Policy Brief
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Morocco's Decarbonization Pathway
Part II: Updated Decarbonization Scenarios[1]

By Berahab Rim, Chami Abdelilah, Derj Atar, Hammi Ibtissem, Morazzo Mariano, Naciri Yassine, Zarkik Afaf, with the technical support of AFRY.

I. Introduction

The consequences of climate change are becoming progressively more visible in Morocco. Changes in rainfall patterns and drought, increases in average temperatures and heatwaves, flooding, and rising sea levels are increasingly affecting several regions. Yet, Morocco has a relatively low greenhouse gas (GHG) emission rate, compared to other countries. In 2016[2], Morocco's total GHG emissions reached 86127.7 gigagram of carbon dioxide equivalent (Gg CO2-eq), totaling around 0.2% of global GHG emissions. However, emission levels are anticipated to increase significantly in the coming decades as a result of the country's continuing economic development.

Seeking to tackle climate change, Morocco aims to contribute to global efforts by pursuing a rapid transition to a resilient, low-carbon economy, while enhancing equity and progress on the sustainable development goals (SDGs). As a result, Morocco submitted its Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) when it ratified the Paris Agreement on September 21, 2016. The country pledged an unconditional 17% reduction in GHG emissions including Agriculture, Forestry and Land Use AFOLU (13 % without AFOLU), by 2030 compared to a BAU scenario and a conditional 42% reduction in GHG emissions including AFOLU (34 % without AFOLU) below the BAU scenario by 2030[3].

Embarking on a sustainable and inclusive development path should transform Morocco's energy production and consumption profile, thus bringing numerous benefits in terms of GHG emission reductions. The Policy Center for the New South and Enel Green Power Morocco, with the technical support of AFRY, have carried out modeling to quantify these changes. Several scenarios have been developed to assess the potential options to be adopted:

- **The Business-As-Usual (BAU) Scenario**: This scenario describes the energy system that is likely to be implemented over the next few decades if current policy options and elements of energy governance, supply, and demand are maintained. The BAU scenario reflects GHG emissions in different sectors as outlined in the Nationally Determined Contributions (NDCs), and the Third Communication

1. The technical component of the study pertaining to modeling was carried out by AFRY, under the strategic and policy direction of the Policy Center for the New South and Enel Green Power Morocco. This study was conducted in 2020, prior to the release, in June 2021, of Morocco's new Nationally Determined Contribution. Therefore, the NDCs in this study refer to those of 2016..
2. Ministry of Energy, Mines and the Environment, 2019. Latest year available.
3. Moroccan Government, 2016.

to the UNFCCC[4] (up to 2040).

- **The Increased Ambition (IA) Scenario**: This scenario goes not only beyond the BAU scenario, but also beyond Morocco's unconditional target. It includes key measures that strongly influence demand, including energy efficiency, gradual reform of the liquefied petroleum gas (LPG) subsidy, clean and electric mobility, and increased use of desalination.

- **The Green Development (GD) Scenario**: This scenario harnesses all possible decarbonization levers.

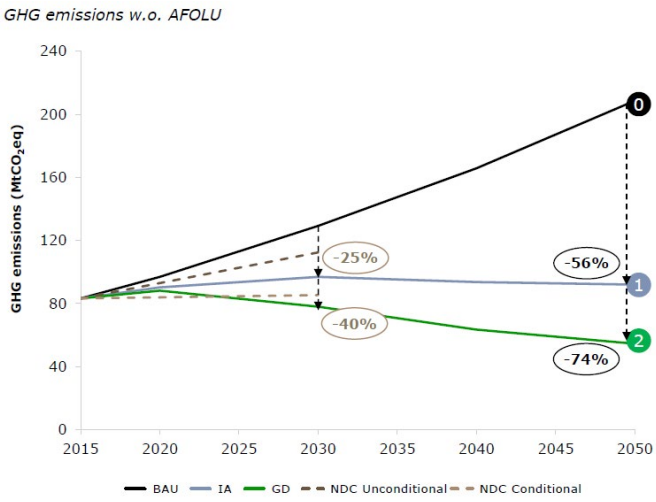
This Policy Brief, the second in a series of four, presents the results of the decarbonization scenario modeling.

II. Decarbonization Scenario Results for Morocco

1. At the National Level

The two decarbonization scenarios—Increased Ambition and Green Development—reach higher decarbonization targets compared to current policy (Figure 1). Excluding AFOLU, in 2030, GHG emissions will fall by 25% in the Increased Ambition scenario, thus exceeding the conditional NDC target, but falling short of the unconditional NDC target. The Green Development scenario goes beyond both conditional and unconditional NDC targets and achieves a 40% decrease in GHG emissions. By 2050, under the Increased Ambition and Green Development scenarios, GHG emissions are reduced by 56% and 74%, respectively, compared to the BAU scenario.

Figure 1: Results of the Decarbonization Scenarios in Morocco to 2050



Source: Authors' calculations[5].

Notes: AFOLU: Agriculture, Forestry, and Other Land Use. BAU: Business as Usual. IA: Increased Ambitions. GD: Green Development.

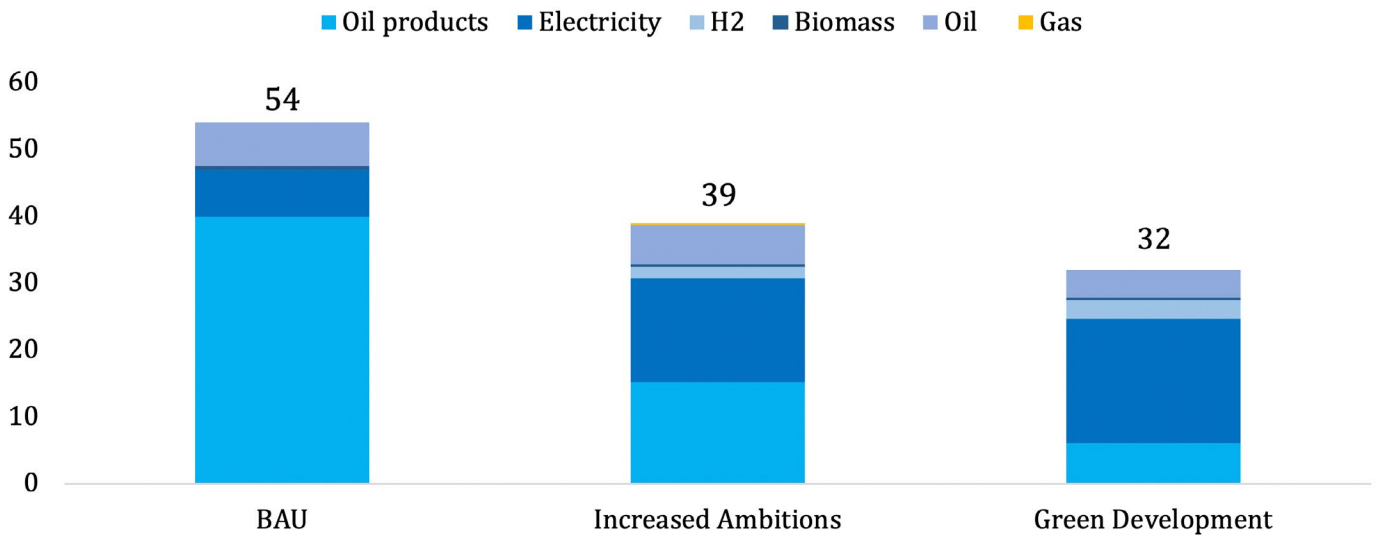
The decarbonization targets under the Increased Ambition and Green Development scenarios would be achieved mainly thanks to extensive electrification of final sectors and increased penetration of renewable energy sources (RES) in the power generation mix including green hydrogen.

By 2050, Morocco's total energy consumption will reach 54 million tons of oil equivalent (Mtoe) under the BAU scenario, versus 39 Mtoe under the Increased Ambition scenario and 32 Mtoe under the Green Development scenario (Figure 2). The savings in energy consumption, in both decarbonization scenarios, are achieved by reducing energy intensity, particularly in the industrial and tertiary sectors, and by increasing the electrification of the transport, residential, and agriculture sectors. As a result, the share of oil products in total energy consumption falls from 74% under the BAU scenario to 39% under the Increased Ambition scenario and 19% under the Green Development scenario. On the other hand, the share of electricity consumption rises from only 13% in the BAU scenario to 40% and 58%, respectively, in the Increased Ambition and the Green Development scenarios.

4. 3rd communication to the UNFCCC further details NDC projections providing sectorial breakdown and including expected emissions in 2040.

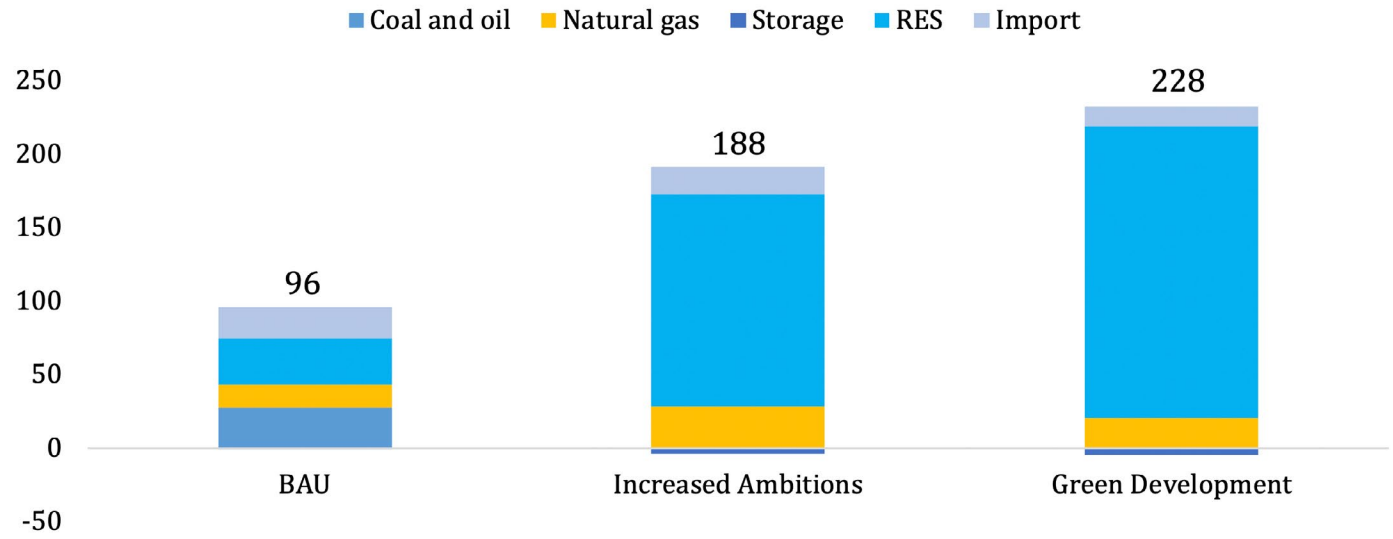
5. For the remainder of the document, refers to AFRY under the policy direction of the Policy Center for the New South and Enel Green Power Morocco.

Figure 2: Energy Consumption Per Fuel Type by 2050 (Mtoe)



Source: Authors calculations. Note: Mtoe: million tons of oil equivalent.

Figure 3: Generation Mix by 2050 (TWh)



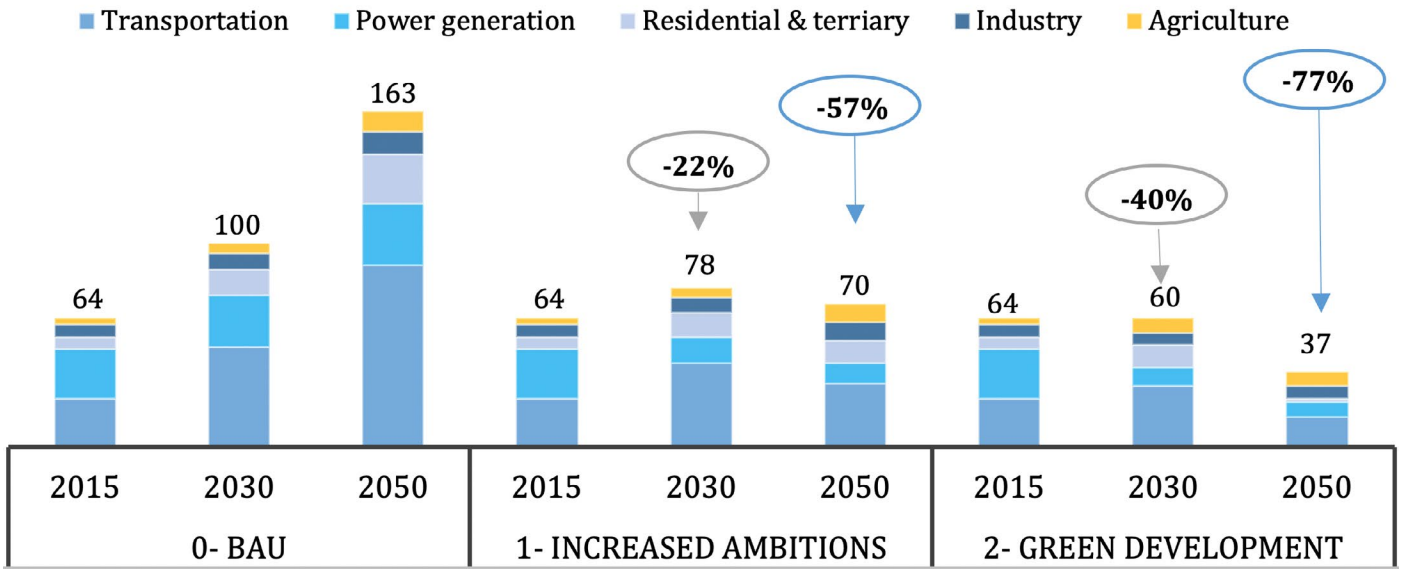
Source: Authors calculations. Note: RES: Renewable Energy Sources.

The rising electricity demand in the two decarbonization scenarios requires a significant increase in electricity generation, which goes from 96 terawatts per hour (TWh) under the BAU scenario to 188 TWH under the Increased Ambition scenario and 228 TWH under the Green Development scenario (Figure 3). The bulk of the electricity generation in the two decarbonization scenarios is achieved by RES, whose share in the total mix is estimated at 77% in the Increased Ambition scenario and 87% in the Green Development scenario, versus 33% in the BAU scenario. In addition, the power sector is assumed to provide flexibility and reliability, which is offered by a diversified portfolio of technologies that reduce the share of natural gas in total capacity and generation in the decarbonized scenarios. Complementary flexible technologies include battery energy storage systems (BESS), demand-response (DR), hydro-pumped storage, and biomass plants.

By sector, the transport, power generation, and residential sectors are the three key sectors for decarbonization of Morocco's energy mix (Figure 4). Considering only energy-related GHG emissions, Morocco's total energy-related GHG emissions would reach 163 MtCO2eq in the BAU scenario in 2050, compared to 70 MtCO2eq in the Increased Ambition scenario and 37 MtCO2eq in the Green Development scenario. The transport sector alone accounts for 55% of total energy-related GHG emissions in 2050 in the BAU scenario, or 89 MtCO2eq. Emissions from this sector can be reduced to 31 MtCO2eq and 15 MtCO2eq by 2050 in the Increased Ambition and Green Development scenarios, respectively, notably through increased electrification of end-uses in this sector.

Electricity generation is the second largest source of energy-related GHG emissions in the BAU scenario, accounting for 18% of total energy-related GHG emissions in 2050, corresponding to 30 MtCO2eq. Thanks to greater penetration of renewable energies in the electricity mix, the emissions of this sector can decrease to 10 MtCO2eq in 2050 in the Increased Ambition scenario and 7 MtCO2eq in the Green Development scenario. Increased electrification and energy intensity reduction in the residential and tertiary sectors, the third largest source of energy-related GHG emissions in the BAU scenario, has the potential to reduce emissions from this sector to 11 MtCO2eq in 2050 in the Increased Ambition scenario and 2 MtCO2eq in the Green Development scenario (versus 24MtCO2eq in the BAU scenario).

Figure 4: Energy-related GHG Emissions by Sector (MtCO2eq)



Source: Authors' calculations.

2. At the Sectoral Level

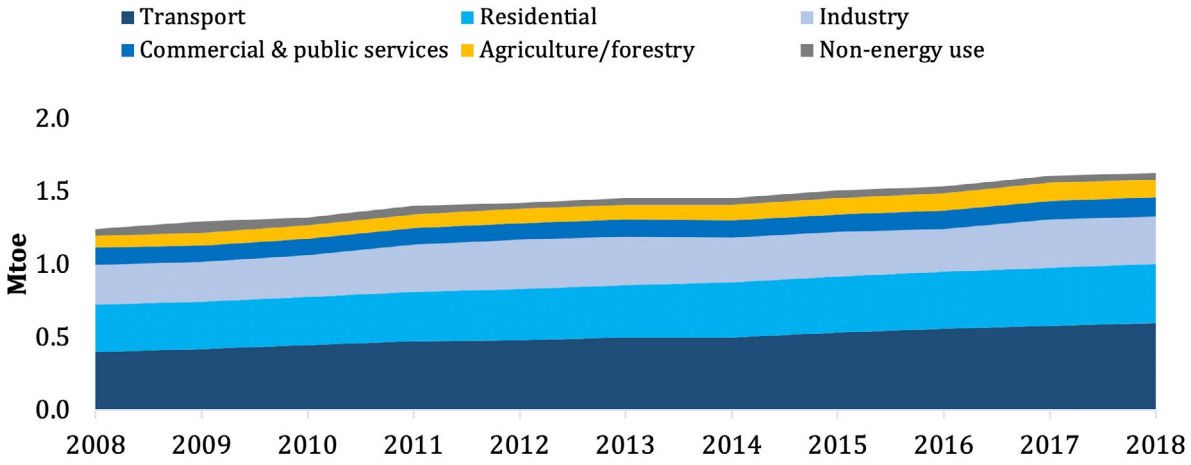
a. Transport Sector

The transport and logistics sector is one of the main drivers of the Moroccan economy. The sector now accounts for 6% of the country's GDP and 9% of the value of tertiary activities, and employs more than 500,000 people, i.e. 5% of the working population, including 6.6% in urban areas. The transport sector includes road, air, rail, and water transport modes, including maritime, and emitted 16 MtCO2eq in 2014[6] (20% of the country's total emissions)[7]. It also dominates Morocco's total final energy consumption, with an average share of 35% between 2010 and 2018 (Figure 5), and has recorded the fastest growth in terms of energy consumption, with a rate of 34% during the same period according to the International Energy Agency (IEA).

6. Latest national inventory of GHG emissions.

7. Ministry of Energy, Mines and the Environment, 2019.

Figure 5: Total Final Energy Consumption (TFC) by Sector, Morocco 2008-2018



Source: International Energy Agency.

Road transport is dominant in terms of economic importance, resulting in high energy consumption and corresponding GHG emissions. The distribution of road fleets and their activities thus give an indication of the priority areas for GHG mitigation and an idea of the complexities involved. GHG emissions from light-utility vehicles (LUVs) account for about 40% of the sector's total emissions. These vehicles mostly use diesel fuel (73%)[8]. Air and maritime transport are difficult to assess accurately given their domestic and international activities. Railroads and urban transport networks currently have relatively low energy consumption and emission values.

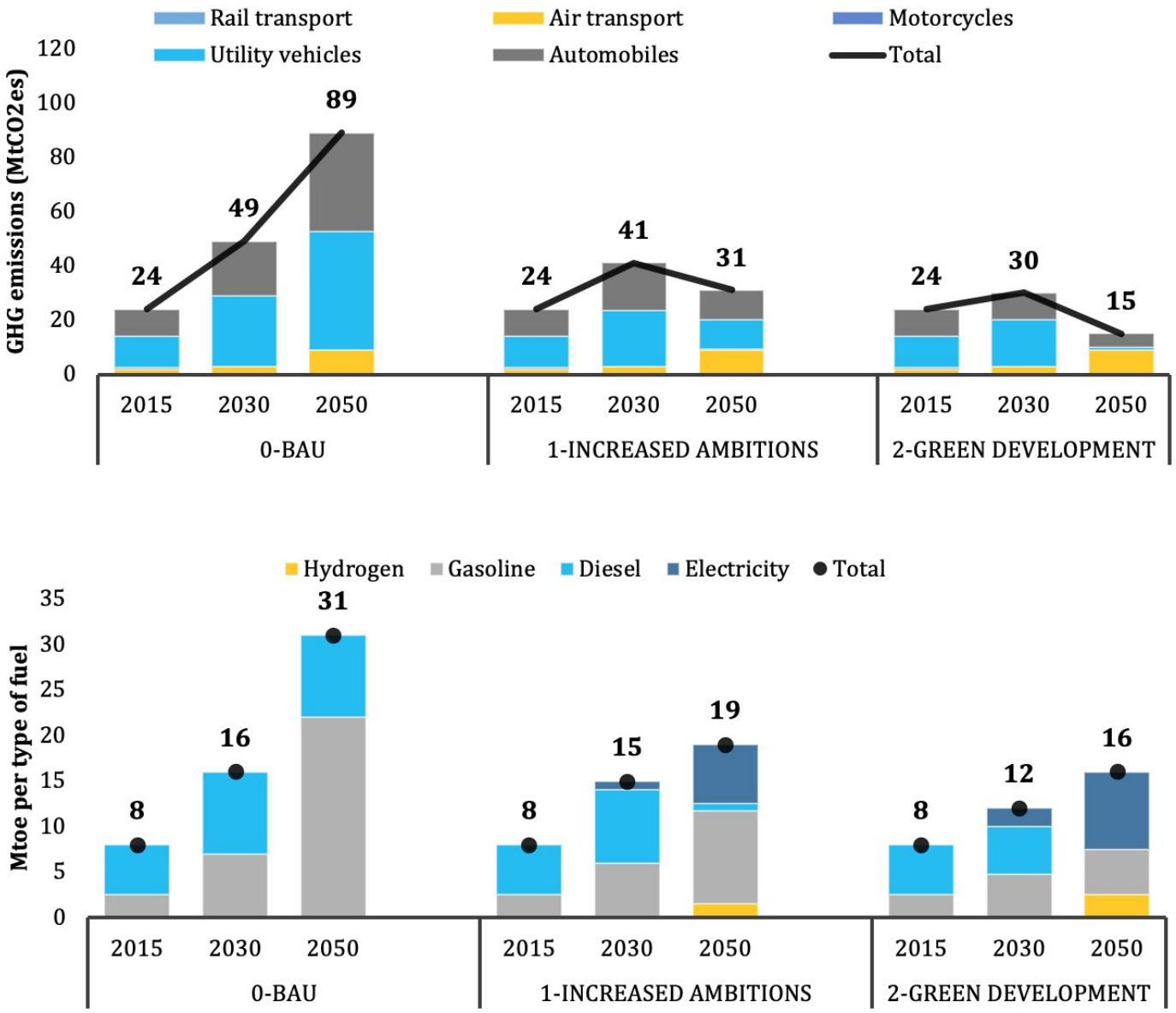
The assumptions underlying the three modeled scenarios for the transport sector are based on the 41st action of Morocco's NDC to "upgrade utility vehicles of 20 years and older to lower their fuel consumption, between 2025 and 2030"[9] and on the following energy-efficiency provisions: (i) Mandating the retirement of 7,500 obsolete and fuel-inefficient goods vehicles; (ii) promoting the withdrawal of 1,700 obsolete public passenger transport vehicles, (ii) removing 250,000 vehicles over 20 years old in 2025 and (iii) lowering the emission level thresholds (opacity[10] rate for diesel vehicles from the current 75% to 65% and CO2 emission rate for gasoline vehicles from the current 4.5% to 3.5%).

Additional measures regarding diesel phase-out, increased electrification, and the introduction of hydrogen are included, to varying degrees:

- The BAU scenario assumes that diesel accounts for 20% of the energy consumed in the transport sector by 2050. Neither electrification nor hydrogen technology measures are considered in this scenario.
- The Increased Ambition scenario calls for the complete elimination of diesel by 2050. It presumes that: (i) the share of electric vehicles in the total vehicles fleet reaches 80% in urban areas[11] and 30% in rural areas[12], (ii) full electrification of buses and railways is achieved in 2030 and 2040 respectively and (iii) the share of hydrogen trucks reaches 50% by 2050.
- The Green Development scenario also calls for the complete elimination of diesel by 2050. It presumes that: (i) the share of electric vehicles in the total vehicles fleet reaches 100% in urban areas[13] and 70% in rural areas[14], (ii) full electrification of buses and railways is achieved in 2030 and 2040 respectively and (iii) the share of hydrogen trucks reaches 85% by 2050.

8. Ibid.
9. Moroccan Government 2016.
10. "Smoke and smoke opacity meters are instruments measuring the optical properties of diesel exhaust. These instruments have been designed to quantify the visible black smoke emission utilizing such physical phenomena as the extinction of a light beam by scattering and absorption", United Nations.
11. 80% for cars, 80% for motorcycles and 80% for light utility vehicles (LUVs).
12. 30% for cars, 30% for motorcycles and 30% for light utility vehicles (LUVs).
13. 100% for cars, 100% for motorcycles and 100% for light utility vehicles (LUVs).
14. 70% for cars, 70% for motorcycles and 70% for light utility vehicles (LUVs).

Figure 6: GHG Emissions (MtCO2eq) and Energy Consumption by Fuel Type (Mtoe) in the Three Modeled Scenarios for the Transport Sector



Source: Authors' calculations.

The modeling results (Figure 6) show that electrification, diesel phase-out, and hydrogen technology are the drivers for the decarbonization of Morocco's transport sector. The BAU scenario is marked by a significant increase in GHG emissions, from 24 MtCO2eq in 2015 to 89 MtCO2eq in 2050, mainly from utility vehicles and automobiles. In this scenario, energy consumption follows a similar upward trend, almost quadrupling, from 8 Mtoe in 2015 to 31Mtoe in 2050, and is dominated by gasoline and diesel. Under the Increased Ambition and Green Development scenarios, GHG emissions from the transport sector peak in 2030, before falling substantially by 2050 to 31 MtCO2eq and 15 MtCO2eq respectively. In the Increased Ambition scenario, the share of diesel consumption in the transport sector decreases to a marginal level in 2050, while gasoline increases, thus becoming the dominant fuel, followed by electricity, the consumption of which also increases considerably between 2030 and 2050. In the Green Development scenario, diesel is completely phased out by 2050, and electricity becomes the dominant fuel, followed by gasoline and a greater share of hydrogen compared to the Increased Ambition scenario.

b. Residential Sector

The residential sector accounts for around 25% of Morocco's total final energy consumption between 2010 and 2018 (Figure 6), the second-highest share after transport, and consumes on average 34% of the country's final electricity during the same period. Average electricity consumption per capita increased from 800kWh to 900 kWh per year between 2010 and 2018[15]. The residential sector is also responsible for 12% of the country's GHG emissions. The most widely-used form of energy in this sector is butane gas (63.3% of primary energy), primarily for cooking, and to a lesser extent for the preparation of domestic hot water. End-use energy consumption in the residential sector is dominated by residential appliances, which account for 85% of the total use, followed by residential space heating and cooling[16]. Heating and cooling consumption is still limited to wealthy households, although it is steadily increasing. The use of renewable energy, such as solar hot water production, remains underdeveloped because of competition from highly subsidized gas.

The assumptions behind the modeling of the decarbonization scenarios for the residential sector are based on: (i) the energy-efficiency strategy[17]; (ii) the 29th[18], 30th[19] , and 31st[20] NDC actions, and (iii) the program for rooftop photovoltaic (PV) in the residential sector by the Ministry of Energy, Mines and Environment (MEME). The BAU scenario does not implement these strategies. Under the Increased Ambition scenario, about 40% of the energy consumption for domestic hot water comes from solar thermal systems (70% under the Green Development scenario) and 50% of the energy consumption for lighting is from LED bulbs (70% under the Green Development scenario). Under both the Increased Ambition and the Green Development scenarios, 2.5 GW of low voltage rooftop PV is installed by 2030 and 4.6 GW by 2050, in line with the MEME program, and further electrification measures (heat pumps and induction cookers[21]) are considered.

15. International Energy Agency, 2021.
16. Ministry of Energy, Mines and the Environment, 2019.
17. Promote solar water heaters and require solar water heaters for new construction.
18. 1.7 million solar panels by 2030.
19. 14.7 million low-energy light bulbs by 2030.
20. 1GW of low voltage PV solar by 2030.
21. A 60% target, each, for heat pumps and induction cookers under the Increased Ambition scenario, and 100% under the Green Development scenario.

The results of the modeling (Figure 7) indicate that heat pumps, solar heaters, and induction cookers will be the drivers for decarbonization in the residential sector. In terms of GHG emissions, cooking and domestic hot water are the main sources of emissions in the BAU scenario, which increase from 6 MtCO2eq in 2015 to 22 MtCO2eq in 2050. In the Increased Ambition scenario, GHG emissions peak at 11 MtCO2eq in 2030, before decreasing to 9 MtCO2eq due to electrification measures related to the implementation of heat pumps, solar hot water systems, induction cookers, and efficient lighting. In this scenario, most of the emissions come from cooking. Under the Green Development scenario, GHG emissions also peak in 2030 before decreasing significantly to net-zero in 2050, thanks to more ambitious implementation of the aforementioned electrification measures.

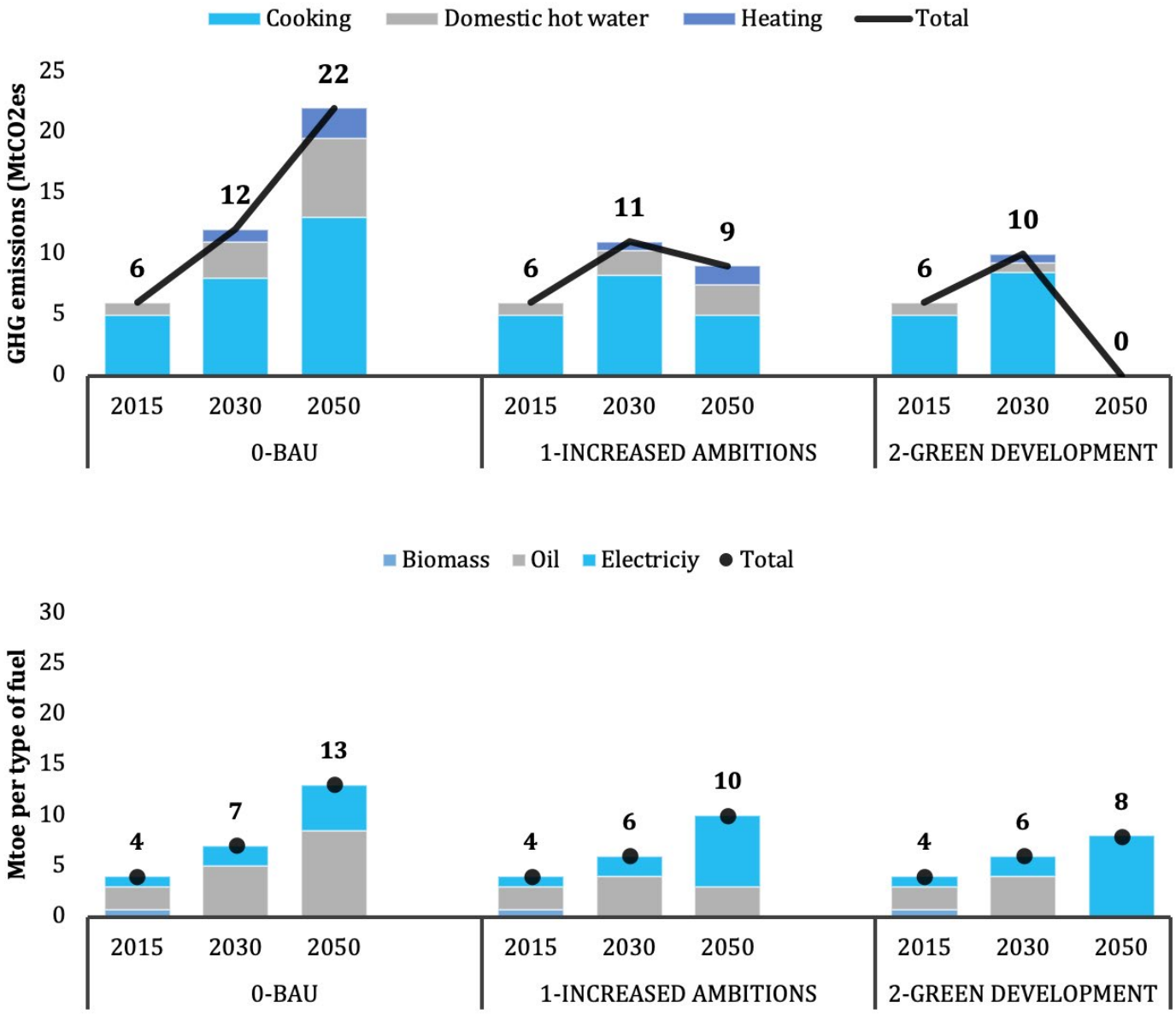
Energy consumption in the residential sector would increase significantly in the BAU scenario, from 4 Mtoe to 13 Mtoe between 2015 and 2050. On the other hand, in both decarbonization scenarios, the increased efficiency of new technologies reduces the growth rate of energy consumption, when compared to the BAU scenario. Energy consumption in the residential sector is thus estimated at 10 Mtoe in 2050 for the Increased Ambition scenario and at 8 Mtoe in 2050 for the Green Development scenario. In terms of the breakdown of energy consumption in the residential sector, oil remains the dominant source in the BAU scenario, while electricity becomes predominant in the two decarbonization scenarios. In the Green Development scenario, electricity even becomes the exclusive source of consumption.

c. Agricultural Sector

Agriculture assumes a central role in the Moroccan economy. It accounts for average for 13% of GDP, but its socio-economic impacts are far greater. Agriculture provides about 38% of national employment and nearly 74% of rural employment, with smallholders representing almost 70% of the agricultural workforce[22]. Nearly 80% of Morocco's agricultural land still depends on rainfall, making the agricultural production system vulnerable to climate change. Consequently, dry years have a significant impact on Morocco's overall agricultural production and GDP[23]. While having the potential to fix CO2, thanks to the photosynthetic capacity of plants to capture CO2 from the air and transform it into organic

22. DEPF, 2019.
23. DEPF, 2019.

Figure 7: GHG Emissions (MtCO2eq) and Energy Consumption by Fuel Type (Mtoe) in the Three Modeled Scenarios for the Residential Sector



Source: Authors' calculations. Note: energy consumption includes self-consumption from solar panels.

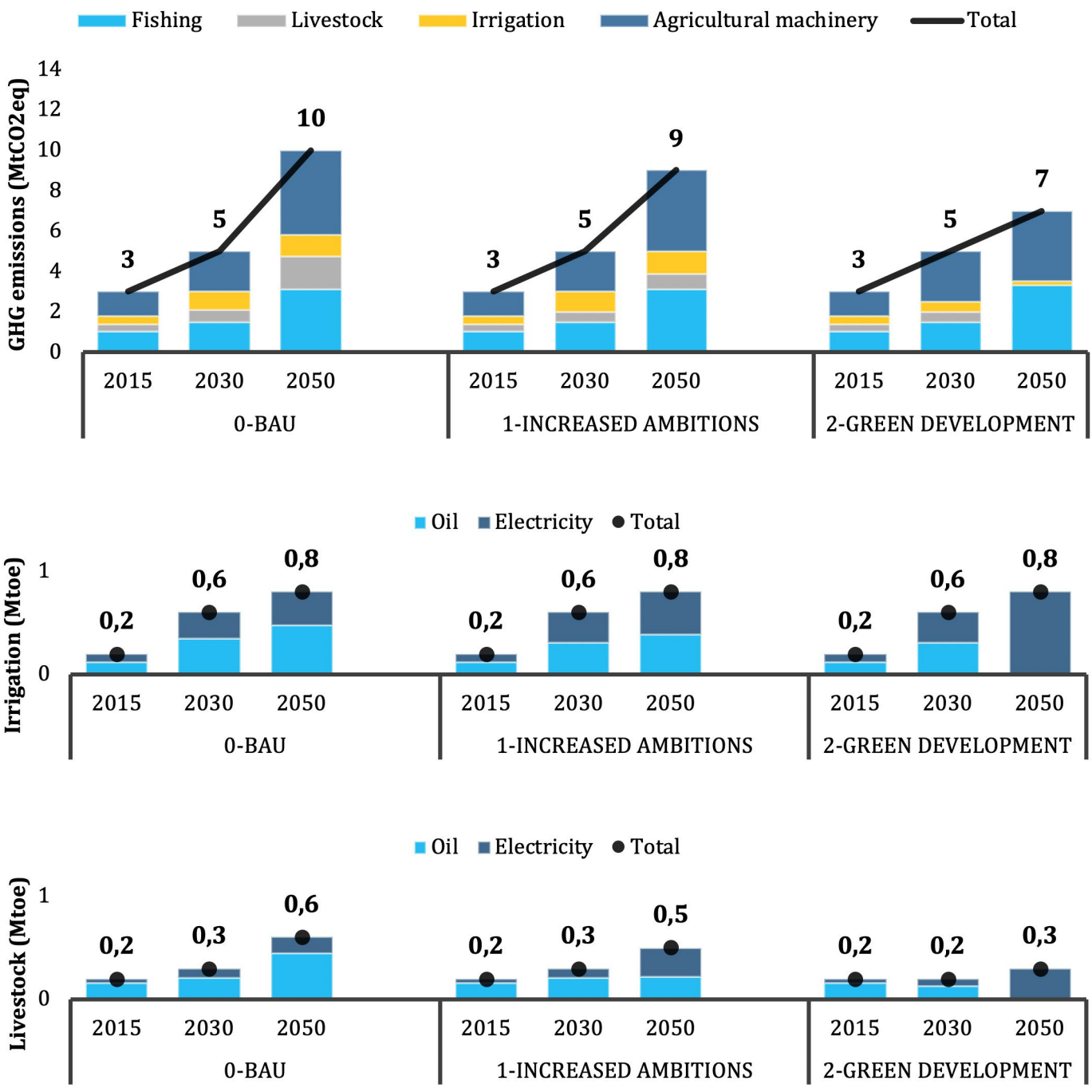
matter, agriculture is also a source of GHG emissions. Moreover, agriculture is the fourth largest consumer of final energy in Morocco and fourth largest consumer of oil products. Of total final energy consumed, agriculture accounted for 7% on average between 2010 and 2018. In terms of oil products consumed, agriculture accounts for 7%[24].

The assumptions behind the decarbonization scenarios for agriculture and fishing are based on: (i) the application of an energy-efficiency strategy by strengthening the national program for the development of solar pumps on agricultural assets (1000 solar pumps per year) in addition to initiating and putting in place incentives for farm energy-efficiency projects, and (ii) introducing new electrification measures to the agricultural sector, including electric pumps for irrigation and heat pumps for livestock heating, effectively replacing oil. The BAU

24. International Energy Agency Data and Statistics, 2020

scenario does not implement any energy efficiency or electrification measures. The Increased Ambition scenario pursues an ambitious target of adding 1000 solar pumps per year from 2020 to 2044 and 2000 solar pumps per year from 2045 to 2050, with a 50% penetration rate, while the Green Development scenario fixes the same targets with a 100% penetration rate.

Figure 8: GHG Emissions (MtCO2eq) and Energy Consumption by Fuel Type (Mtoe) in the Three Modeled Scenarios for the Agricultural Sector



Source: Authors' calculations. Note: Agricultural machinery and farms not included.

The results of the developed models (Figure 8) indicate that under the BAU scenario, the agricultural sector will generate 5 MtCO2eq by 2030 and double that amount by 2050. Carbon emissions will originate mainly from agricultural machinery, fishing, irrigation pumps, and livestock heating. The Increased Ambition and Green Development scenarios will result in GHG savings of 1 MtCO2eq for the former and 3 MtCO2eq for the latter by 2050. In terms of Moroccan agriculture's energy needs for irrigation, we notice higher electrification and decreasing reliance on oil products in the Increased Ambition scenario. Moreover, the modeled scenarios will also show energy savings in the order of 0.1 and 0.3 Mtoe respectively in livestock heating by 2050, combined with greater penetration of electricity to different degrees, depending on the scenario. The Green Development scenario promises full electrification of the agricultural sector by 2050. Among the positive outcomes of those two targets would be decreasing pressure on the grid from agriculture because of promotion of self-consumption.

d. Industry and Tertiary Sector

Morocco has chosen development through industrialization. The industrial sector has thus been the subject of many reforms. Before the 2000s, industry accounted for about 15% of GDP and employed only about 10% of the population. It now accounts for almost 30% of GDP and 21% of employment and is responsible for 8% of Morocco's GHG emissions. Prior to the new reforms, production was directed towards textile manufacturing and agri-food. Morocco has since launched several development plans for the sector, the latest of which (Industrial Acceleration Plan 2014-2020 and its update in 2016) seeks to create industrial ecosystems and unite small and medium-sized enterprises around industrial clusters locomotives (offshoring, automotive, aeronautics, electronics, etc.).

Energy is the second-largest cost item for industrial enterprises[25]. According to the IEA, industrial energy uses alone accounts on average for 19% of total national oil consumption, 21% of national energy consumption and 37% of national electricity consumption between 2010 and 2018. Therefore, industry is increasingly aware of the importance of energy savings in order to reduce production costs. The tertiary sector mainly consumes electricity and biomass, and to a much lesser degree relies on LPG or fuel for the production of sanitary hot water in hotels. The main energy uses are for lighting and running offices (37% and 38%), but also air conditioning and heating with 16% and 9% respectively[26].

The main driver of decarbonization in the industrial and tertiary[27] sectors is energy intensity reduction[28]. Therefore, the assumptions behind the decarbonization scenarios for these two sectors are based on: (i) the application of an energy-efficiency strategy; and (ii) the application of the following NDC actions: industrial energy efficiency (NDC action 11), introducing natural gas in the industrial sector by 2030 (NDC action 33) by promoting LPG imports, and finally introducing a biomass valorization program for industry (NDC action 34).

The BAU scenario assumes an annual energy-intensity reduction factor of 2.5% for the period 2020-2050 for both the industrial and tertiary sectors. The Increased Ambition scenario pursues a yearly energy-intensity reduction factor of 3.2% for the period 2020-2030 and 2.7% for the period 2030-2050, for both the industrial and tertiary sectors. Finally, the Green Development scenario considers an annual energy-intensity reduction factor of 4.5% for the period 2020-2030 for both the industrial and tertiary sectors; and 4.5% and 2.5% for the industrial and tertiary sectors respectively for the period 2030-2050.

The results of the developed models (Figure 9) indicate that under the BAU scenario, the energy needs of industry will continue growing instead of beginning a long-awaited decline, even with an annual energy intensity reduction factor of 2.5% between 2020 and 2050. The lion's share of energy needs will be covered by oil, followed by electricity, biomass, coal, and gas (in decreasing order). In line with industry's energy needs and given its energy mix, industrial GHG emissions are projected to continue growing from 6.2 MtCO2eq in 2015, to 8 MtCO2eq by 2030 and 10.5 MtCO2eq by 2050.

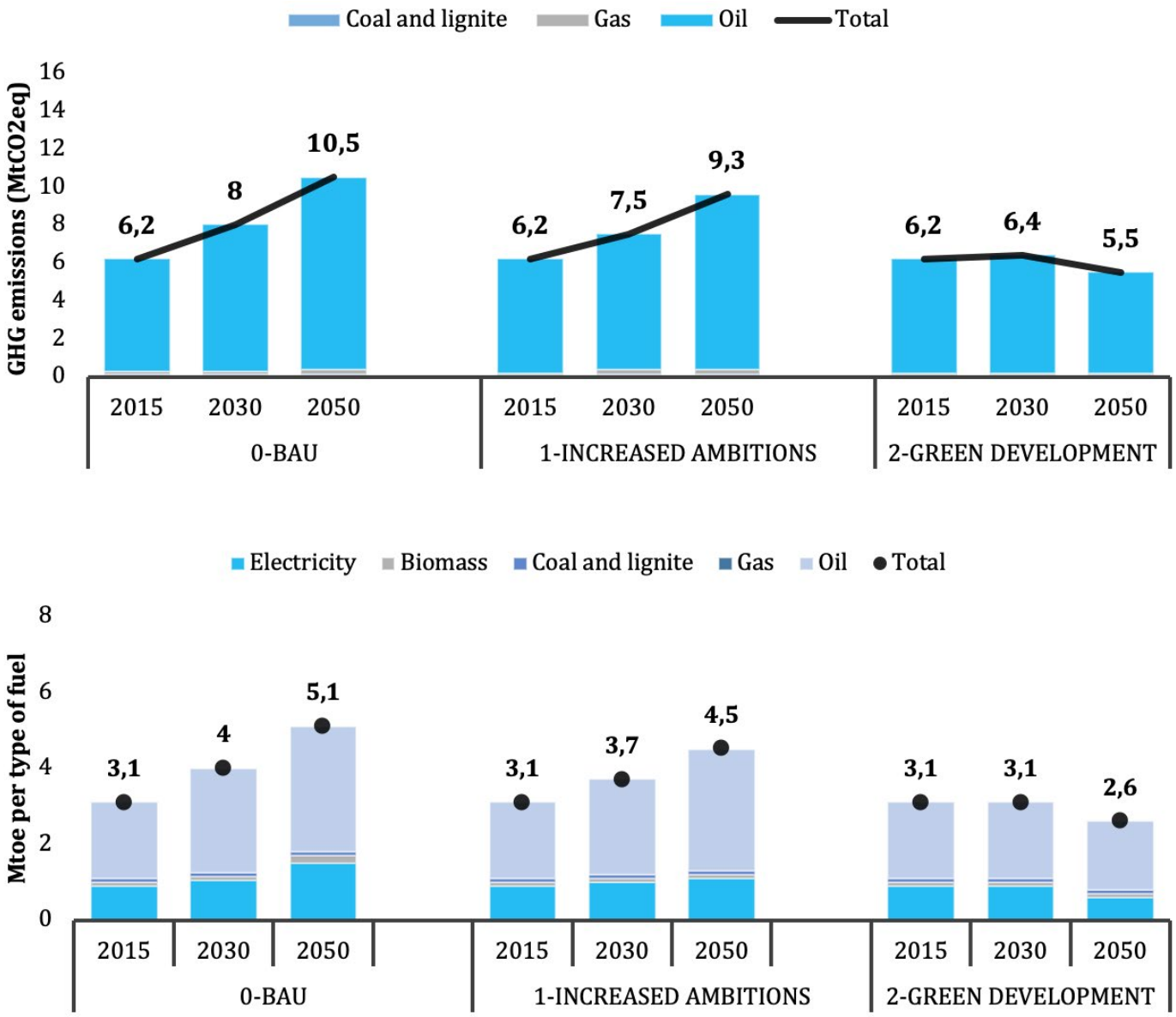
25. Ministry of Energy, Mines and the Environment, 2019.

26. Ministry of Energy, Mines and the Environment, 2019.

27. The tertiary industry is a technical name for the service sector, which encompasses a wide range of businesses that provide services but do not make end products, for example financial institutions, shops, schools, hotels, etc.

28. Energy intensity is a measure of the energy inefficiency of an economy. It is calculated as units of energy per unit of GDP (Mtoe/GDP).

Figure 9: GHG Emissions (MtCO2eq) and Energy Intensity Reduction by Fuel Type (Mtoe) in the Three Modeled Scenarios for the Industrial Sector

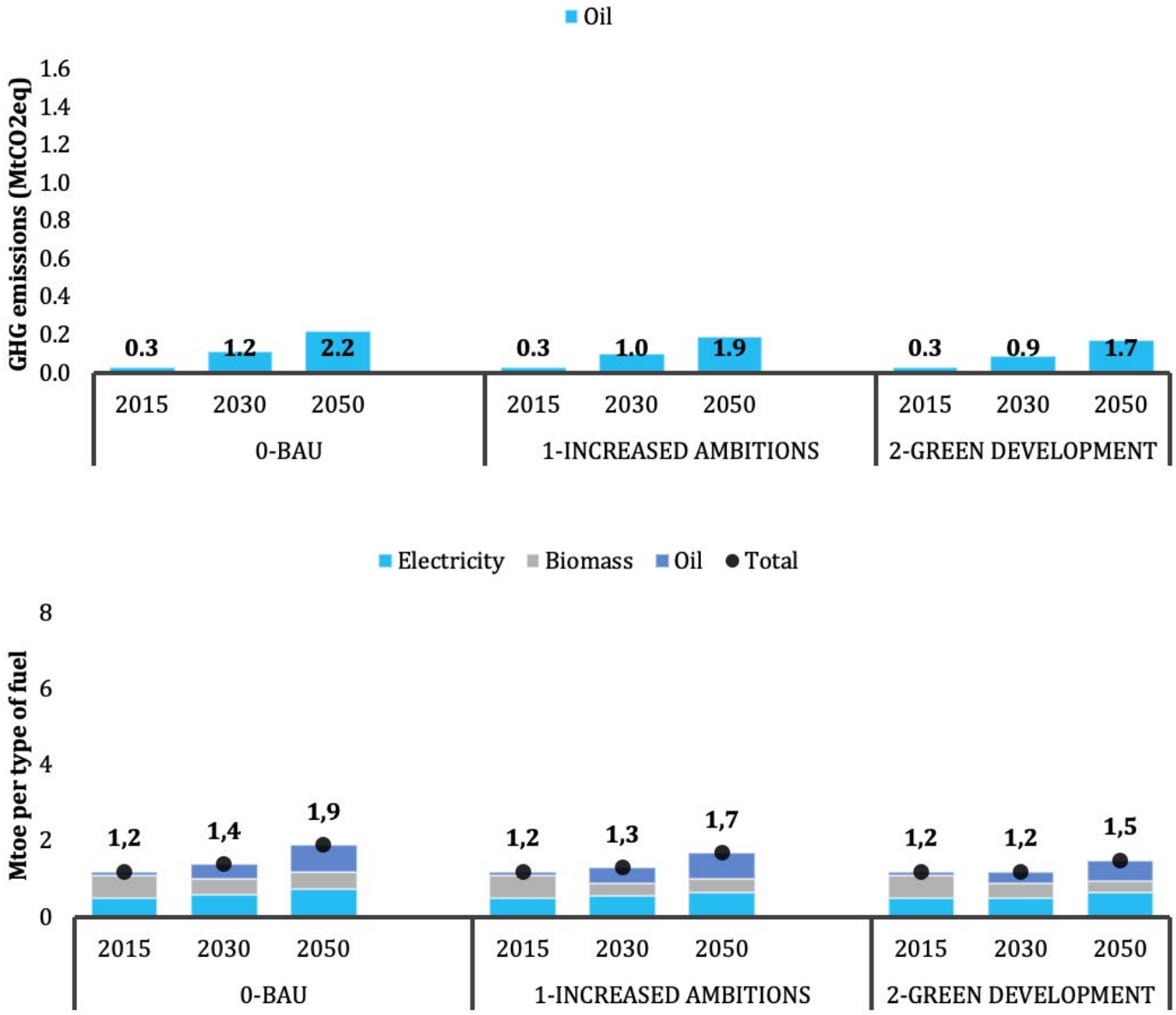


Source: Authors' calculations.

Under the Increased Ambition scenario, in which the yearly reduction of energy intensity will be in the order of 3.2% between 2020-2030 and 2.7% between 2030 and 2030, we notice ever-increasing energy needs as per the previous scenario, with an energy savings potential in the order of 0.3 Mtoe between 2015 and 2030 and 0.6 Mtoe between 2030 and 2050 compared to BAU. This approach will result in modest GHG emissions savings compared to BAU, while still pursuing an upward emissions trend.

It seems that the tipping point at which energy savings will be coupled with decreasing consumption and GHG emissions in industry will only occur under the Green Development scenario (4.5% yearly reduction of energy intensity between 2020-2050). By 2050, in this scenario, the energy needs and GHG emissions of industry will be almost halved compared to BAU, representing a major environmental achievement.

Figure 10: GHG Emissions (MtCO2eq) and Energy Intensity Reduction by Fuel Type (Mtoe) in the Three Modeled Scenarios for the Tertiary Sector



Source: Authors' calculations.

The tertiary sector currently only requires a fraction of the energy used by the industrial sector. However, in view of its future energy needs, which could lead to substantial oil penetration and a decreasing share of biomass, it will become a significant GHG emitter (Figure 10).

Under the BAU scenario (annual energy-intensity reduction factor of 2.5% between 2020 and 2050), the tertiary sector's current energy needs (2015) are in the order of 1.2 Mtoe but will reach 1.4 Mtoe by 2030 and 1.9 Mtoe by 2050. Oil currently has the lowest share in the sector's energy mix, but it will grow to represent about a third by 2030 and the majority share by 2050. The sector's emissions under this scenario will more than double by 2030 reaching 1 MtCO2eq compared to 2015 levels (0,3 MtCO2eq) and increase by more than 500% by 2050 (1.9 MtCO2eq).

Neither the Increased Ambition scenario (yearly reduction of energy intensity of 3.2% in the 2020-2030 period, and 2.7% from 2030 to 2050), nor the Green Development scenario (4.5% in the 2020-2030 period,

and 2.5% from 2030 to 2050) will be successful in containing these emissions; they will only reduce them slightly. In the Increased Ambition modeled scenario, the energy-efficiency measures will yield energy savings of 0.1 Mtoe by 2030 and 0.2 Mtoe by 2050 compared to the BAU, while these figures will double for the Green Development scenario, as emission cuts are proportional to energy savings.

e. Power Sector

According to the IEA, electricity production consumes around 17% of the total final energy[29] in Morocco. Faced with risks related to the increasing cost of fossil-fuel imports and the subsequent high burden on public finances, Morocco adopted a national energy strategy in 2009 that was based on two main axes: strengthening power generation capacity through renewable energy deployment, and improving energy efficiency. Therefore, Morocco planned to increase the share of renewables in its power generation mix to 42% by 2020 and 52% by 2030.

However, by the end of 2019, the electricity mix was still dominated by thermal energy, which comes in part from steam thermal like fuel and coal, and other thermal power plants such as gas, combined cycle, and diesel. Renewable energy accounted for 35% of installed capacity, with hydropower stations and pumped storage power plants (STEP) accounting together for 17% of the total share, solar energy for 7%, and wind for 11%[30] (Figure 11). In 2020, the share of installed electrical capacity from RES reached about 36.8%[31]. According to the IEA, electricity demand increased on average by 4% per year from 2010 to 2018 in Morocco, and is split between industry (38%), residential (34%), commercial and public services (17%), agriculture (17%) and transportation (1%). According to the MEME, the total emissions of the power sector reached around 21.9 MtCO2 in 2016 (the latest available year).

The assumptions underlying the three modeled scenarios for the power sector are based on higher electricity demand, which will require additional installed capacities mainly from RES and gas, while phasing out coal. Therefore, the assumptions behind the decarbonization scenarios for the power sector are based on: (i) Reaching NDC targets of RES penetration in the capacity mix of 42% by 2020 and 52% by 2030, split equally between solar, wind, and hydraulic energy (2 GW each) by 2020; in addition to (ii) applying the following NDC actions:

- Implementing the 2020 national wind and solar plans, consisting of reaching 2 GW of installed wind capacity and solar capacity (CSP+PV) each by 2020 (NDC actions 1 and 2) [32]; with an underlying PV target under the National Program for PV consisting of adding 1GW of PV by 2030 (NDC action 3);
- Adding a capacity of 725 MW of pumped storage power plants (NDC action 4);
- Introducing combined-cycle gas plants with a total capacity of 3.55 GW by 2025 (NDC action 5);
- Introducing private wind farms by 2030 (NDC action 10);
- Implementing the 2030 national wind and solar plans, under which installed wind and solar (CSP+PV) capacity would each increase by an additional 2 GW by 2030 (4GW in total each by 2030) (NDC actions 25 and 26); adding 100 MW of micro-hydropower plants to the grid by 2030 (NDC action 27), and adding a 4.75 GW capacity from combined-cycle gas plants by 2030 (NDC action 28).

By 2050, the RES penetration in the capacity mix is presumed to reach 46% in the BAU scenario, 59% in the Increased Ambition scenario, and 70% in the Green Development scenario. In the BAU scenario, only the capacity for hydro is achieved by 2020, while the two decarbonization scenarios achieve all three RES installed capacity targets, with some variations[33]. The BAU scenario does not implement the NDC actions, unlike the two decarbonization scenarios, with Green Development implementing higher targets[34]. All three scenarios implement NDC actions 4 and 27 with hydro capacity.

29. Final energy consumption is the total energy consumed by end users, such as industry, agriculture, the power sector, households etc.

30. ONEE, 2019.

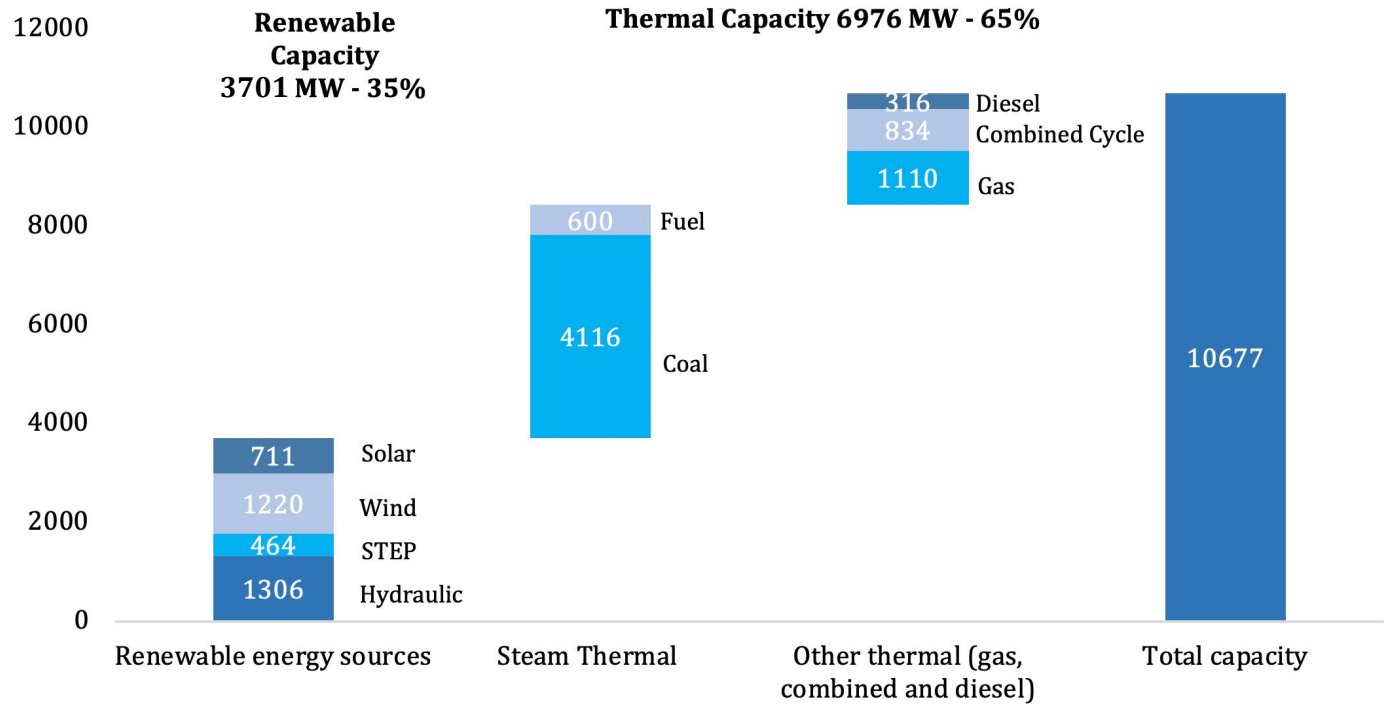
31. ONEE, 2021.

32. It should be noted, however, that the 2020 targets have not been met. According to ONEE, the share of installed electrical capacity from renewable energy sources reached about 36.8% in 2020 (ONEE, 2021).

33. In the Increased Ambition scenario: 2.2 GW of solar, 2.1 GW of wind and 1.9 GW of hydro, while in the Green development scenario: 2.3 GW of solar, 2.5 GW of wind and 1.9 GW of hydro.

34. Increased Ambition scenario: 2.2 GW for NDC action 2, 5 GW for NDC action 26 and 3, 2.1 GW for NDC action 1, 4.2 GW for NDC action 25 and 10 and 4.8 GW by 2030 for NDC action 5 and 28. Green development scenario: 2.3 GW for NDC action 2, 9 GW for NDC action 26 and 3, 2.5 GW for NDC action 1, 10.4 GW for NDC action 25 and 10 and 4.9 GW by 2030 for NDC action 5 and 28.

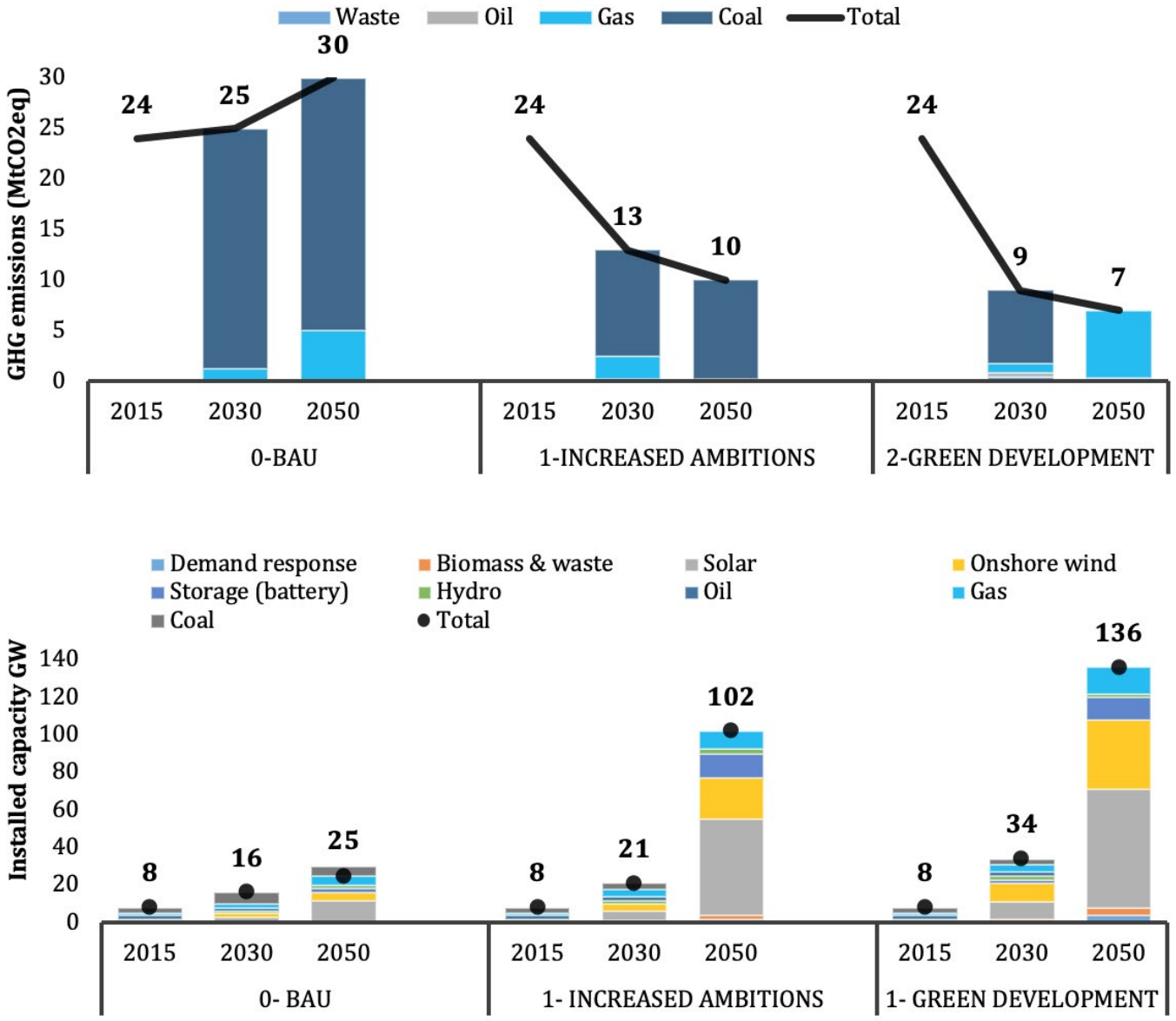
Figure 11: Moroccan Electricity Generation Capacity by Source in MW, 2019



Source: ONEE, Key Figures, 2019

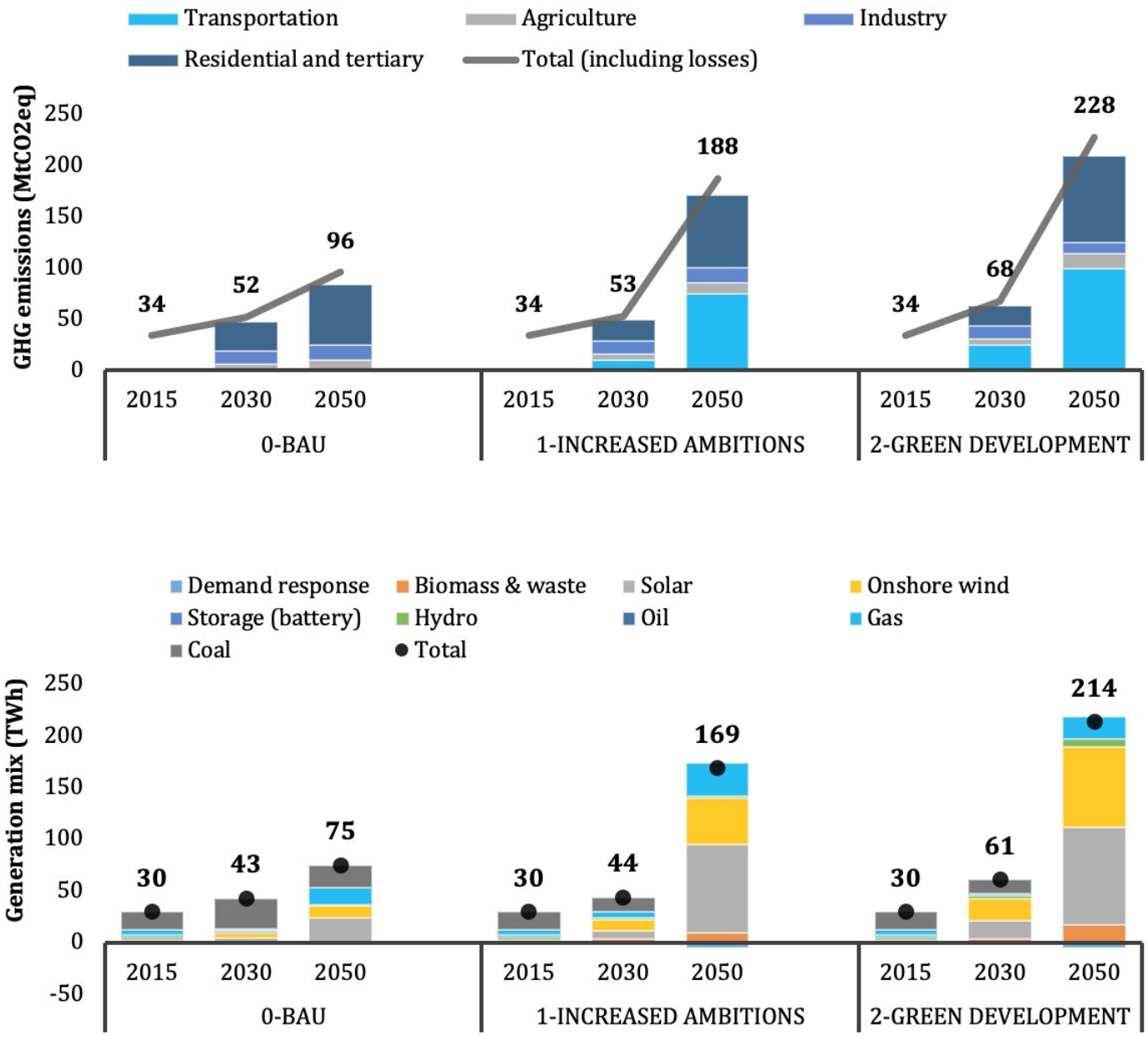
Thanks to increased RES penetration in the energy mix, GHG emissions will drop significantly in the low-carbon scenarios. While reaching 90 MtCO2eq in the BAU scenario, GHG emissions will decrease to 10 MtCO2eq and 7 MtCO2eq in the Increased Ambition and Green Development scenarios respectively (Figure 12). Furthermore, the electricity demand curve will record a steep rise in the future, for all three scenarios, in line with a growing population responsible for energy demand from the residential sector, and expanding electricity demand from different sectors such as transportation, industry, and agriculture (Figure 13). In the BAU scenario, total electricity demand will attain 52 TWh by 2030 and 96 TWh by 2050, compared to a meager 34 TWh in 2015, while the installed capacity will reach 16 GW in 2030 and 30 GW by 2050, compared to 8 GW in 2015.

Figure 12: Power Sector Modeling Results



Source: Authors' calculations. Note: BAU and Increased Ambitions: Only merchant RES, IRR› Hurdle rate. Green Development: Potential need for support, IRR‹ Hurdle rate in short term.

Figure 13: Electricity Demand and Generation Mix in the Three Modeled Scenarios



Source: Author's calculations.

Under the additional pressure of the economy's decarbonization, which directly translates into increasing electrification of major energy-intensive sectors, the national installed capacity must not only evolve to meet exponential electricity demand growth, but must also facilitate the environmental transition through an appropriate mix in which renewable energy sources predominate. This means that Morocco will need to gradually transform its power systems so that solar and wind become the backbone of its electricity supply. Consequently, electricity demand will jump to an outstanding 188 TWh and 228 TWh by 2050 under the Increased Ambition and Green Development scenarios respectively. The higher electricity demand, mostly driven by transport electrification, will require a more than tenfold increase in the installed electric

capacity in Morocco, from 8 GW at the end of 2015 to a total installed capacity reaching 102 GW and 136 GW under the Increased Ambition and Green Development scenarios respectively, which will be met mainly by wind and solar generation.

Moreover, significant additional pressure will be exerted on the grid in the future by rising electricity demand coupled with the increased share of variable renewable energy sources, especially under the Increased Ambition and Green Development scenarios. This highlights the need for power system flexibility, or the power system's ability to respond to both expected and unexpected changes in demand and supply. While the overall shape of electricity demand depends on a mix of climatic and socio-economic parameters (such as weather, season, GDP, level of industrialization, and energy intensity), other sources of uncertainty will appear in the future, especially from new technologies, such as electric vehicles (For instance, charging one EV can consume as much as 32 kWh, which is comparable to one household's daily consumption) or by steps to guarantee low-carbon configurations (for instance a shift to heat pumps and solar heaters instead of LPG boilers in housing).

Increasing the share of variable renewable energy sources in the energy mix also introduces additional levels of variability and uncertainty from the supply side. As the share of renewables in a power system increases, the operations of the power system increase in complexity. Large-scale renewables integration makes the process of balancing supply and demand more challenging because of the greater frequency of occurrence and magnitude of forecast errors on net load, and has been associated with many flexibility gaps. System flexibility in the Increased Ambition and Green Development scenarios is provided by a diversified portfolio of technologies, including battery energy storage systems (BESS), demand-response, hydro-pumped storage and biomass plants, and to a lesser degree by new gas installations (for environmental purposes).

Conclusion

This second brief in the Morocco's Decarbonization Pathway series emphasizes conspicuously how much remains to be done in order to reach significant GHG reduction targets. The Business-As-Usual scenario reflected GHG emissions across sectors as outlined in Morocco's Nationally Determined Contribution and 3rd communication to the UNFCCC (up to 2040). It has been determined that, in terms of GHG emissions, it is not enough to reach Morocco's unconditional NDC emissions reductions targets of -13% (without AFOLU) by 2030. The Increased Ambition and Green Development modeled scenarios would both see greater decarbonization compared to that envisaged by current policy as these scenarios would include more electrification of the final sectors, and less-polluting energy sources (such as renewable energy and hydrogen). These scenarios would also be innovation and technology-oriented in line with energy trends in developed economies.

The modeling efforts show that the transportation, power generation, and residential sectors are key to the decarbonization of Morocco's energy consumption with the proper technology switching, energy efficiency, and electrification of final uses, and phasing out of polluting energy sources. These ambitious targets will arguably not only reduce local pollution but will lead to a new engine of growth, built on an innovative system of economic activities that stimulate transformation and nurture competitive yet responsible development. Achieving the long-term goals of 2050 will involve passing through an intermediate transition to 2030, and will require additional incentives to reduce the costs of the transition. In this sense, analyzing the costs and benefits of the energy transition is crucial to determine the right incentives and specific strategies to adopt. The third brief in the Morocco's Decarbonization Pathway series will present the results of a cost-benefit analysis, carried out in order to identify technological levers and estimate the global economic costs and benefits of the three modeled scenarios.

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About Enel Green Power Morocco

Enel Green Power was founded in December 2008 inside the Enel Group to develop and manage power generated from renewable resources worldwide.

The company is present in 32 countries across 5 continents and has over 1,200 plants. It has around 49 GW of installed renewable capacity generated from a mix of resources, including wind, solar, hydroelectric and geothermal. Enel Green Power is playing a fundamental role in the energy transition, as it is one of the world's leading renewable energy companies. Its goal is to accompany the planet into a new era in which everyone has access to sustainable, decarbonized energy.

Enel Green Power is also a founding member of RES4MED, Renewable Energy Solutions for the Mediterranean and Beyond, an association created in 2012 to promote renewable energy and the infrastructures needed to deliver the generated electricity throughout the Mediterranean area.

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Policy Center for the New South, is a Moroccan policy-oriented think tank based in Rabat, Morocco, striving to promote knowledge sharing and to contribute to an enriched reflection on key economic and international relations issues. By offering a southern perspective on major regional and global strategic challenges facing developing and emerging countries, the Policy Center for the New South aims to provide a meaningful policy-making contribution through its four research programs: Agriculture, Environment and Food Security, Economic and Social Development, Commodity Economics and Finance, Geopolitics and International Relations.

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Policy Center for the New South

Suncity Complex, Building C, Av. Addolb, Albortokal Street,
Hay Riad, Rabat, Maroc.
Email : contact@policycenter.ma
Phone : +212 (0) 537 54 04 04 / Fax : +212 (0) 537 71 31 54
Website : www.policycenter.ma