Baseline)

In order to assess the impact of higher imports of clean fuels on the power system, two additional variants have been developed, assuming 80% and 100% of imports respectively, while Decarb_Supply assumes an import share of 50%. In these cases, the investment in RES capacity is lower, while no investments are needed for Power-to-X plants. However, in the 100% imports scenario, there are higher needs for battery storage to balance the intermittent power generation from variable RES, while this is not the case for the other two scenarios (main Decarb_Supply and Decarb_Supply with 80% imports), since part of the excess electricity was channeled for chemical storage through Power-to-X.

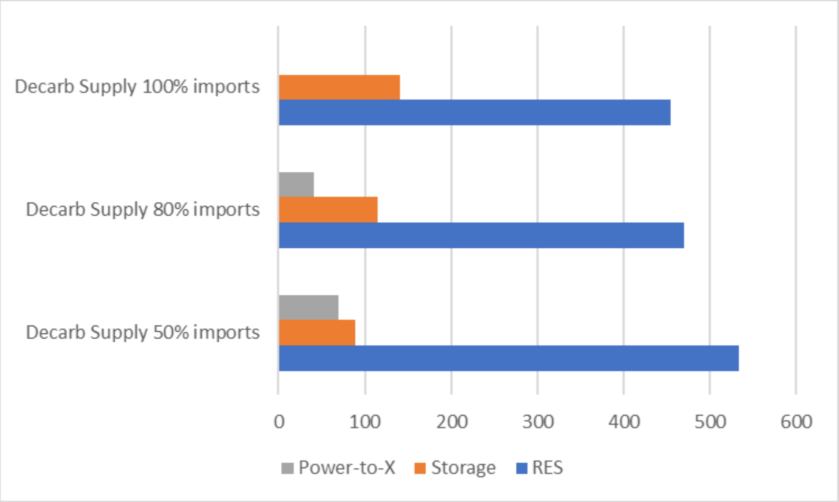
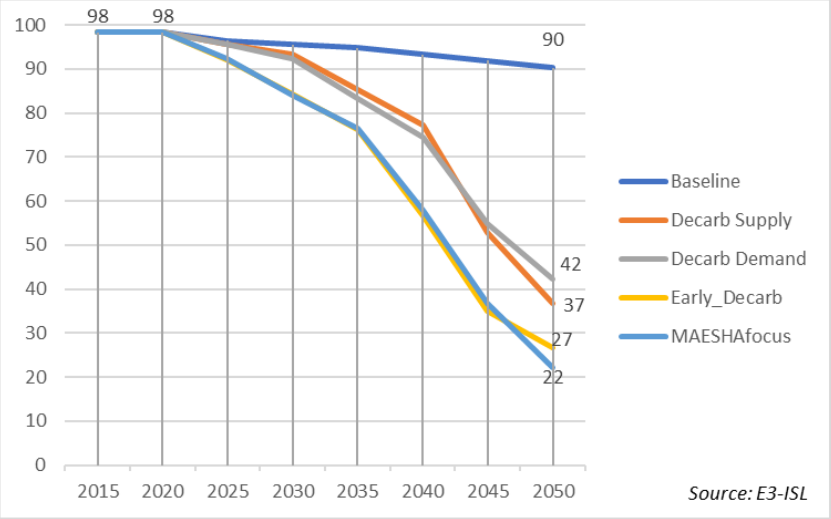


Figure 70: Variants of Decarb_Supply – Installed power capacity in 2050 by type in MW

The Early_Decarb and MAESHAfocus scenarios score best in term of energy import independence, as they rely more on the use of domestically produced renewable-based electricity and less on the use of hydrogen, e-fuels, diesel, biodiesel, and kerosene, which are imported to Mayotte (at least to some extent). More specifically, these scenarios assume the installation of more geothermal power capacity that provide a reliable, always available to be used, source of energy, unlike the intermittent sources such as wind and solar power. This reduces the need for the operation of ICE plants for balancing, thus decreasing the biodiesel and diesel imports for power generation. The energy import dependence ratio is projected to massively decline from Baseline levels (90% in 2050) in all decarbonization scenarios (ranging between 22%-42% in 2050).



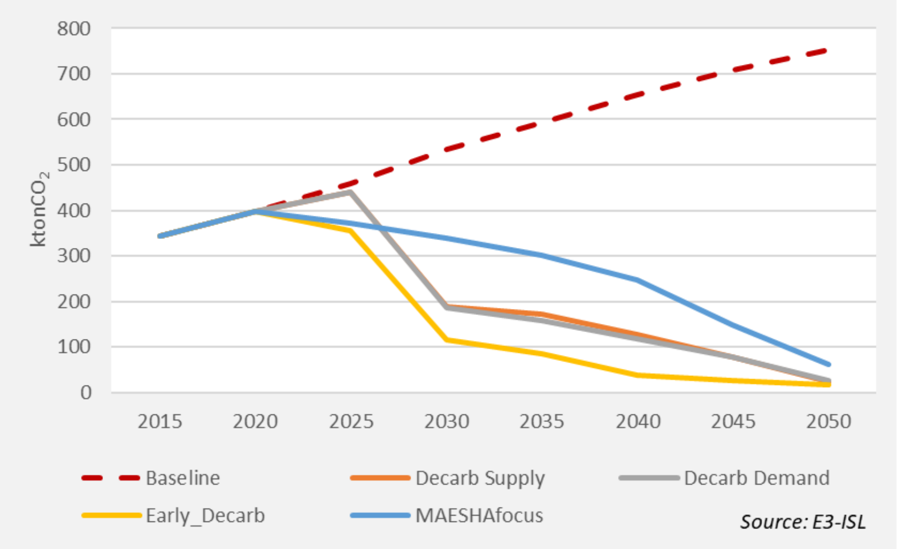
Source: E3-ISL

Figure 71: Evolution of energy import dependence by scenario

5.4. EMISSIONS

Power generation and transport sectors account for about 94% of total emissions in 2020 in Mayotte. The alternative decarbonization scenarios developed for this analysis follow differentiated pathways to carbon neutrality, but they all end up with an emissions reduction of about 97% in 2050.

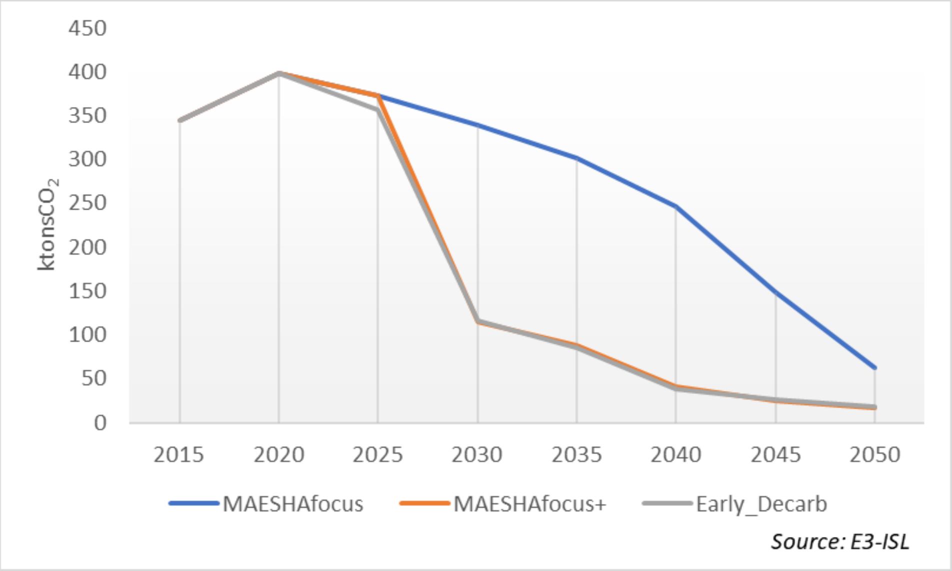
The Decarb_Supply is a scenario mainly focused on the supply side transformation, assuming that limited energy saving efforts are performed in the demand side. Thus, it is a more technology- and less citizen-oriented pathway and stresses the boundaries of the power system and the renewable energy potentials, due to the high deployment of hydrogen and e-fuels. The emission reduction is achieved with the use of hydrogen, ammonia, and synthetic fuels in the demand-side, while on the supply side a significant reduction is attained in the medium run, through the fuel switching of diesel plants currently producing 95% of the island's electricity requirements, to biodiesel. The same assumption is also used in the Decarb_Demand, Decarb_Supply and Early_Decarb scenarios, as this is considered as a top priority in the agenda of EDM. The Decarb_Demand scenario focuses on high electrification of transport, heat recovery in industry and the use of highly efficient equipment in buildings. On the other hand, MAESHAfocus envisages the gradual underutilization of the diesel-fired power plants and their replacement by a combination of variable RES and storage.



Source: E3-ISL

Figure 72: CO$_2$ emission trajectories by scenario

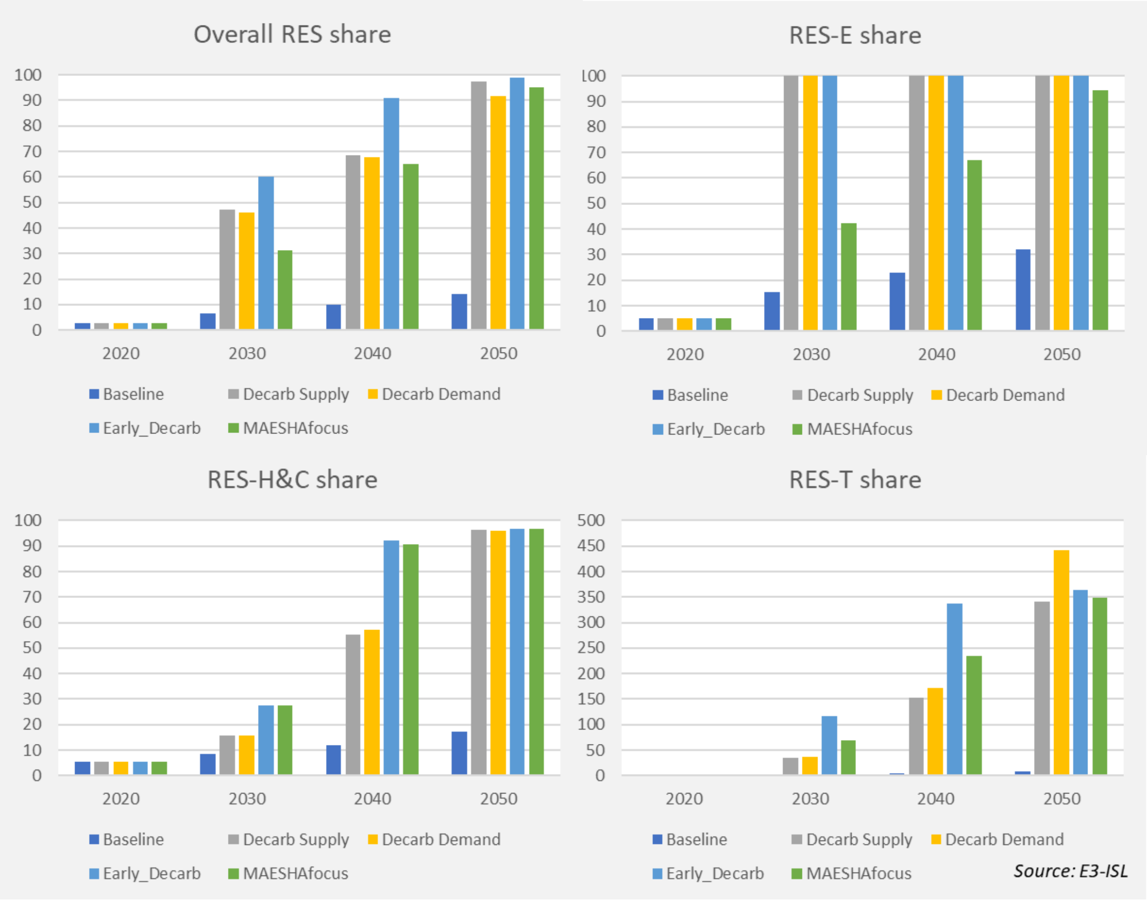
A variant of MAESHAfocus scenario (MAESHAfocus+) has been developed assuming the fuel switching of the existing plants by 2030 (in addition to the MAESHAFocus specifications). Scrutinizing the results of the scenarios, it is evident that the ambition of MAESHAfocus+ is similar to the Early_Decarb scenario.



Source: E3-ISL

Figure 73: CO$_2$ emission trajectory of MAESHAfocus+ scenario vs MAESHAfocus and Early_Decarb

Figure 74 presents the evolution of the RES shares in Mayotte in the series of scenarios explored. The overall RES share is projected to substantially increase from the current 2% to around 12% in the Baseline scenario and further to between 90%-100% in the series of decarbonization scenarios in 2050. The increase is very high even in the medium term, especially in the Decarb_Demand scenario in which the RES share is projected to reach 60% in 2030 driven by the rapid transformation of the energy system assumed in the scenario. The increase is more limited in other decarbonization scenarios, with RES share ranging between 30%-40% in 2030. As the electricity sector is commonly considered the easier and faster to decarbonize given the high cost competitiveness of various RES-based technologies (solar PV, wind), the RES-E share is projected to increase to 100% even from 2030 onwards in all decarbonization scenarios; The MAESHAfocus scenario is an exception as some small diesel quantities are used in the thermal power plants, as the fuel switch to biodiesel is not included in this scenario. The decarbonization of the electricity sector combined with the emergence of RES and clean fuels drives the extensive increases in the RES shares in Heating and Cooling (e.g., through solar heaters and zero-emissions electricity) and in the transport sector, triggered by the deployment of renewable-based electricity, green hydrogen, clean e-fuels, and biofuels.



Source: E3-ISL

Figure 74: RES shares by scenario[76]

Figure 75 shows the development of the energy and carbon intensity of GDP in Mayotte in alternative policy scenarios. As expected, the carbon intensity of GDP is projected to reach levels close to zero in all decarbonization scenarios by 2050 driven by the assumption of carbon neutrality. However, there

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[76] Share of renewable energy in transport for the period 2015 to 2020: final energy from renewable sources consumed in transport (cf. Article 5(1)(c) and 5(5) of Directive 2009/28/EC). Share of renewable energy in transport for the period 2025 to 2050: The calculation of the Renewable energy share in transport follows the rules specified in the Article 27 of the Directive (EU) 2018/2001. The calculation includes the multipliers specified in Article 27(2) to demonstrate compliance with the minimum shares referred to in Article 25(1) on the promotion of the use of energy from renewable sources.

are large differences in the 2030 timeframe, with the Early_Decarb scenario achieving larger reductions relative to the other decarbonization scenarios triggered by the accelerated transformations dynamics incorporated in this scenario. Energy intensity of GDP declines in all scenarios by 2050 from 2020 levels, but the rate of reduction ranges from 41% in the Baseline scenario to 45%-53% in the various decarbonization scenarios; with Decarb_Demand having the largest energy intensity reduction as it focuses on energy efficiency improvements in all demand sectors.

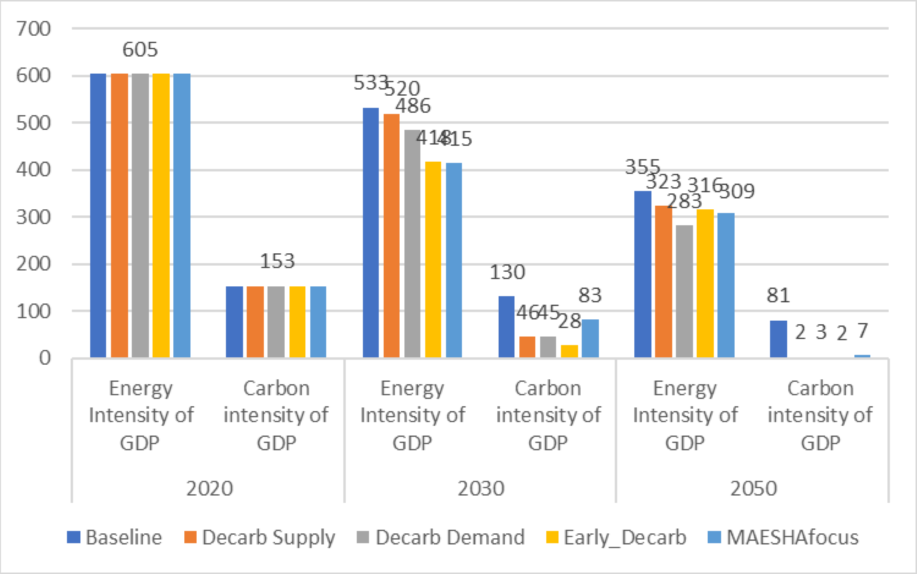
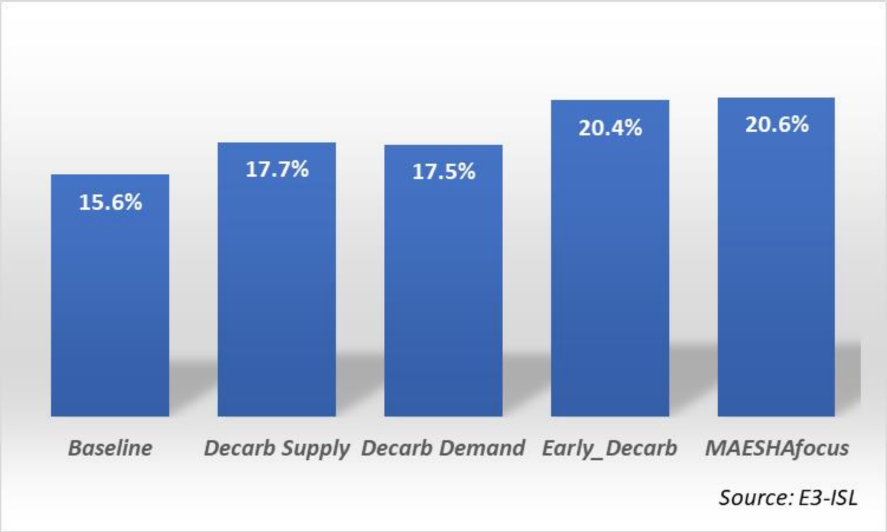


Figure 75: Energy and Carbon intensity of GDP by scenario

5.5. COSTS

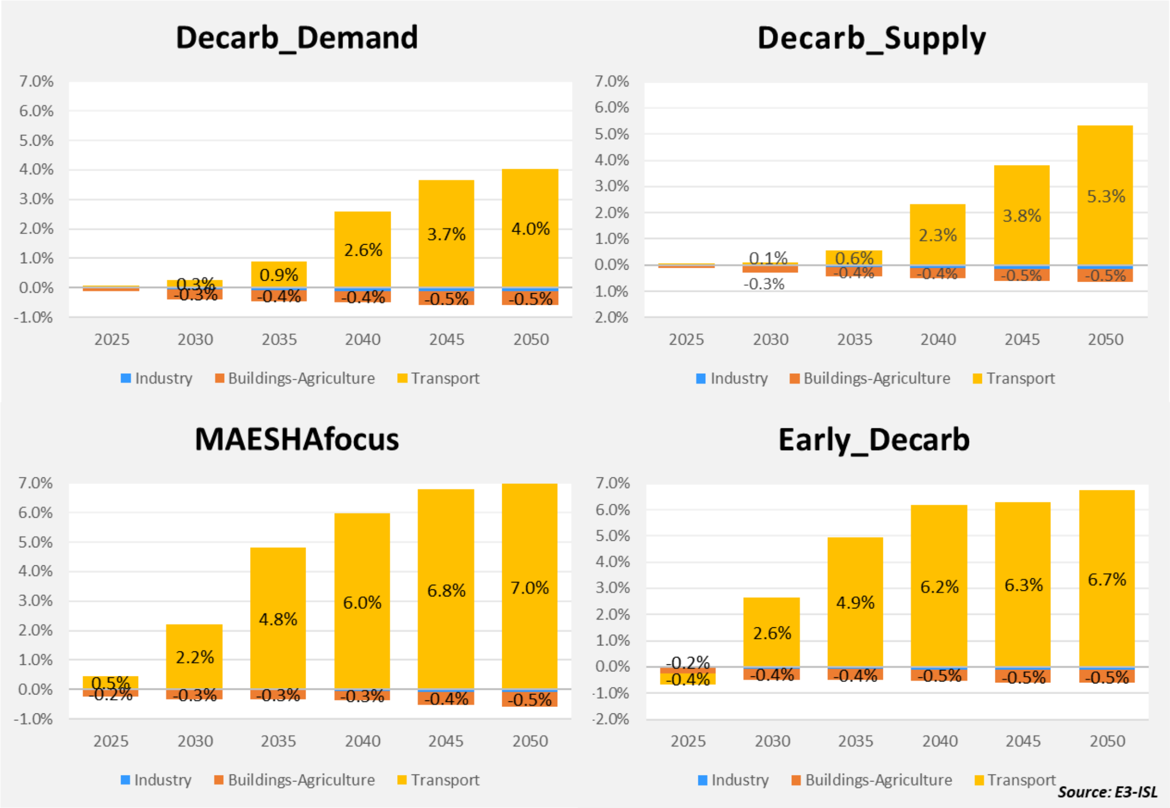
The transition to carbon neutrality is projected to entail rising energy system costs in Mayotte above Baseline scenario levels, mostly due to the increase of investment and capital expenditure for clean technologies, efficient equipment, and low-emission vehicles. This increase is mostly triggered by the high capital expenditure to decarbonize the transport sector, which results in an increase of total energy system costs of about 2-5 percentage points of Mayotte's GDP above the Baseline scenario. Lower costs are incurred in the Decarb_Demand scenario, 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 that are mostly used in Decarb_Supply.

Judging from the cumulative energy system costs of each scenario, the costlier scenario is the MAESHAfocus. This is stipulated by the fact that it sets the clean transition of the transport sector very early in the decarbonization agenda. The decarbonization of transport entails high costs to purchase zero-emission vehicles for road, water, and air transport, as well as to build the required infrastructure (recharging stations, fuel production). Since the capital costs of the emerging clean technologies and vehicles are assumed to gradually decline over time (learning effects), the scenarios assuming a more gradual transition (Decarb_Suppply, Decarb_Demand) have lower costs than those assuming a very rapid transformation by 2030 (Early_Decarb, MAESHAFocus), as shown in Figure 76.



Source: E3-ISL

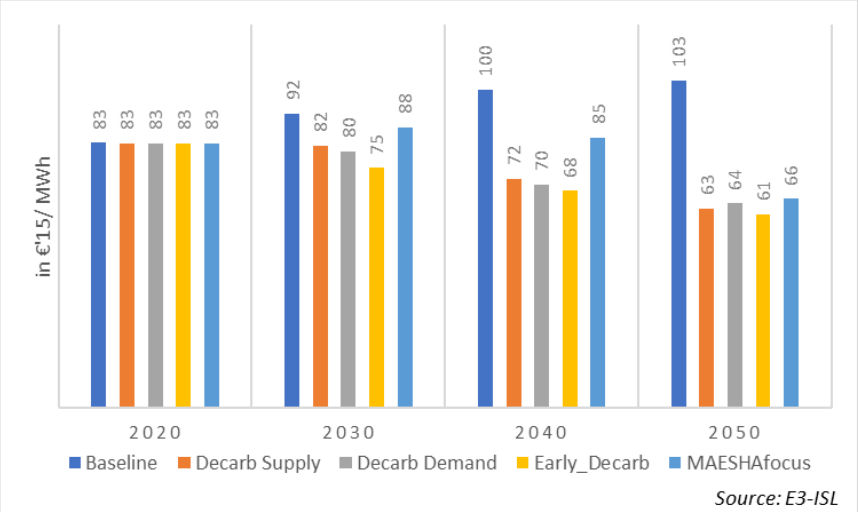
Figure 76: Cumulative system costs as % of cumulative GDP by scenario



Source: E3-ISL

Figure 77: Energy system cost difference as % of GDP by scenario vs Baseline

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 scenarios 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. As shown in Figure 78, the reduction in pre-tax electricity price in Mayotte is projected to be significant, ranging between 5%-18% in 2030 and 36%-41% from Baseline levels in 2050.



Source: E3-ISL

Figure 78: Evolution of pre-tax electricity prices by scenario in €/MWh

Consequently, the energy costs of a household (without accounting for private transportation but only for energy consumption in the buildings) are also declining, since electricity is basically the sole energy carrier used and paid by the consumers.

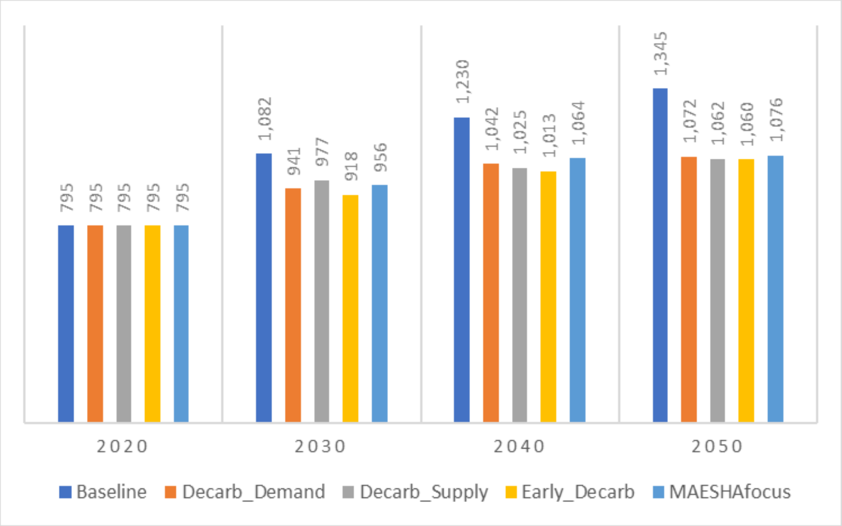


Figure 79: Evolution of Household energy costs (w/o transport costs) by scenario in €'2015 per HH

6. SOCIO-ECONOMIC IMPACTS

The current section presents the main macro-economic, employment, industrial and trade impacts of the ambitious decarbonization scenarios for Mayotte. The alternative policy scenarios are simulated with the GEM-E3-ISL model, which is a multi-sectoral, recursive dynamic computable general equilibrium (CGE) model that provides details on the macro-economy and its interactions with the energy system. The GEM-E3-ISL version is developed and used in the MAESHA project and identifies Mayotte as a single region and captures its linkage with the rest of world through endogenous trade and financial transfers. GEM-E3-ISL performs dynamic simulations, covering the period from 2020 up to 2050 with a five-year time step and projects to the future the national/regional accounts, investment, consumption, activity by sector, prices, employment, and trade. GEM-E3-ISL incorporates a detailed representation of the energy system and related technologies, including: i) a bottom-up modelling of the electricity supply sector with power producing technologies treated as separate production sectors, ii) energy demand for households, divided into heating and cooking demand and electric appliances, and separated into different fuels, iii) a bottom-up representation of transport, simulating the choice of alternative (passenger and freight) transport modes and technologies and the way of using transport equipment, and iv) a representation of production and demand of green hydrogen, triggered by ambitious climate policies. The modelling enhancements recently implemented in GEM-E3 to improve the representation of the energy and transport sectors and relevant decarbonization options are described in (Fragkos, Fragkiadakis, 2022).

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 section 2.3 of the deliverable. The soft link was enabled by the harmonization of the sectoral and technology representation and granularity of the two models (i.e., the 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 examining and synchronizing different sets of energy-related variables and parameters, including among others, power generation mix, energy demand, fuel mix by sector, transport by fuel, mode and technology, and energy efficiency measures. The same set of decarbonization scenarios has been studied in the two models, described in detail in section 11.1.

6.1. MACRO-ECONOMIC IMPACTS

The transition to a low carbon economy 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 policy makers, industrial manufactures, R&D providers, the finance sector, infrastructure developers and final consumers. Energy system decarbonization involves the substitution of fossil fuels (which are imported in Mayotte) by products and services related to low and zero-carbon technologies and energy-efficient equipment and appliances. The construction/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. 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 economies.

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 and towards a more capital-intensive structure. Depending on the costs of low-carbon technologies, this process may be costly in the short-term, thus increasing the average price of energy services (e.g., the average 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 low- and zero-carbon technologies, reduced energy import bill as well as environmental benefits (e.g., reduced climate damages). In addition, in the specific case of 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 Levelized Cost of Electricity (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 (Karkatsoulis et al., 2016), given that low-carbon investments are more capital intensive relative to fossil fuels (Polzin et al., 2021). As financing of new products and technologies is not available at uniform interest rates, the supply of finance depends on the risks of new clean energy technologies (i.e., limited financial resources for high-risk capital).

The main policy instruments used to drive decarbonization in Mayotte are the same as in E3-ISL, already described in section 2.1. The imposition of high carbon pricing is the key measure driving 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 imposition of high carbon pricing drives energy system transformation towards a more capital-intensive structure, with increased investment in renewable energy, energy efficiency projects 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[77], while the cost of capital across the economy is projected to increase from Baseline scenario levels due to the increased requirement for capital-intensive investment related to renewable energy and energy efficiency..

High carbon prices increase the cost of energy and mobility services for firms and households and hence production costs throughout the economy and tends to have a depressive impact on GDP. However, in the context of 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 economic activity is found to be minimal in the medium term; but as transformation progresses and the impacts on electricity prices become increasingly pronounced, the transition positively influences the island's GDP, which is projected to increase by 1.5%-4.5% in different decarbonization scenarios relative to the Baseline in 2050. The scenario focusing on consumer-driven transition (Decarb_Demand) with the active involvement of communities (engaging in energy savings, demand response, V2G, car sharing, rooftop PVs, and high electrification) is found to generate more positive economic impacts relative to Decarb_Supply where the transition is driven by supply-side changes and large 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 energy efficiency, electrification, and active citizen participation in the transition to carbon neutrality.

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[77] Crowding-out effects can diminish in case a favorable 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).

In the scenarios achieving early decarbonization (MAESHA Focus and Early_decarb), the rapid energy system transformation poses stresses in capital markets in the decade 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 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 80) 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.

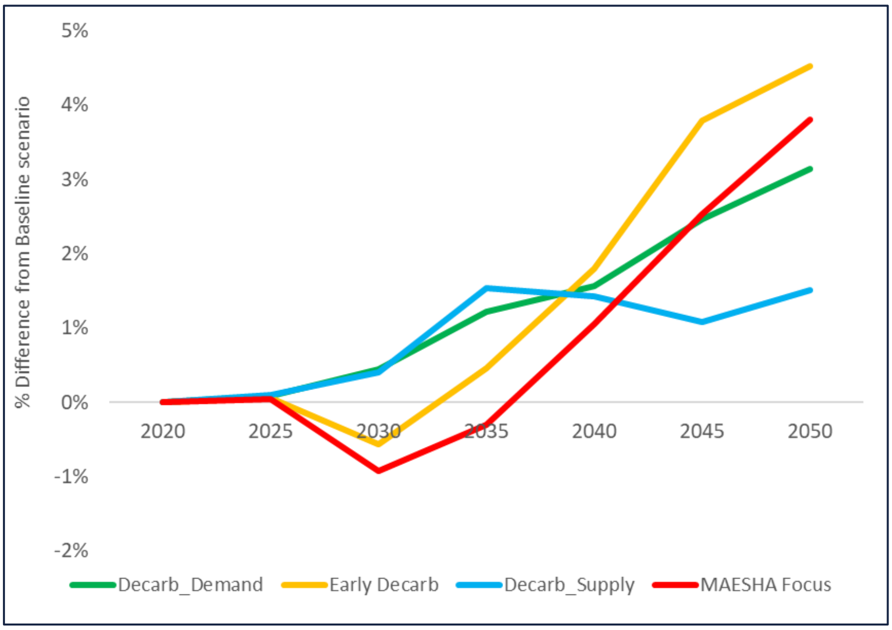

Figure 80: Impacts of decarbonization scenarios on Mayotte's GDP over 2020-2050

The ambitious climate policies implemented in the series of decarbonization scenarios would have large impacts on macro-economic indicators, including investment, consumption, exports, and imports (Figure 81). The transition to carbon neutrality would lead to a large increase in investment which are projected to grow by 8%-11% in decarbonization scenarios relative to the Baseline scenario, cumulatively over 2020-2050. The increased investment is the main driving factor towards increasing GDP in Mayotte; while increased economic activity would also positively influence in its turn all macro-economic variables, like investment and consumption. The cumulative GDP impacts of alternative decarbonization scenarios range between 1.3%-2.1% increase from Baseline levels in the period 2020-2050. The positive impacts on consumption are projected to be relatively more limited, as production costs tend to increase due to high carbon pricing and the reallocation of resources compared to the Baseline scenario, having some depressive impacts on the private consumption.

The transition to carbon neutrality would also have impacts on Mayotte's imports, exports, and trade with other regions, which are also assumed to undertake strong decarbonization efforts towards meeting the 1.5°C temperature goal of the Paris Agreement (Fragkos and Fragkiadakis, 2022). The imposition of carbon prices globally would affect the relative competitiveness of economies and sectors depending on their relative carbon intensity. In contrast to other economies, Mayotte would experience a reduction in electricity prices from Baseline levels due to the phase-out of expensive diesel-fired plants. This would result in reduced production costs, thus leading to enhanced competitiveness in international markets and increased exports to other regions. The higher economic activity would lead to increased import requirements, as Mayotte does not have a strong industrial base and does not produce domestically several goods, industrial products and low-carbon equipment, technologies, or vehicles. This effect is counterbalanced by the reduced imports of oil products, with limited net impacts on total imports in Mayotte relative to the Baseline scenario (Figure 81). In addition to the overall socio-economic benefits of the transition to carbon neutrality, Mayotte's economy is also positively influenced by the reduced energy import bill leading to an improved balance of trade relative to the Baseline scenario. The socio-economic benefits of decarbonization would be much larger in case that Mayotte could also develop local industrial capacities to manufacture (at least some of the) relevant products and equipment.

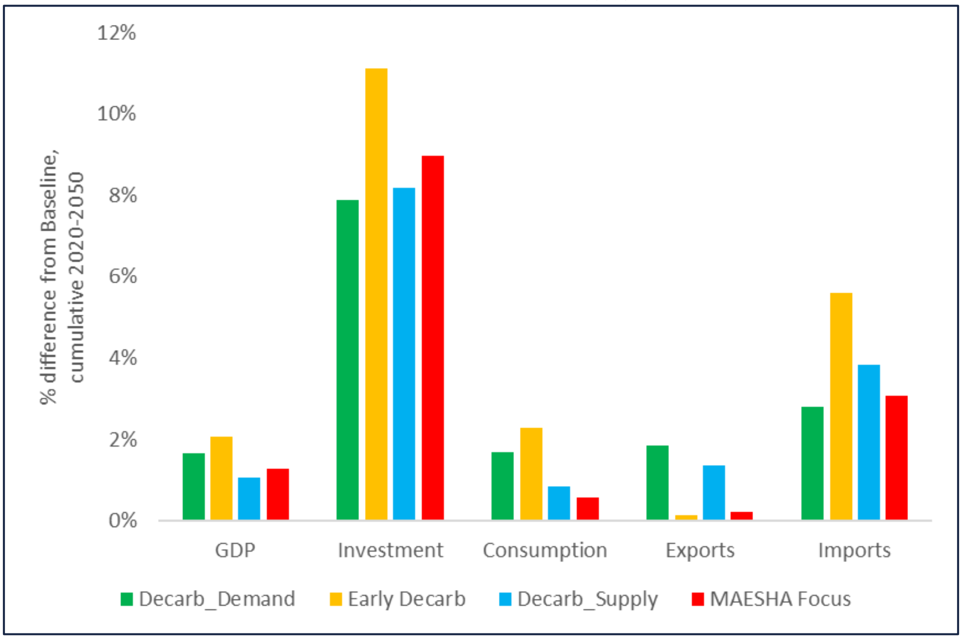

Figure 81: Macro-economic impacts of decarbonization scenarios in Mayotte

6.2. EMPLOYMENT

The decarbonization of Mayotte's energy system would have profound impacts on employment by sector and labor markets. As shown in Figure 82, 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 labor. 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 various decarbonization scenarios, while in the Baseline it stands at 21% in 2050. The increased labor requirements have limited effects on the 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 labor 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 labor 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, but previous research has shown that its implications in the decarbonization context are not very pronounced (Fragkos, Fragkiadakis, 2022).

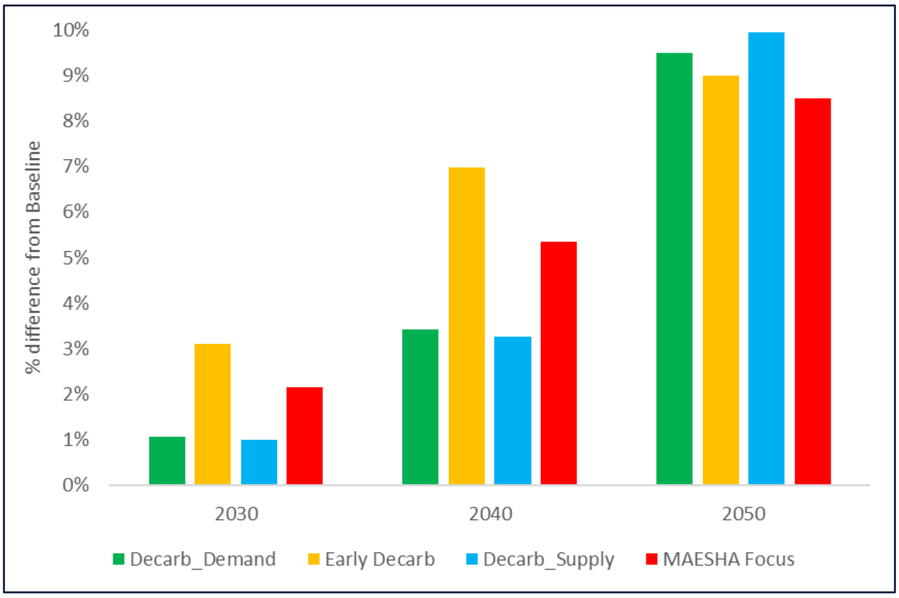

Figure 82: Impacts of decarbonization scenarios on Mayotte's employment

The increased economic activity in the decarbonization scenarios would have positive impacts on employment in all economic sectors and activities in Mayotte. As shown in Figure 82, the positive impacts are more pronounced in the longer term, leading to the creation of about 10,000-11,000 additional jobs relative to the Baseline scenario 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, and is projected to amount to about 1,000 to 2,500 additional jobs from the Baseline scenario in 2030. The transition to carbon neutrality requires the creation of jobs related to low- and 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 (IEA, 2018; Fragkos et al., 2018) show that renewable energy and low-carbon technologies have a higher labor 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 labor markets.

The sectoral composition of job creation opportunities in Mayotte due to decarbonization (Figure 83) reveals interesting findings. First, despite the small size of the electricity sector in Mayotte, the sector is set for a rapid expansion under decarbonization scenarios as electrification of energy and mobility end uses is a prominent emissions reduction strategy. Therefore, the electricity sector is projected to account for about 15% in 2030 and 20% in 2050 of total jobs created in Mayotte relative to the Baseline scenario. Most of these jobs are related to the operation and maintenance of renewable energy plants; a limited number of jobs in 2050 are also created to produce hydrogen and e-fuels. Second, the indirect impacts of decarbonization on the island economy, i.e., those manifested through the supply chain effects and inter-sectoral linkages, are particularly important for the creation of new employment opportunities in Mayotte. The construction sector provides its services to install the renewable energy power plants, the expanded power grids, the efficient equipment, and low-emission vehicles, resulting in the creation of new construction jobs, which amount to about 20% of total job gains relative to the Baseline scenario. The services sector accounts for more than 80% of the island's GDP and thus it is also influenced positively by the increasing economic activity. The new jobs created in the services sector are projected to account for 60% in 2030 and 50% in 2050 of the total additional jobs created in the decarbonization scenarios compared to the Baseline scenario in Mayotte. Finally, the manufacturing sector, despite its limited size in Mayotte, is also found to be positively affected by the transition to carbon neutrality, triggered both by increased domestic demand and exports. Most new jobs are created in the food industry and other industries, which account for most of the island's manufacturing activity.

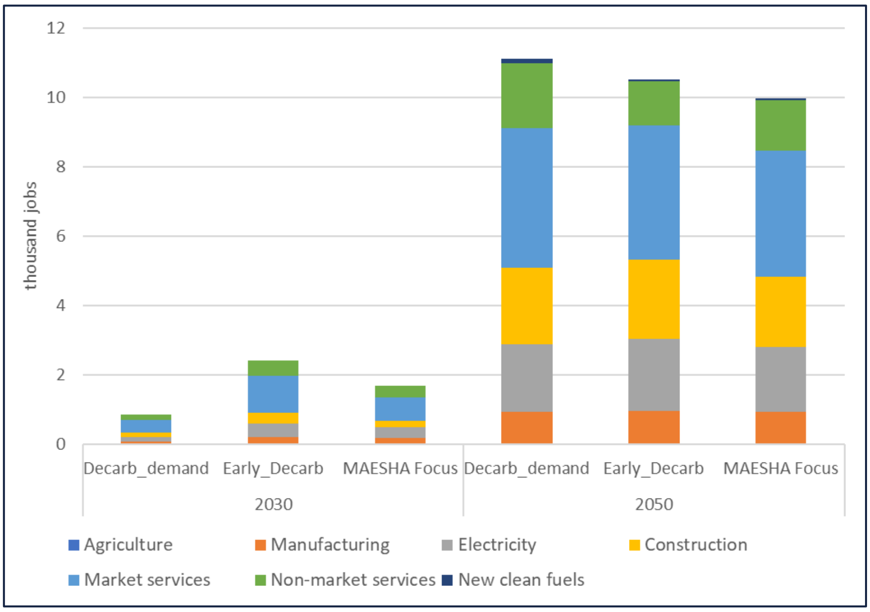

Figure 83: Impacts of decarbonization scenarios on Mayotte's employment by sector

7. CONCLUSIONS

The decarbonization of a geographical island in a rapidly developing economy is feasible, though challenging, as technical, economic, and regulatory barriers should be overcome. The clean energy transition requires the cross-sectoral integration, the adoption of ambitious climate policy measures and the wide deployment of low- and zero-carbon technologies both in the demand and supply side of the energy system, accounting for the specificities of each individual sector. Measures and technologies could range from the use of highly efficient equipment, the widespread electrification of end uses (e.g., wide uptake of electric vehicles), the massive roll-out of renewables as well as the use of green hydrogen and synthetic fuels to reduce emissions from hard-to-abate transport and industrial sectors.

The high economic growth coupled with the rising population and the increase in electricity access of the citizens leads to limited decoupling of the economic activity from the final energy consumption. Under the Business-as-usual case, the final energy demand continues to increase, driven by limited differentiation of the fuel mix (still dependent on oil products) and energy efficiency improvements. The further deployment of variable RES, and especially solar PV, in the power sector (RES-E share: 32% by 2050) is based on the current market trends with rapid cost reductions of solar panels and the increasing EU ETS carbon price. The Baseline scenario projections for RES uptake are rather conservative as they fall well short of what is required for getting Mayotte on track for carbon neutrality. Similarly, the slow and conservative decrease of carbon standards for private cars and vans leads to limited uptake of low- and zero-carbon vehicles even in the longer term. In this regard, CO_2 emissions in the Baseline scenario follow a constantly increasing trend by 2050, albeit with some deceleration after 2040, due to the extensive use of fossil-based liquids in power generation and transport and the rapid growth of economic activity and energy consumption.

The impacts, challenges and opportunities related to the transition to carbon neutrality in Mayotte are comprehensively assessed with the development of alternative decarbonization scenarios, differentiated by their policy, technology, and temporal scope. These scenarios can reveal the different dynamics, synergies, and trade-offs among the transformation of energy end-use sectors – including transport, residential and commercial buildings, and industries – and the uptake of clean energy technologies, as well as the associated costs and benefits for the citizens and market agents. Pursuing a diverse set of decarbonization levers reduces the risk of over-dependence on one technology or a specific set of technologies and assess the requirements towards climate resilience – such as the ability to avoid system outages and withstand extreme weather events (e.g., low solar irradiance) coupled with high load seasonality. Key take-aways for the decarbonization strategies of Mayotte are emerging from the multiple-scenario-based analysis, anchored in detailed economy-wide modelling. It should be highlighted that the scenarios achieve over 95% of emission reduction by 2050 compared to the 2015 levels.

Electrification is found to be a cost-effective decarbonization lever, as the early decarbonization of the power grid (through large-scale uptake of renewable energy sources) facilitates the increased use of zero-carbon electricity in end-use sectors. Moreover, it goes hand in hand with energy efficiency improvements, as the electrified equipment is highly efficient. Electricity will play a key role for the transformation of all sectors, including transport, buildings, and industry. The buildings, agricultural and manufacturing sectors are, already electrified to a large extent– their full electrification and the emergence of renewables, wherever possible, is a cost-saving measure, judging from the fact that the energy-related costs of these sectors are lower in decarbonization scenarios than in the Baseline scenario, due to the reduction of the electricity price as expensive diesel-fired power plants are phased out. The gross electricity demand increases in all decarbonization scenarios, driven mainly by the high uptake of electric vehicles in transport and the growing use of electricity as input for clean fuel production, including green hydrogen and synthetic e-fuels.

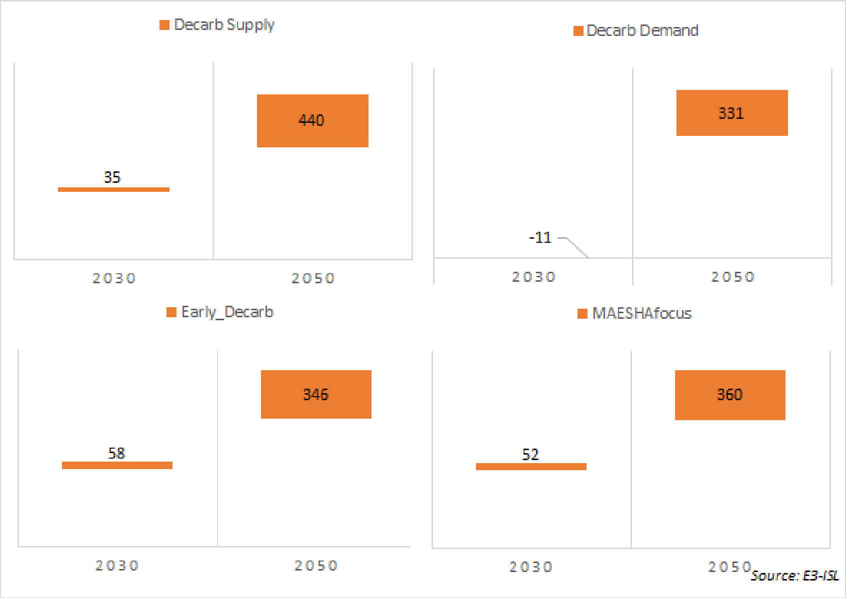

Figure 84: Additional gross electricity demand in GWh by scenario as compared to the Baseline in 2030 & 2050

The results of this analysis showcase the significant contribution of clean fuels, hydrogen, and biofuels to reach the goal of carbon neutrality. Across all decarbonization scenarios, **clean fuels (hydrogen, synthetic liquids, ammonia) enable the decarbonization by delivering low-carbon fuels to the hardest-to-abate sectors**. Clean fuels constitute a viable choice to decarbonize hard-to-electrify parts of the economy such as industry, heavy-duty transportation, navigation, and aviation. Hydrogen and hydrogen-based fuels shall be needed to fill the gaps where electricity cannot easily or economically replace fossil fuels. In the case of transport, these fuels can be complemented with the blending of fossil fuels with sustainable food-based and advanced biofuels. The quantities of hydrogen and e-fuels needed to decarbonize the economy are considerable in the case of Mayotte. This fact entails steep increases in gross electricity demand, pushing the power sector and the local renewable energy resources to their limits. Consequently, importing part of the clean fuels can be considered as an option, keeping the import dependency of the island at reasonable levels. Sustainable bioenergy delivers emissions reductions across a wide range of areas, including low-emissions fuels for planes, ships, and other forms of transport.

The power sector is at the forefront of the decarbonization of Mayotte's economy. The full exploitation of the renewable energy potential of the island is a "no-regret" option. The deployment of RES needs to be ramped up quickly – in particular, solar PV, as it constitutes a highly cost-competitive source of electricity leading to a reduction of electricity costs and prices as expensive diesel-fired generation is phased out. According to several reports, Mayotte has considerable potential on solar PV, wind onshore and offshore as well as geothermal high-temperature resources. Nevertheless, these renewable energy resources should be further explored and accurately quantified via dedicated studies. The present scenario analysis leverages the island's currently estimated RES potentials. The high integration of variable RES should be accompanied by significant increases in electricity system flexibility – such as batteries, demand response, Power-to-X units with multi-day and inter-seasonal storage cycle, etc. – to ensure reliable electricity supplies. The current analysis explores the different types of flexible reserves, each coping with different needs of the system (short-term, multi-hour and long-term). The Power-to-X capacity expansion is directly driven by the demand for clean fuels derived from the end-use sectors (transport, industry), while batteries contribute to the balancing of the system.

Moreover, the consideration of EDM to perform fuel switching of the Longoni and Badamiers plants from diesel to biodiesel allows for further zero-carbon flexibility and reliability of the power system,

while reducing emissions. In an environment with rising carbon price under the EU ETS, such conversion could render these plants a cost-effective choice for readily available dispatchable reserve capacity, facilitating the integration of variable RES (solar PV and wind).

Local energy communities could also unlock the untapped efficiency potential on the demand side and largely contribute to the endeavors for carbon neutrality. Achieving net zero emissions by 2050 can be implemented in an efficient and less costly way with the sustained support and participation from citizens via behavioral changes – such as using soft mobility options, purchase energy-efficient equipment, etc. –, installation of small-scale rooftop PVs and participating in demand-response techniques. The involvement of the local citizens, either as associations (energy communities) or individually, could enable the restructuring of the Mayotte's energy system with lower costs, easing the pressure on the energy supply side.

Decarbonization requires restructuring of the energy sector, maturity of clean energy technologies and ambitious investments plans for all sectors of the economy. Special attention should be given to the horizon of 2030 as a time checkpoint of the pace until reaching net zero emissions in the longer term. **Early climate action sets the decarbonization horizon earlier than 2050. This entails certain trade-offs: energy transition accelerates as all mitigation options are deployed more rapidly, and cumulative emissions in the projection period decline more than other decarbonization scenarios, albeit with higher energy system costs**.

Through a detailed soft link between an energy system and a macro-economic model, the socio-economic impacts of deep decarbonization pathways for Mayotte are assessed. 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 low and 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 is an investment-intensive and technology-intensive process that requires economic restructuring away from fossil fuels and towards a more capital-intensive structure. The large-scale deployment of renewables will reduce the average cost of electricity production, 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 **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 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 (Early_Decarb), as the rapid energy transformation poses stresses in capital markets influencing the 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 sector), 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.

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