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Senegal: Energy Development Plan to Decarbonise the Economy

prepared for Power Shift Africa

By The University of Technology Sydney
Institute for Sustainable Futures

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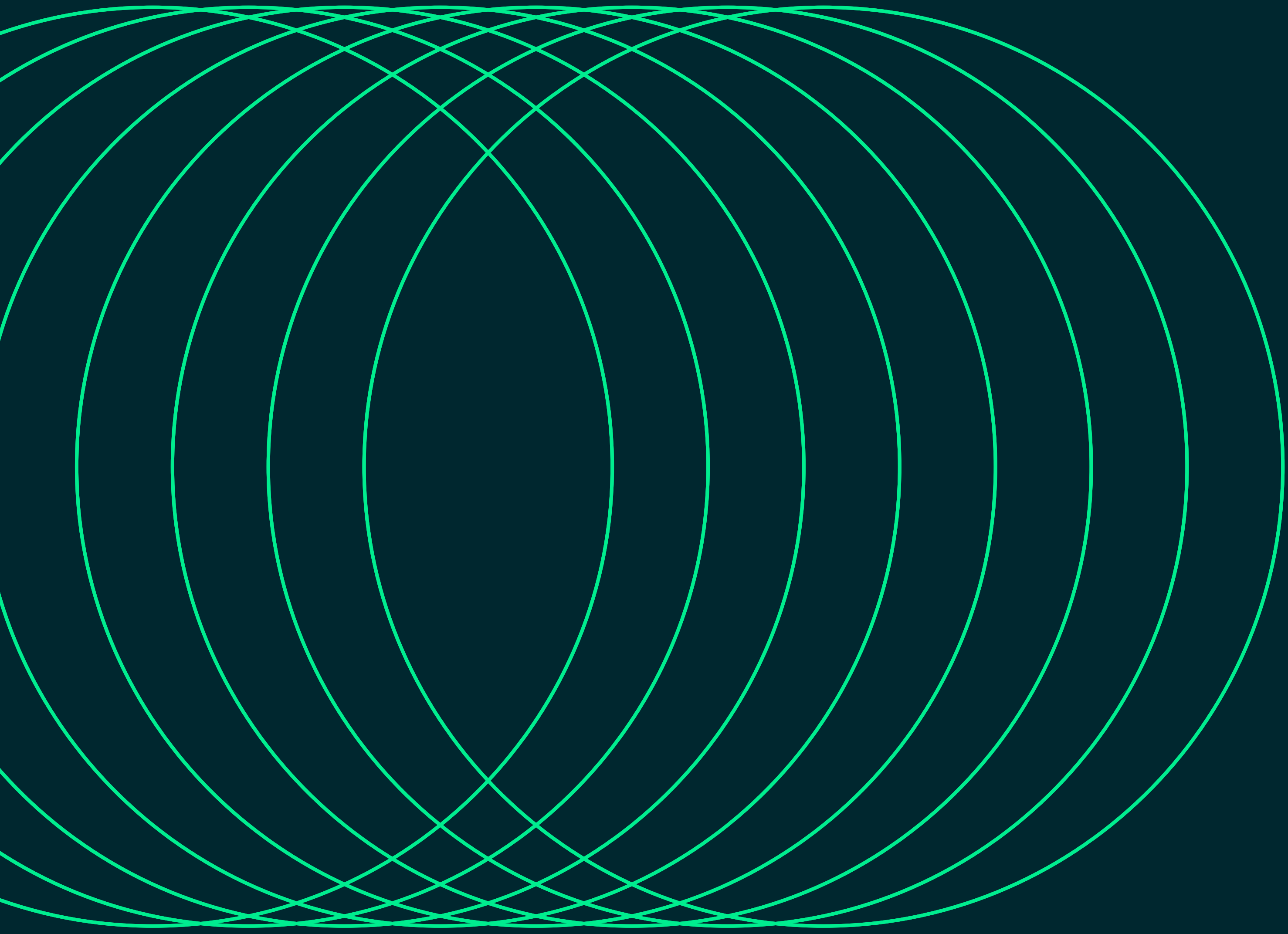

About the authors

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human well-being, and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

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The energy scenario software – the One Earth Climate Model – for the long-term projections and economic parameters is based on the development of the German Aerospace Centre (DLR), Institute for Technical Thermodynamics, Pfaffenwaldring 38-40, 70569 Stuttgart/ Germany, and has been applied to over 100 energy scenario simulations for global, regional, and national energy analysis.

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All conclusions and any errors that remain are the authors own.

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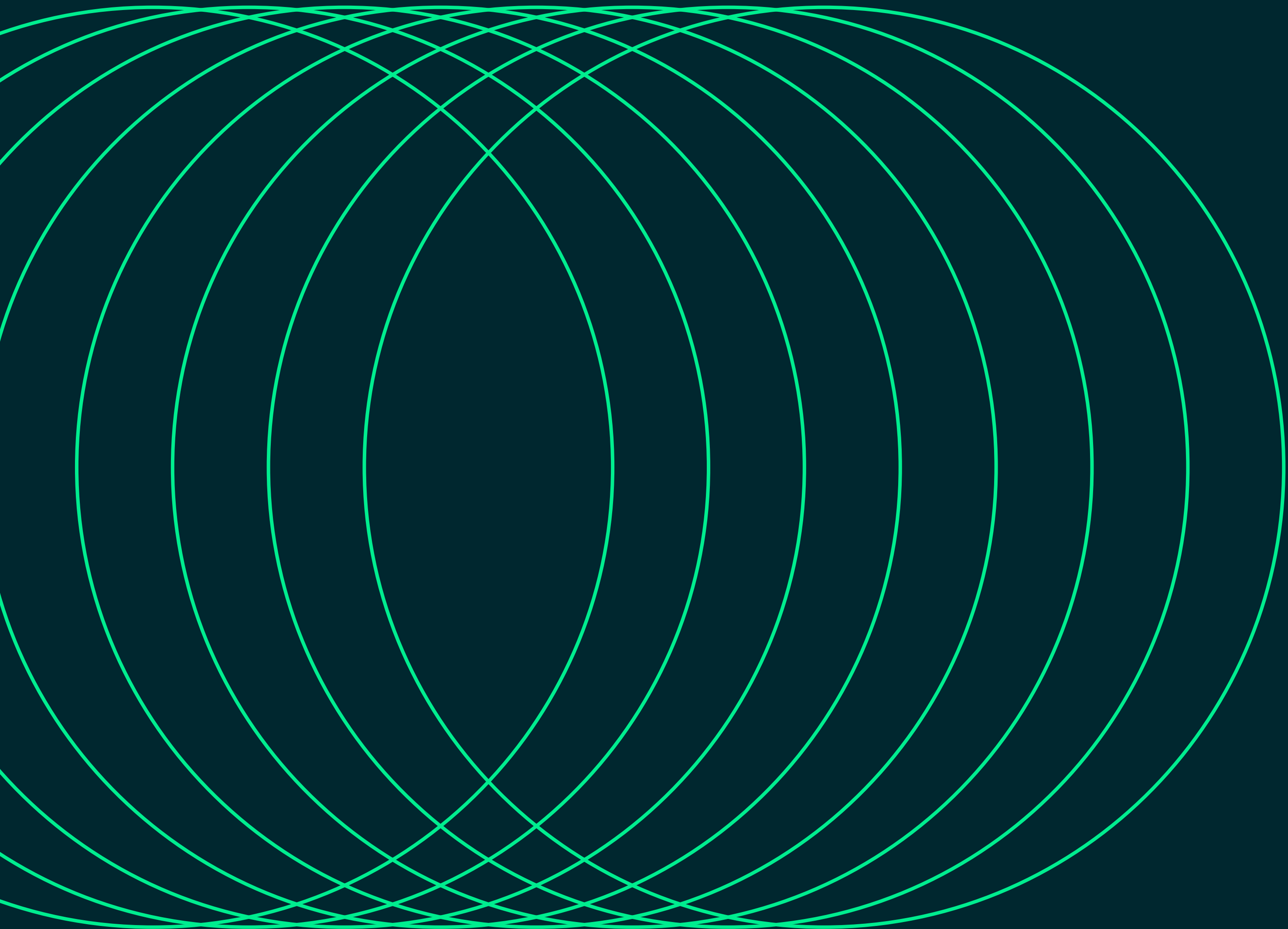
Executive Summary



Senegal submitted its first National Determined Contribution (NDC) at the end of 2020 and the country is currently advancing its climate policy to reduce CO_2e emissions by 29% by 2030 (conditional upon external support) and to achieve a cumulative installed capacity of 235 MW for solar and 150 MW for wind energy by 2030.[1] However, the former President of Senegal, Macky Sall, has spoken out against developments that would reduce financing for fossil fuel projects.[2]

The political agenda of the current president, Bassirou Diomaye Diakhar Faye, includes a simultaneous focus on fossil fuels, with the renegotiation of oil contracts with major energy companies, and an increase in Senegalese renewable energy development. The movement towards renewables is illustrated by Senegal's policies summarised in a 2023 overview from the IEA. In one of those policies, the Just Energy Transition Partnership (JETP), Senegal will receive €2.5 billion over a 3–5-year period to support its energy transition. Within this framework, Senegal has pledged to achieve 40% renewable energy generation by 2030.

Positive steps towards climate action are urgently required, with climate change affecting every aspect of Senegalese daily life, including fishing, agriculture, health, safety (with rising sea levels), productivity, and climate adaptation to heat and extreme weather events.[3]

Table E1. IEA Senegal Energy Policy Review 2023

Policy	Key Targets and Measures
Plan Sénégal Émergent	Transforming Senegal into an emerging market economy with growth in infrastructure and industrialisation, and the modernisation of agriculture.
Lettre de politique de développement du secteur énergétique (LPDSE 2019-2023)	Securing access to low-cost sustainable energy, modern cooking, and improved regulation.
Lettre de politique de développement du secteur énergétique (LPDSE 2024 -2028)	Under development.
Plan Intégré à Moindre Coût PIMC (10-year low-cost plan)	Replacing Heavy Fuel Oil (HFO) with natural gas.
Just Energy Transition Partnership (JETP)	In a partnership with France, Germany, the EU, the UK, and Canada, Senegal will be supported with €2.5 billion in a 3–5-year period to achieve its energy transition ambitions. Senegal has pledged a 40% share of renewable energy generation by 2030 within the JETP.

According to the World Bank, Senegal has achieved respectable GDP growth in the past, averaging 4.6% in 2009–2019. However, Senegal faces significant difficulties in achieving inclusive and sustainable growth. The global disruptions caused by the COVID-19 pandemic have been compounded by structural constraints in Africa, such as slow domestic job creation, high vulnerability to natural disasters, climate change, environmental degradation, and large infrastructure gaps. Furthermore, the pandemic has recently triggered a surge in debt levels, which must be addressed. However, strong economic growth is assumed for the development of the energy scenario.

Senegal's electricity demand is currently 272 kWh per capita, one of the lowest in the world, with the global average consumption exceeding 3,000 kWh per capita per annum. The primary energy supply is dominated by crude oil (around 49% in 2020) and biomass (around 41%); crude oil supplies electricity generation, whereas biomass is mainly used for cooking and heating. If the primary energy supply continues according to its development over the past 5 years (by 4.2% annually), the primary energy demand will increase to 637 PJ/a by 2050.

Power Shift Africa and the University of Technology Sydney (UTS) have developed a comprehensive energy pathway for Senegal that is aligned with the goals of the Paris Climate Agreement.

The following section provides an overview of the key results of that energy scenario.

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[1] Republique du Senegal, Contribution Déterminée au Niveau National Du Senegal, December 2020, Online retrieved from on 7th of August 2024: https://climatepromise.undp.org/what-we-do/where-we-work/senegal

[2] https://climateactiontracker.org/documents/1067/2022_08_CAT_Governance_Report_Senegal.pdf

[3] https://www.usaid.gov/climate/country-profiles/senegal

Development of the electricity demand

To develop a projection for the residential electricity demand in Senegal over the coming 30 years that will achieve the Senegal 1.5 °C (S-1.5°C) scenario, a bottom-up electricity demand analysis was undertaken. The S-1.5°C scenario aims to increase the access to energy – especially electricity – for all by 2050, while increasing the electrification and comfort standards to the levels of OECD countries. The growing economy requires a reliable power supply for small and medium businesses, industry, and the transport sector. It is assumed that households will use modern energy-efficient applications, according to the highest efficiency standards, to slow the growth of the power demand and to allow the parallel expansion of the energy infrastructure and the construction of renewable power plants. Electrification will be organised from the 'bottom up' in a new and innovative approach developed by the University of Technology Sydney-Institute for Sustainable Futures (UTS-ISF).

It is assumed that households with annual consumption in 'phase 1', as defined according to household type, will increase their demand to 'phase 2' or 'phase 3' values over time. There are currently three household types, separated according to their annual electricity demand: rural households, which have an average annual electricity demand of just under 340 kWh; semi-rural households, which consume around 500 kWh per year; and urban households, with an annual consumption of 840 kWh.

The electricity demand will gradually increase as the electric applications for each of the three household types progress from those households with very basic needs, such as light and mobile phone charging, to a household standard equivalent to that of industrialised countries. The different levels of electrification and the utilisation of appliances are described with the affixes 'phase 1', 'phase 2', and 'phase 3' for rural households. In contrast, semi-urban and urban households are assigned to two groups: one with the basic level of electrification and one with the more-advanced stage. These households will develop over time from the basic group towards the more advanced group.

The third phase of a rural household includes an electric oven, refrigerator, washing machine, air-conditioning, and entertainment technologies, and aims to provide the same level of comfort as households in urban areas in industrialised countries. Adjustments will be made to the levels of comfort in households in city and rural areas to discourage residents – especially young people – from leaving their home regions and moving to big cities. The phase-out of unsustainable biomass liquefied pressurised gas (LPG) and paraffin, for cooking is particularly important in decarbonising Senegal's household energy supply. A staged transition towards electrical cooking is assumed.

Energy for cooking

The main energy demand for Senegal's households is for cooking. Firewood is the main energy source for rural households, whereas cylinders of LPG are the main source of energy for cooking in semi-urban and urban households[4]. Senegal's households also use charcoal. Based on current cooking energy usage, a transition scenario from fuel-based cooking to electric cooking (e-cooking) has been developed for the S-1.5°C scenario. However, with an increasing population and a growing number of households, the overall fuel demand is likely to remain high, and a phase-out of emissions and fuel demand cannot be achieved with this measure alone. Fuel-based cooking applications will be gradually phased-out and replaced with electric cooking appliances.

The total phase-out of fuel-based systems will be for environmental and economic reasons. Fuel-based cooking requires fuel that generates emissions, and the fuel supply is, in most cases, not sustainable. Collecting fuel wood puts forests under pressure, is time-consuming, and has a negative economic impact on the country's productivity. Burning LPG causes CO_2 emissions, and its production is based on fossil gas, which must be phased-out by 2050 to remain within the global carbon budget to limit the global mean temperature rise to a maximum of +1.5 °C. The remaining wood- and bio-energy-based cooking in 2050 will be with sustainable charcoal. Electric cooking can be supplied by renewable energy sources and will be emissions-free.

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[4] IEA (2020) Senegal fuels and technologies used for cooking by scenario, 2018–2030, 15th of August 2024, Online retrieved from: https://www.iea.org/data-and-statistics/charts/senegal-fuels-and-technologies-used-for-cooking-by-scenario-2018-2030

However, there are some challenges to the introduction of electric cooking stoves:

- Firewood remains freely available.
- In relative terms, the initial investment and monthly costs are high.
- Concerns exist about the safety of the technology. However, there are safety benefits compared with more combustible energy sources, such as LPG.
- (Initial) concerns exist around the learnability of new appliances.
- In the cold climate of mountainous regions, fire from cooking also heats rooms.
- The use of e-cooking is perceived to be expensive.
- There are concerns about the quality of the appliances.
- It is a new technology that requires education to operate it.
- The current business models of distribution are not well suited to low-income households. Most vendors use the upfront model of payment rather than other innovative models, such as pay as you go, which have proven beneficial for many other technologies.
- Perceived and/or actual differences in taste and quality between food prepared with biomass and e-cooking.

Projection of the transport energy demand

Senegal's transport sector is currently dominated by passenger cars, which account for 57% of all registered vehicles, and vans and motorcycles represent 11% and 7% of the vehicle fleet, respectively.[5] Other vehicles, such as tractors (3%), buses (3%), and trucks (4%), together make-up ~10% of the vehicle fleet, almost as large a proportion as that of vans. Although cars represent the largest fraction of registered vehicles, many residents use colorful minibuses ("cars rapides") or larger white buses ("Ndiaga Ndiaye") for inter-city or longer-distance transport. Therefore, these two forms of transport form an essential component of everyday life.

The total numbers of passenger- and freight-kilometres are the basis for the projection of the future transport demand. The contraction of the transport demand in 2020 due to COVID is expected to end. It is anticipated that the pre-COVID transport demand of 2019 will be reached by 2023 and will increase with population growth and GDP. It is assumed that the annual passenger-kilometres (pkm) for passenger and freight transport will remain constant. It is also assumed that the annual pkm will increase by 3% annually until 2050; similarly, the freight transport demand will increase by 3% annually. All assumptions and calculated energy demands are shown in Table 14. The energy intensities for all vehicles are assumed to decrease over time with the implementation of more-efficient engines, the phase-out of fossil-fuel-based drives, and their replacement with electric drives. To achieve the terms of the Paris Climate Agreement, all energy-related CO_2 emissions must be phased-out by 2050. Therefore, all fossil-fuel-based vehicles must be phased-out, and electric drives will dominate, supplemented with a limited number of biofuel-based vehicles.

However, it is assumed that the share of cars will grow at the expense of two-wheeler vehicles – which will increase the average energy intensity per kilometre. Although electric drives are significantly more efficient, the increased vehicle sise combined with more public transport options – mainly buses – will limit the increase in the energy demand.

On average – across all passenger vehicle types – energy intensity will decrease from around 1.88 MJ per pkm (MJ/pkm) to 1.75 MJ/pkm in 2030 and to 1.6 MJ/pkm in 2050. The energy required by freight vehicles to move 1 tonne for 1 kilometre will decrease from around 1.51 MJ to 1.14 MJ by 2030 and to 1.06 MJ by 2050. Both reductions will only be possible with high shares of electric drives. The electrification of large parts of these fleets is unavoidable if the transport sector is to be decarbonised.

The supply of (sustainably produced) biofuels will be limited and will be directed to large commercial vehicles, buses, and the large trucks used in remote rural areas where the required charging infrastructure for electric vehicles is unlikely to be developed in the next two decades. Senegal submitted an updated NDC report to the UNFCCC in 2020. The new NDC sets a target to reduce greenhouse gas (GHG) emissions by 7% (unconditional) or 29.5% (conditional) by 2030 compared with the 'business-as-usual' (BAU) scenario.[6]

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[5] Republique du Senegal, Agence nationale de la statistique et de la demographie, Situation Economique et sociale du senegale 2017–,2018.

[6] NDC partnership, Senegal, https://ndcpartnership.org/country/sen

The NDC does not include a detailed transport pathway but highlights the following priority mitigation activity for the transport sector: '***low-carbon and efficient transportation systems***'.

Based on the average technical lifespans for motorcycles and cars, a country-wide overall market share of electric drives for the entire existing car fleet may not exceed 20% by 2030 for passenger and freight cars. It is assumed that the railway system will not be expanded beyond the current plans after 2030.

Projections of electricity supply: assessment of solar and wind energy potential

The average annual solar irradiation (DNI) level in Senegal is 1,325–1,325 kWh/m^2/year, and the higher end of that range is in the western part of the country. The overall onshore wind resources on land are significantly lower than the solar potential in Senegal. The wind speeds in Senegal range from 3 to 8 m/s at 100 m height, and high-wind-speed areas are predominantly located in the mid-northern region (Global Wind Atlas). In this analysis, we have included only areas with an average annual wind speed of ≥ 5 m/s. Senegal's solar and wind potential has been mapped under two different scenarios:

- **Scenario 1:** Available land – excluding protected areas (PA), extreme topography (slope > 30% ([mountainous areas], S30), and certain land-cover classes, including closed forests, wetlands, moss and lichen, snow and ice, and water (permanent water bodies) (LU).
- **Scenario 2:** See 1, with the additional restriction that excludes areas ≤ 10 km from existing transmission lines (PT10).

Senegal is blessed with huge solar and wind energy resources. Scenario 1 provides 133,225 km^2 of areas with solar potential and a total potential for solar photovoltaic (PV) capacity of 3,331 GW. The solar potential under Scenario 2, when the land area is restricted by its proximity to power lines (£10 km), decreases to 64,182 km^2, which will allow utility-scale solar farms that generate 1,605 GW in Senegal. The overall wind potential under all restrictions is 584 GW from 116,728 km^2 for Scenario 1 and 297 GW from 59,447 km^2 under Scenario 2.

Senegal's total solar and onshore wind potential will exceed the projected electricity demand in 2050 – with full electrification of all households, industry, and the entire transport sector – by an order of magnitude. The potential is so large that Senegal could also export electricity to all neighbouring countries.

Assumptions for energy scenario development

Senegal must build up and expand its power generation system to increase the energy access rate to 100%. Building new power plants – no matter the technology – will require new infrastructure (including power grids), spatial planning, a stable policy framework, and access to finance. With lower solar PV and onshore wind prices, renewable power has become an economic alternative to building new hydro and gas power plants. Consequently, renewables achieved a global market share of over 80% of all newly built power plants in 2021. Senegal has significant solar resources and large wind potential. The costs of renewable energy generation are generally lower with stronger solar radiation and stronger wind speeds. However, constantly shifting policy frameworks often lead to high investment risks and higher project development and installation costs for solar and wind projects relative to those in countries with more stable policies.

The scenario-building process for all scenarios includes assumptions about policy stability, the role of future energy utilities, centralised fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** This research assumes that Senegal will establish a secure and stable framework for investments in new renewable power generation. Financing a gas power plant or a wind farm is quite similar. In both cases, a power purchase agreement that ensures a relatively stable price for a specific quantity of electricity is required to finance the project. However, daily spot market prices for electricity and/or renewable energy or carbon are insufficient for long-term investment decisions for any power plant with a technical lifetime of 20 years or longer.

- **Strengthened energy efficiency policies:** Existing policy settings – energy efficiency standards for electrical applications, buildings, and vehicles – must be strengthened to maximise the cost-effective use of renewable energy and to achieve high energy productivity by 2030.
- **Role of future energy utilities:** With 'grid parity' of roof-top solar PV below most current retail tariffs, this modelling assumes that the energy utilities of the future will take up the challenge of increased local generation and develop new business models that focus on energy services, rather than simply on selling kilowatt-hours.
- **Population and GDP:** Projections of population and GDP are based on historical growth rates. Projections of population growth are taken from the World Bank Development Indicators.
- **Firm capacity:** The scale of each technology deployed and the combination of technologies in both – the S-1.5°C and the REFERENCE -scenarios target the firm capacity. Firm capacity is the "proportion of the maximum possible power that can reliably contribute towards meeting the peak power demand when needed." Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewable energy systems still have a firm capacity rating, and the combination of technology options increases the firm capacity of the portfolio of options.

Assumptions for the Senegal 1.5 °C scenario

The Senegal 1.5 °C (S-1.5°C) scenario is built on a framework of targets and assumptions that strongly influence the development of individual technological and structural pathways for each sector. The main assumptions considered in this scenario-building process are detailed below.

- **Emissions reductions:** The main measures taken to meet the CO_2 emissions reductions in the S-1.5°C scenario include strong improvements in energy efficiency, which will double energy productivity over the next 10–15 years, and the dynamic expansion of renewable energy across all sectors.
- **Growth of the renewables industry:** The dynamic growth of new capacities for renewable heat and power generation is assumed based on current knowledge of the potential, costs, and recent trends in renewable energy deployment. Communities will play a significant role in the expanded use of renewables, particularly in terms of project development, the inclusion of the local population, and the operation of regional and/or community-owned renewable power projects.
- **Fossil-fuel phase-out:** The operational lifetime of gas power plants is approximately 30 years. Under both scenarios, coal power plants will be phased-out early, followed by gas power plants.
- **Future power supply:** The capacity of large hydro power will remain relatively flat in Senegal over the entire scenario period, whereas the quantities of bioenergy will increase within the nation's potential for sustainable biomass (see below). Solar PV is expected to be the main pillar of the future power supply, complemented by the contributions of bio-energy and wind energy. The figures for solar PV combine the figures for roof-top and utility-scale PV plants, including floating solar plants.
- **Security of energy supply:** The scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. Power generation from biomass and gas-fired back-up capacities and storage are considered important for the security of supply in a future energy system and are related to the output of firm capacity, discussed above. Storage technologies will increase after 2030, including battery electric systems, dispatchable hydro power, and hydro pump storage.
- **Sustainable biomass levels:** Senegal's sustainable level of biomass use is assumed to be limited to 76 PJ – precisely the amount of bioenergy used in 2020. However, low-tech biomass use, such as in inefficient household wood burners, is largely replaced in the S-1.5°C scenario by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors. This will result in an overall lowering of the total biomass use to 15 PJ.
- **Electrification of transport:** Efficiency savings in the transport sector will result from fleet penetration by new, highly efficient vehicles, such as electric vehicles, but also from assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The scenarios assume the limited use of biofuels for transportation, given the limited supply of sustainable biofuels.

- **Hydrogen and synthetic fuels:** Hydrogen and synthetic fuels generated by electrolysis using renewable electricity will be introduced as a third renewable fuel in the transportation sector, complementing biofuels, the direct use of renewable electricity, and battery storage. Hydrogen generation can have high energy losses. However, the limited potential of biofuels, and probably battery storage, for electric mobility means it will be necessary to have a third renewable option in the transport sector. Alternatively, this renewable hydrogen could be converted into synthetic methane or liquid fuels, depending on the economic benefits (storage costs versus additional losses) and the technological and market developments in the transport sector (combustion engines versus fuel cells). Senegal's hydrogen demand could be filled with local generation or hydrogen and/or synthetic fuels can be imported. Hydrogen utilisation will be limited to the industry sector, and is not expected to contribute more than 5% of industry's energy supply by 2050.

Senegal's 1.5 °C scenario (S-1.5°C) takes an ambitious approach to transforming Senegal's entire energy system to an accelerated new renewable energy supply. However, under the S-1.5°C scenario, the much faster introduction of new technologies will lead to the complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry), and transportation. In the transport sector, there will be a strong role for storage technologies, such as batteries, synthetic fuels (aviation), and hydrogen (shipping).

Assumptions for the Senegal REFERENCE scenario

The REFERENCE scenario for Senegal has been developed based on the Senegal 1.5 °C scenario but assumes an implementation delay of 15 years. The REFERENCE scenario is similar – but not identical – to the BAU scenario in Senegal's NDC submission from 2021.

The key differences between the scenarios are:

1. **Heating a sector:** In the REFERENCE scenario, the phase-out of coal, oil and gas is delayed by 15 years for the residential, service, and industry sectors. Accordingly, electric heat pumps and solar collector systems will remain niche technologies until 2040, but will grow thereafter and increase their shares by 2050.
2. **Transport sector:** In the REFERENCE scenario, electric mobility will experience significant delays, whereas the transport demand will increase as projected in the S-1.5°C scenario. Vehicles with internal combustion engines (ICEs) will remain dominant until 2040. Market shares for electric vehicles will start to grow significantly from 2040 onwards. Biofuels will also increase in the road transport sector.
3. **Power supply:** In the REFERENCE scenario, the delayed electrification in the heating and transport sectors will lead to slower growth in the power demand compared with the S-1.5°C scenario. It is also assumed that renewable power generation will not fill the gap created by the increased electricity demand because its implementation is delayed, and fossil-fuel-based power generation will therefore increase.

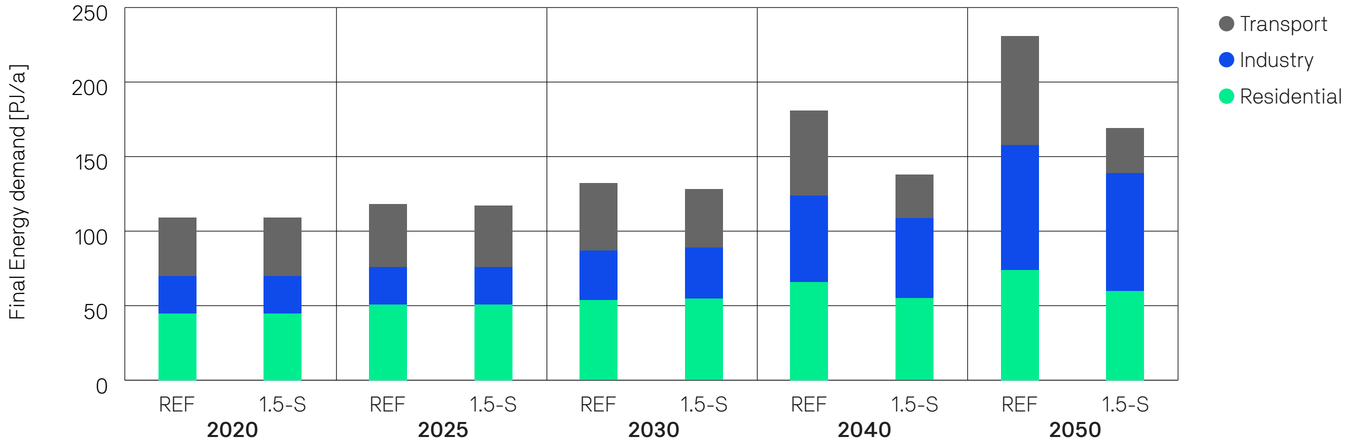
Senegal – Final Energy Demand

The projections for population development, GDP growth, and energy intensity are combined to project the future development pathways for Senegal's final energy demand. As a result of the projected continued annual GDP growth by 7.3% on average until 2030 and 6.7% thereafter until 2050, the overall energy demand is expected to grow under both scenarios. The residential sector will remain dominant in Senegal's energy demand, but the energy demand of the industry sector will increase slightly.

The energy demand of the transport sector will increase by 84% by 2050 under the REFERENCE scenario, whereas it will decrease by 39% under the S-1.5°C scenario. The main reason for this significant difference in growth projections is the high rate of electrification in the S-1.5°C pathway.

The large efficiency gains achieved in the S-1.5°C scenario are attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

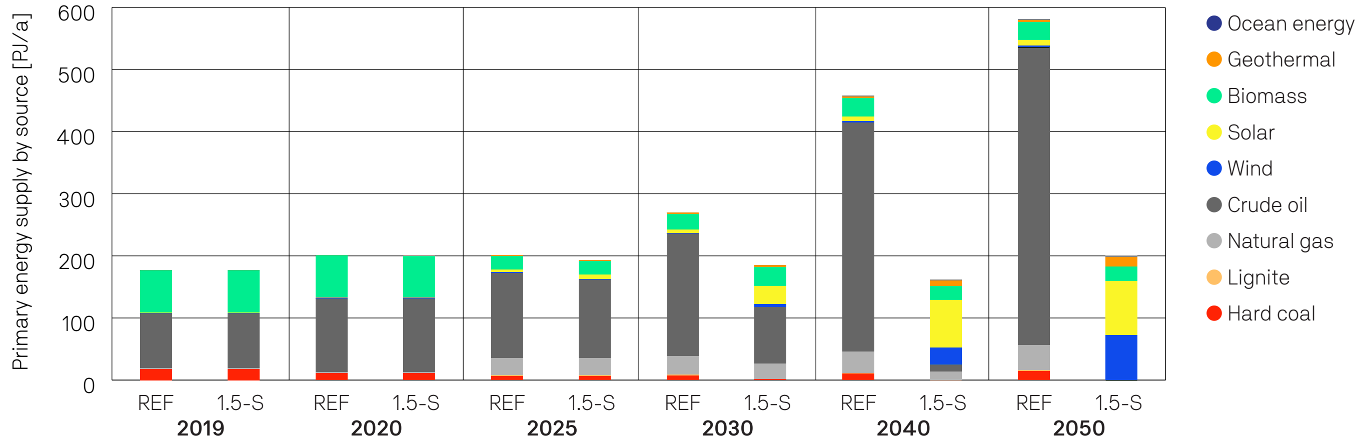
Figure E1. Projection of the total final energy demand by sector (excluding non-energy use and heat from combined heat and power [CHP]-using automobile producers)



Primary Energy Consumption

The S-1.5°C scenario aims to phase-out oil in the transport sector and oil for industrial use as fast as is technically and economically possible, through the expansion of renewable energies. The rapid introduction of very efficient vehicle concepts in the road transport sector will replace oil-based combustion engines. This will lead to an overall renewable primary energy share of 100% in 2050 under the S-1.5°C scenario (non-energy consumption is included).

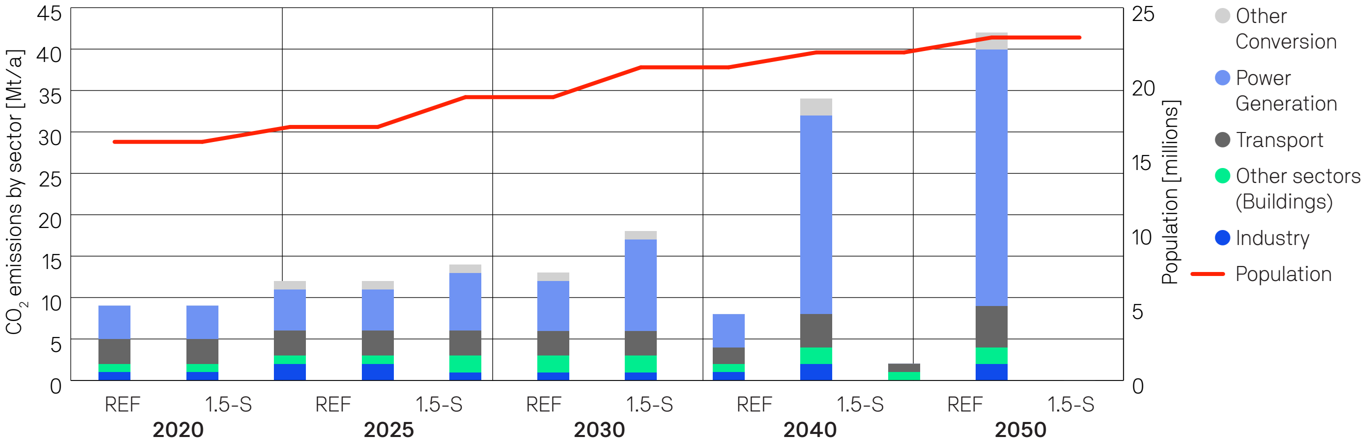
Figure E2. Projection of total primary energy demand by energy carrier (including electricity import balance)



CO_2 Emissions Trajectories

The S-1.5°C scenario reverses the trend of increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 2% relative to 2020 by 2030 and of about 81% by 2040. In 2050, the full decarbonisation of Senegal's energy sector will be achieved under the S-1.5°C scenario. In the S-1.5°C scenarios, the cumulative emissions will sum to 275 Mt for 2005–2050 compared with 693 Mt CO_2 for the REFERENCE scenario.

Figure E3. Development of CO_2 emissions by sector



Cost analysis

Finally, the fuel costs for the power, heating, and transport sectors are presented.

Fuel costs in all three sectors will decrease over time because electricity generation will be based on renewables – with significant shares of solar and wind power. However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Senegal.

The S-1.5°C scenario requires an investment of 15.5 trillion CFA (US$26.4 billion) in power generation and 9.6 trillion CFA (US$16.3 billion) in heat generation. Therefore, the total investment in power and heat generation capacities will add up to 25 trillion CFA (US$43 billion).

Across the entire scenario period, fuel cost savings under the S-1.5°C scenario relative to the REFERENCE scenario will be 19.2 trillion CFA (US$32.6 billion) – and will cover the entire investment in new power generation capacities until 2050 – about 16 times the additional investment in comparison of the S-1.5°C pathway.

Whereas fuel cost predictions are subject to a great deal of uncertainty, this result makes the cost-effectiveness of electrification very clear.

Table E2. Accumulated fuel costs for heat generation under the REFERENCE and S-1.5°C scenarios in billion US$ and trillion CFA

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD
Power	Total	4.8	8.2	4.8	8.2	7.5	12.7	17.1	29.1	0.6	1.0
Heat	Total	1.5	2.5	1.7	3.0	1.5	2.6	4.7	8.1	0.2	0.3
Transport	Total	1.1	1.8	1.4	2.3	1.6	2.7	4.0	6.8	0.1	0.2
Summed Costs		**7.4**	**12.5**	**7.9**	**13.5**	**10.5**	**17.9**	**25.9**	**43.9**	**0.9**	**1.5**
		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
S-1.5°C		[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD
Power	Total	0.2	0.4	0.2	0.4	0.0	0.0	0.5	0.8	0.0	0.0
Heat	Total	1.6	2.7	1.4	2.4	1.1	1.8	4.0	6.9	0.1	0.2
Transport	Total	1.0	1.7	0.7	1.2	0.4	0.7	2.1	3.6	0.1	0.1
Summed Costs		**2.8**	**4.8**	**2.4**	**4.0**	**1.5**	**2.5**	**6.6**	**11.3**	**0.2**	**0.4**
Difference REFERENCE versus S-1.5°C		**4.5**	**7.7**	**5.6**	**9.5**	**9.1**	**15.4**	**19.2**	**32.6**	**0.6**	**1.1**

Power sector analysis

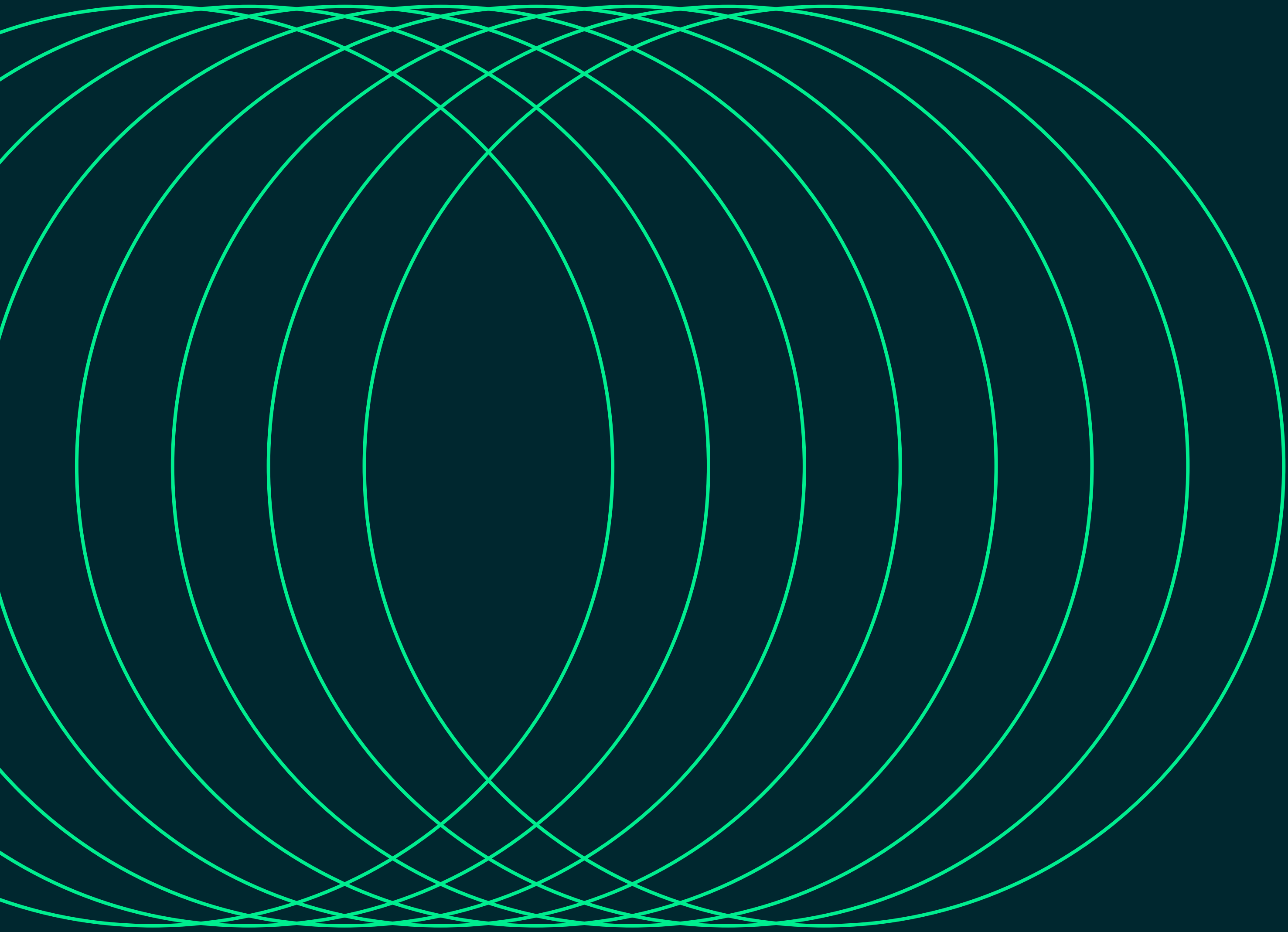
In a last step, after the assessment of the solar and wind potential and the projection of the future electricity demand for households, industry, and the transport sector, the power sector is analysed. The electricity demand projections and resulting load curves are calculated as important factors, especially for power supply concepts with high shares of variable renewable power generation. Furthermore, the calculation of the required dispatch and storage capacities is vital to the development of energy electricity supply concepts that lead to high security of supply. A detailed bottom-up projection of the future power demand, based on the applications used, demand patterns, and household types, allowed a detailed forecast of the demand. The energy sector analysis was conducted for Senegal's projected electricity demand and supply for 2030 and 2050 under the S-1.5°C pathway.

Conclusion

We found that Senegal can cost-effectively build a reliable electricity supply based on local power generation with a high proportion of solar and wind power.

The potential for solar and wind power will not only reliably cover future electricity needs, but will also allow renewable electricity to be exported to neighbouring countries.

1 Introduction



This report focuses on the development of a 100% renewable energy pathway for Senegal. Here, the 100% renewable energy pathways is constructed to be robust and technically and financially feasible. The 100% renewable energy pathway will also be a clear demonstration of the security of supply for Senegal's industry, transport, and residential sectors.

The scenarios for the energy pathways do not claim to predict the future, but provide useful tools with which to describe and compare potential development pathways from the broad range of possible 'futures.' The Senegal 1.5°C (S-1.5°C) scenario is designed to calculate the efforts and actions required to achieve the ambitious objective of a 100% renewable energy system and to illustrate the options available to change Senegal's energy supply system into a truly sustainable one. It may also be used as a reliable basis for further analyses of the possible ideas and actions required to implement pathways to achieve the desired results.

100% renewable energy scenarios for electricity generation, energy demand, energy supply, and transport are included. The investments required to achieve these scenarios and the policies that will enable them are described for the specific scenarios.

Finally, the report includes simulations of the national grid capacity required now and in the future, and the necessary linkages between different parts of the country's power grid. The simulations support the assessment of the grid expansion requirements, the power trade balance, and the investments required to strengthen the backbone of Senegal's electricity infrastructure to ensure its reliability and resilience.

In this report, we aim to inform policymakers, researchers, and practitioners of the extent of the interventions required for Senegal to reach its target of 100% renewable energy by 2050. The decade-by-decade scenarios identify important milestones that will allow further sector-wise energy-related targets to be defined and tracked.

1.1 Research Scope

Since 2017, the University of Technology Sydney-Institute of Sustainable Future (UTS-ISF) has undertaken detailed country-specific energy analyses (see reference list), ranging from the global south, including Senegal, to industrialised countries, including all the G20 countries and Switzerland.

All UTS-ISF energy analyses include the following components:

- A renewable energy resource analysis based on spatial GIS data under constrained land availability conditions (excluding protected areas, areas with a steep slope, and certain land-cover classes, such as closed forests, wetlands, snow and ice, and permanent water).
- The development of future energy demands for 2025, 2030, 2035, 2040, 2045, and 2050, based on the latest available statistics – the base year for energy demand is 2019 – broken down into the main energy sectors (power, buildings, industry, and transport).
- The sectoral energy demands (see above) are broken down to the level of provinces.
- The development of the following scenarios:
    - 1.5 °C scenario[7] – 100% renewable energy plan to decarbonise the energy sector by 2050 within the carbon budget required to achieve a temperature rise of 1.5 °C with 66% certainty (based on IPCC AR6 2021).
    - The REFERENCE scenario for comparison.

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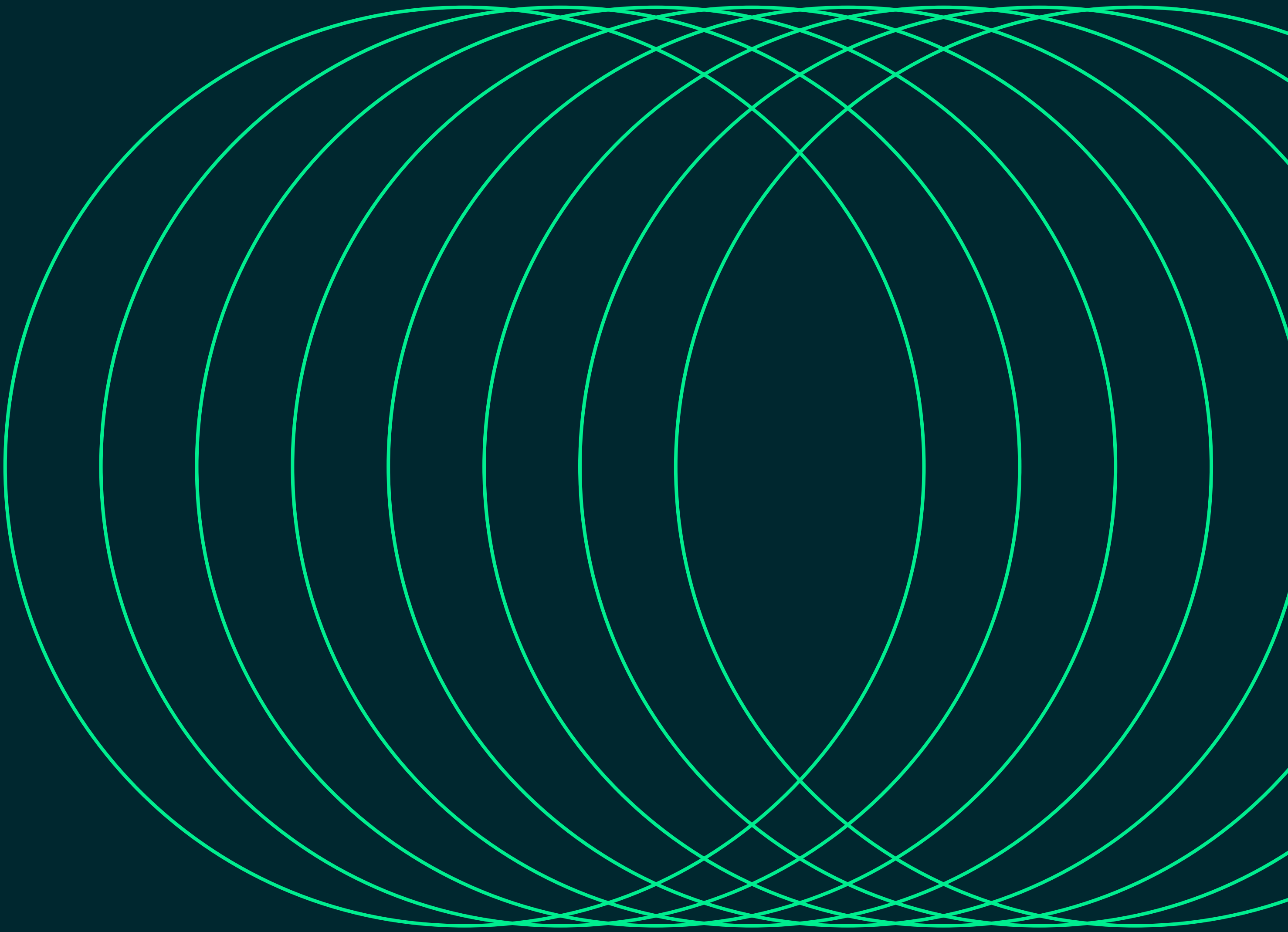
[7] 1.5 °C scenario: Series of scenarios with a total global carbon budget of 400 $GtCO_2$ to limit the global mean temperature rise to a maximum of 1.5 °C with 67% likelihood, as defined in IPCC AR6.

- These scenarios are combined with renewable energy scenarios with different shares of variable power generation (solar PV, wind, bioenergy, and hydro power).
- Based on the different power demand and supply scenarios, a projection of the required loads from industry, commercial, and residential demands is compared with the available power generation capacity – to stress-test the security of supply.
- The power generation capacity is simulated at 1-hourly resolution for seven provinces with regional long-term average meteorological data for solar and onshore wind.
- The current and future required national grid capacities are simulated, together with the required linkages between different parts of the country's national power grid and import and export transactions with neighbouring countries.

This simulation is particularly important in terms of the role of 24/7 power generation and the power flows between regions and neighbouring countries. Included are the:

- Grid expansion and storage requirements;
- Visualisation of the hourly demand and supply curves;
- Carbon emissions (annual and cumulative);
- Investment required in additional power generation capacity – including fuel costs and fuel cost savings, and the operation and maintenance costs for all power generation capacities;
- The power sector trade balance (electricity and fuel) with neighbouring countries;
- A cost comparison of all scenarios.

2 Scenario Assumptions



2.1 Senegal: Country overview

Senegal is situated on the equator in West Africa. It has a coastline on the Atlantic Ocean, which is interrupted by Gambia. The official language is French, and Wolof is an unofficial but widely spoken second common language. Since its official founding in 1960, Senegal has played a major role in West Africa. The capital, Dakar, is a prominent harbour city in West Africa and is a major regional hub for industrial and service centres – representing major Senegalese commodities, such as peanuts, petroleum, fish, phosphates, and cotton[8].

Senegal ranks fourth in GDP per capita and overall magnitude of GDP in West Africa.

The socio-economic assumptions, all data related to the energy demand and supply and GHG emissions, and the statistical data that were used for the development of the energy scenarios are based on publicly available databases.

2.1.1 Political Context

The Senegalese Government has joined 139 other countries with its updated NDC in 2020. However, there is direct political friction between the climate plans and the aim to make Senegal an emerging economy by stepping into fossil fuel development. There is significant support from the Just Energy Transition Partnership (€2.5 billion) for Senegal to increase its energy transition ambitions.[9] Senegal confirmed its ambitions in a joint statement with the European partners to strive towards strengthening renewable energy development as a part of the Integrated Low-Cost Electricity Plan.

> *"The multifaceted crises we are experiencing today are straining African economies, particularly in their significant efforts devoted to economic development, access to energy and industrialisation. Diversifying our energy sources and our supply chains will increase our resilience. The partnership for a just energy transition (JETP) that we are establishing today with our partners will make it possible to support the Senegalese dynamic that we started several years ago of incorporating renewable energies into our energy mix and securing our energy system thanks to all our natural resources in line with the Paris Agreement."*

Former President of Senegal Macky Sall:

The IEA Senegal Energy Policy Review 2023, published in 2023, provides an overview to Senegal's higher-level climate changes and energy targets.

Table 1: IEA Senegal Energy Policy Review 2023

Policy	Key Targets and Measures
Plan Sénégal Émergent	Transforming Senegal into an emerging market economy with growth in infrastructure, industrialisation, and modernisation of agriculture.
Lettre de politique de développement du secteur énergétique (LPDSE 2019–2023)	Securing access to low-cost sustainable energy, modern cooking, and improved regulation.
Lettre de politique de développement du secteur énergétique (LPDSE 2024–2028)	Under development.
Plan Intégré à Moindre Coût PIMC (10-year Low-cost plan)	Replacing Heavy Fuel Oil (HFO) with natural gas.
Just Energy Transition Partnership (JETP)	In partnership with France, Germany, the EU, the UK, and Canada, Senegal will be supported with €2.5 billion in a 3–5-year period to achieve its energy transition ambitions. Senegal has pledged a 40% share in renewable energy generation by 2030 within the JETP.

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[8] DFAT Australia, accessed August 2024, https://www.dfat.gov.au/geo/senegal

[9] European commission, 22nd June 2023, The EU and the International Partners Group announced a Just Energy Transition Partnership with Senegal combining climate and development goals. Accessed online 28th of August 2024, https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3448

2.1.2 Population development

Table 2: Overview – seven modelling regions of Senegal (source: Total Population in Senegal[10])

Scenario Region	Modelling Regions	Regions	Population [2023]	Area [km²]	Population Density
1	Dakar Region	Dakar	4,030,300	525	7,383
	Dakar Region		**4,030,300**	**525**	**7,383**
2	North-eastern Region	Matam	795,813	29,108	28
		Saint-Louis	1,147,050	18,508	56
	North-eastern Region		**1,942,863**	**47,616**	**41**
3	Central North Region	Louga	1,120,320	25,472	45
	Central North Region		**1,120,320**	**25,472**	**45**
4	Central East Region	Fatick	972,607	8,063	144
		Kaffrine	787,580	11,268	70
		Kaolack	1,269,670	4,197	242
	Central East Region		**3,029,857**	**23,528**	**129**
5	Central West Region	Diourbel	1,987,420	4,368	411
		Thiès	2,275,220	6,594	342
	Central West Region		**4,262,640**	**10,962**	**389**
6	South-eastern Region	Kédougou	204,809	16,759	12
		Tambacounda	944,410	42,723	22
	South-eastern Region		**1,149,219**	**59,482**	**19**
7	South-western Region	Kolda	878,615	13,800	64
		Sédhiou	616,386	6,972	84
		Ziguinchor	732,960	6,884	102
	South-western Region		**2,227,961,**	**27,656**	**80.6**

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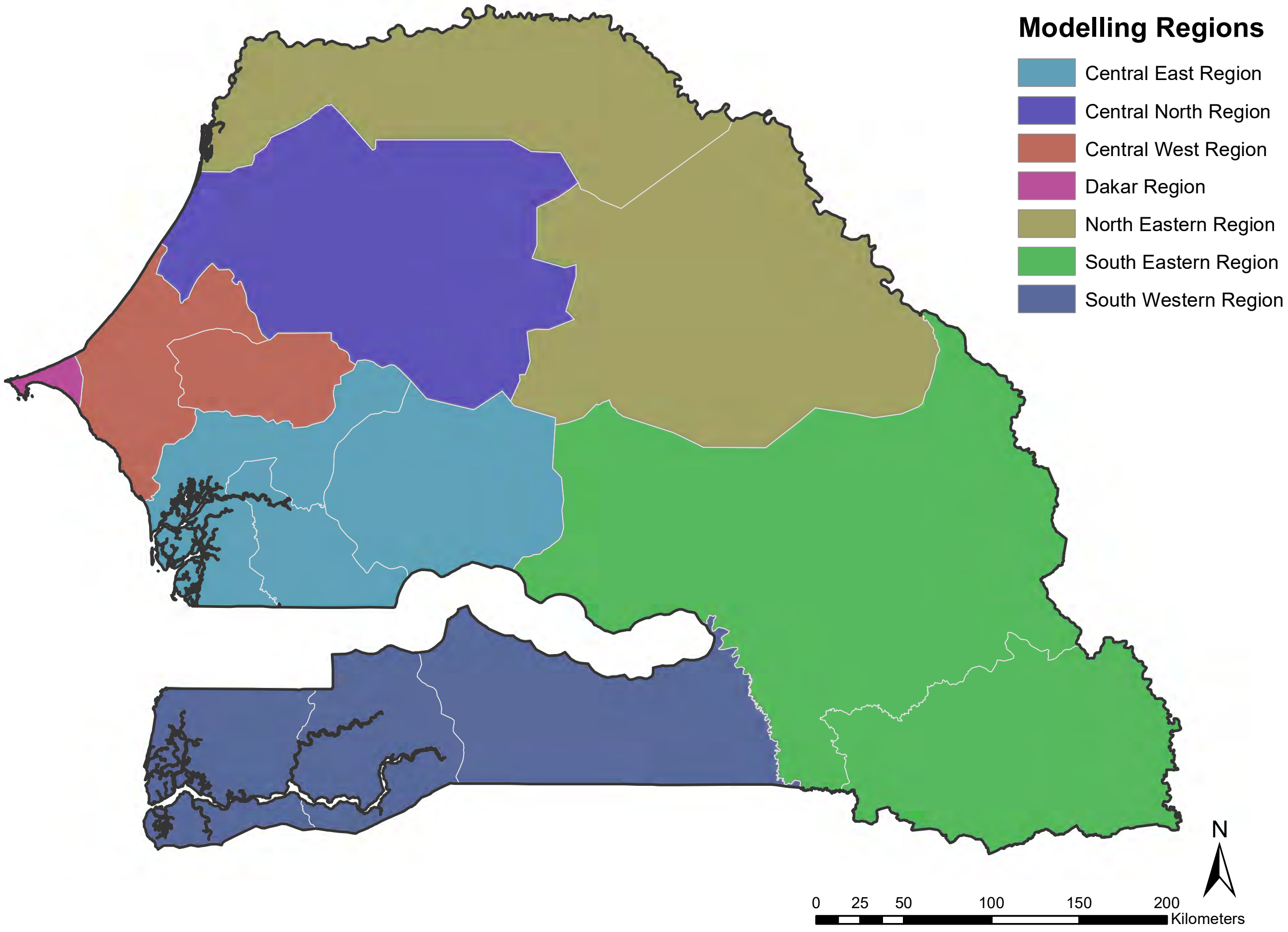
[10] Total Population in Senegal generated by data source by Michael Bauer GmbH: https://www.arcgis.com/home/item.html?id=9b08bc9c41ef4f459cc0be47f23cb646

Figure 1: Senegal – Modelling Regions



Source: generated by ISF from World Administrative Divisions[11]

2.1.3 Economic Context

According to the World Bank, Senegal has achieved respectable GDP growth in the past, averaging 2.8% between 2009 and 2019 (World Bank 2022)[12] However, Senegal faces significant difficulties in achieving inclusive and sustainable growth. The on-going global disruptions caused by the COVID-19 pandemic have been compounded by structural constraints in Africa, such as slow domestic job creation, high vulnerability to natural disasters, climate change, environmental degradation, and large infrastructure gaps. The pandemic has also recently triggered a surge in debt levels, which must be addressed. However, strong economic growth is assumed for the development of the energy scenario.

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[11] World Administrative Divisions, https://hub.arcgis.com/datasets/esri::world-administrative-divisions/explore

[12] World Bank 2022, Country Overview Senegal, database from 2022.

Population and economic development projections until 2050

The population and gross domestic product (GDP) are shown in Table 3

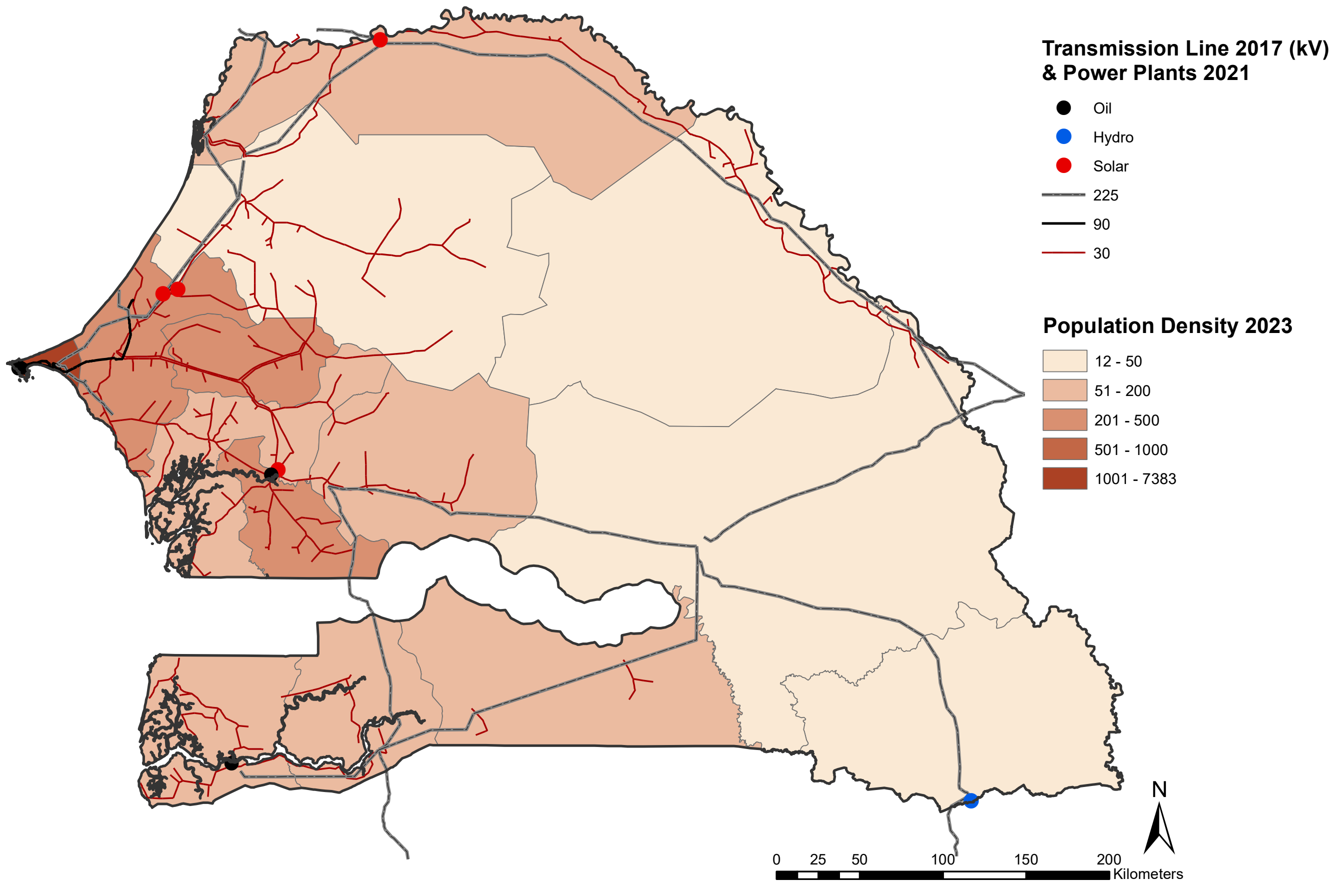
Table 3: Senegal's population and GDP projections until 2050

Senegal	Units	2019	2025	2030	2035	2040	2045	2050
Population	[individuals]	16,296,362	18,687,799	21,125,871	23,753,289	26,568,155	29,516,981	32,562,868
Annual Population Growth	[%/a]	2.75%	2.56%	2.44%	2.33%	2.21%	2.04%	1.93%
GDP	[US$ billion]	22.89	30.79	46.08	70.25	100.38	136.88	168.13
Annual Economic Growth (data for 2030, 2040, and 2050)	[%/a]	1.50%	6.00%	10.00%	8.00%	7.00%	6.00%	3.00%
GDP/Person (calculated)	[US$/capita]	1382	1648	2181	2957	3778	4637	5163

2.2 Electricity infrastructure and energy access

For this analysis, Senegal's power sector is divided into seven regions. The regional distribution of the population and the availability of the energy infrastructure correlate with the socio-economic situation in all regions. The following map provides an overview of the locations of power lines and power plants, a regional breakdown of energy pathways, and the power sector analysis (Chapter 6).

Figure 2: Distribution of population and the existing electricity infrastructure in Senegal



Generated by ISF from Total Population in Senegal (2023), Global Power Plant Database (v1.3.0) and Senegal Electricity Transmission Network (2017).

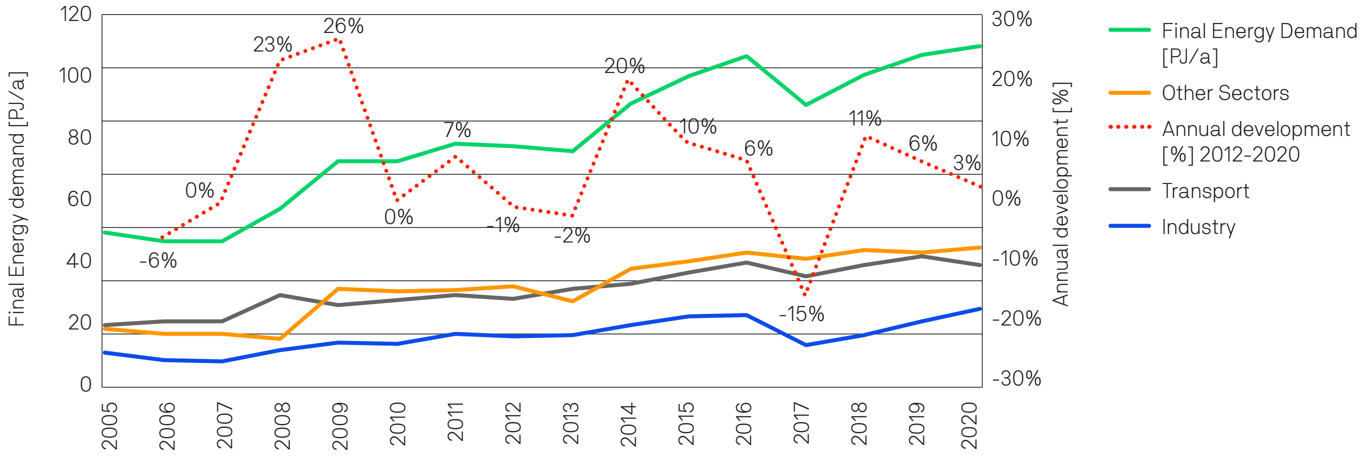
Figure 2 shows the population density in Senegal. The highest population concentrations are shown in dark red and the lowest in beige. The map clearly shows the high population densities in the metropolitan areas of Dakar and the Central West Region. The existing constructed electricity infrastructure (power lines, power plants, and sub-stations), with their different types of grids, are shown as lines, and the differently coloured dots mark grid-connected power plants – each colour represents a specific technology, identified in the legend. The lines represent power transmission lines with different voltage levels. The figure visualises the distribution of the grid, power plants, and population density, but does not claim to be complete. The electricity access rate of the local population in Senegal is around 68%[13], although access to energy services does not necessarily mean that the supply is always available.

2.3 Energy demand – development since 2005

It is necessary to analyse the development of the past energy demand to project that of the future. Therefore, the statistical data for Senegal's energy demand in 2005–2019 have been analysed (IEA 2022)[14].

Figure 3 shows Senegal's final energy demand development between 2005 and 2020. The overall energy demand grew continuously, despite years of reduced demand due to reduced economic activity. The gross final energy demand has grown by about 115% since 2005 to around 110 petajoules per annum (PJ/a). The main energy demand is required in the residential sector (category "Other Sectors", with 41%), whereas only 23% of energy is for industry use and 36% for the transport sector.

Figure 3: Final energy demand development in Senegal from 2005 to 2019



The electricity demand has increased significantly faster than the final energy demand. By 2019, the annual electricity demand was close to 4.7 TWh/a, up from 1.7 TWh/a in 2005 (Figure 4), increasing by a factor 2. Again, the residential sector ("Other Sectors") grew fastest, followed by the industry sector. The electricity demand for transport was almost negligible. However, with the increased electrification of vehicles, the electricity demand for transport is expected to rise significantly. However, Senegal's electricity demand is currently 272 kWh per capita, one of the lowest in the world (OWD 2024)[15], whereas the global average consumption exceeds 3,000 kWh/capita per annum (World Bank 2019)[16].

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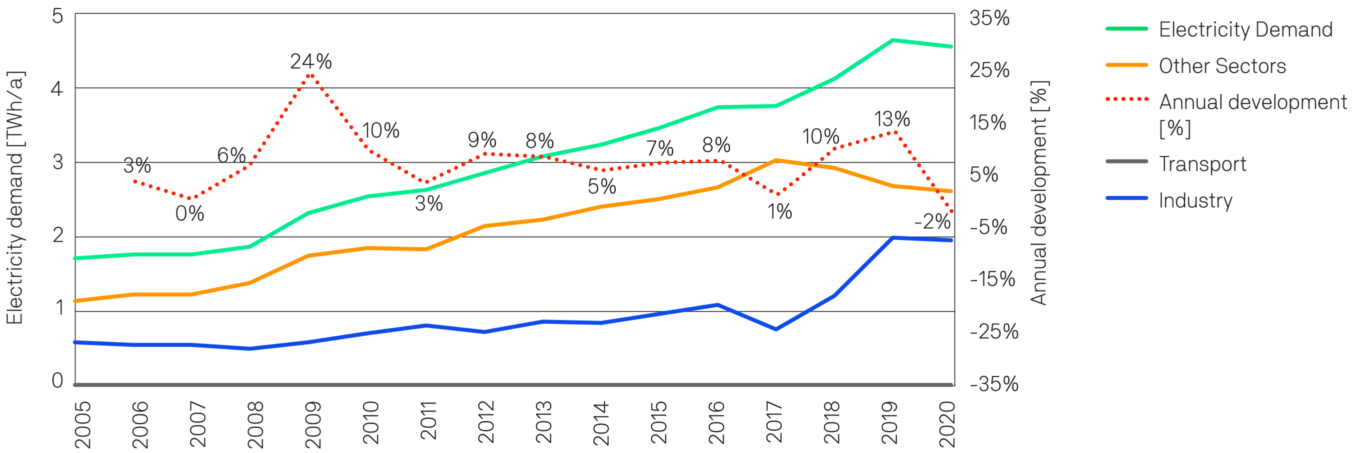
[13] World Bank Senegal, https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=SN

[14] IEA (2022) Advanced World Energy Balances, Senegal

[15] Our World in Data – Total electricity demand per person, online database, assessed April 2024; https://ourworldindata.org/grapher/per-capita-electricity-demand

[16] World Bank Database 2019, https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?end=2019&name_desc=true&start=1960&view=chart

Figure 4: Electricity demand development in Senegal from 2005 to 2020



2.3.1 Energy supply

The primary energy supply is dominated by biomass (around 41% in 2020), used mainly for cooking and heating, as shown in Table 4, whereas electricity is almost entirely supplied by oil (85% in 2020). If the primary energy supply continues according to its development over the past 5 years (by 4.2% annually), the primary energy demand will hypothetically increase to 637 PJ/a by 2050.

Table 4: Senegal's primary energy supply between 2005 and 2019 (IEA World Energy Balances 2021)

Primary Supply	Units	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual development		-	-3.8%	0.0%	19.0%	24.2%	-0.1%	2.4%	-1.2%	-45.3%	88.8%	5.0%	5.4%	14.2%	1.4%	-4.8%	4.8%
Primary energy	PJ/a	98	94	94	112	139	139	142	140	77	145	152	160	183	186	177	185
Net Exports (–)/Imports (+)	PJ/a	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Fossil fuels	PJ/a	57	53	53	66	67	68	69	66	75	82	94	104	121	123	108	107
Hard Coal	PJ/a	4	4	4	6	7	7	10	9	9	12	16	19	14	18	18	15
Lignite	PJ/a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural gas	PJ/a	2	1	1	1	1	2	1	2	2	2	2	2	2	1	2	2
Crude oil	PJ/a	51	48	48	59	59	59	58	56	63	68	77	83	105	103	88	90
Nuclear	PJ/a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conventional Renewables	PJ/a	40	40	40	45	70	69	71	72	0	62	58	56	62	63	69	78
Hydro	PJ/a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind	PJ/a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Solar (A)	PJ/a	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Biomass	PJ/a	40	40	40	45	70	69	71	72	0	62	58	56	62	62	68	76
Geothermal	PJ/a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ocean energy	PJ/a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conventional Renewables Share	%	41.4%	42.8%	42.8%	40.8%	51.0%	50.2%	50.5%	52.2%	0.0%	43.1%	38.3%	35.1%	34.0%	34.0%	38.9%	42.2%
New Renewables Share	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%

(A) Solar is not zero because it is used in various on- and off-grid applications. However, the overall energy generation is < 0.1 PJ/a

Definition of renewable energy

The IPCC is the leading international body assessing climate change. In its Special Report on Renewable Energy Sources and Climate Change Mitigation,[17] the IPCC defines the term 'renewable energy' as follows:

'RE is any form of energy from solar, geophysical, or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. RE is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes resources such as biomass, solar energy, geothermal heat, hydro power, tide and waves, ocean thermal energy, and wind energy. However, it is possible to utilise biomass at a greater rate than it can grow or to draw heat from a geothermal field at a faster rate than heat flows can replenish it. On the other hand, the rate of utilisation of direct solar energy has no bearing on the rate at which it reaches the Earth. Fossil fuels (coal, oil, natural gas) do not fall under this definition, as they are not replenished within a time frame that is short relative to their rate of utilisation.'

2.4 Development of the Residential energy demand

To develop a projection for the residential electricity demand in Senegal over the coming 30 years, to achieve the Senegal S-1.5°C scenario, a bottom-up electricity demand analysis was performed. The S-1.5°C aims to increase the access to energy – especially electricity – for all by 2050, while increasing the electrification and comfort standards to the levels of OECD countries. The growing economy requires a reliable power supply for small and medium businesses, industry, and the transport sector. It is assumed that households will use modern energy-efficient applications, based on the highest efficiency standards, to slow the growth of the power demand and to allow the parallel expansion of the energy infrastructure and the construction of renewable power plants. Electrification will be organised from the 'bottom up' in a new and innovative approach developed by UTS-ISF.

2.4.1 Household electricity demand

The current and future developments of the electricity demand for Senegal's households were analysed from the second half of 2021 onwards under the leadership of Power Shift Africa. The future development of the household demand has been discussed in a multiple-stakeholder dialogue with representatives from Senegal's academia, civil society, and government.

Figure 5 shows the breakdown of Senegal's households by size (UN-ES 2019)[18]. The current average electricity demands of Senegal's households are significantly lower than those of OECD countries.

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[17] Arvisu D, Bruckner T, Chum H, Edenhofer O, Estefen S, Faaij A, Fischedick M, Hansen G, Hiriart G, Hohmeyer O, Hollands KGT, Huckerby J, Kadner S, Killingtveit Å, Kumar A, Lewis A, Lucon O, Matschoss P, Maurice L, Mirza M, Mitchell C, Moomaw W, Moreira J, Nilsson LJ, Nyboer J, Pichs-Madruga R, Sathaye J, Sawin J, Schaeffer R, Schei T, Schlömer S, Seyboth K, Sims R, Sinden G, Sokona Y, von Stechow C, Steckel J, Verbruggen A, Wiser R, Yamba F, Zwickel T (2011). Technical Summary. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. (eds) O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

[18] UN-ES (2019) United Nations, Department of Economic and Social Affairs, Population Division (2019). Database of Household Sise and Composition 2019, https://www.un.org/development/desa/pd/data/household-sise-and-composition

Figure 5: Households by sise – Senegal

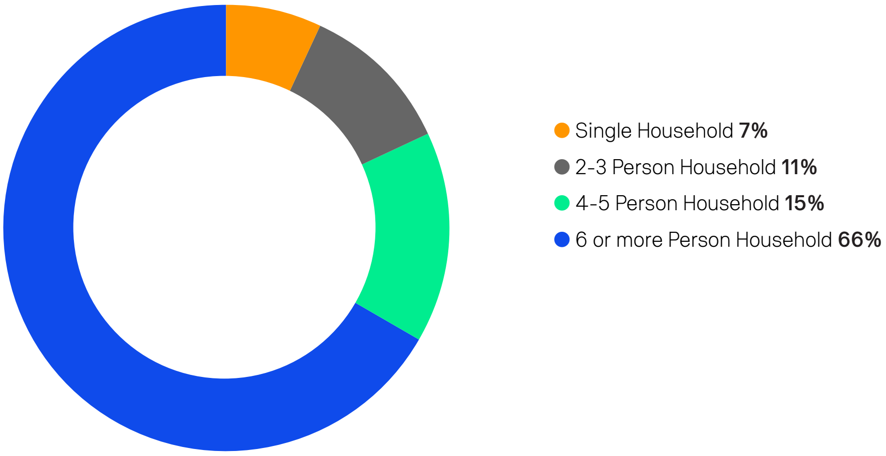

Table 5 shows the electricity demand, the electrical appliances used by households in Senegal in 2020, and the projected '***phases***', with increased demand for electrification. It is assumed that households with an annual consumption in 'phase 1' according to household type will increase their demand to 'phase 2' or 'phase 3' values over time. There are currently three household types, distinguished by their annual electricity demand: rural households, which have an average annual electricity demand of just under 808 kWh; semi-rural households, which consume around 990 kWh per year; and urban households, with an annual consumption of 1228 kWh.

The electricity demand will gradually increase as the electrical applications for each of the three household types progress from those households with very basic needs, such as light and mobile phone charging, to a household standard equivalent to that of industrialised countries. The different levels of electrification and the utilisation of appliances are described with the affixes 'phase 1', 'phase 2', and 'phase 3' for rural households. In contrast, semi-urban and urban households are assigned to two groups: one for the basic level of electrification and one for the more-advanced stage. The households will develop over time, from the basic group towards the more advanced group.

The third phase of a rural household includes an electric oven, refrigerator, washing machine, air-conditioning, and entertainment technologies, and aims to provide the same level of comfort as households in urban areas in industrialised countries. Adjustments will be made to the levels of comfort in households in city and rural areas to discourage residents – especially young people – from leaving their home regions and moving to big cities. The phase-out of unsustainable biomass, liquefied pressurised gas (LPG) and paraffin, for cooking is particularly important in decarbonising Senegal's household energy supply. A staged transition towards electrical cooking is assumed (see section 2.1.8).

Table 5: Household types used in all scenarios and their assumed annual electricity demands in 2020

Senegal – Annual household electricity demands			
Household Type	**Group**		**Annual Electricity Demand [kWh/a]**
Rural	Phase 1	– Very-low-income rural household – Low-income rural household	808
	Phase 2	– Lower-middle-income rural household	990
	Phase 3	– Upper-middle-income rural household	1,228
Semi-Urban	Basic	– Low-to-middle-income semi-urban household	436
	Advanced	– Middle-income semi-urban household	497
Urban – Apartment	Basic	– Low-to-middle-income urban household (apartment)	820
	Advanced	– Middle-income urban household (apartment)	775
Urban House	Basic	– Middle-income urban household (house)	1,012
	Advanced	– Middle-to-high-income urban household (house)	1,012

The typical household electricity demands are compared with:

i. Regional countries in South Asia: India, Sri Lanka, Pakistan, and Bhutan;
ii. A representative OECD country. The authors selected Switzerland for its well-documented electricity demands and good exemplification of energy-efficient but highly electrified households among OECD countries.

OECD household: Switzerland

Table 6 shows an example of the electricity demands of different household types in the OECD country of Switzerland. The example of Switzerland was chosen because of its well-documented electricity demands and its good representation of the energy-efficient and highly electrified households in the OECD countries. In predicting the future development of Senegal's electricity demand, we assumed that the level of electrification and the household appliances used will be like those in industrialised countries. Although the electricity demand of households in industrialised countries – excluding electric mobility – can be reduced through technical efficiency measures and more-efficient appliances with improved technical standards, the current demand provides an orientation for the future demands in developing countries.

Table 6: Standard household demands in an industrialised country (Switzerland)

Standard Household – OECD	**Apartment**			**Separate House**			
Category	**2 People [kWh/a]**	**Additional person [kWh/a]**	**4 People [kWh/a]**	**2 People [kWh/a]**	**Any additional person/s [kWh/a]**	**4 People [kWh/a]**	**Calculated Urban Family 2 [kWh/a]**
Cooking/baking including special equipment, e.g., coffee maker	300	80	460	300	80	460	0
Dishwasher	250	25	300	250	25	300	
Refrigerator with or without freezer compartment	275	40	355	325	60	445	340
Separate freezer	275	25	325	350	25	400	
Lighting	350	90	530	450	125	700	198
Consumer electronics (TV, video, hi-fi, various players, etc.)	250	60	370	275	80	435	110
Home office (PC, printer, modem, comfort phone, etc.)	200	60	320	200	80	360	
Div. Nursing and small appliances including humidifier	250	45	340	325	60	445	272
Washing machine	225	65	355	250	78	405	127
Laundry dryer (about 2/3 of the laundry, with a tumbler)	250	85	420	275	88	450	
General (building services)	400		400+	900	150	1200	
Total	**3025**	**575**	**4175**	**3900**	**850**	**5600**	**1047**
Climatisation							1,013
Total, including climatisation	**3025**	**575**	**4175**	**3900**	**850**	**5600**	**2060**

Source: Der typische Haushalt-Stromverbrauch Energieverbrauch von Haushalten in Ein- und Mehrfamilienhäusern/Schweis, https://www.energieschweiz.ch/stories/energieeffiziente-elektrogeraete/

The development of the country-wide shares of the electricity demand in Senegal according to the various household types is presented in Table 7. Electrification starts with the basic household types, rural, semi-urban, and urban (apartments or houses), and moves to better-equipped households. Thus, the proportion of fully equipped households will grow continuously, whereas the proportion of basic households will increase in the early years and then decrease towards the end of the modelling period. By 2050, most households will have a medium-to-high level of comfort equipment. The authors of this report have deliberately chosen a high standard for Senegal's households to close the gap between households in OECD countries and those in countries in the global south, to achieve greater equity.

Table 7: Household types – development of household shares of the electricity demand country-wide in Senegal

Household type	Country-wide Electricity Shares [%] (rounded)			
	2020	**2030**	**2040**	**2050**
No access to electricity	10.00%	4.00%	2.00%	0%
Rural – Phase 1	75.00%	72.00%	65.00%	55.00%
Rural – Phase 2	4.00%	8.00%	9.00%	15.00%
Rural – Phase 3	0.00%	3.00%	4.00%	10.00%
Semi-Urban – basic	10.00%	4.00%	3.00%	5.00%
Semi-Urban – advanced	0.00%	2.00%	0.00%	0.00%
Urban Apartment – basic	0.00%	0.00%	0.00%	0.00%
Urban Apartment – advanced	0.00%	4.00%	8.00%	10.00%
Urban House – basic	0.00%	2.00%	5.00%	1.00%
Urban House – advanced	1.00%	1.00%	4.00%	4.00%
Total	**100%**	**100%**	**100%**	**100%**

Source: CDP, REB, DESCO, and UTS-ISF research

According to the most recent data from the World Bank in 2022, over 78.6% of Senegal's households have access to electricity.[19] However, households might not have access to reliable and uninterrupted electricity. Here, rapidly expanding cities are problematic because the infrastructure for transport and energy supply and the requirements of residential apartment buildings cannot meet the demand, often leading to social tensions. Mini-grids for remote areas have proven a successful technology option for bringing energy services to remote communities, helping villages develop local economies, and providing alternative opportunities for young people to establish careers outside the metropolitan areas.

2.4.2 Household Fuel demand – cooking

The main energy demand of Senegal's households is for cooking. Firewood is the main energy source for rural households, whereas cylinders of LPG are the secondary source of energy for cooking in semi-urban and urban households. Senegal's households also use charcoal.[20]

Table 8 shows the variety of fuels used for cooking. Firewood and LPG dominate markedly, whereas in 2021, only 23.9% of the population had access to clean fuels and technologies for cooking, such as an electric cooking appliance (Figure 6); 51.3% of the urban population had access to clean fuels and technologies for cooking; and only 8.3% of the rural population had access (World Bank 2023).[21] Table 8 provides an overview of the most important cooking technologies and their key technical and economic parameters (WFC 2019).[22] The data are taken from a comprehensive analysis of cooking technologies and the sustainability and cost-effectiveness of electric cooking. One key finding of this analysis was that cooking with electricity (whether with solar home systems [SHSs] or in a mini-grid context) using high-efficiency appliances can make cooking even cheaper than it is in many households that currently use firewood and charcoal. The World Bank's bottom-up research from across sub-Saharan Africa indicates that households spend US$1–31 per month on cooking fuels, on average (World Bank 2014)[23]. Because slow cookers and pressure cookers allow household cooking costs of US$15–21/month for SHSs and US$3.56–9.53/month for mini-grids, the economics of cooking with high-efficiency cooking appliances is becoming increasingly compelling (WFC 2019).

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[19] World Bank, New World Bank Support to Increase Access to Electricity Services in Senegal, March 10 2022, Online retrieved from: https://www.worldbank.org/en/news/press-release/2022/03/10/new-world-bank-support-to-increase-access-to-electricity-services-in-senegal

[20] IEA 2019, Energy Outlook Africa: Senegal.

[21] https://databank.worldbank.org/source/world-development-indicators/Series/EG.CFT.ACCS.ZS

[22] WFC (2019) Beyond fire – How to achieve electric cooking; Toby D. Couture (E3 Analytics); Dr. David Jacobs (IET– International Energy Transition GmbH), Eco Matser and Harry Clemens (Hivos), Anna Skowron (WFC) and Joseph Thomas (E3 Analytics), World Future Council, Lilienstrasse 5–9, 22095 Hamburg, Germany, May 2019–costs are converted from Euro to US$ with the exchange rate of 25th August 2022: 1 Euro = US$1

[23] World Bank (2014) Clean and Improved Cooking in Sub-Saharan Africa: Second Edition. World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/164241468178757464/pdf/98664-REVISED-WP-P146621-PUBLIC-Box393185B.pdf

Based on current cooking energy usage, a transition scenario from fuel-based cooking to electric cooking (e-cooking) has been developed for the S-1.5°C scenario. However, with an increasing population and a growing number of households, the overall fuel demand is likely to remain high, and a phase-out of emissions and fuel demand cannot be achieved with this measure alone.

Table 8: Basic data on technologies and energy use

Appliance	Cost Range [EUR]	Median Cost [EUR]	Median Cost CFA	Watts (range)	Approximate Daily Household Consumption (in Wh/day for electric options or in kg/day for solid and gas-based fuels)	Approximate Daily Household Consumption [MJ/day]
Three Stones (Wood)	0	0	0	N/A	4.15–20.76 kg/day	68.48–342.54
Traditional Cooking Stove (Wood)	0–5	2.5	413	N/A	3.32–8.3 kg/day	54.78–136.95
Improved Cooking Stove (Wood)	5–65	35	5,775	N/A	2.08–5.53 kg/day	34.32–91.25
Three Stones (Charcoal)	0	0	0	N/A	1.92–4.81 kg/day	54.72–137.09
Traditional Cooking Stove (Charcoal)	0–10	5	825	N/A	1.6–4.01 kg/day	45.60–114.29
Improved Cooking Stove (Charcoal)	5–65	35	5,775	N/A	1.2–2.4 kg/day	34.20–68.40
Improved Cooking Stove (Wood-based Biomass Pellets)	16–80	48	7,920	N/A	1.76–3.96 kg/day	30.41–68.43
Improved Cooking Stove (Agro-waste Pellets)	16–80	48	7,920	N/A	2.42–5.44 kg/day	30.49–68.54
Single Burner Hot Plate	8–35	21.5	3,548	600–2000	1200–4000 Wh/day	4.32–14.40
Induction Hot Plate	45–95	67.5	11,138	1000–2300	2000–4600 Wh/day	7.20–16.56
Slow Cooker/Rice Cooker/Crock Pot	10–130	70	11,550	120–300	175–700 Wh/day	0.63–2.52
Electric Pressure Cooker	19–140	79.5	13,118	500–1000	160–340 Wh/day	0.58–1.22
Microwave Oven	50–100	75	12,375	600–1200	100–1200 Wh/day	0.36–4.32
Gas Stove (single burner)	20–60	40	6,600	N/A	0.3 kg/day	13.7
Gas Stove (double burner)	30–90	60	9,900	N/A	0.3 kg/day	13.7
Gas Stove (four burners)	40–100	70	11,550	N/A	0.3 kg/day	13.7

Table 9: Cooking energy demand by technology and household type in 2021, Senegal

	Demand per Household and Day [MJ/day]	Demand per Household and Year [MJ/year per household (HH)]								
		Rural – Phase 1	Rural – Phase 2	Rural – Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Wood + Bio-energy Fuel-based cooking	96	2,803	2,803	3,504	17,520	4,380	2,803	2,803	2,803	3,504
Gas/liquid-natural-gas-based cooking	13.7	400	400	500	2,500	625	400	400	400	500
Electric cooking	3.3	96	96	120	602	151	96	96	96	120

The daily and annual energy demands for the three main fuel-based cooking technologies are shown in Table 9. A scenario for transitioning from fuel-based cooking to electricity-based cooking was developed based on these (Table 10).

Fuel-based cooking applications will be gradually phased-out and replaced with electric cooking appliances. The total phase-out of fuel-based systems will be for environmental and economic reasons. Fuel-based cooking requires fuel that generates emissions, and the fuel supply is, in most cases, not sustainable. Collecting fuel wood puts forests under pressure, is time-consuming, and has a negative economic impact on the country's productivity. Burning LPG causes CO_2 emissions, and its production is based on fossil gas, which must be phased-out by 2050 to remain within the global carbon budget to limit the global mean temperature rise to a maximum of +1.5 °C. The remaining wood and bio-energy-based cooking in 2050 will be with sustainable charcoal.

Electric cooking can be supplied by renewable energy sources and will be emissions-free.

Table 10: Transition scenario from fuel-based to electricity-based cooking in Senegal under the S-1.5°C pathway

	Share of Households with Wood and Bio-energy Fuel-based Cooking		Rural – Phase 1	Rural – Phase 2	Rural – Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Average Energy Demand by Household (HH; based on World Future Council 2019)			2,803	2,803	3,504	17,520	4,380	2,803	2,803	2,803	3,504
2020	75%	[MJ/a HH]	2,105	2,105	2,632	13,158	3,289	2,105	2,105	2,105	2,632
2025	75%	[MJ/a HH]	2,102	2,102	2,628	13,140	3,285	2,102	2,102	2,102	2,628
2030	75%	[MJ/a HH]	2,102	2,102	2,628	13,140	3,285	2,102	2,102	2,102	2,628
2035	75%	[MJ/a HH]	2,102	2,102	2,628	13,140	3,285	2,102	2,102	2,102	2,628
2040	50%	[MJ/a HH]	1,402	1,402	1,752	8,760	2,190	1,402	1,402	1,402	1,752
2045	20%	[MJ/a HH]	561	561	701	3,504	876	561	561	561	701
2050	10%	[MJ/a HH]	280	280	350	1,752	438	280	280	280	350
	Share of Households with Gas/liquid-natural-gas-based Cooking		**Rural – Phase 1**	**Rural – Phase 2**	**Rural – Phase 3**	**Semi-Urban 1**	**Semi-Urban 2**	**Urban Apartment 1**	**Urban Apartment 2**	**Urban House 1**	**Urban House 2**
Average Energy Demand by Household (HH; based on World Future Council 2019)			400	400	500	2,500	625	400	400	400	500
2020	24%	[MJ/a HH]	96	96	120	600	150	96	96	96	120
2025	24%	[MJ/a HH]	96	96	120	600	150	96	96	96	120
2030	24%	[MJ/a HH]	23	23	29	144	36	23	23	23	29
2035	20%	[MJ/a HH]	80	80	100	500	125	80	80	80	100
2040	15%	[MJ/a HH]	60	60	75	375	94	60	60	60	75
2045	10%	[MJ/a HH]	40	40	50	250	63	40	40	40	50
2050	0%	[MJ/a HH]	0	0	0	0	0	0	0	0	0
	Phase-in of Electric Cooking 2020–2050										
	Share of Households with Electric Cooking		**Rural – Phase 1**	**Rural – Phase 2**	**Rural – Phase 3**	**Semi-Urban 1**	**Semi-Urban 2**	**Urban Apartment 1**	**Urban Apartment 2**	**Urban House 1**	**Urban House 2**
Average Energy Demand by Household (HH; based on World Future Council 2019)			96	96	120	602	151	96	96	96	120
2020	1%	[kWhelectric/a HH]	1	1	1	5	1	1	1	1	1
2025	1%	[kWhelectric/a HH]	1	1	1	6	2	1	1	1	1
2030	1%	[kWhelectric/a HH]	1	1	1	6	2	1	1	1	1
2035	5%	[kWhelectric/a HH]	5	5	6	30	8	5	5	5	6
2040	35%	[kWhelectric/a HH]	34	34	42	211	53	34	34	34	42
2045	70%	[kWhelectric/a HH]	67	67	84	422	105	67	67	67	84
2050	90%	[kWhelectric/a HH]	87	87	108	542	136	87	87	87	108

However, there are some challenges to the introduction of electric cooking stoves:

- Firewood remains freely available.
- In relative terms, the initial investment and monthly costs are high.
- Concerns exist about the safety of the technology.
- (Initial) concerns exist around the learnability of new appliances.
- In the cold climate of mountainous regions, fire from cooking also heats rooms.
- The use of e-cooking is perceived to be expensive.
- There are concerns about the quality of the appliances.
- It is a new technology that requires education to operate.

- The current business models of distribution are not well suited to low-income households. Most vendors use the upfront model of payment rather than other innovative models, such as pay as you go, which have proven beneficial for many other technologies.
- Perceived and/or actual differences in the taste and quality of food prepared using biomass or e-cooking.

There are already numerous electric cooking devices on Senegal's market, including:

- Induction stoves
- Electric pressure cookers
- Electric ovens
- Hot plates
- Microwave ovens
- Electric and gas hobs
- Roti makers
- Infrared stoves
- Rice cookers
- Slow cookers
- Electric frying pans
- Air fryers
- Electric kettles.

Among these, the most viable energy-efficient appliances are:

- Induction stoves
- Infrared stoves
- Rice cookers
- Electric pressure cookers.

The supply-side barriers to e-cooking are:

- Electric cooking stoves do not seem to be manufactured locally.
- After-sales service is poor (i.e., poor access to repairs and maintenance).
- Concerns exist around the quality and stability of the electricity supply.

Technical challenges posed by e-cooking for electric utilities and energy service companies:

The increase in the peak load that occurs during mealtimes will require an upgrade of the electricity distribution grid in terms of load management and the ability of the power grid to supply higher loads. The introduction of electric vehicles to replace fossil fuels will further increase the electric load and require grid expansion and reinforcement to be implemented by electric grid operators.

The current electricity connections of households are often limited to 5-ampere meters, which significantly limits the load for each household, and the parallel operation of multiple appliances is not possible when electric stoves are used. The technical standard of household wiring is low; cables are often improperly installed, or the lack of protective earthing compromises electrical safety.

Policy and social challenges in promoting electric cooking

Local-level governments in Senegal have already formulated policy frameworks, such as specific energy policies, acts, procedures, and/or guidelines, to support the increased utilisation of electric cooking devices. These policies include support for additional renewable electricity generation to supply stoves.

However, the implementation of sustainable cooking technologies is challenging for rural households in terms of their access to those technologies, technology standards, and financing.

Therefore, the development of clean cooking programs is lagging behind the actual targets. Finally, the general awareness of the benefits of e-cooking – particularly in rural areas – is still low because the necessary information is unavailable. Finally, this lack of information means that the acceptance of e-cooking devices in the supply chain – specialised kitchenware and hardware shops – is low. Therefore, awareness programs for retail staff are required.

2.5 Industry and business demands

The analysis of Senegal's economic development is based on a breakdown of the fiscal year 2020. It assumes that the overall structure of the economy will not change, and that all sectors will grow at a rate equal to that of GDP over the entire modelling period.

Figure 6 shows that in the fiscal year 2020/21, food, beverage, and tobacco services contributed most strongly to the growth of GDP (in the basic price), whereas machinery, transport equipment, and textiles and clothing contributed least. Moreover, for the largest sectors, the contribution of the food, beverages, and tobacco industry to the economic growth rate in that fiscal year was 42%, and the contribution of agriculture, forestry, and fishing was 17%.

Figure 7 presents the annual GDP growth rates of different sub-sectors from 2005 to 2020.

Figure 6: Contributions of sub-sectors to GDP growth [billion 2015 USD]

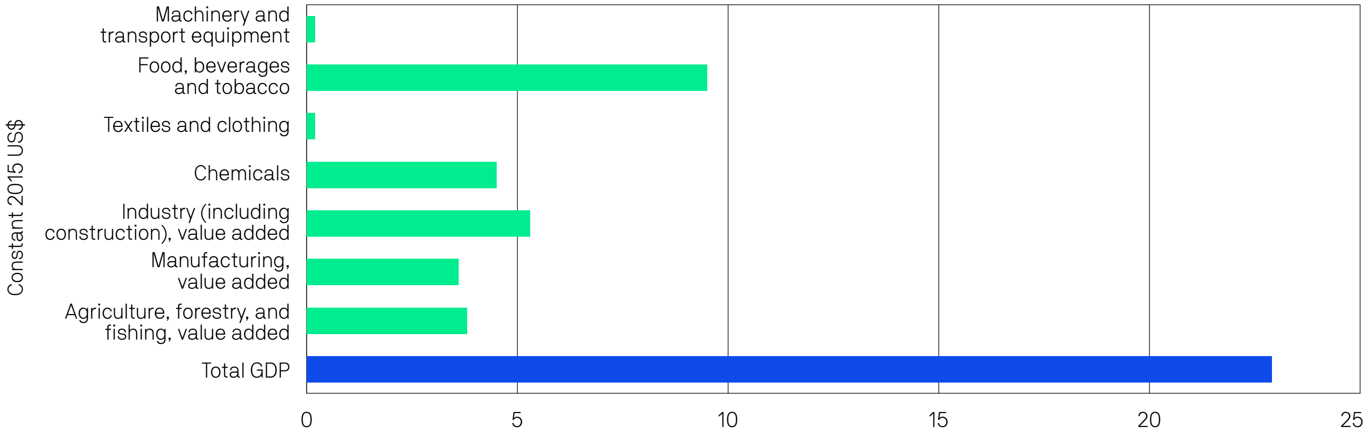
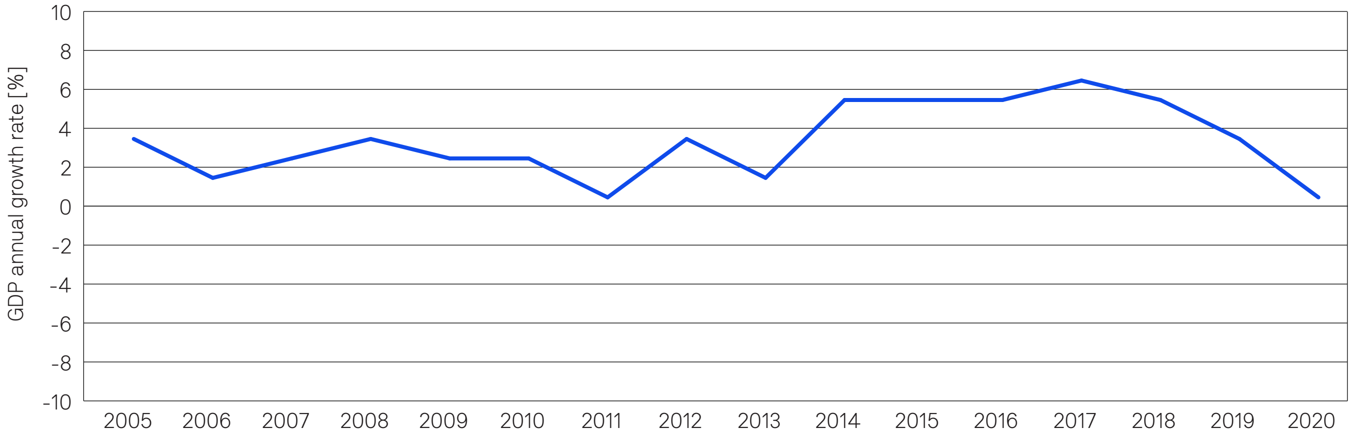


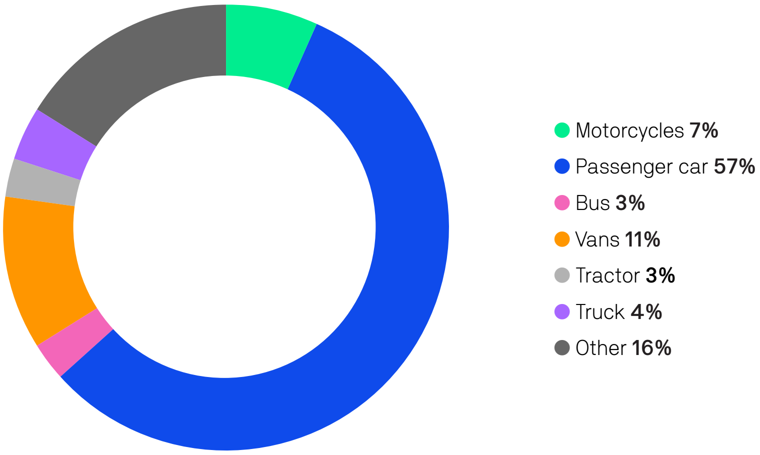
Figure 7: Growth rate of gross domestic product (GDP)



2.6 Transport Demand

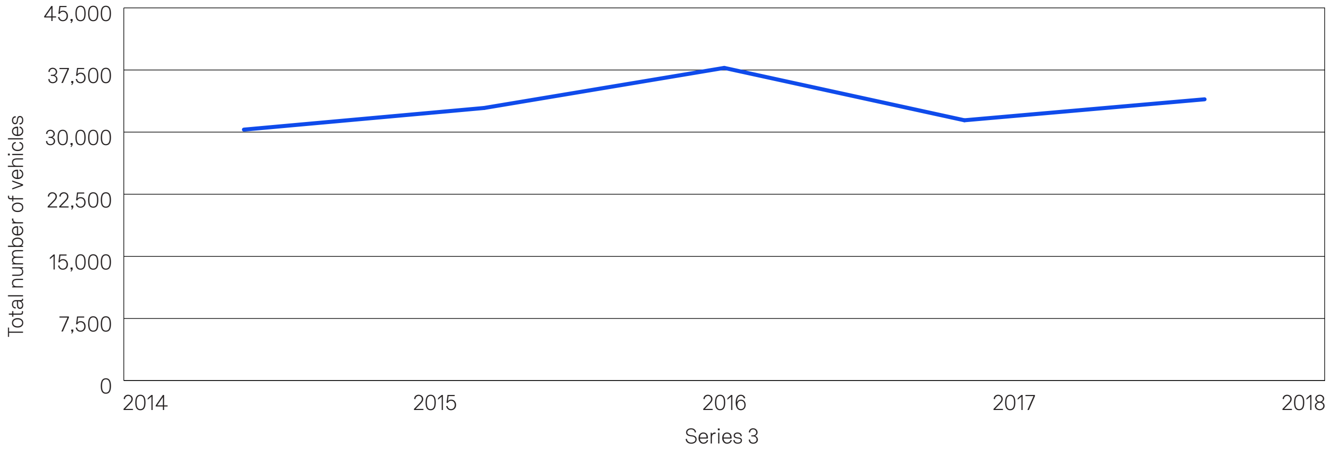
Senegal's transport sector is currently dominated by passenger cars, which account for 57% of all registered vehicles, whereas vans and motorcycles represent 11% and 7% of the vehicle fleet, respectively.[24] Other vehicles, such as tractors (3%), buses (3%), and trucks (4%), together make-up < 10% of the vehicle fleet, a proportion almost equivalent to that of vans. Whereas cars represent the largest fraction of registered vehicles, many residents use colorful minibuses ("cars rapides") or larger white buses ("Ndiaga Ndiaye") for inter-city or longer-distance transport. Therefore, these two forms of transport form an essential component of everyday life.

Figure 8: Categories of registered vehicles, with percentages of total number of registered vehicles (financial year 2017/2018)



Source: 24

Figure 9: Total number of registered vehicles[24]



To develop a future transport scenario, the technical parameters of all vehicle options are required to project their energy demands. The following section provides an overview of the vehicular energy intensities for passenger and freight transport. Based on these, the actual utilisation – in terms of annual kilometres per vehicle – was estimated to calculate the energy demand over time until 2050. The energy intensities for the different vehicle types and each available drive train play an important role in calibrating the transport modes and projections. Each transport mode has different vehicular options. Each of the vehicles has different drive-train and efficiency options.

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[24] Republique du Senegal, Agence nationale de la statistique et de la demographie, Situation Economique et sociale du senegale 2017–2018.

The technical variety of passenger vehicles, for example, is extremely large. The engine sizes for five-seater cars range from ~20 kW to > 200 kW. Furthermore, drive trains can use a range of fuels, from gasoline, diesel, and bio-diesel to hydrogen and electricity. Each vehicle has a different energy intensity in megajoules per passenger kilometre (MJ/pkm). Therefore, the energy intensities provided in the following tables are average values.

2.6.1 Technical Parameters – Passenger Transport

Passenger transport by road is the commonest and most important form of travel (TUMI 2021)[25]. There are numerous technical options to 'move people with vehicles': bicycles, motorcycles, tricycles, city cars, and four-wheel-drive SUVs. Each vehicle has a very different energy intensity per km. Although this research project aims for high technological resolution, simplifications are required. Table 11 shows the energy intensities for the main vehicle types (electric and with ICEs), and forms the basis for the energy scenario calculations.

Table 11: Energy intensities of individual transport – road transport

Passenger Transport			Passengers		Vehicle Demand Average	Consumption per Passenger Average	Energy Demand Assumption for Scenario Calculation
			Average Passengers per Vehicle	Assumed Occupation Rate			
		Fuels			**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
Scooters & motorbikes	2-wheeler	Gasoline	1	1	3.0	3.0	1.21
E-bikes Scooters Motorbikes Rickshaw		**Electricity**			**kWhel/100 km**	**kWhel/100 pkm**	**[MJ/pkm]**
	2-wheeler	Battery	1	1	1.0	1.0	0.04
	2-wheeler	Battery	1	1	1.8	1.9	0.06
	2-wheeler	Battery	1	1	4.8	4.8	0.17
	3-wheels	Battery	3	2	8.0	4.0	0.14
Cars		**Fuels**	**0**	**0**	**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
	Small	ICE-oil	2	1.8	5.0	2.8	1.12
	Medium	ICE-oil	4	2	7.5	3.8	1.51
	Large	ICE-oil	5	2	10.5	5.3	2.11
	Small	ICE-gas	2	1.8	4.5	2.5	0.63
	Medium	ICE-gas	4	2	7.0	3.5	1.41
	Large	ICE-gas	5	2	10.0	5.0	1.25
	Small	ICE-bio	2	1.8	5.0	2.8	0.91
	Medium	ICE-bio	4	2	7.5	3.8	1.51
	Large	ICE-bio	5	2	10.5	5.3	1.72
	Small	Hybrid-oil	2	1.8	4.0	2.2	0.89
	Medium	Hybrid-oil	4	2.5	6.0	2.4	0.96
	Large	Hybrid-oil	5	2.5	8.5	3.4	1.37
		Electricity			**kWhel/100 km**	**kWhel/100 pkm**	**[MJ/pkm]**
	Small	Battery	2	1.8	16.0	8.9	0.32
	Medium	Battery	4	2	25.0	12.5	0.45
	Large	Battery	5	2	32.5	16.3	0.59
	Large	Fuel Cell	4	2	37.5	18.8	1.36

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[25] TUMI (2021), Teske S, Niklas, S, Langdon R (2021). TUMI Transport Outlook 1.5 °C–A global scenario to decarbonise transport; Report prepared by the University of Technology Sydney for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIS) GmbH; Published by TUMI Management, Deutsche Gesellschaft für International Zusammenarbeit (GIS) GmbH, Friedrich-Ebert-Allee 36 + 40, 53113 Bonn, Germany; https://www.transformative-mobility.org/assets/publications/TUMI-Transport-Outlook.pdf

2.6.2 Technical Parameters – Public transport

There is a huge variety of public transport vehicles – from two wheelers to taxis and mini-buses to long-distance trains. The occupation rates for those vehicles are key factors in calculating the energy intensity per passenger per kilometre. For example, a diesel-powered city bus transporting 75 passengers uses, on average, about 27.5 litres per 100 kilometres. If the bus operates at full capacity during peak hour, the energy demand per passenger is as low as 400 mL per kilometre, lower than almost all fossil-fuel-based road transport vehicles. However, if the occupancy drops to 10% – e.g., for a night bus – the energy intensity increases to 3.7 litres per kilometre, equal to that of a small energy-efficient car. Occupation rates vary significantly and depend upon the time of day, day of the week, and season.

There are also significant regional differences, even within a province. Again, the parameters shown in Table 12 are simplified averages and are further condensed for the scenario calculations. Although high technical resolution is possible for the scenario model, it would pretend an accuracy that does not exist because the statistical data required for this resolution are not available at the regional level.

Table 12: Energy intensities for public transport – road and rail transport

Public Transport			Passengers		Vehicle Demand Average	Consumption per Passenger Average	Energy Demand Assumption for Scenario Calculation
			Average Passengers per Vehicle	Assumed Occupation Rate			
Buses		**Fuels**			**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
	Small	Diesel	12	40%	8.8	1.8	0.73
	Small	Bio	12	40%	8.8	1.8	0.60
	12m	Diesel	75	40%	27.5	0.9	0.37
	12m	Bio	75	40%	27.5	0.9	0.30
	Large	Diesel	135	40%	57.5	1.1	0.43
		Electricity	**0**	**0**	**kWhel/100 km**	**kWhel/100 pkm**	**[MJ/pkm]**
	Small	Battery	12	40%	31	6.4	0.23
	Small	Fuel Cell	12	40%	77	15.9	0.57
	12m	Battery	75	40%	143	4.8	0.17
	12m	Fuel Cell	75	40%	358	11.9	0.43
	Large	Overhead lines	135	40%	263	4.9	0.18
Trains		**Fuels**	**0**	**0**	**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
	Metros	Diesel	400	40%	150	0.9	0.38
	Metros	Bio	400	40%	150	0.9	0.31
	Commuter trains	Diesel	600	40%	300	1.3	0.50
	Commuter trains	Bio	600	40%	300	1.3	0.41
		Electricity	**0**	**0**	**kWhel/100 km**	**kWhel/100 pkm**	**[MJ/pkm]**
	Trams	Electric	300	40%	495	4.1	0.14
	Metros	Electric	300	40%	1,200	10.0	0.14
	Commuter trains	Electric	600	40%	1,950	8.1	0.17

2.6.3 Technical Parameters – Freight transport

The energy intensity data for freight transport are not as diverse as those for passenger transport because the transport vehicle types are standard and the fuel demands are well known. However, the utilisation rates of the load capacities vary significantly, and consistent data are not available for the calculated regional and global levels. Therefore, the assumed utilisation rate greatly influences the calculated energy intensity per tonne-km (tkm). The average energy intensities per tkm used in the scenario are shown in Table 13 and are largely consistent with those from other sources in the scientific literature (EEA 2021)[26]. The assumed energy intensities for electric and fuel cell/hydrogen freight vehicles are only estimates because this technology is still in the demonstration phase. Therefore, none of the scenarios factor in large shares of electric freight transport vehicles before 2035.

Table 13: Energy intensities for freight transport – road and rail transport

Freight Transport			**Maximum Load Capacity (tonnes)**	**Assumed Utilisation Rate**	**Vehicle Demand Average**	**Consumption per Tonne Average**	**Energy Demand Assumption for Scenario Calculation**
Trucks		Fuels			litre/100 km	litre/tkm	[MJ/tkm]
	3.5 tonne	Diesel	3.5	40%	11	7.9	3.16
	3.5 tonne	Bio	3.5	40%	11	7.9	2.57
	7.5 tonne	Diesel	7.5	40%	20	6.5	2.61
	7.5 tonne	Bio	7.5	40%	20	6.5	2.13
	12.5 tonne	Diesel	12.5	40%	25	5.0	2.01
	12.5 tonne	Bio	12.5	40%	25	5.0	1.64
		Electricity			**kWhel/100 km**	**kWhel/tkm**	**[MJ/tkm]**
	3.5 tonne	Battery	3.5	40%	19	13.6	1.34
	3.5 tonne	Fuel Cell	3.5	40%	46	33.2	1.33
	7.5 tonne	Battery	7.5	40%	41	13.6	0.49
	7.5 tonne	Fuel Cell	7.5	40%	100	33.2	1.19
	12.5 tonne	Battery	12.5	40%	68	13.6	0.49
	12.5 tonne	Fuel Cell	12.5	40%	166	33.2	1.19
Trains		**Fuels**			**litre/100 km**	**litre/ton-km**	**[MJ/tkm]**
	Freight–740 m	Diesel	1,000	40%	300	0.8	0.30
	Freight–740 m	Bio	1,000	40%	300	0.8	0.25
		Electricity			**kWhel/100 km**	**kWhel/tkm**	**[MJ/tkm]**
	Freight–740 m	Electric	1,000	40%	5,840	14.6	0.53

2.6.4 Utilisation of vehicles

In the second step, the utilisation of vehicles must be analysed to develop a projection into the future. No up-to-date surveys are available. The annual passenger-kilometres (pkm) and tonne-kilometres (tkm) for freight transport are calculated based on the current energy demand and the energy intensities of the vehicles in use. The average energy intensity across all passenger vehicles is assumed to have been 1.5 MJ per kilometre in 2020 – which reflects the current vehicle fleet of motorcycles (average energy demand of 1.2–1.3 MJ/pkm), cars (1.5 MJ/pkm), and SUVs and pick-up trucks (2–6 MJ/pkm). The assumed average energy intensity for freight vehicles is calculated accordingly, assuming vans and mini-vans are the main transport vehicles. It is also assumed that ICEs and not electric drives are in use.

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[26] European Environment Agency, https://www.eea.europa.eu/publications/ENVISSUENo12/page027.html

Table 14: Senegal – projected passenger and freight transport demands under the S-1.5°C scenario

		2019	2020	2025	2030	2035	2040	2045	2050
Road: Passenger Transport Demand	[PJ/a]	40	37	35	29	18	15	12	12
Annual passenger-kilometres	[million pkm]	14,834	13,663	13,663	13,663	13,663	13,663	13,663	13,663
Average energy intensity – passenger vehicles	[MJ/pkm]	2.50	2.50	1.88	1.75	1.71	1.66	1.63	1.60
Annual demand variation:	[%/a]	-	-	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Kilometres per person per day	[km/person/day]	769	751	741	706	680	658	646	647
Road: Freight Transport Demand	[PJ/a]	43	43	39	38	29	28	26	27
Annual freight kilometres	[million tkm]	7,941	7,315	8,730	8,730	8,730	8,730	8,730	8,730
Average energy intensity – freight vehicles	[MJ/tkm]	1.51	1.51	1.20	1.14	1.11	1.08	1.07	1.06
Annual demand variation	[%/a]			0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

The total numbers of passenger and freight kilometres are the basis for the projection of the future transport demand. The contraction of the transport demand in 2020 due to COVID is expected to end. It is anticipated that the pre-COVID transport demand of 2019 will be reached by 2023, and that the transport demand will increase with population growth and GDP. It is assumed that the annual passenger kilometres will increase by 3% annually until 2050, whereas the freight transport demand will increase by 2% annually. All assumptions and calculated energy demands are shown in Table 14. The energy intensities for all vehicles are assumed to decrease over time with the implementation of more-efficient engines, the phase-out of fossil-fuel-based drives, and their replacement with electric drives. To achieve the terms of the Paris Climate Agreement, all energy-related CO_2 emissions must be phased-out by 2050. Therefore, all fossil-fuel-based vehicles must be phased-out, and electric drives will dominate, supplemented with a limited number of biofuel-based vehicles.

However, it is assumed that the share of cars will grow at the expense of two-wheeler vehicles – which will increase the average energy intensity per kilometre. Although electric drives are significantly more efficient, the increased vehicle sise combined with more public transport options – mainly buses – will limit the increase in the energy demand. On average – across all passenger vehicle types – the energy intensity will decrease from around 1.5 MJ/pkm to 1.07 MJ/pkm in 2030 and to 0.54 MJ/pkm in 2050.

The energy required by freight vehicles to move 1 tonne for 1 kilometre will decrease from around 1.5 MJ to 1.11 MJ by 2030 and to 0.68 MJ by 2050. Both reductions will only be possible with high shares of electric drives. Figure 10 and Figure 11 show the development of drive trains for passenger and freight transport vehicles, respectively, over time. The electrification of large parts of these fleets is unavoidable if the transport sector is to be decarbonised. The supply of – sustainably produced – biofuels will be limited and will be directed to large commercial vehicles, buses, and the large trucks used in remote rural areas, where the required charging infrastructure for electric vehicles is unlikely to be developed in the next two decades.

Figure 10: Passenger transport – drive trains by fuel

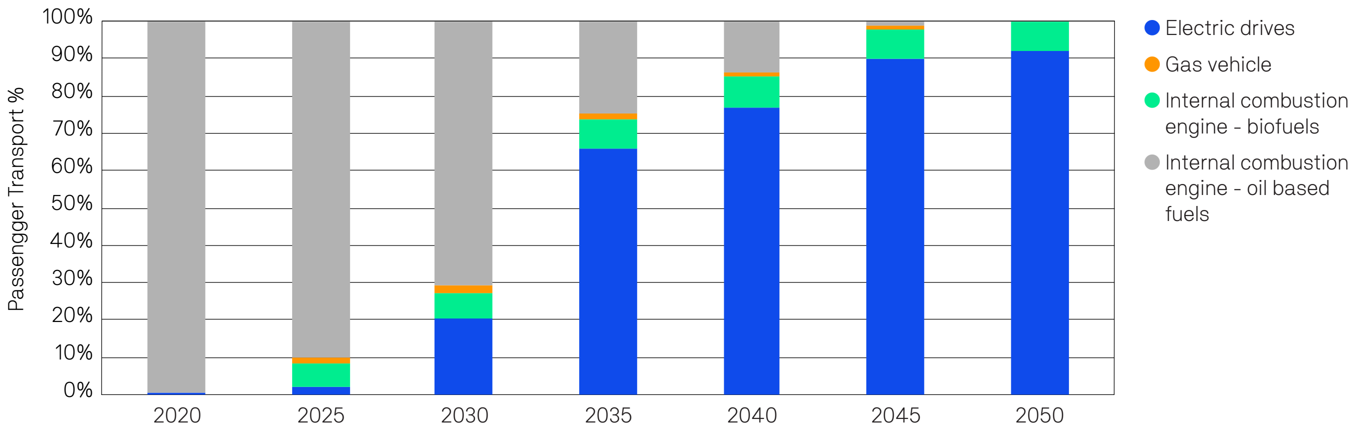
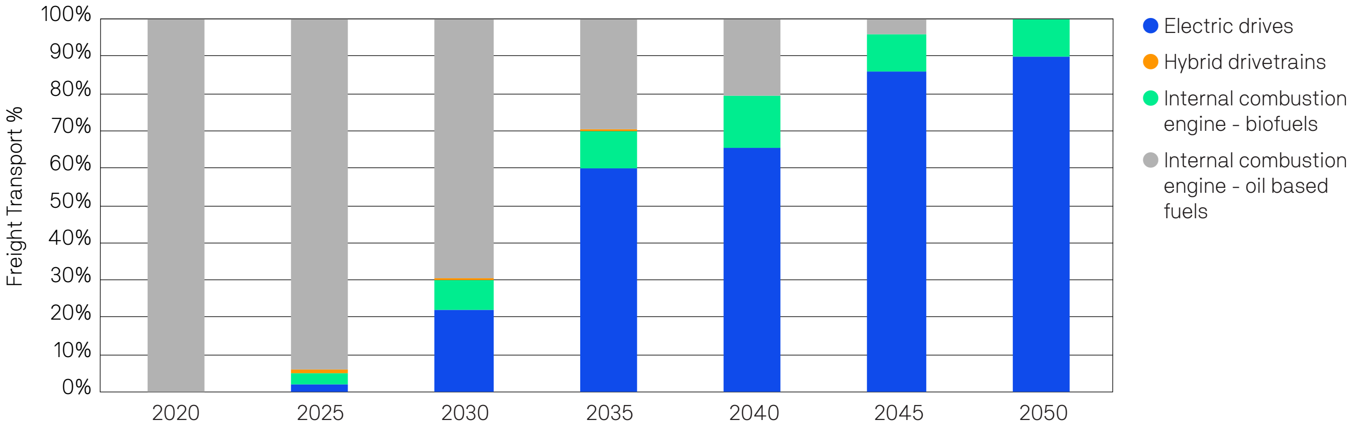


Figure 11: Freight transport – drive trains by fuel



Senegal submitted its first NDC report to UNFCCC in December 2020[27]. The new NDC sets a target to reduce GHG emissions by 7% (unconditional) or 29.5% (conditional) by 2030 compared with the 'business-as-usual' (BAU) scenario.[28]

The NDC does not include a detailed transport pathway, but highlights the following priority mitigation activity for the transport sector: ***'low-carbon and efficient transportation systems'***.

Therefore, the assumed trajectory for the transport sector (Figure 10 and Figure 11) offer a proposal for a transport sector concept for future decarbonisation pathways.

Based on the lifespans of motorcycles and cars, a country-wide overall market share of electric drives for the entire existing car fleet may not exceed 5% by 2030 for passenger and freight cars. Furthermore, it is assumed that the railway system will not be expanded beyond the current plans after 2030.

Supply-side barriers to e-vehicles

Currently, most e-vehicles are imported. The infrastructure required for electric mobility, in terms of maintenance and service centres and charging stations across urban and rural areas, is lagging. The resilience and reliability of the electricity supply – especially in rural areas – is still under development and faces challenges. Therefore, a rapid expansion of the charging infrastructure, which will increase the load even further, will depend on the progress of electricity services. However, the decarbonisation of Senegal's energy sector will require increased electrification of the transport sector, and the expansion of a resilient power supply based on sustainable power generation technologies is essential.

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[27] Senegal, Senegal First NDC, December 2020, https://unfccc.int/documents/497880

[28] NDC partnership, Senegal, https://ndcpartnership.org/country/sen

2.7 Technology and fuel cost projections

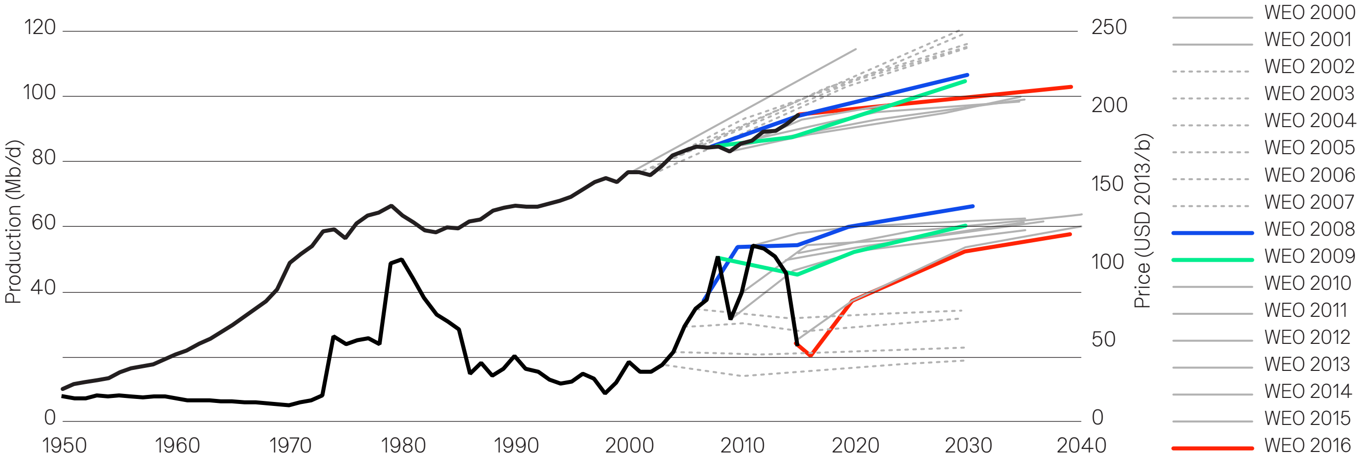
All cost projections in this analysis are based on a recent publication by Teske et al. (2019)[29]. Section 5.2 is based on Chapter 5 of that book, written by Dr. Thomas Pregger, Dr. Sonja Simon, and Dr. Tobias Naegler of the German Aerospace Center/DLR. The parameterisation of the models requires many assumptions about the development of the characteristic technologies, such as specific investments and fuel costs. Therefore, because long-term projections are highly uncertain, we must define plausible and transparent assumptions based on background information and up-to-date statistical and technical information.

The speed of an energy system transition also depends on overcoming economic barriers. These largely involve the relationships between the cost of renewable technologies and that of their fossil and nuclear counterparts. For our scenarios, the projection of these costs is vital to ensure a valid comparison of energy systems. However, there have been significant limitations to these projections in the past in terms of investment and fuel costs.

Moreover, efficiency measures generate costs that are usually difficult to determine, and depend on technical, structural, and economic boundary conditions. Therefore, in the context of this study, we have assumed uniform average costs of 3 cents per kWh of electricity consumption avoided in our cost accounting.

During the last decade, fossil fuel prices have seen huge fluctuations. Figure 12 shows the oil prices since 1997. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar fluctuations (IEA 2017)[30]. Therefore, fossil fuel price projections have also seen considerable variations (IEA 201733; IEA 2013[31]) and this has influenced the scenario results.

Figure 12: Historical development and projections of oil prices (bottom lines) and historical world oil production and projections (top lines) by the World Energy Outlook (WEO)



Published by the International Energy Agency (IEA), according to Wachtmeister et al. (2018)

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[29] Teske S (2019). Achieving the Paris Climate Agreement Goals – Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5 °C and +2.0 °C, ISBN 978-3-030-05842-5, Springer, Switzerland 2019.

[30] IEA (2017) World Energy Outlook 2017. International Energy Agency, Organisation for Economic Co-operation and Development, Paris.

[31] IEA (2013) World Energy Outlook 2013. International Energy Agency, Organisation for Economic Co-operation and Development, Paris.

Although oil-exporting countries have provided the best oil price projections in the past, institutional price projections have become increasingly accurate, with the IEA leading the way in 2018 (Roland Berger 2018)[32]. An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[33] showed that the accuracy of price projections has varied significantly over time. Whereas the IEA's oil production projections seem comparatively accurate, oil price projections showed errors of 40%–60%, even when made only 10 years ahead. Between 2007 and 2017, the IEA price projections for 2030 varied from US$70 to US$140 per barrel, providing significant uncertainty regarding future costs in the scenarios. Despite this limitation, the IEA provides a comprehensive set of price projections. Therefore, we have based our scenario assumptions on these projections, as described below.

However, because most renewable energy technologies provide energy without fuel costs, the projections of investment costs become more important than fuel cost projections, and this limits the impact of errors in the fuel price projections. It is only for biomass that the cost of feedstock remains a crucial economic factor for renewables. These costs range from negative costs for waste wood (based on credit for the waste disposal costs avoided), through inexpensive residual materials to comparatively expensive energy crops. Because bioenergy has a significant market share in all sectors in many regions, a detailed assessment of future price projections is provided below.

Investment cost projections also pose challenges for scenario development. Available short-term projections of investment costs depend largely on the data available for existing and planned projects. Learning curves are most commonly used to assess the future development of investment costs as a function of their future installations and markets (McDonald and Schrattenholzer 2001[34]; Rubin et al. 2015[35]). Therefore, the reliability of cost projections largely depends on the uncertainty of future markets and the availability of historical data.

Fossil fuel technologies provide a large cost dataset, featuring well-established markets and large annual installations. They are also mature technologies, so many cost-reduction potentials have already been exploited.

For conventional renewable technologies, the picture is more mixed. For example, like fossil fuels, hydro power is well established and provides reliable data on investment costs. Other technologies, such as solar PV and wind, are experiencing tremendous installation and cost-reduction developments. Solar PV and wind are the focus of cost monitoring and big data are already available on existing projects. However, their future markets are not readily predictable, as seen in the evolution of the IEA market projections over recent years in the World Energy Outlook series (compare, for example, IEA 2007, IEA 2014, and IEA 2017). Small differences in cost assumptions for PV and wind lead to large deviations in the overall costs, so cost assumptions must be made with particular care.

Furthermore, many technologies have only relatively small markets, such as geothermal, modern bio-energy applications, and concentrated solar power (CSP), for which costs are still high and for which future markets are insecure. The cost reduction potential is correspondingly high for these technologies. This is also true for technologies that might become important in a transformed energy system but are not yet widely available. Hydrogen production, ocean power, and synthetic fuels might deliver important technology options in the long term after 2040, but their cost reduction potential cannot be assessed with any certainty today.

Therefore, cost assumptions are a crucial factor in evaluating scenarios. Because costs are an external input into the model and are not internally calculated, we assume the same progressive cost developments for all scenarios. In the next sections, we present a detailed overview of our assumptions for power and renewable heat technologies, including the investment, fuel costs, and potential CO_2 costs in the scenarios.

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[32] Roland Berger (2018). 2018 oil price forecast: who predicts best? Roland Berger study of oil price forecasts. https://www.rolandberger.com/en/Insights/Publications/2018-oil-price-forecast-who-predicts-best.html

[33] Wachtmeister H, Henke P, Höök M (2018) Oil projections in retrospect: Revisions, accuracy and current uncertainty. Applied Energy 220:138–153. doi: https://doi.org/10.1016/j.apenergy.2018.03.013

[34] McDonald A, Schrattenholzer L (2001) Learning rates for energy technologies. Energy Policy 29 (4):255–261. doi: https://doi.org/10.1016/S0301-4215(00)00122-1

[35] Rubin ES, Azevedo IML, Jaramillo P, Yeh S (2015) A review of learning rates for electricity supply technologies. Energy Policy 86:198–218. doi: https://doi.org/10.1016/j.enpol.2015.06.011

2.7.1 Power technologies

The focus of cost calculations in our scenario modelling is the power sector. We compared the specific investment costs estimated in previous studies (Teske et al. 2015)[36], which were based on a variety of studies, including the European Commission-funded NEEDS project (NEEDS 2009), projections of the European Renewable Energy Council (Zervos et al. 2010)[37], investment cost projections by the IEA (IEA 2014), and current cost assumptions by IRENA and IEA (IEA 2016c). We found that investment costs generally converged, except for PV. Therefore, for consistency, the power sector's investment and operation and maintenance costs are based primarily on the investment costs within WEO 2016 (IEA 2016c) up to 2040, including their regional disaggregation. We extended the projections until 2050 based on the trends in the preceding decade.

For renewable power production, we used investment costs from the 450-ppm scenario from IEA 2016c. For technologies not distinguished in the IEA report (such as geothermal combined heat and power [CHP]), we used cost assumptions based on our research (Teske et al. 2015). Because the cost assumptions for PV systems made by the IEA do not reflect recent cost reductions, we based our assumptions on a more recent analysis by Steurer et al. (2018)[38], which projects lower investment costs for PV in 2050 than does the IEA.

The costs for onshore wind were adapted from the same source (Steurer et al. 2018) to reflect more-recent data. Table 15 summarises the cost trends for power technologies derived from the assumptions discussed above for Senegal. It is important to note that the cost reductions are not a function of time but of cumulative capacity (production of units), so dynamic market development is required to achieve a significant reduction in specific investment costs. Therefore, overall, we might underestimate the cost of renewables in the REFERENCE scenario compared with the With the Existing Measures (WEM) scenario and the S-1.5°C pathway (see below).

However, our approach is conservative when we compare the REFERENCE scenario with the more ambitious renewable energy scenarios under identical cost assumptions. Fossil-fuel power plants have limited potential for cost reductions because they are at advanced stages of the technology and market development. The products of gas and oil plants are relatively cheap, at around US$670/kW and US$822/kW, respectively.

In contrast, several renewable technologies have seen considerable cost reductions over the last decade. This is expected to continue if renewables are deployed extensively. Hydro power and biomass have remained stable in terms of costs. Tremendous cost reductions are still expected for solar energy and wind power, even though they have experienced significant reductions already. Whereas concentrated solar power (CSP) might deliver dispatchable power at half its current cost in 2050, variable PV costs could drop to 35% of today's costs.

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[36] Teske S, Sawyer S, Schäfer O, Pregger T, Simon S, Naegler T, Schmid S, Özdemir ED, Pagenkopf J, Kleiner F, Rutovitz J, Dominish E, Downes J, Ackermann T, Brown T, Boxer S, Baitelo R, Rodrigues LA (2015) Energy [R]evolution – A sustainable world energy outlook 2015. Greenpeace International.

[37] Zervos A, Lins C, Muth J (2010) RE-thinking 2050: a 100% renewable energy vision for the European Union. European Renewable Energy Council (EREC).

[38] Steurer M, Brand H, Blesl M, Borggrefe F, Fahl U, Fuchs A-L, Gils HC, Hufendiek K, Münkel A, Rosenberg M, Scheben H, Scheel O, Scheele R, Schick C, Schmidt M, Wetzel M, Wiesmeth M (2018) Energiesystemanalyse Baden-Württemberg: Datenanhang zu techoökonomischen Kenndaten. Ministerium für Umwelt Klima und Energiewirtschaft Baden-Württemberg, STrise: Universität Stuttgart, Deutsches Zentrum für Luft- und Raumfahrt, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Stuttgart.

Table 15: Investment cost assumptions for power generation plants in US dollars (US$) and the local currency (CFA by kW until 2050

Assumed Investment Costs for Power Generation Plants										
	2020		2025		2030		2040		2050	
Technology	[US$/kW]	[CFA/kW]	[US$/kW]	[CFA/kW]	[US$/kW]	[CFA/kW]	[US$/kW]	[CFA/kW]	[US$/kW]	[CFA/kW]
Coal power plants	2,018	1,187,059	2,018	1,187,059	2,018	1,187,059	2,018	1,187,059	2,018	1,187,059
Diesel generators	908	534,118	908	534,118	908	534,118	908	534,118	908	534,118
Gas power plants	504	296,471	504	296,471	504	296,471	504	296,471	676	397,647
Oil power plants	938	551,765	918	540,000	898	528,235	865	508,824	827	486,471
Conventional Renewables										
Hydro power plants*	2,674	1,572,941	2,674	1,572,941	2,674	1,572,941	2,674	1,572,941	2,674	1,572,941
New renewables										
PV power plants	989	581,765	744	437,647	736	432,941	565	332,353	474	278,824
Onshore wind	1,594	937,647	1,559	917,059	1,523	895,882	1,463	860,588	1,412	830,588
Offshore wind	3,723	2,190,000	3,097	1,821,765	2,472	1,454,118	2,295	1,350,000	2,119	1,246,471
Biomass power plants	2,371	1,394,706	2,346	1,380,000	2,320	1,364,706	2,220	1,305,882	2,129	1,252,353

*Values apply to both run-of-the-river and reservoir hydro power

2.7.2 Heating technologies

Assessing the costs in the heating sector is even more challenging than in the power sector. Costs of new installations differ significantly between regions and are linked to construction costs and industrial processes, which are not addressed in this study. Moreover, no data are available to allow the comprehensive calculation of the costs of existing heating appliances in all regions. Therefore, we have concentrated on the additional costs of new renewable applications in the heating sector.

Our cost assumptions are based on a previous survey of renewable heating technologies in Europe, which focused on solar collectors, geothermal energy, heat pumps, and biomass applications. Biomass and simple heating systems in the residential sector are already mature. However, more-sophisticated technologies that can provide higher shares of heat demand from renewable sources are still under development and rather expensive. Market barriers will slow the further implementation of and cost reductions for renewable heating systems, especially for heating networks. Nevertheless, significant learning rates can be expected if renewable heating is increasingly implemented, as projected in all scenarios.

Table 16 presents the investment cost assumptions for heating technologies, disaggregated by sector. Geothermal heating shows the same high costs in all sectors. In Europe, deep geothermal applications are being developed for heating purposes at investment costs ranging from €500/kWthermal (shallow) to €3000/kWthermal (deep), with the costs strongly dependent on the drilling depth. The cost reduction potential is assumed to be around 30% by 2050. No data are available for the specific situation in Senegal. However, geothermal power and heating plants are not assumed to be built under any scenario.

Heat pumps typically provide hot water or space heat for heating systems with relatively low supply temperatures, or they supplement other heating technologies. Therefore, they are currently mainly used for small-scale residential applications. Costs currently cover a large bandwidth and are expected to decrease by only 20% to US$1450/kW by 2050.

We assume the appropriate differences between the sectors for biomass and solar collectors. There is a broad portfolio of modern technologies for heat production from biomass, ranging from small-scale single-room stoves to heating or CHP plants on a megawatt scale. Investment costs show similar variations: simple log-wood stoves can be run for US$100/kW, but more sophisticated automated heating systems that cover the whole heat demand of a building are significantly more expensive to run. The running costs of log-wood or pellet boilers range from US$500/kW to US$1300/kW, and large biomass heating systems are assumed to reach their cheapest in 2050 at around US$480/kW for industry. For all sectors, we assume a cost reduction of 20% by 2050.

In contrast, solar collectors for households are comparatively simple and will become cheap to run, at US$680/kW, by 2050. The costs of simple solar collectors for service water heating might have been optimised already, whereas their integration into large systems is neither technologically nor economically mature. For larger applications, especially in heat-grid systems, the collectors are large and more sophisticated. Because there is not yet a mass market for such grid-connected solar systems, we assume there is a cost reduction potential until 2050.

Table 16: Specific investment cost assumptions (in US$2015) for heating technologies in the scenarios until 2050

Investment Costs for Heat Generation Plants									
		2020		**2030**		**2040**		**2050**	
		[US$/kW]	**[CFA/kW]**	**[US$/kW]**	**[CFA/kW]**	**[US$/kW]**	**[CFA/kW]**	**[US$/kW]**	**[CFA/kW]**
Solar collectors	Industry	820	482,353	730	429,412	650	382,353	550	323,529
	In heat grids	970	570,588	970	570,588	970	570,588	970	570,588
	Residential	1,010	594,118	910	535,294	800	470,588	680	400,000
Geothermal		2,270	1,335,294	2,030	1,194,118	1,800	1,058,824	1,590	935,294
Heat pumps		1,740	1,023,529	1,640	964,706	1,540	905,882	1,450	852,941
Biomass heat plants		580	341,176	550	323,529	510	300,000	480	282,353
Commercial biomass heating systems	Commercial scale	810	476,471	760	447,059	720	423,529	680	400,000
Residential biomass heating stoves	Small scale/ Rural	110	64,706	110	64,706	110	64,706	110	64,706

2.7.3 Renewable Energy costs in Senegal In 2021

The following tables provide an overview of the assumed renewable energy costs in Senegal. This information is based on research by the authors and energy scenarios developed for various countries in the global south. The costs may vary from region to region.

Table 17: Solar Home Systems – estimated costs

Solar Home Systems	**[CFA]**	**[US$]**	**[US$/kWpeak]**
10 W	27,059	46	4,572
20 W	50,588	86	4,322
50 W	93,529	159	3,186
55 W	101,765	173	3,152
60 W	108,235	184	3,059
80 W	123,529	210	2,629
100 W	147,059	250	2,495
Institutional Solar Power Systems	**[CFA]**	**[$]**	**[US$/kWpeak]**
1000 W	1,339,412	2,277	2,277
2000 W	2,244,706	3,816	1,908

Source: UTS-ISF own research, March 2023

Table 18: Solar dryers – estimated costs

Solar Dryers [1 sqft = 0.0929 m^2]	[CFA]	[US$]	[US$/$m^2$]
3–6 sqft (household)	151,765	258	617
10–15 sqft (household)	344,706	586	505
> 21 sqft (institutional)	532,941	906	464

Source: UTS-ISF own research, March 2023

Table 19: Solar cookers – estimated costs

Solar Cookers	[CFA]	[US$]
Solar Cookers	**[CFA]**	**[US$]**
Parabolic – household	115,294	196
Parabolic – institutional	705,882	1,200

Source: UTS-ISF own research, March 2023

Table 20: Biomass stoves – estimated costs

Biomass Stoves	[CFA]	[US$]
Institutional improved stove – type 1	228,824	389
Institutional improved stove – type 2	240,000	408
Institutional improved stove – type 3	285,294	485
Natural draft stove	20,588	35
Forced draft stove	41,765	71
Improved metallic stove	57,059	97

Source: UTS-ISF own research, March 2023

2.7.4 Fuel cost projections

Fossil Fuels

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions up to 2040 on ***World Energy Outlook 2023*** (IEA 2023). Beyond 2040, we extrapolated the price developments between 2035 and 2040 and present them in Table 21. Although these price projections are highly speculative, they provide prices consistent with our investment assumptions.

Table 21: Development projections for fossil fuel prices in US$2015 based on World Energy Outlook 2023 (STEPS) (IEA 2023)

Development Projections for Fossil Fuel Prices										
	2019		2025		2030		2040		2050	
All Scenarios	[US$/GJ]	[CFA/GJ]	[US$/GJ]	[CFA/GJ]	[US$/GJ]	[CFA/GJ]	[US$/GJ]	[CFA/GJ]	[US$/GJ]	[CFA/GJ]
Oil	8.5	5,000	12	7,059	11	6,471	10	5,882	10.5	6,176
Gas	9.8	5,765	20	11,765	10	5,882	11	6,471	12	7,059
Coal	3.2	1,882	3.5	2,059	4	2,353	3.8	2,235	3.5	2,059

2.7.5 Biomass prices

Biomass prices depend on the quality of the biomass (residues or energy crops) and the regional supply and demand. The global variability is large. Lamers et al. (2015)[39] reported a price range of €4–€4.8/GJ for forest residues in Europe in 2020, whereas agricultural products might cost €8.5–€12/GJ. Lamers et al.42 modelled a range for wood pellets from €6/GJ in Malaysia to €8.8/GJ in Brazil. IRENA modelled a cost supply curve on a global level for 2030, ranging from US$3/GJ for a potential of 35 EJ/yr up to US$8–US$10/GJ for a potential of up to 90–100 EJ/yr (IRENA 2014) (and up to US$17/GJ for a potential extending to 147 EJ/yr).

Bioenergy prices in Senegal in 2021

Table 22: Biogas prices – small quantities – in Senegal by region

	2 m^3		4 m^3		6 m^3		8 m^3	
Biogas	[CFA]	[US$]	[CFA]	[US$]	[CFA]	[US$]	[CFA]	[US$]
Household – low cost assumption	241,765	411	345,294	587	397,647	676	444,706	756
Household – average cost assumption	282,941	481	380,588	647	440,588	749	480,588	817
Household – high cost assumption	324,118	551	415,882	707	482,941	821	515,882	877

Source: UTS-ISF own research – March 2023

Table 23: Biogas prices – medium quantities – in Senegal by region

Biogas	12.5 m^3		40 m^3		60 m^3		100 m^3	
	[CFA]	[US$]	[CFA]	[US$]	[CFA]	[US$]	[CFA]	[US$]
Household – low cost assumption	1,277,059	2,171	3,679,412	6,255	4,884,706	8,304	7,124,706	12,112
Household – average cost	1,398,235	2,377	3,906,471	6,641	5,620,588	9,555	8,189,412	13,922
Household – high cost assumption	1,518,824	2,582	4,133,529	7,027	6,356,471	10,806	9,253,529	15,731

Source: UTS-ISF own research – March 2023

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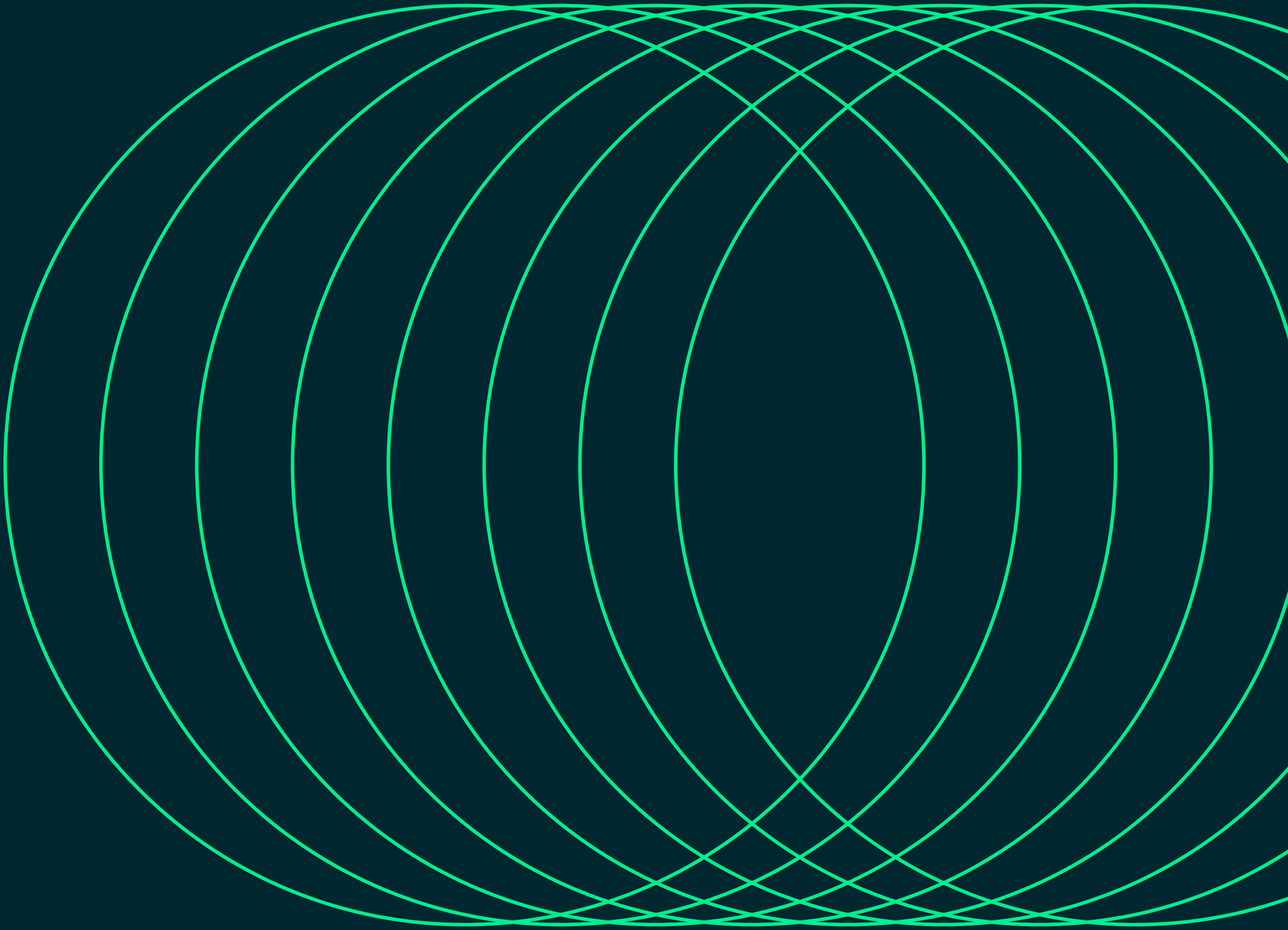
[39] Lamers P, Hoefnagels R, Junginger M, Hamelinck C, Faaij A (2015) Global solid biomass trade for energy by 2020: an assessment of potential import streams and supply costs to North-West Europe under different sustainability constraints. GCB Bioenergy 7 (4):618–634. doi: https://doi.org/10.1111/gcbb.12162

3

Senegal: Renewable Energy Potential



Senegal's solar and wind potential was assessed as an input for the development of energy scenarios. In this section, we examine the technical potential under space-constrained conditions.

3.1 The [R]E SPACE Methodology

The [R]E Space methodology is part of the One Earth Climate Model (OECM) methodology. GIS mapping was used to determine Senegal's renewable energy resources (solar and wind). It was also used in the regional analysis of the geographic and demographic parameters and the available infrastructure that could be leveraged in developing the scenarios. Mapping was performed with the software ESRI ArcGIS10.6.1, which allows spatial analysis and maps the results. It was used to allocate solar and wind resources and to project the demand for the seven modelling regions. Population density, access to electricity infrastructure, and economic development projections are key input parameters in a region-specific analysis of Senegal's future energy situation, which will clarify the requirements for additional power grid capacities and/or micro-grids.

The [R]E Space methodology is used to map solar energy potential and onshore energy potential[40]. Open-source data and maps from various sources were collected and processed to visualise the country, its regions, and districts. Further demographic data related to the population and poverty were plotted on the maps, together with transmission networks and power plants. The main data sources and assumptions made for this mapping are summarised in Table 24.

Table 24: Senegal – [R]E 24/7 – GIS-mapping – data sources

Data	Assumptions	Source
Land Cover	Land cover classes suitable for solar energy and wind energy production were identified from Copernicus Global Land Cover 2019.	Copernicus Global Land Cover-2019[41]
Digital Elevation Model (DEM)	For both wind and solar analyses, any land with a slope of > 30% was excluded from all scenarios.	SRTM Digital Elevation Data Version 4[42]
Population and Population Density	Latest population was estimated by country and region by Michael Bauer Research GmbH.	Total Population in Senegal (2023)
Protected Areas	All protected areas designated national parks, wildlife reserves, hunting reserves, conservation areas, or buffer zones were excluded from all scenarios.	World Database on Protected Areas[43]
Power Plants, Transmission Lines, and Network	Solar and wind potential of areas ≤ 10 km from transmission lines was considered (Scenario 2).	Global Power Plant Database (v1.3.0)[44] Senegal Electricity Transmission Network (2017)[45]
Solar Irradiance (direct normal irradiation, DNI)	The average yearly direct normal insolation/irradiation (DNI) values range from 1 to 5 MWh/m^2 per year (2.7–13.6 kWh/m^2 per day).	Global Solar Atlas[46]
Wind Speeds	Wind speeds ≥ 5 m/s were considered at a height of 100 m.	Global Wind Atlas[47]

The [R]E Space mapping procedure is summarised in Figure 13. The land areas available for potential solar and wind power generation were calculated and visualised at the national and provincial levels with ArcGIS. The land-cover map, elevation (digital elevation model: DEM), World Database of Protected Areas, solar irradiation (direct normal irradiation, DNI), and wind speed data were obtained as raster data from the websites cited above, and were all converted into binary maps (0 = area not suitable as a potential area, 1 = area suitable as a potential area) against all the assumptions in Table 24. They were then combined into one binary map by overlaying all the raster data. This map integrates all the criteria cited above in one map, with a value of 1 (land included in the potential area) or a value of 0 (land not included in the potential area).

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[40] Miyake S, Teske S, Rispler J, and Feenstra M (2024) Solar and wind energy potential under land-resource constrained conditions in the Group of Twenty (G20). Renewable and Sustainable Energy Reviews 202:114622. https://doi.org/10.1016/j.rser.2024.114622

[41] Copernicus Global Land Cover–2019: https://land.copernicus.eu/global/products/lc

[42] SRTM Digital Elevation Data Version 4: https://srtm.csi.cgiar.org/

[43] World Database on Protected Areas: https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA

[44] Global Power Plant Database (v1.3.0): https://datasets.wri.org/dataset/globalpowerplantdatabase

[45] Senegal – Electricity Transmission Network: https://energydata.info/en/dataset/senegal-electricity-transmission-network-2017

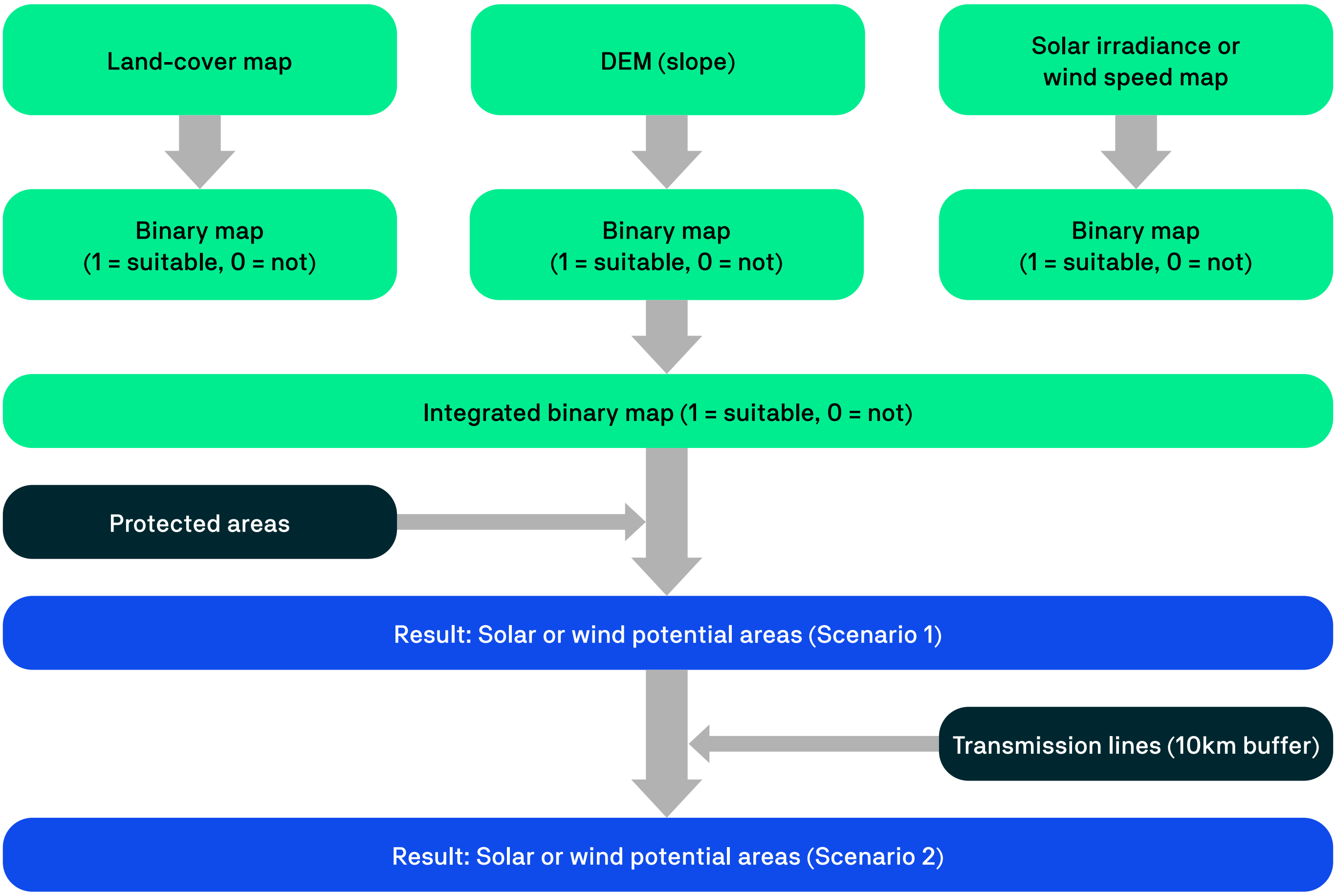
[46] Global Solar Atlas: https://globalsolaratlas.info/map

[47] Global Wind Atlas: https://globalwindatlas.info/en

Data on transmission lines and protected areas exist as vector data. All protected areas were excluded from the above value-1 areas in the integrated raster data using a mask layer generated from the 'erase' function. For Scenario 2 (see Figure 21), buffer layers were generated from transmission line (10 km) data, and then the raster data without protected areas were clipped by these buffer layers to generate potential area maps under Scenario 2. This input was fed into the calculations for the [R]E 24/7 model, as described below.

Disclaimer: The environmental criteria used to identify suitable areas for utility-scale solar and wind projects do not reflect the current legislation in Senegal, and the potential provided is a conservative estimate and may ultimately be larger.

Figure 13: [R]E Space Methodology – solar potential analysis and wind potential analysis



3.2 Mapping methodology for offshore wind

Offshore wind energy potential for Senegal is also mapped for the two scenarios. Open-source data and maps from various sources were collected and processed to visualise the offshore wind potentials.

Table 25: Senegal – Offshore wind – GIS-mapping – data sources

Data	Assumptions	Source
Gridded Bathymetry Data – Water depth	For offshore wind mapping, two scenarios were generated: areas with water depths < 50 m (for fixed bottom fundaments) and areas with water depths < 500 m (floating fundaments) were excluded from all scenarios.	GEBCO_2023 Grid[48]
Protected Areas	All protected areas designated national parks, wildlife reserves, hunting reserves, conservation areas, or buffer zones were excluded from all scenarios.	World Database on Protected Areas
Ports	100 km radii from ports are marked on the map.	World Port Index 2019[49]
Maritime Boundaries		Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM) (version: 11)[50]
Wind Speeds	Wind speeds ≥ 6 m/s at a height of 100 m were considered.	Global Wind Atlas

The mapping procedure for offshore wind potential involved gridded bathymetry data or water depth, marine and coastal protected areas in the World Database of Protected Areas, and wind speed data (≥ 6 m/s). Similar to the [R]E Space methodology, all data were converted into binary maps (0 = area not suitable as a potential area, 1 = area suitable as a potential area) based on all the assumptions in Table 25, and then combined into one binary map by overlaying all the raster data. Data from World Port Index 2019 were used to map the locations of ports and the 100 km radii around them.

3.3 Mapping Senegal

Senegal has large untapped potential for renewable energy and over 12% of Senegal's electricity was generated from renewable sources in 2020. Solar PV remained the most important renewable energy source of the country's electricity in 2020, followed by wind energy.

3.3.1 Solar Potential

The average annual solar irradiation (DNI) level in Senegal is 1,611–1,325 kWh/m2/year, and the higher end of that range is in the north-western part of the country.

Senegal's solar potential has been mapped under two different scenarios.

- **Scenario 1:** Available land – excluding protected areas (PA), extreme topography (slope > 30% [mountainous areas], S30), and certain land-cover classes, including closed forests, wetlands, moss and lichen, snow and ice, and water (permanent water bodies) (LU).
- **Scenario 2:** See 1, with an additional restriction that excludes areas ≤ 10 km from existing transmission lines (PT10).

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[48] GEBCO_2023 Grid: https://www.gebco.net/data_and_products/gridded_bathymetry_data/

[49] World Port Index 2019: https://msi.nga.mil/Publications/WPI

[50] Maritime Boundaries Geodatabase: http://comlmaps.org/how-to/layers-and-resources/boundaries/maritime-boundaries-geodatabase/

Table 26: Senegal's potential for solar photovoltaic energy

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Regions	**Solar Potential Area (km²)**	**Solar Potential (GW)**	**Solar Potential Area (km²)**	**Solar Potential (GW)**
1. Dakar Region	492	12	492	12
2. North-eastern Region	27,836	696	12,902	323
3. Central North Region	17,046	426	10,465	262
4. Central East Region	18,366	459	13,097	327
5. Central West Region	10,597	265	9,959	249
6. South-eastern Region	44,175	1,104	9,714	243
7. South-western Region	14,713	368	7,552	189
Total	**113,225**	**3,331**	**64,182**	**1,605**

Figure 14 shows the results of the spatial analysis, and indicates the areas of solar potential under Scenario 1 (LU + PA + S30). The Scenario provides 133,225 km^2 of areas with solar potential and a total potential for a solar PV capacity of 3,331 GW. Scenario 1 excludes all protected areas and areas with slopes > 30%, because installing solar panels in steep mountainous areas is unrealistic. Open forests, shrubs, herbaceous vegetation, bare/spare vegetation, agricultural land, and urban/built-up land-cover classes in the Copernicus Global Land Cover 2019 dataset are included. However, certain land-cover classes (e.g., closed forests, wetlands, water bodies, snow and ice) are excluded from the scenarios selected for the consideration of solar energy potential.

Figure 15 shows the areas of solar potential for Scenario 2 (LU + PA + S30 + PT10). When the land area is restricted by its proximity to power lines (≤10km), the potential solar areas decrease to 64,182 km^2. This is because most electricity and road infrastructure is currently developed in the coastal regions of the country. Under Scenario 2, solar farms in Senegal can potentially harvest 1,605 GW of solar PV.

Figure 14: Senegal – Areas of Solar Potential (Scenario 1: LU + PA + S30)

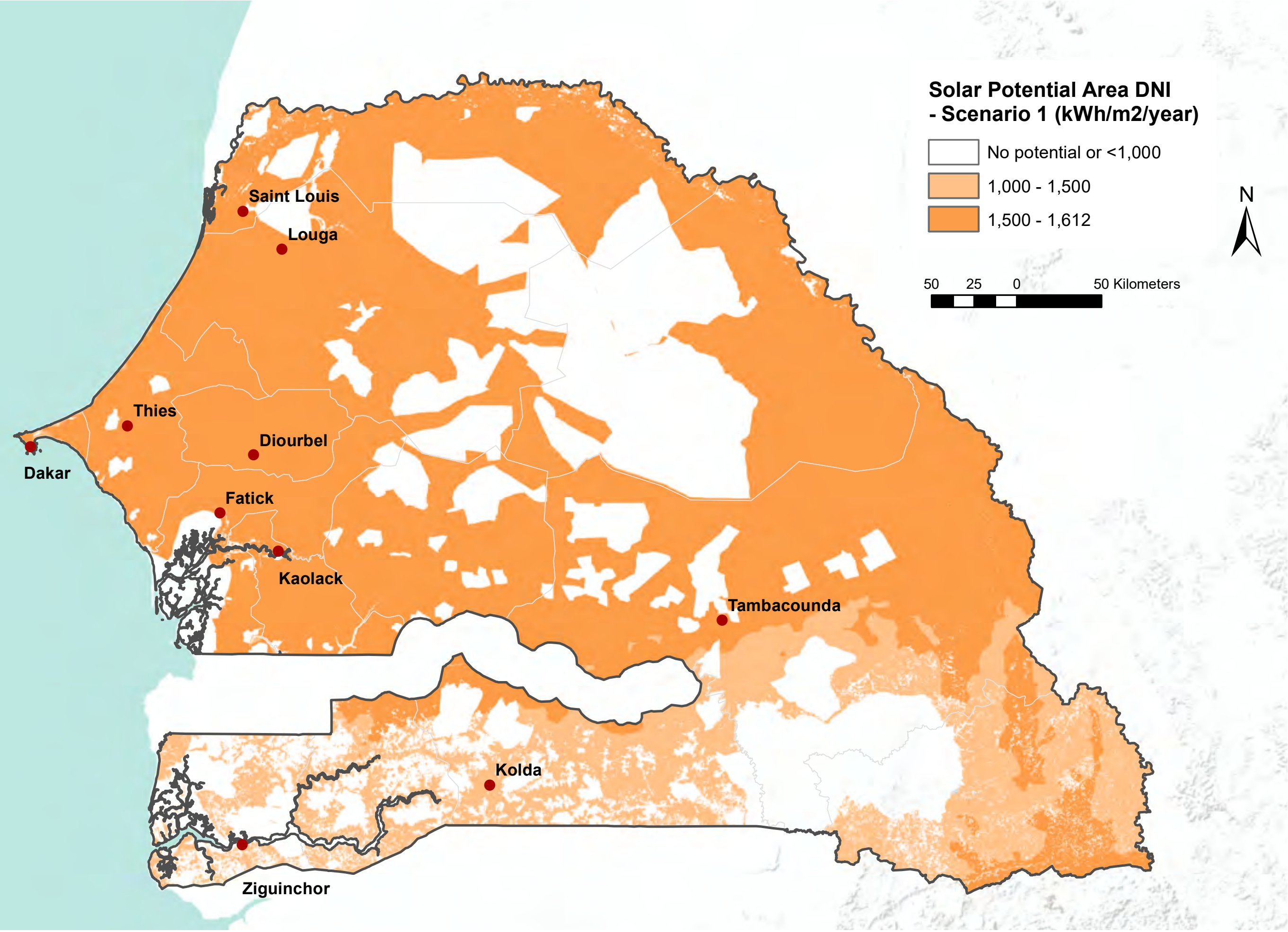
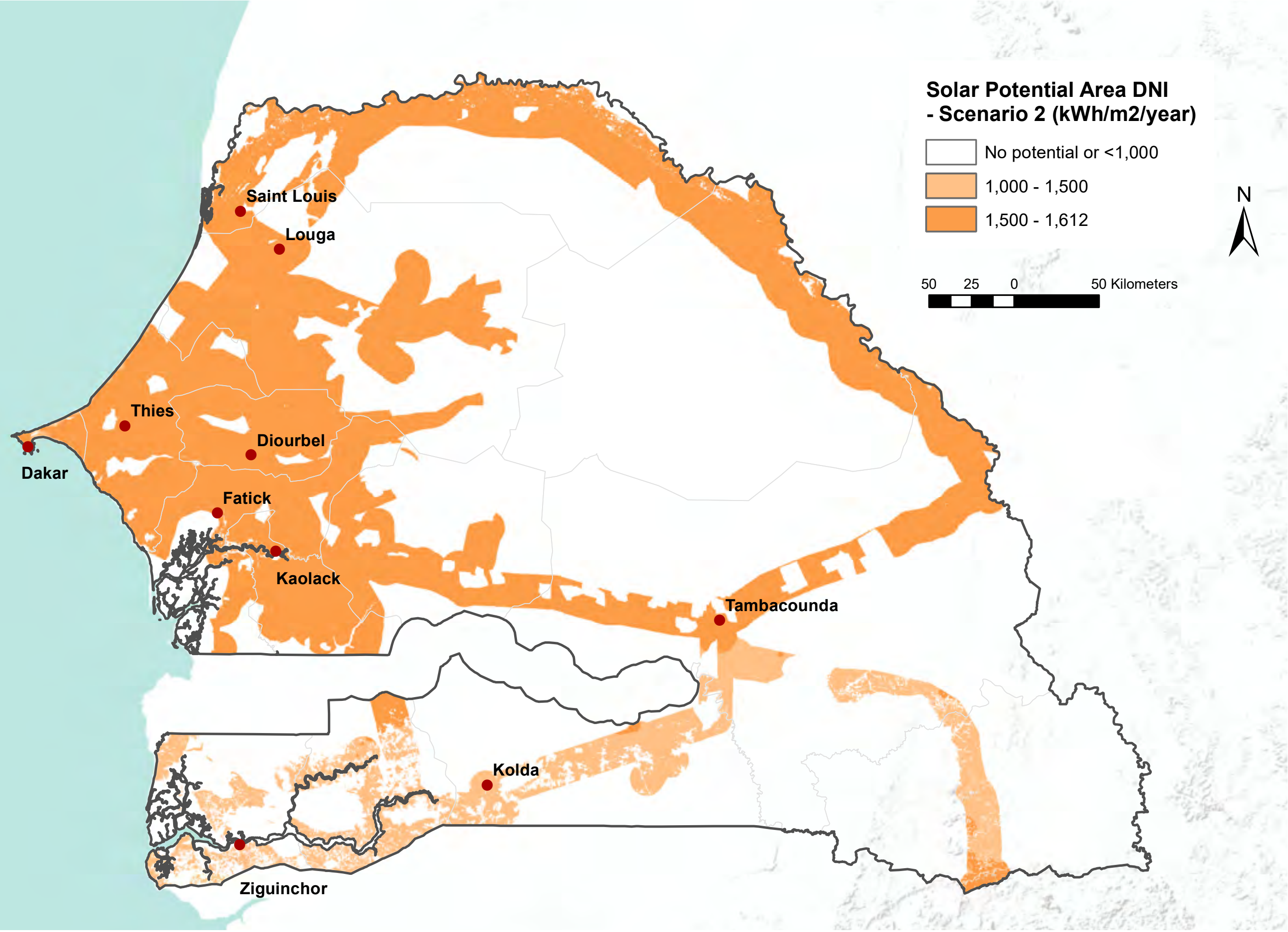


Figure 15: Senegal – Areas of Solar Potential (Scenario 2: LU + PA + S30 + PT10)



3.3.2 Onshore Wind Potential

The overall onshore wind resources on land are lower than the solar potential in Senegal. The wind speeds in Senegal range from 3 to 8 m/s at 100 m height, and high-wind-speed areas are predominantly located in the north and central regions (Global Wind Atlas). In this analysis, we have only included areas with an average annual wind speed of ≥ 5 m/s. Senegal's wind potential has been mapped under two different scenarios.

- **Scenario 1:** Available land – excluding protected areas (PA), topography (slope > 30% [mountain areas], S30), and existing land use, including forests and urban areas (LU).
- **Scenario 2:** See 1, with the additional restriction excluding areas ≤ 10 km from existing transmission lines (PT10).

Open forest, shrubs, herbaceous vegetation, bare/sparse vegetation, and agricultural land were included in the available land (LU) for the two wind scenarios, whereas the land-cover classes closed forests, wetland, moss and lichen, urban/built up areas, snow and ice, and permanent water bodies were excluded from this analysis of wind potential.

Table 27 shows that the overall area of wind potential under all appropriate restrictions is 116,728 km^2, which has a total wind energy potential of 584 GW for Scenario 1. Overall, the spatial analysis identified slightly limited wind potential in Senegal, especially under Scenario 2 (59,447 km^2, 297 GW), because there are few areas with an annual wind speed of ≥ 5 m/s and most of these areas are not located within close proximity to transmission lines (≤ 10 km).

Table 27: Senegal's potential for utility-scale onshore wind power

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Regions	Onshore Wind Potential Area (km²)	Onshore Wind Potential (GW)	Onshore Wind Potential Area (km²)	Onshore Wind Potential (GW)
1. Dakar Region	337	2	337	2
2. North-eastern Region	27,694	138	12,833	64
3. Central North Region	16,991	85	10,413	52
4. Central East Region	18,225	91	13,018	65
5. Central West Region	10,298	51	9,663	48
6. South-eastern Region	35,061	175	8,584	43
7. South-western Region	8,123	41	4,600	23
Total	**116,728**	**584**	**59,447**	**297**

Figure 16: Senegal – Areas of Onshore Wind Potential (Scenario 1: LU + PA + S30)

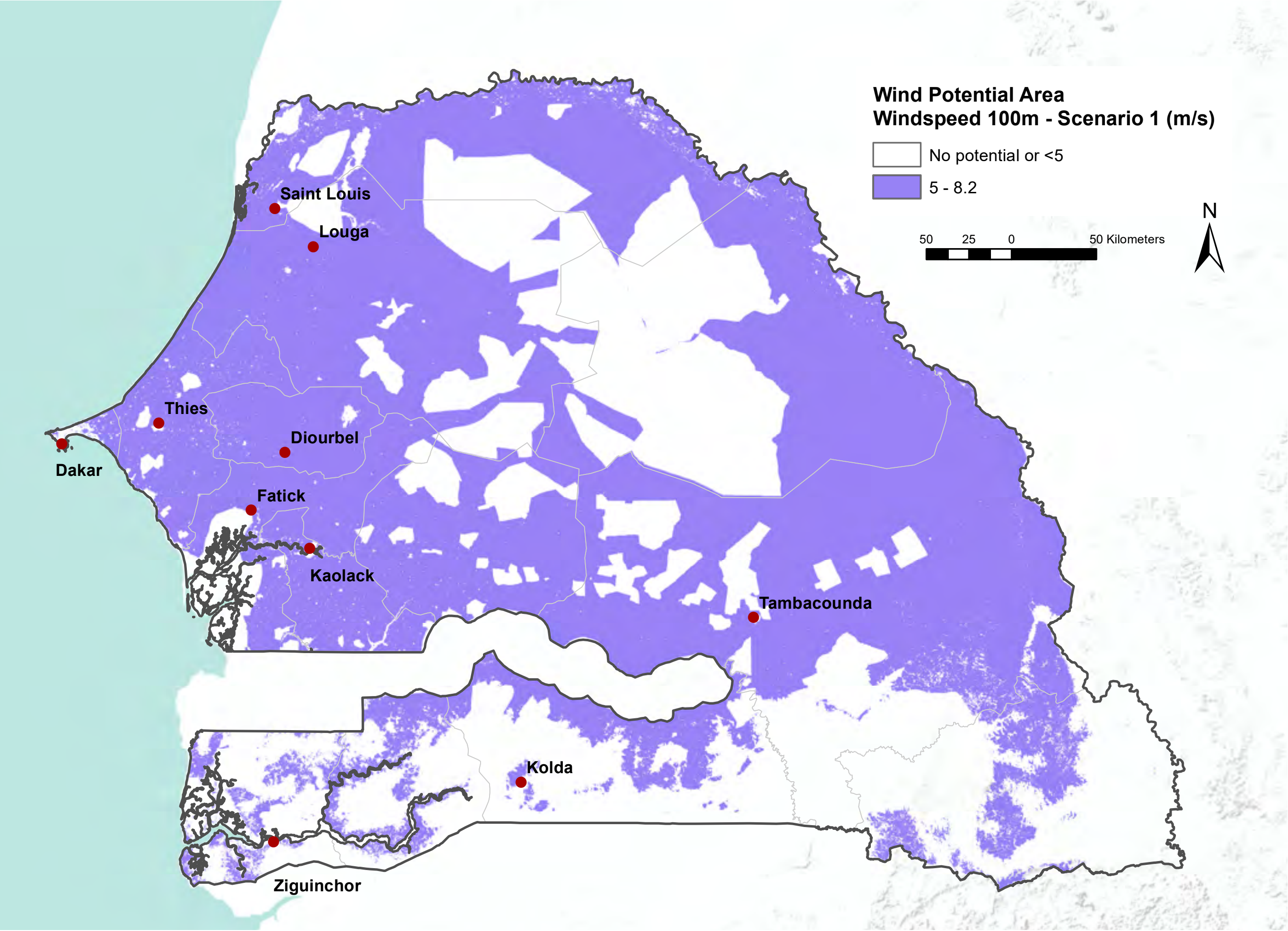
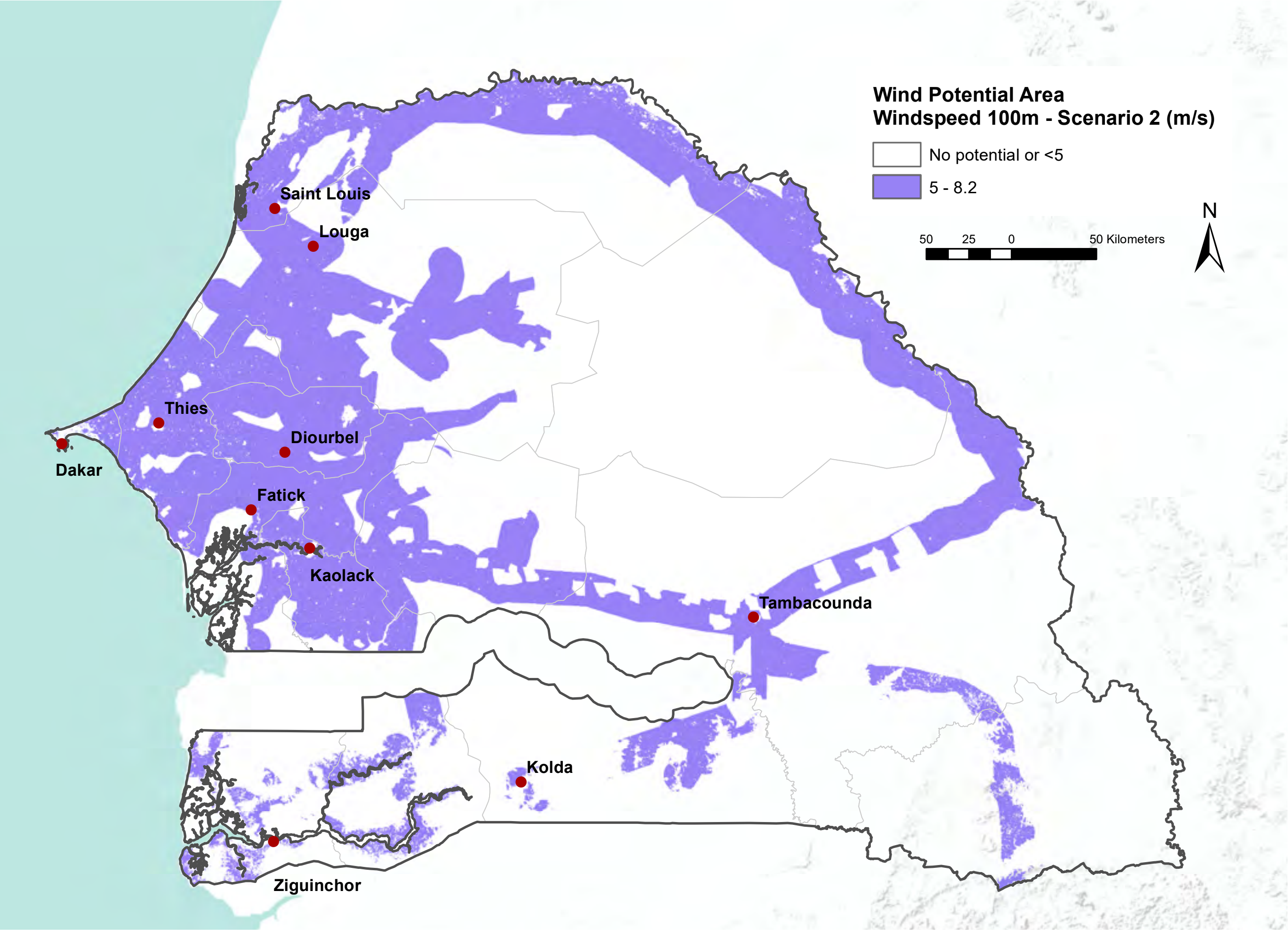


Figure 17: Senegal – Areas of Onshore Wind Potential (Scenario 2: LU + PA + S30 + PT10)



3.3.3 Offshore Wind Potential

The wind speeds in the offshore areas in Senegal range from 5 to 8 m/s at 100 m height. For the offshore wind analysis, we included areas with an average annual wind speed of ≥ 6 m/s, because offshore wind projects usually require higher wind speeds than onshore wind projects for economic viability. Senegal's wind potential was mapped under two different scenarios.

- **Scenario 1:** Available offshore areas – excluding protected areas (PA) and water depths > 50 m (WD50) (PA + WD50).
- **Scenario 2:** Available offshore areas – excluding protected areas (PA) and water depths > 500 m (WD50) (PA + WD500).

The total offshore wind potential is 59,003 MW (59 GW) for Scenario 1 (11,801 km^2) and 106,272 MW (106 GW) for Scenario 2 (21,254 km^2). Figures 17 and 18 show the offshore wind potential areas for Scenario 1 and Scenario 2, respectively.

Figure 18: Senegal – Areas of Offshore Wind Potential (Scenario 1)

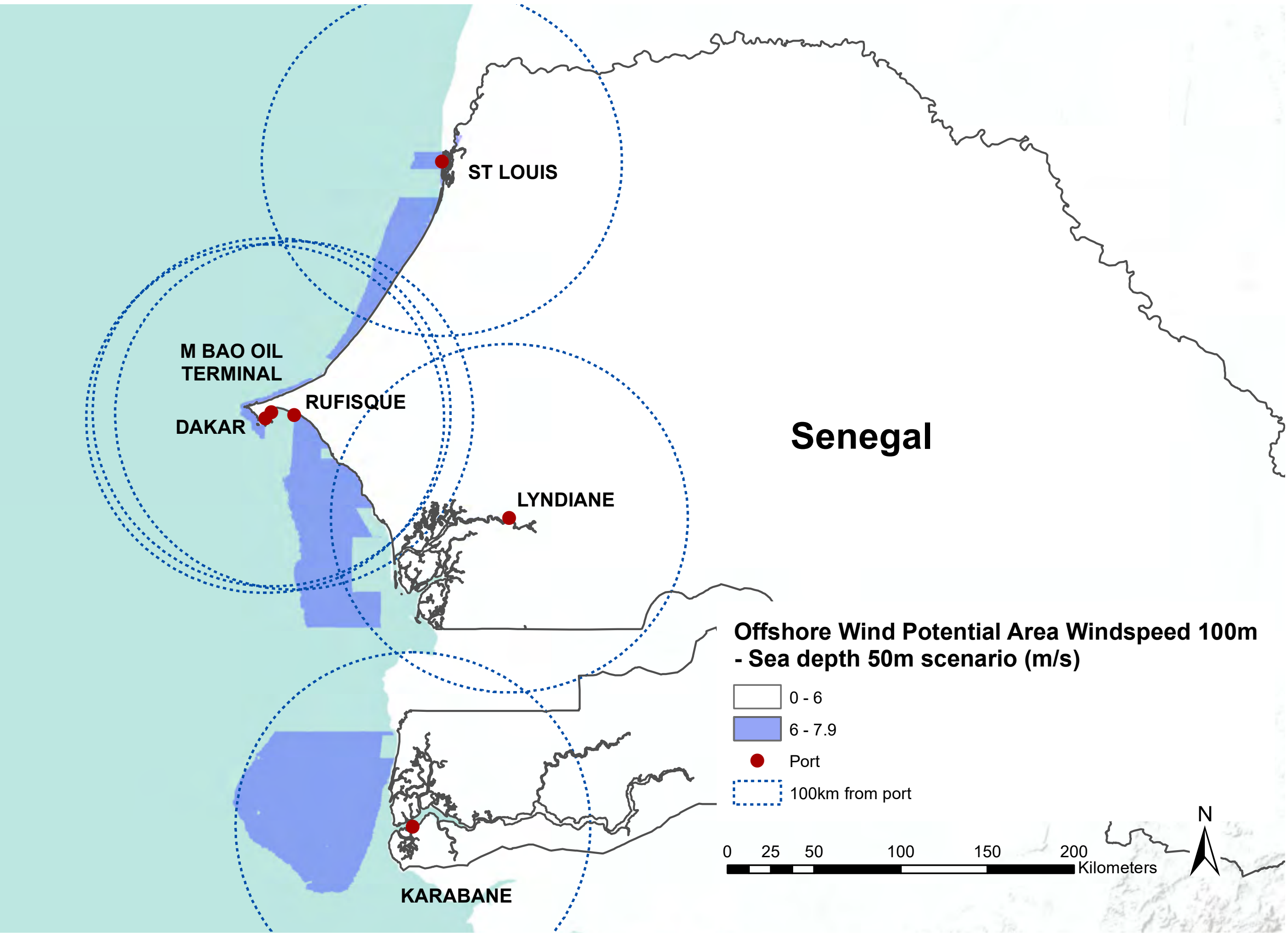
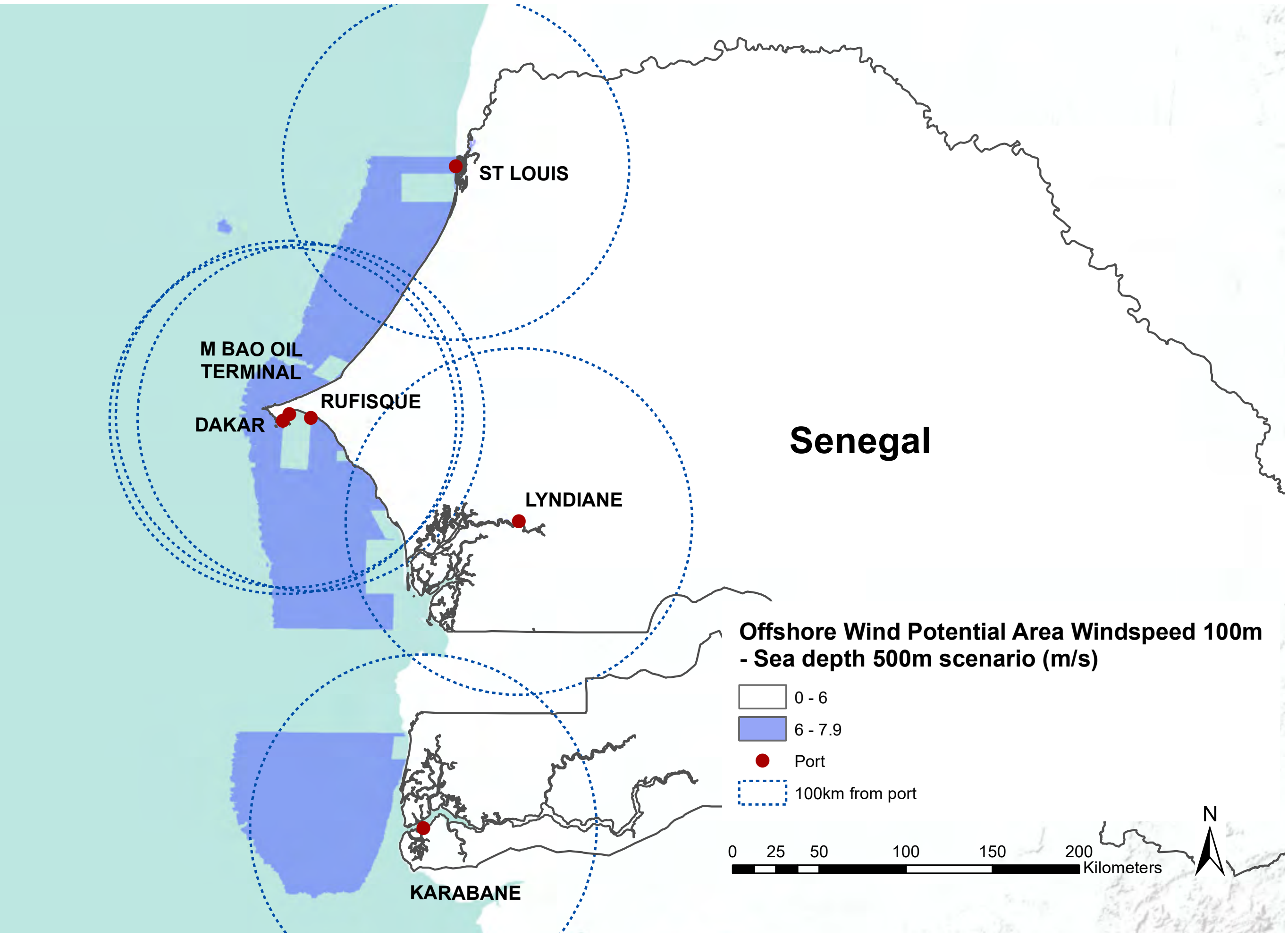


Figure 19: Senegal – Areas of Offshore Wind Potential (Scenario 2)



Main challenges for utility-scale solar PV are the availability of land and policy stability

To use Senegal's utility-scale solar PV potential as efficiently as possible, further research is required that breaks down the utility-scale PV potential further into ground-mounted solar PV, agricultural solar PV, and floating solar PV.

- **Utility-scale solar PV:** Large-scale solar PV generators require space. Space is limited in Senegal and energy generation must often compete with other forms of land use. Therefore, space for solar power should be utilised as efficiently as possible, and multiple use options should be considered.
  - Agricultural solar PV is a new development that combines agricultural food production techniques with solar PV equipment. The solar generator is mounted above the field – sometimes several meters high – to leave enough space for harvesting and to ensure light access.
  - Research and development is required into floating solar generators on lakes, especially the water storage reservoirs of hydro power stations with dams. Floating solar is a fairly new form of solar PV. In standardised floating devices for utility-scale projects, solar panels designed for ground-mounted systems are usually used.

Policy regarding licensing and electricity rates for generated solar electricity has undergone changes in the past, which increase the risks to project development and the operation of systems. Higher risks lead to higher capital costs and lower economic advantages. Therefore, policy stability is a key driver of every technology, including utility-scale solar PV power plants.

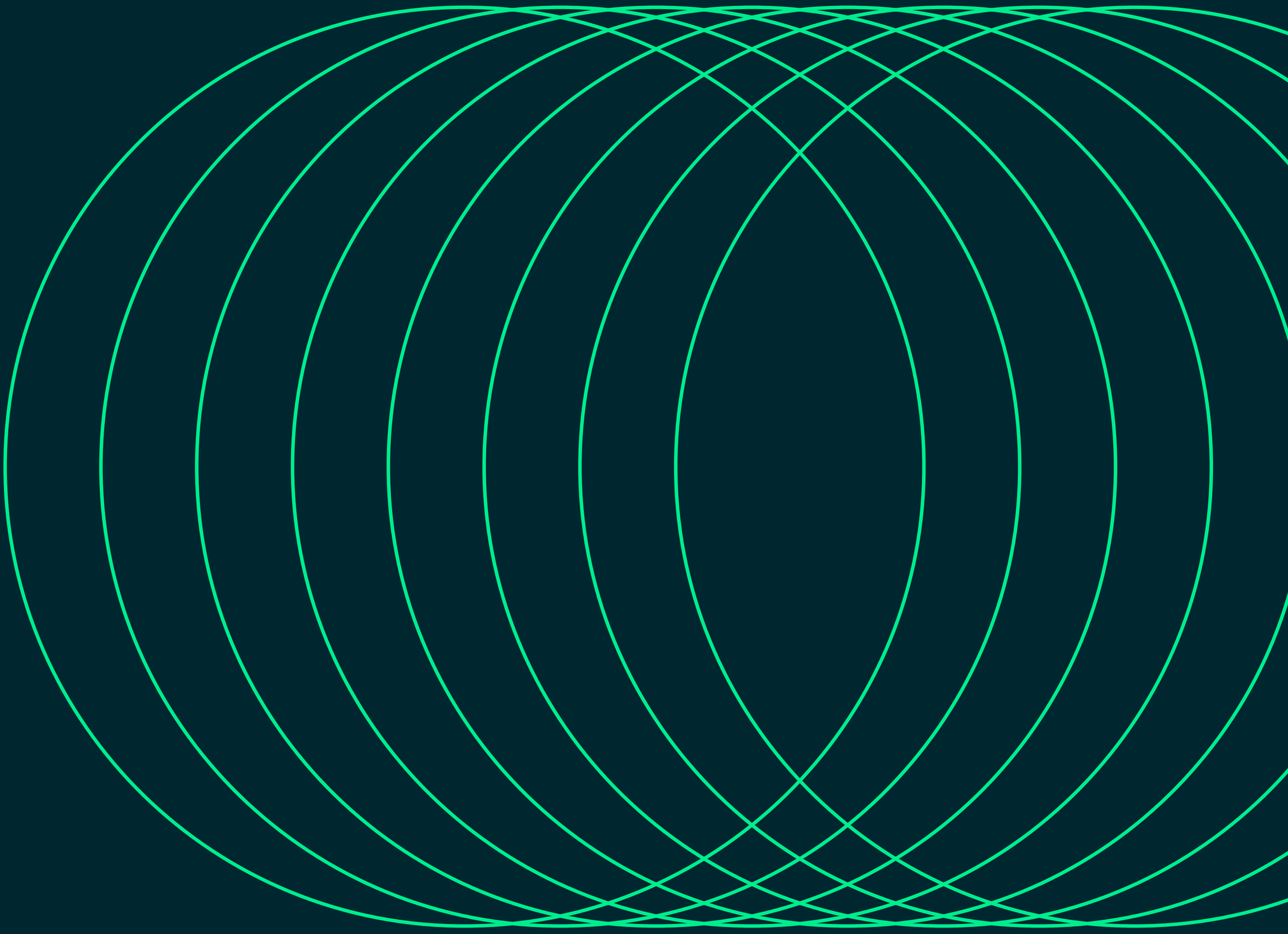
3.3.4 Assumptions for hydrogen and synfuel production

In the Senegal 1.5 °C (S-1.5°C) scenario, hydrogen and sustainable synthetic fuels will be introduced as substitutes for natural gas. Unsustainable biomass will only play a minor role and will be used almost exclusively by industry after 2030. Hydrogen is assumed to be produced by electrolysis, generating an additional electricity demand, which will be supplied by the extra renewable power production capacity, predominantly solar PV and hydro power. Renewable hydrogen and synthetic fuels will be essential for a variety of sectors.

- In the industry sector, hydrogen will be an additional renewable fuel option for high-temperature applications, supplementing biomass in industrial processes whenever the direct use of renewable electricity is not applicable.
- The transport sector will also rely increasingly on hydrogen as a renewable fuel, where battery-supported electric vehicles reach their limits and where limited biomass potential restricts the extension of biofuel use. However, future hydrogen applications may be insufficient to replace the whole fossil-fuel demand, especially in aviation, heavy-duty vehicles, and navigation. The S-1.5°C scenario introduces synthetic hydrocarbons from renewable hydrogen, electricity, and biogenic/atmospheric CO_2. These synthetic fuels will be introduced after 2030 and provide the remaining fossil fuel demand that cannot be met with biofuels because their potential is limited.

4

Areas of Forest Loss in Senegal



The Food and Agriculture Organisation of the United Nations (FAO) is a specialised agency that leads international efforts to abolish hunger and improve nutrition and food security. The FAO has published extensive food production data and other data related to agriculture and forestry.

According to the FAO[51], the forested area in Senegal in 2020 was 80,682 km^2 (including 80,362 km^2 of naturally regenerated forest), which is a 13.3% reduction from 1990 and an 8.9% reduction from 2000. These increases in forest loss resulted in negative carbon emissions from the forest sector (Table 28).

Table 28: Extent of forest areas and net emissions from forested land in Senegal (FAO)

	Extent of Forest	
Year	**Area (km^2)**	**Change from 1990**
1990	93,032	-
2000	88,532	-4.8%
2010	84,682	-9.0%
2020	80,682	-13.3%

Source: Extent of forest (FAO Global Forest Resources Assessment Country Reports (2020)

Global Forest Watch also reported that between 2001 and 2023, Senegal lost 50.9 km^2 of tree cover (equivalent to a 13% reduction in tree cover since 2000), which generated 1.93 Mt of CO_2e emissions. This includes a loss of 0.08 km^2 of humid primary forest in 2002–2023. Forest was predominantly cleared for the expansion of agriculture during that period[52]. The loss of forest areas in Senegal was also visualised with ArcGIS. The spatial dataset published by Hansen et al. (2013) was used to highlight forest loss (2000–2023) with ArcGIS (Figure 20). Areas of forest loss are mostly found in southern regions (e.g., Ziguinchor, Sédhiou). Global Forest Watch reported that Ziguinchor was responsible for 99% of all tree cover loss between 2018 and 2023. Table 29 shows the areas of forest loss (km^2), which were also estimated from Hansen et al.[53], together with the estimated CO_2e emissions since 2000 (the baseline year of this dataset).

Table 29: Senegal – areas of forest loss (km^2) and estimated CO_2e emissions from that forest loss

Years	Area (km^2)	CO_2e emissions (kilotonnes)
2001–2005	4.7	239.8
2006–2010	8.1	280.5
2011–2015	12.0	463.7
2016–2020	19.8	629.6
2021–2023	6.3	317.0
Total area of forest loss (2001–2023)	**50.9**	**1,930.6**

Source: Global Forest Watch

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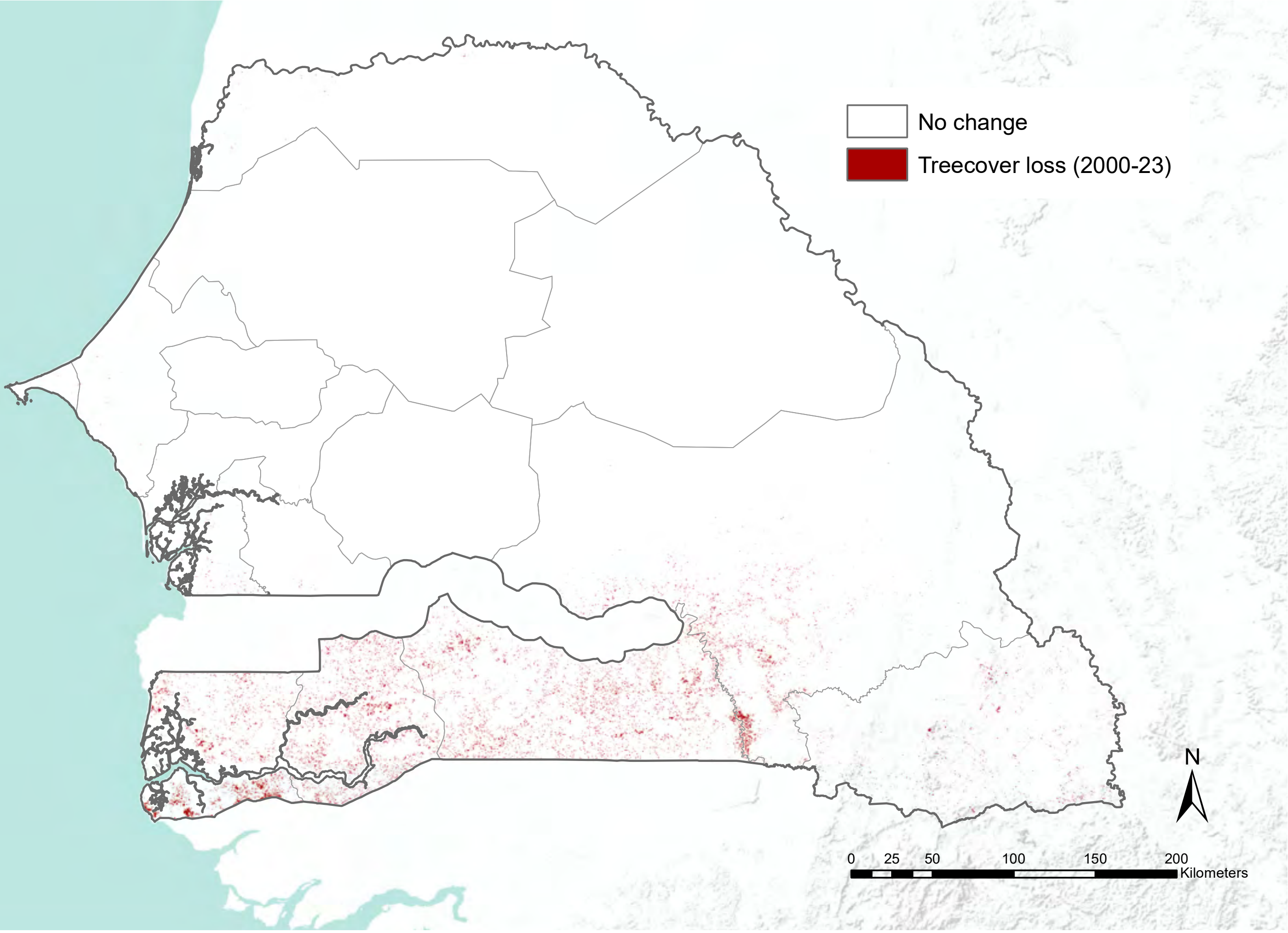
[51] FAO Global Forest Resources Assessment 2020 (Senegal): https://openknowledge.fao.org/server/api/core/bitstreams/a301bee2-617e-4b02-80bc-d621c9e8790a/content

[52] Global Forest Watch (Senegal): https://www.globalforestwatch.org/dashboards/country/SEN/?map=eyJjYW5Cb3VuZCI6dHJ1ZX0%3D

[53] Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG (2013) High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342 (15 November):850–853. Data available online at: https://glad.earthengine.app/view/global-forest-change

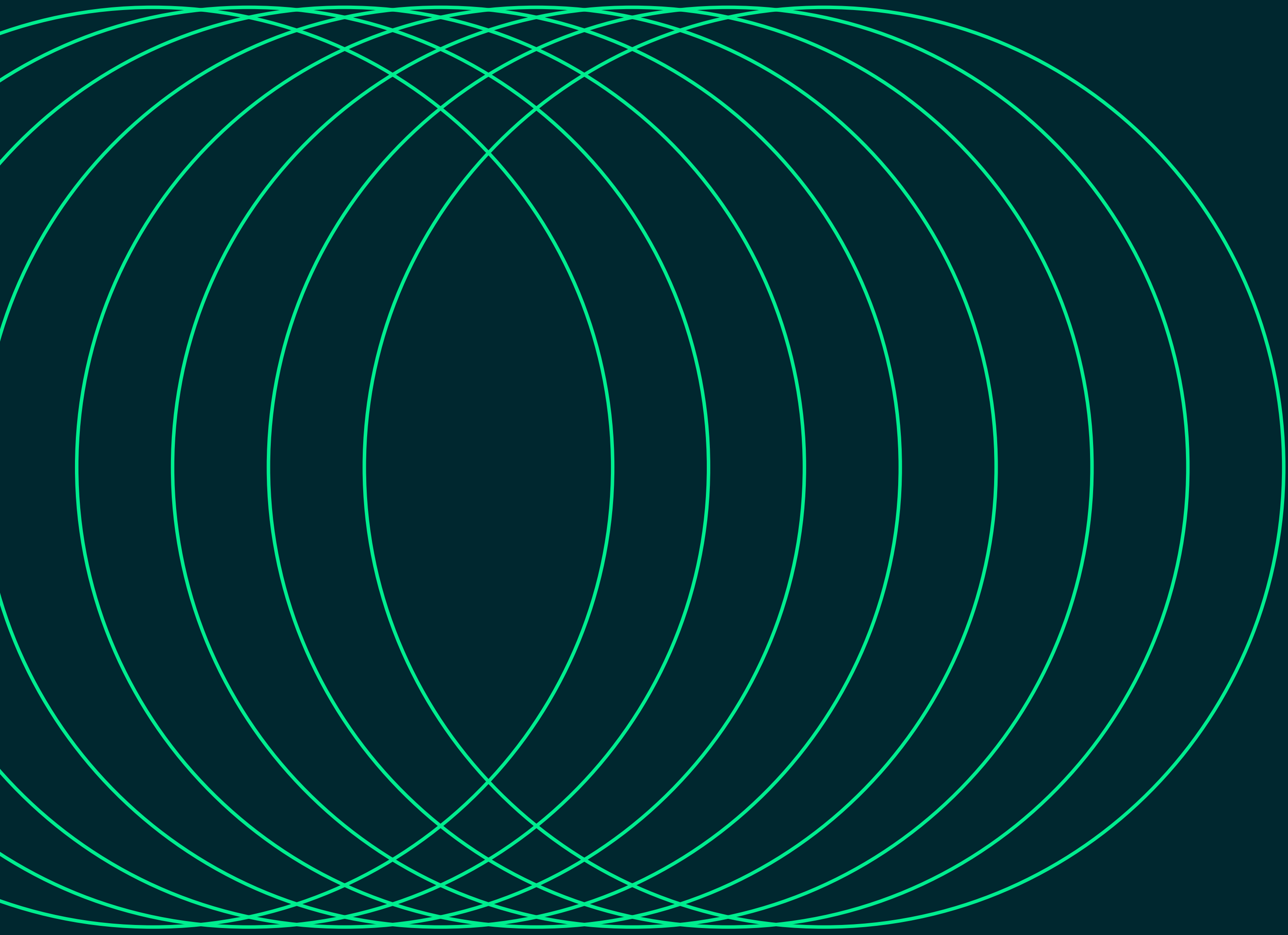
Figure 20: Areas of forest loss in Senegal 2000–2023



Source: generated by UTS-ISF using data from Hansen et al. 2013

5

Key Results – Long-term Scenario



Senegal must build up and expand its power generation system to increase the energy access rate to 100%. Building new power plants – no matter the technology – will require new infrastructure (including power grids), spatial planning, a stable policy framework, and access to finance.

With lower solar PV and onshore wind prices, renewables have become an economic alternative to building new hydro or gas power plants. Consequently, renewables achieved a global market share of over 80% of all newly built power plants in 2021[54]. Senegal has significant solar resources, but only very limited wind potential. The costs of renewable energy generation are generally lower with stronger solar radiation and stronger wind speeds. However, constantly shifting policy frameworks often lead to high investment risks and higher project development and installation costs for solar and wind projects relative to those in countries with more stable policies.

The scenario-building process for all scenarios includes assumptions about policy stability, the role of future energy utilities, centralised fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** This research assumes that Senegal will establish a secure and stable framework for deploying renewable power generation. Financing a gas power plant or a wind farm is quite similar. In both cases, a power purchase agreement that ensures a relatively stable price for a specific quantity of electricity is required to finance the project. However, daily spot market prices for electricity and/or renewable energy or carbon are insufficient for long-term investment decisions for any power plant with a technical lifetime of 20 years or longer.
- **Strengthened energy efficiency policies:** Existing policy settings – energy efficiency standards for electrical applications, buildings, and vehicles – must be strengthened to maximise the cost-effective use of renewable energy and to achieve high energy productivity by 2030.
- **Role of future energy utilities:** With the ‘grid parity’ of roof-top solar PV below most current retail tariffs, this modelling assumes that the energy utilities of the future will take up the challenge of increased local generation and develop new business models that focus on energy services, rather than simply on selling kilowatt-hours.
- **Population and GDP:** Projections of population and GDP are based on historical growth rates. Projections of population growth are taken from the World Bank Development Indicators.[55]
- **Firm capacity:** The scale of each technology deployed and the combination of technologies in the two scenarios target the firm capacity. Firm capacity is the “proportion of the maximum possible power that can reliably contribute towards meeting the peak power demand when needed.”[56] Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewable energy systems still have a firm capacity rating, and the combination of technology options increases the firm capacity of the portfolio of options.
- **Cost assumptions:** The cost assumptions are documented in Chapter 2.

5.1 The Reference Scenario

Several energy and/or electrification plans for Senegal are available.

Therefore, the One Earth Climate Model (OECM) builds on existing information. Table 31 provides an overview to the published energy scenarios and/or energy plans, including the NDC. To compare the OECM for Senegal, a new REFERENCE scenario has been developed because a direct comparison with published energy plans is not possible because the sectoral breakdowns and technical resolution differ.

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[54] REN21-Global Status report 2021.

[55] World Bank (2023) Reviewed at: https://data.worldbank.org/indicator/SP.POP.TOTL

[56] http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf

Table 30: Senegal – Energy scenarios and parameters published in literature reviews

	Senegal – Parameter	Analysis		
Nr.	Key graphs made from our own modelling results:	One Earth Climate Model	Info IEA, Africa Energy Outlook 2019 1. Stated policy scenario 2. Africa case	Info IEA, Africa Energy Outlook 2022
1.	Final energy demand until 2050, according to sector (transport, industry, residential)	Yes	Only 2018 and 2040 values	
2.	Development of electricity demand until 2050, TWh/a (transport, industry, residential)	Yes	Yes	
3.	Heat demand final energy [PJ/a] until 2050 (industry, residential)	Yes	No	
4.	Development road transport final energy [PJ/a] until 2050 (road passenger, road freight	Yes	No	
5.	Breakdown of electricity generation capacity [GW] until 2050 (according to source PV, wind, biomass, hydrogen, fossil fuels)	Yes	Yes, electricity generation in TWh from 2010 to 2040	
6.	Energy supply for cooking heat supply [PJ/a] until 2050 (according to source: solar collectors, heat pumps, electric direct heating, etc.)	Yes	Only 2018 and 2030 values	
7.	Installed capacity for renewable heat generation [GW] until 2050 (according to source)	Yes	No	~27% solar PV and wind for average African electricity generation
8.	Transport energy supply by energy source [PJ/a] until 2050 (source: electricity, hydrogen, natural gas, synfuels, biofuels, fossil)	Yes	No	
9.	Total primary energy demand by energy source [PJ/a] until 2050 (wind, solar, etc.)	Yes	Yes	
10.	CO_2 emissions per sector [Mt/a] until 2050 (industry, buildings, transport, power generation, Other)	Yes	No	
11.	Investment cost [billions US$/a] until 2050	Yes	Yes, cumulative investment needs 2019–2040	
12.	Shares of cumulative investment in power generation 2020–2050	Yes	Yes, cumulative investment in 2019–2040, for fuels, heating, but also networks	
13.	Cumulative investment in heating technologies 2020–2050	Yes	No	
14.	Installed PV capacities up to 2050	Yes	No	

5.1.1 Assumptions for the Senegal 1.5°C scenario

The Senegal 1.5 °C (S-1.5°C) scenario is built on a framework of targets and assumptions that strongly influence the development of individual technological and structural pathways for each sector. The main assumptions considered in this scenario-building process are detailed below.

- **Emissions reductions:** The main measures taken to meet the CO_2 emissions reductions in the S-1.5°C scenario include strong improvements in energy efficiency, which will double energy productivity over the next 10–15 years, and the dynamic expansion of renewable energy across all sectors.
- **Growth of renewables industry:** Dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge of the potential, costs, and recent trends in renewable energy deployment. Communities will play a significant role in the expanded use of renewables, particularly in terms of project development, the inclusion of the local population, and the operation of regional and/or community-owned renewable power projects.
- **Fossil-fuel phase-out:** The operational lifetime of gas power plants is approximately 30 years. Under both scenarios, coal power plants will be phased-out early, followed by gas power plants.

- **Future power supply:** The capacity of large hydro power remains relatively flat in Senegal over the entire scenario period, whereas the quantities of bio-energy will increase with the nation's potential for sustainable biomass (see below). Solar PV is expected to be the main pillar of the future power supply, complemented by the contributions of bio-energy and wind energy. The figures for solar PV combine those for roof-top and utility-scale PV plants, including floating solar plants.
- **Security of energy supply:** The scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. Power generation from biomass and gas-fired backup capacities and storage are considered important for the security of supply in a future energy system and are related to the output of firm capacity discussed above. Storage technologies will increase after 2030, including battery electric systems, dispatchable hydro power, and hydro pump storage.
- **Sustainable biomass levels:** Senegal's sustainable level of biomass use is assumed to be limited to 66 PJ – precisely the amount of bio-energy used in 2020. However, the use of low-tech biomass, such as in inefficient household wood burners, is largely replaced in the S-1.5°C scenario by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors. This will result in an overall lowering of the total biomass used to 15 PJ/a.
- **Electrification of transport:** Efficiency savings in the transport sector will result from fleet penetration by new, highly efficient vehicles, such as electric vehicles, but also from assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The scenarios assume the limited use of biofuels for transportation because the supply of sustainable biofuels is limited.
- **Hydrogen and synthetic fuels:** Hydrogen and synthetic fuels generated by electrolysis using renewable electricity will be introduced as a third renewable fuel in the transport sector, complementing biofuels, the direct use of renewable electricity, and battery storage. Hydrogen generation can have high energy losses. However, the limited potential of biofuels, and probably battery storage, for electric mobility means it will be necessary to have a third renewable option in the transport sector. Alternatively, this renewable hydrogen could be converted into synthetic methane or liquid fuels, depending on the economic benefits (storage costs versus additional losses) and the technological and market development in the transport sector (combustion engines versus fuel cells). Because Senegal's hydrogen generation potential is limited, it is assumed that hydrogen and synthetic fuels will be imported. Furthermore, hydrogen utilisation will be limited to the industry sector only and is not expected to contribute more than 5% of industry's energy supply by 2050.

Senegal's 1.5 °C (S-1.5°C) scenario takes an ambitious approach to transforming Senegal's entire energy system to an accelerated new renewable energy supply. However, under the S-1.5°C scenario, a much faster introduction of new technologies will lead to the complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry), and transportation. In transport, there will be a strong role for storage technologies, such as batteries, synthetic fuels, and hydrogen.

Under the S-1.5°C scenario, the share of electric and fuel cell vehicles will increase. This scenario also relies on the greater production of synthetic fuels from renewable electricity, for use in the transport and industry sectors. Renewable hydrogen will be converted into synthetic hydrocarbons, which will replace the remaining fossil fuels, particularly in heavy-duty vehicles and air transportation – albeit with the low overall efficiency typical of synthetic fuel systems. Renewable synthetic fuels require a (gas) pipeline infrastructure, but this technology is not widely used in Senegal's energy plan because the costs in the early development stages are relatively high. It is assumed that synthetic fuels and hydrogen will not enter Senegal's energy system before 2040. Compensating for the high energy losses associated with producing synthetic fuels will require fundamental infrastructure changes, which seem too costly for a developing country. Electricity and hydrogen will play larger roles in the heating sector (mainly heat for industry), replacing fossil fuels. In the power sector, natural gas will also be replaced by hydrogen. Therefore, electricity generation will increase significantly under this scenario, assuming that power from renewable energy sources will be the future's main 'primary energy'.

The S-1.5°C scenario also models a shift in the heating sector towards the increased direct use of electricity because of the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high-temperature process heat in industry. Increased implementation of a district heating infrastructure (interconnections of buildings in central business districts), bio-energy-based heat generation, and solar collectors and heat pumps for office buildings and shopping centres in larger cities are assumed, leading to a growth in electricity demand that partly offsets the efficiency savings in these sectors. A rapid expansion of solar and geothermal heating systems is also assumed.

The increasing shares of variable renewable power generation, principally solar PV, will require the implementation of smart-grids and the fast interconnection of micro- and mini-grids with regional distribution networks, storage technologies such as batteries and pumped hydro, and other load-balancing capacities. Other infrastructure requirements include an increasing role for the on-site generation of renewable process heat for industries and mining, and the generation and distribution of synthetic fuels.

5.1.2 Assumptions for the Senegal Reference Scenario

The REFERENCE scenario for Senegal has been developed based on the Senegal 1.5 °C scenario, but assumes an implementation delay of 15 years. The REFERENCE scenario is similar – but not identical – to the BAU scenario in Senegal's NDC submission of 2021.

The key differences are:

1. **Heating a sector:** In the REFERENCE scenario, the phase-out of coal, oil, and gas is delayed by 15 years in the residential, service, and industry sectors. Accordingly, electric heat pumps and solar collector systems will remain niche technologies until 2040, but will grow thereafter and increase their shares by 2050.
2. **Transport sector:** In the REFERENCE scenario, electric mobility will experience significant delays, whereas transport demand will increase as projected in the 1.5 °C scenario. Vehicles with ICEs will remain dominant until 2040. Market shares for electric vehicles will start to grow significantly from 2040 onwards. Furthermore, biofuels will increase in the road transport sector.
3. **Power supply:** In the REFERENCE scenario, the delayed electrification in the heating and transport sectors will lead to the slower growth of the power demand compared with that in the 1.5 °C scenario. It is also assumed that renewable power generation will not meet the increased electricity demand because its implementation is delayed, and fossil-fuel-based power generation will therefore increase.

5.2 Senegal – energy pathway until 2050

The following section provides an overview of the key results of two different energy scenarios for Senegal. The energy scenarios by no means claim to predict the future. Instead, they provide useful tools with which to describe and compare potential development pathways from the broad range of possible 'futures'. The S-1.5°C scenario was designed to demonstrate the efforts and actions required to achieve the ambitious objective of a 100% renewable energy system and to illustrate the options available to change our energy supply system into one that is truly sustainable. The scenarios may be used as a reliable basis for the further analysis of the possible concepts and actions required to implement technical pathways to achieve measurable results.

5.2.1 Senegal – Final Energy Demand

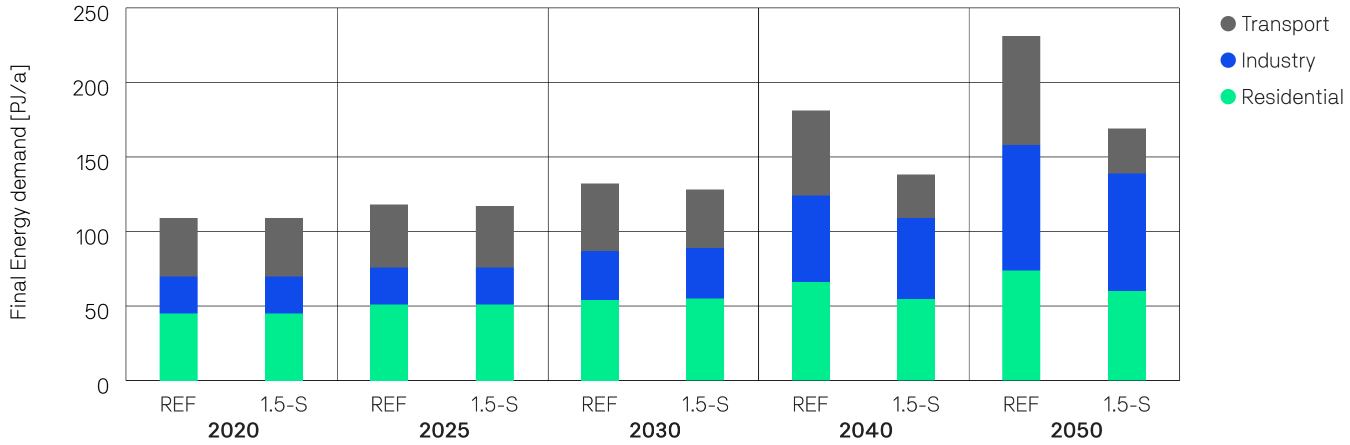
The projections for population development, GDP growth, and energy intensity are combined to project the future development pathways for Senegal's final energy demand. These scenarios are shown in Figure 21 for the REFERENCE and S-1.5°C scenarios. In the REFERENCE scenario, the total final energy demand will increase by 108% from 110 PJ/a to 230PJ/a between 2020 and 2050. In comparison, in the S-1.5°C scenario, the total final energy demand will increase by 54% from 110 PJ/a to 170 PJ/a. The S-1.5°C scenario will reduce any additional costs by a higher proportion of electric cars.

As a result of the projected continued annual GDP growth of 6.1% on average until 2025 and 7.0% thereafter until 2050, the overall energy demand is expected to grow under both scenarios (Figure 21). The residential sector will become the second most important sector in Senegal's energy demand, and the energy demand of the industry sector will increase continuously. By 2050, industry will consume at least three times more energy than in 2020, making this sector the highest primary consumer (before the residential sector) in both scenarios.

The energy demand of the transport sector will increase by 84% by 2050 under the REFERENCE scenario, whereas it will decrease by 24% under the S-1.5°C scenario. The main reason for this significant difference in growth projections is the high rate of electrification in the latter two pathways.

The large efficiency gains achieved in the S-1.5°C pathway is attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

Figure 21: Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP autoproducers)



The increased projected electrification of the heating, cooking, and transport sectors, especially under the S-1.5°C scenario, will lead to a significantly increased electricity demand (see Figure 22).

The S-1.5°C scenario will accelerate the electrification of the heating, cooking, and transport sectors compared with other pathways, and aims to replace more fossil and biofuels with electricity. By 2050, Senegal's electricity demand will increase to 34 TWh per year.

Electricity will become the major renewable 'primary' energy, not only for direct use for various purposes, but also for the generation of a limited amount of synthetic fuels to substitute for fossil fuels in the provision of industrial process heat. Under S-1.5°C, around 6 TWh will be used for electric vehicles and rail transport in 2050.

Figure 22: Development of electricity demand by sector

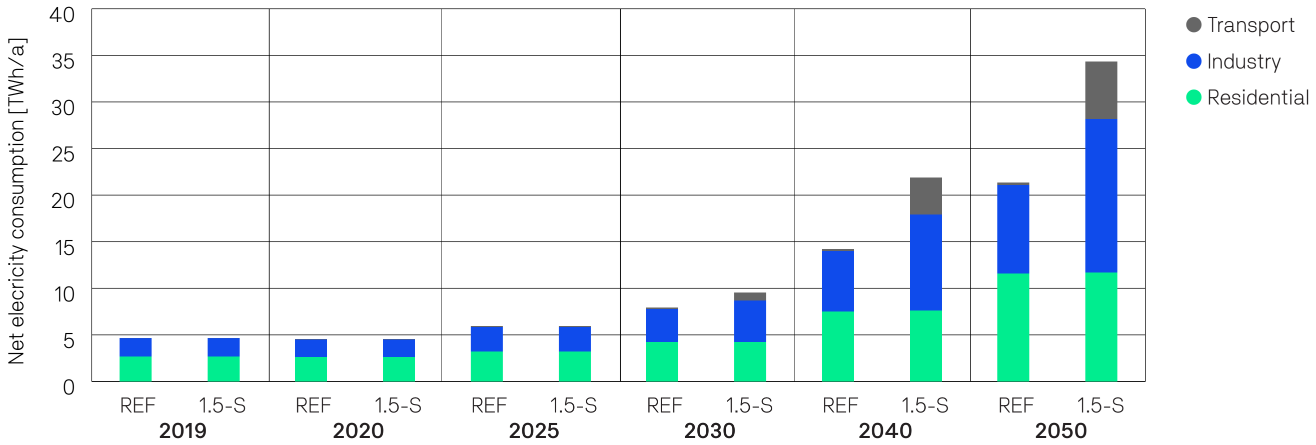
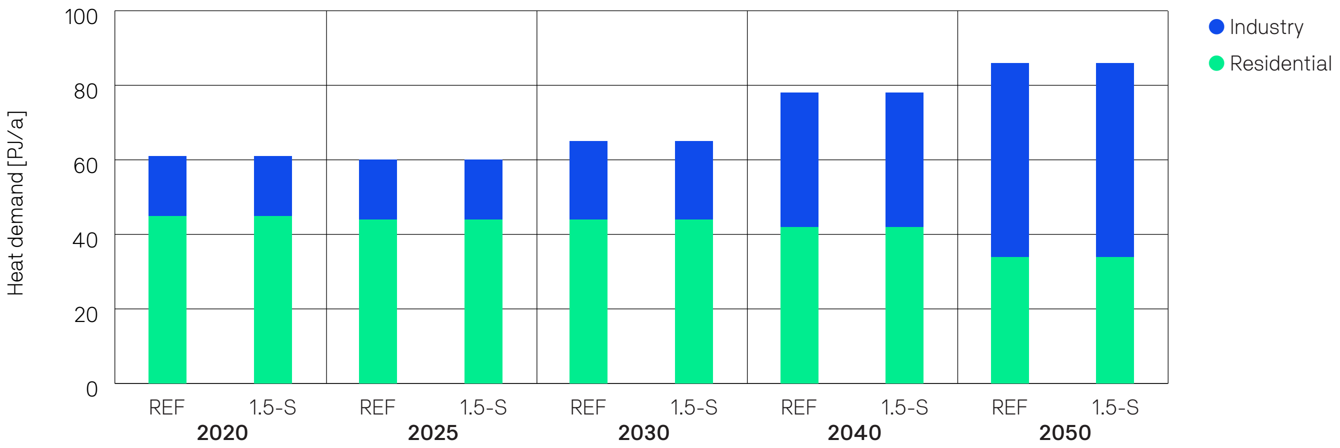


Figure 23: Development of the final energy demand for heat by sector

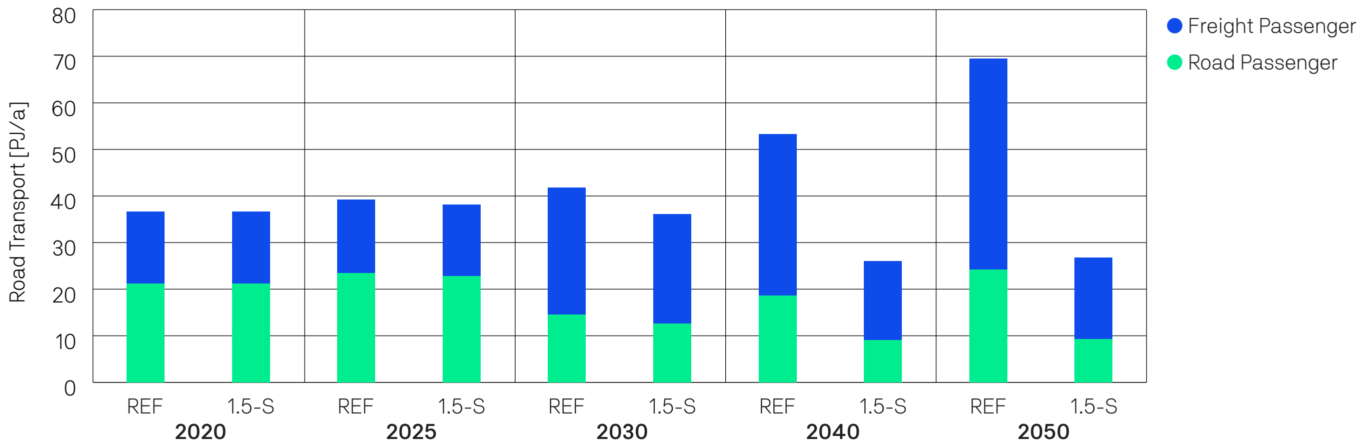


The energy demand for process heat, space heating of residential and commercial buildings, and cooking will continues to grow in the S-1.5°C pathway. The main driver will be a combination of population growth and the increased role of the industry sector in Senegal's GDP. The S-1.5°C pathway includes an increased role for electrification in the heating supply (with heat pumps) and the implementation of electric cooking.

As a result, the S-1.5°C pathway will lead to an annual heat demand of around 86 PJ/a.

The projected development of the road transport sector (see Figure 24) differs considerably between the different scenarios for Senegal, with increased electrification in the S-1.5°C scenario (with associated higher efficiency and lower energy demand). More details of the assumptions made for the transport sector projections, broken down into freight and passenger transport, are documented in section 2.6.

Figure 24: Development of the road transport energy demand for passengers and freight



5.2.2 Electricity generation

Electricity generation, capacity, and breakdown by technology

The development of the electricity supply sector is characterised by a dynamically growing renewable energy market and an increasing share of new renewable electricity, mainly from solar PV. The additional electricity demand caused by accelerated electric cooking and electric vehicles under the S-1.5°C scenario will greatly increase the use of new renewables, whereas hydro power will continue to generate bulk electricity for industry and export.

By 2025, the share of new renewable electricity production will reach 20% and increase to 100% by 2050 under the S-1.5°C scenario. The installed capacity of new renewables will reach about 5 GW in 2030 and 19 GW in 2050.

Table 31 shows the comparative evolution of Senegal's power generation technologies over time. Wind will be the main power source. The continuing growth of solar PV and additional wind power capacities will lead to a total capacity of 17 GW, supplemented with 1.6 GW of solar thermal under the S-1.5°C scenario. It will lead to a high share of variable power generation and demand-side management, and the management of electric vehicle charging and other storage capacities, such as stationary batteries and pumped hydro power. The development of smart-grid management will be required from 2025 onwards to increase the power system's flexibility for grid integration, load balancing, and a secure supply of electricity.

Figure 25: Breakdown of electricity generation by technology

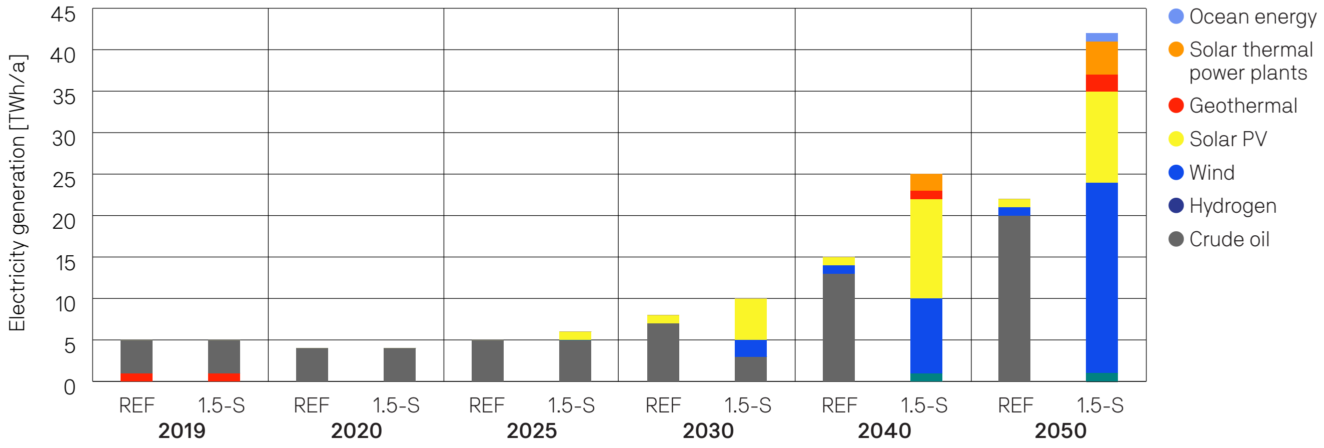


Table 31: Projection of renewable electricity generation capacities

Generation Capacity [GW]			2020	2030	2035	2040	2050
Hydro	REFERENCE	GW	0.00	0.00	0.00	0.00	0.00
	S-1.5°C	GW	0.00	0.00	0.00	0.00	0.00
Biomass	REFERENCE	GW	0.02	0.01	0.05	0.07	0.10
	S-1.5°C	GW	0.02	0.01	0.00	0.00	0.00
Wind	REFERENCE	GW	0.10	0.14	0.20	0.28	0.47
	S-1.5°C	GW	0.09	0.69	1.94	3.54	9.08
PV	REFERENCE	GW	0.25	0.37	0.47	0.61	0.93
	S-1.5°C	GW	0.25	3.99	3.99	8.87	7.84
Total	**REFERENCE**	**GW**	**4.25**	**6.92**	**9.42**	**12.51**	**19.07**
	S-1.5°C	**GW**	**4.26**	**7.18**	**10.45**	**13.94**	**19.48**

5.2.3 Energy supply for cooking and Industrial Process heat

Today, bioenergy meets around 52% of Senegal's energy demand for fuel-based cooking and heating, combined with 29% LPG and 19% charcoal. Dedicated support instruments are required to ensure dynamic development, particularly of electric cooking stoves, renewable heating technologies for buildings, and renewable process heat production. In the S-1.5°C scenario, fuel-based cooking (mainly firewood and LPG) will be replaced by electric cooking stoves. The increased electricity used for e-cooking will increase the electricity demand but will replace a significant amount of bio-energy (firewood) because the efficiency of firewood is low. Under S-1.5°C, the use of heat pumps as one of the leading new heating supply technologies will accelerate, and direct electric heating, such as radiators, will be introduced, but only as an interim measure between 2025 and 2030. These will be exchanged for heat pumps at the end of their lifetimes.

- Energy efficiency measures will help to reduce the currently growing energy demand for heating, specially building standards.
- In the industry sector, solar collectors, geothermal energy (including heat pumps), and electricity and hydrogen from renewable sources will increasingly substitute for fossil-fuel- and biofuel-fired systems.

Figure 26: Projection of heat supply by energy carrier (REFERENCE and S-1.5°C scenarios)

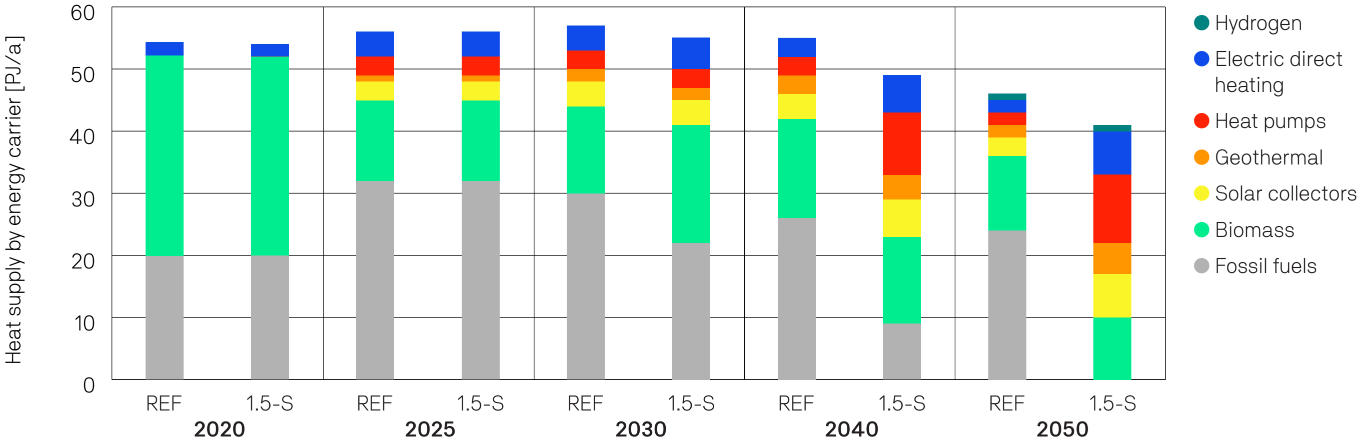


Table 32: Projection of renewable heat supply (cooking and process heat)

Supply (in PJ/a)		2020	2025	2030	2040	2050
Biomass	REFERENCE	32	13	14	16	12
	S-1.5°C	32	13	19	14	10
Solar Collectors	REFERENCE	0	3	4	4	3
	S-1.5°C	0	3	4	6	7
Heat Pumps (electric & geothermal)	REFERENCE	0	3	3	3	2
	S-1.5°C	0	3	3	10	11
Geothermal	REFERENCE	0	1	2	3	2
	S-1.5°C	0	1	2	4	5
Direct Electric Heating	REFERENCE	2	4	4	3	2
	S-1.5°C	2	4	5	6	7
Total	**REFERENCE**	**54**	**55**	**55**	**54**	**47**
	S-1.5°C	**54**	**55**	**55**	**49**	**41**

Table 32 shows the development of different renewable technologies for heating in Senegal over time. Biomass will remain the main contributor, with increasing investments in highly efficient modern biomass technology. The installed capacity is presented in Table 33. After 2030, an increase in solar collectors and growing proportions of geothermal and environmental heat, as well as electrical heat and some limited renewable hydrogen for industrial process heat, will compensate for the phase-out of fossil fuels. The S-1.5°C scenario includes many efficient heat pumps, which can also be used for demand-side management and load flexibility (see also section 6.7.2.).

Table 33: Installed capacities for renewable heat generation

Capacity (in GW)		2020	2025	2030	2040	2050
Biomass	REFERENCE	6	2	2	3	3
	S-1.5°C	6	2	3	2	2
Geothermal	REFERENCE	0	0	0	1	0
	S-1.5°C	0	0	0	1	1
Solar Heating	REFERENCE	0	1	1	1	1
	S-1.5°C	0	1	1	3	3
Heat Pumps (electric and geothermal)	REFERENCE	0	1	1	2	2
	S-1.5°C	0	1	2	5	6
Total	**REFERENCE**	**10**	**10**	**11**	**12**	**12**
	S-1.5°C	**10**	**10**	**11**	**13**	**14**

5.2.4 Transport

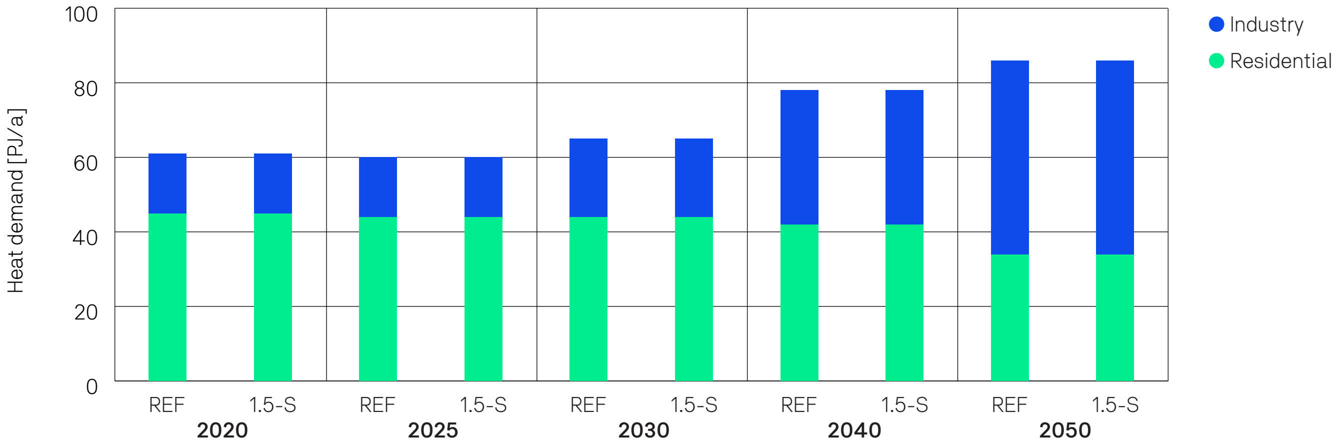
A key target in Senegal is to introduce incentives for people to support the transition towards electric mobility, especially in urban and semi-urban regions. It is also vital that transport use shifts to efficient public transport modes, such as rail, light rail, and buses, especially in the large expanding metropolitan areas.

Highly efficient propulsion technology, with plug-in hybrid and battery-electric power trains, will bring large efficiency gains. By 2030, electricity will provide over 7.6% of transport under the S-1.5°C scenario. The S-1.5°C scenario will achieve the total decarbonisation of the transport sector in Senegal by 2050, with over 74% of the transport energy provided by electricity. More details of the assumptions made to calculate the transport demand and supply development are documented in section 2.6.

Table 34: Projection of transport energy demands by mode

Transport mode		Units	2020	2025	2030	2040	2050
Rail	REFERENCE	[PJ/a]	0	0	0	0	0
	S-1.5°C	[PJ/a]	0	0	0	0	0
Road	REFERENCE	[PJ/a]	37	39	42	53	70
	S-1.5°C	[PJ/a]	37	38	36	26	27
Domestic Aviation	REFERENCE	[PJ/a]	0	0	0	0	0
	S-1.5°C	[PJ/a]	0	0	0	0	0
Total	**REFERENCE**	**[PJ/a]**	**39**	**42**	**45**	**57**	**73**
	S-1.5°C	**[PJ/a]**	**39**	**41**	**39**	**29**	**30**

Figure 27: Final energy consumption by transport under the two scenarios

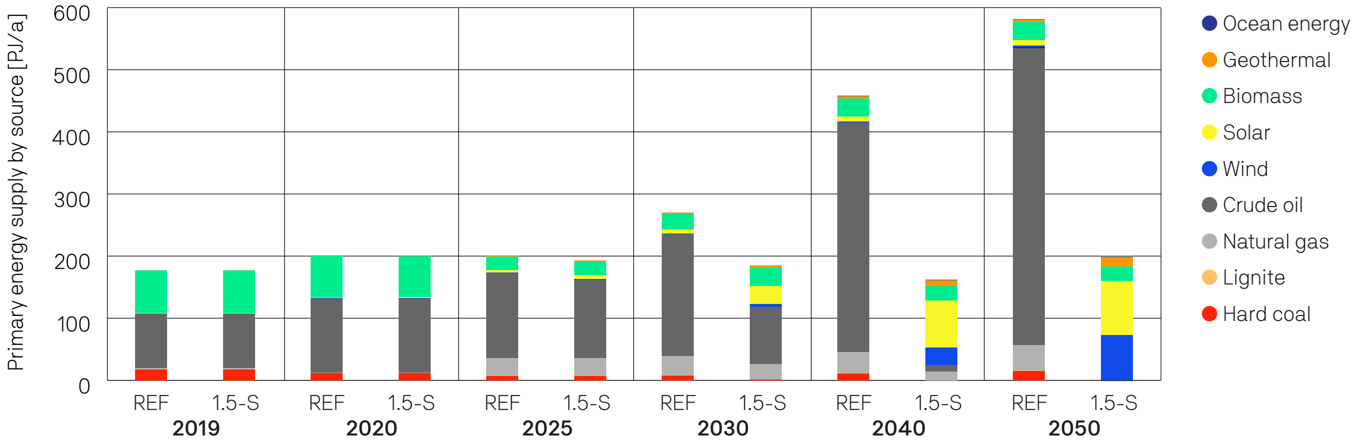


5.2.5 Primary energy consumption

Based on the assumptions discussed above, the resulting primary energy consumption under the S-1.5°C is shown in Figure 28. The S-1.5°C scenario will result in primary energy consumption of around 200 PJ in 2050.

The S-1.5°C scenario aims to phase-out oil in the transport sector and oil for industrial use as fast as is technically and economically possible, through the expansion of renewable energies. The fast introduction of very efficient vehicle concepts in the road transport sector will replace oil-based combustion engines. This will lead to an overall renewable primary energy share of 100% in 2050 under the S-1.5°C scenario (when non-energy consumption is included).

Figure 28: Projection of total primary energy demand by energy carrier (including electricity import balance)

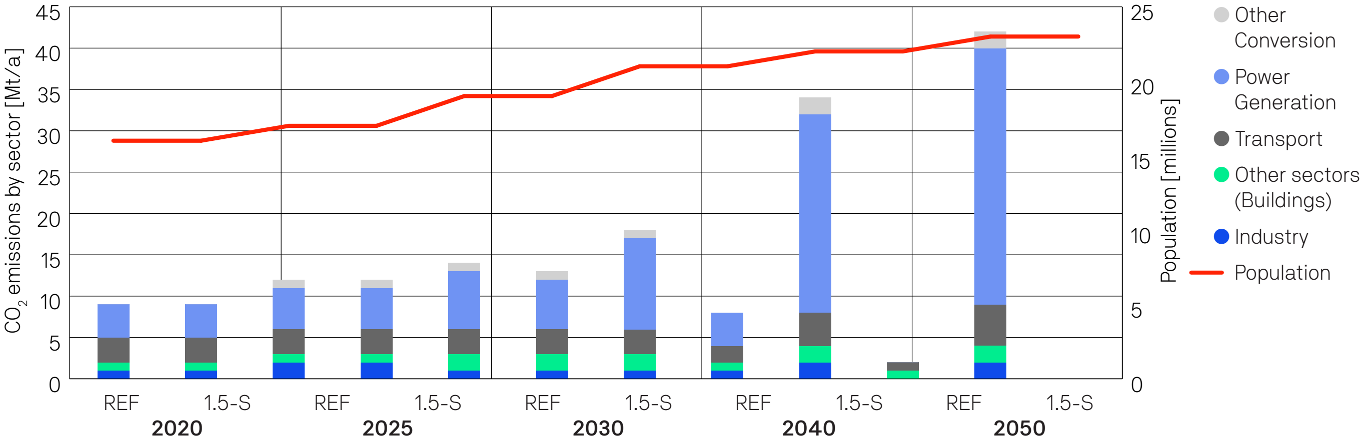


5.2.6 CO_2 emissions trajectories

The S-1.5°C scenario will reverse the trend of increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 2% relative to 2020 by 2030 and of about 81% by 2040 (see Figure 29). In 2050, full decarbonisation of Senegal's energy sector will be achieved under the S-1.5°C scenario.

Under the S-1.5°C, the cumulative emissions will sum to 275 Mt CO_2 for 2005–2050 compared with 693 Mt CO_2 under the REFERENCE scenario.

Figure 29: Development of CO_2 emissions by sector



5.2.7 Cost analysis

Future costs of electricity generation

Figure 30 shows that introducing new-generation capacities will increase the average electricity generation costs due to new investments. Therefore, additional capital costs will be required.

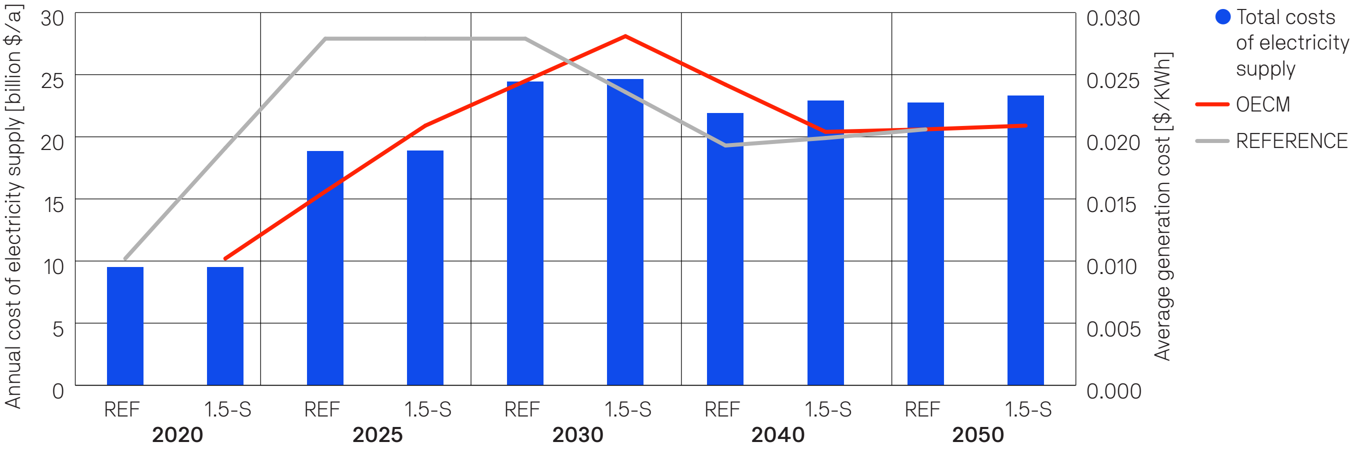
The solar PV capacity will increase 25-fold between 2020 and 2050 under the S-1.5°C scenario. The reason for the high generation capacity is the far-reaching electrification strategy used to replace fossil and biofuels with electricity for cooking, heating, and transport.

The S-1.5°C will have a cost advantage until 2030 relative to the REFERENCE scenario. Between 2030 and 2050, electricity generation costs will be slightly higher than under the REFERENCE scenario after 2030 due to the accelerated investment in renewable power generation capacities.

The full cost of generation is about 16.0 CFA/kWh (US$0.027/kWh) in 2030 under the S-1.5°C, when no consideration is given to the integration costs for storage or other load-balancing measures. By 2050, the S-1.5°C scenario will lead to average electricity generation costs of 11.0 CFA/kWh (US$0.019/kWh).

Senegal's total electricity supply costs will increase with the increasing electricity demand. The S-1.5°C pathway has the highest total electricity costs, but these will directly replace the costs for bioenergy and oil fuels.

Figure 30: Development of total electricity supply costs and specific electricity generation costs



Investments in power generation

Under the S-1.5°C scenario, Senegal will invest in new power generation – mainly solar PV and wind. Here, the main difference between the S-1.5°C scenario and the other scenarios is their investment in other technologies, such as fossil gas.

The projected onshore wind potential of Senegal in 2050 is 1 GW. The electrification of remote villages under the S-1.5°C pathway is mainly based on solar PV power mini-grids with (battery) storage systems. However, wind energy systems can and should play a role in some limited locations. The generation pattern differs from that of solar and will therefore reduce the energy storage requirements because electricity generation is distributed throughout the day and is not limited to daylight hours.

Figure 31: Shares of cumulative investment in power generation, S-1.5°C scenario, 2020–2050 [billion US$]

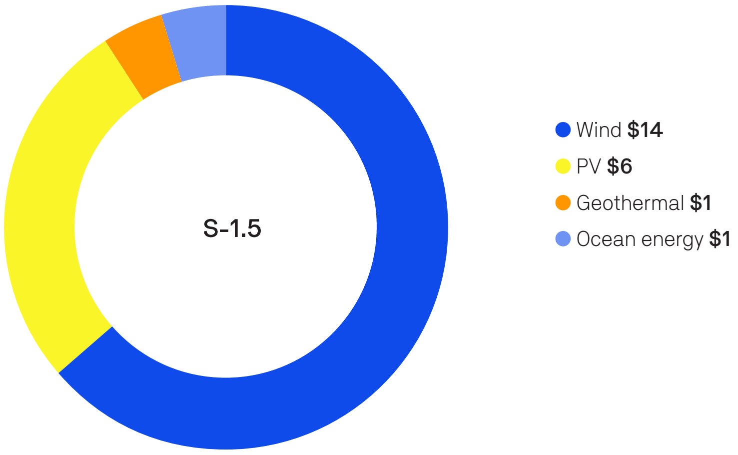
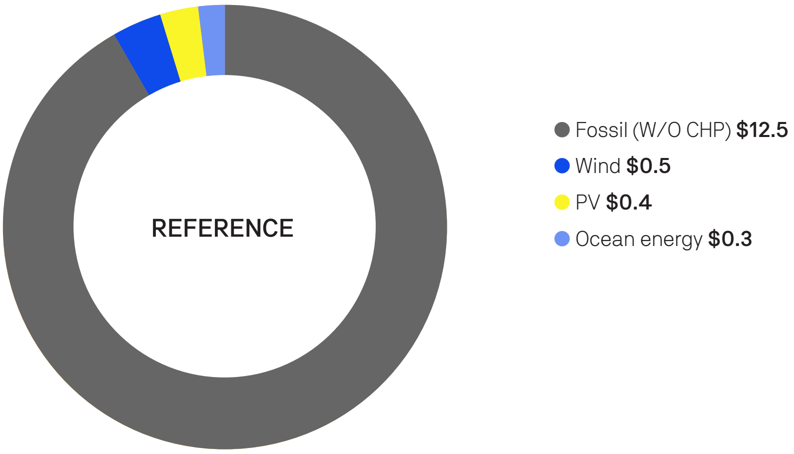


Figure 32: Shares of cumulative investment in power generation, REFERENCE scenario, 2020–2050 [billion US$]



The investment in solar PV under the S-1.5°C scenario will amount to around 9 trillion CFA (US$16 billion) over 30 years. This electricity will primarily be used to replace biomass for cooking and heating and to charge various electric vehicles, from two- and three-wheeler vehicles to cars and small delivery trucks.

Table 35: Investment costs in new power generation in the S-1.5°C scenarios and REFERENCE scenario (exchange rate: 1 CFA = US$0.0017, November 2024)

	2020–2050		Annual Average	
S-1.5°C	[trillion CFA]	[billion US$]	[trillion CFA]	[billion US$]
Hydro	0.0	0.0	0.0	0.0
Biomass	0.0	0.0	0.0	0.0
PV	9.2	5.4	0.3	0.2
Wind	1.6	0.9	0.1	0.0
Fossil & other	4.9	2.9	0.2	0.1
Total	**15.7**	**9.2**	**0.5**	**0.3**
	2020–2050		Annual Average	
REFERENCE	[trillion CFA]	[billion US$]	[trillion CFA]	[billion US$]
Hydro	0	0	0.0	0.0
Biomass	0	0	0.0	0.0
PV	0	0	0.0	0.0
Wind	0	0	0.0	0.0
Fossil & other	8	5	0.3	0.2
Total	**8**	**5**	**0.3**	**0.2**

Future investments in the heating sector

The main difference between the S-1.5°C and other scenarios is the significant variety in bio-energy use and the diversification of heating technologies. Electrical heat pumps, geothermal heat pumps, and solar thermal applications for space and water heating and drying will lead to a considerable reduction in demand for biogas and solid biomass, and will therefore reduce fuel costs. Figure 33 shows the shares of cumulative investments in the heating sector between 2020 and 2050 under the S-1.5°C scenario, which are compared with the cumulative investments under the REFERENCE scenario (Figure 34).

Figure 33: Cumulative investments in the heating technologies (generation) under the S-1.5°C scenario for 2020–2050 [billion US$]

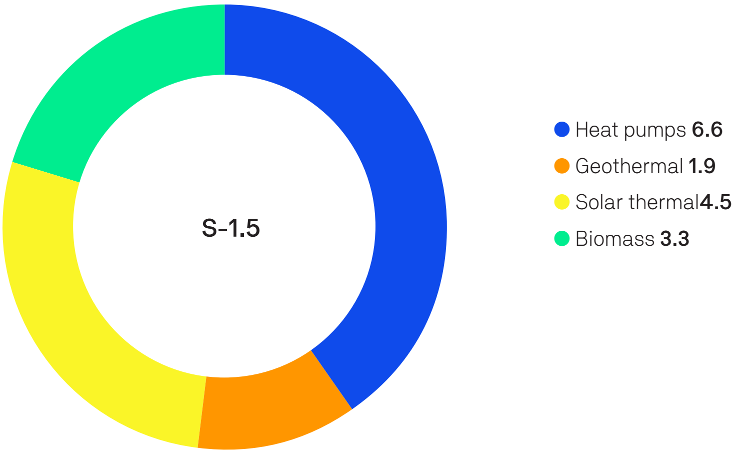


Figure 34: Cumulative investments in the heating technologies (generation) under the REFERENCE scenario for 2020–2050 [billion US$]

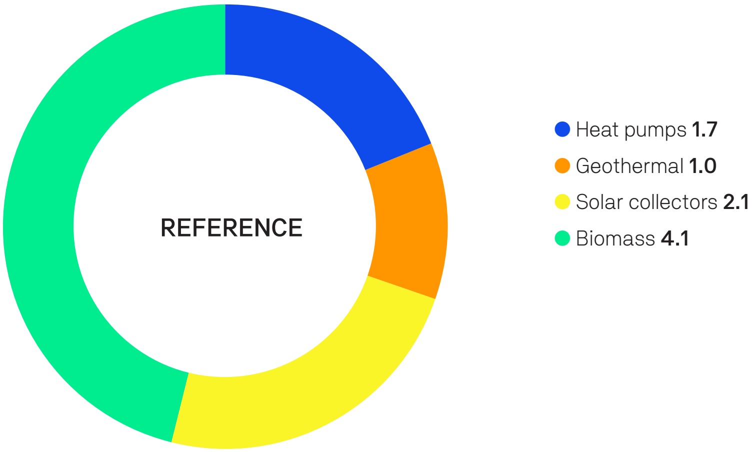


Table 36 shows the cumulative investment and fuel costs in the heating sector under the S-1.5°C and the REFERENCE scenario. The overall heat sector costs – investment and fuel costs – over the entire scenario period until 2050 will be US$406 billion (239 trillion CFA) for the S-1.5°C.

Table 36: Senegal – heating, electricity, and fuel: cumulative investment and fuel costs in 2020–2050

	2020–2050		Annual Average	
S-1.5°C, costs	[trillion CFA]	[billion US$]	[trillion CFA]	[billion US$]
Cumulative heating investment	10	16	0.4	0.7
Cumulative fuel cost	6.6	11	0.22	0.38
Cumulative electricity investment	10	16	0.4	0.7
Total	**27**	**43**	**1**	**1**
	2020–2050		Annual Average	
REFERENCE scenario, costs	[trillion CFA]	[billion US$]	[trillion CFA]	[billion US$]
Cumulative heating investment	5	9	0.2	0.3
Cumulative fuel cost	25.9	44	0.86	1.46
Cumulative electricity investment	8	14	0.3	0.5
Total	**39**	**67**	**1**	**2**

5.2.8 Investment and fuel cost savings

Finally, the fuel costs for the power, heating, and transport sectors are presented.

All three sectors will reduce fuel costs over time because electricity generation is based on renewables – with significant shares of solar and wind power. However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Senegal.

Table 37 shows all the accumulated fuel costs by sector and scenario and the calculated fuel cost savings in 10-year intervals between 2020 and 2050 in Central African francs and US dollars.

The S-1.5°C scenario requires an investment of 16 trillion CFA (US$26 billion) in power generation and 10 trillion CFA (US$16 billion) in heat generation. Therefore, the total investment in power and heat generation capacities will add up to 25 trillion CFA (US$43 billion).

Across the entire scenario period, fuel cost savings under the S-1.5°C scenario relative to the REFERENCE scenario will be 19.2 trillion CFA (US$32.6 billion) – and will cover the entire investment in new power generation capacities until 2050 – about 16 times the additional investment in comparison of the S-1.5°C pathway.

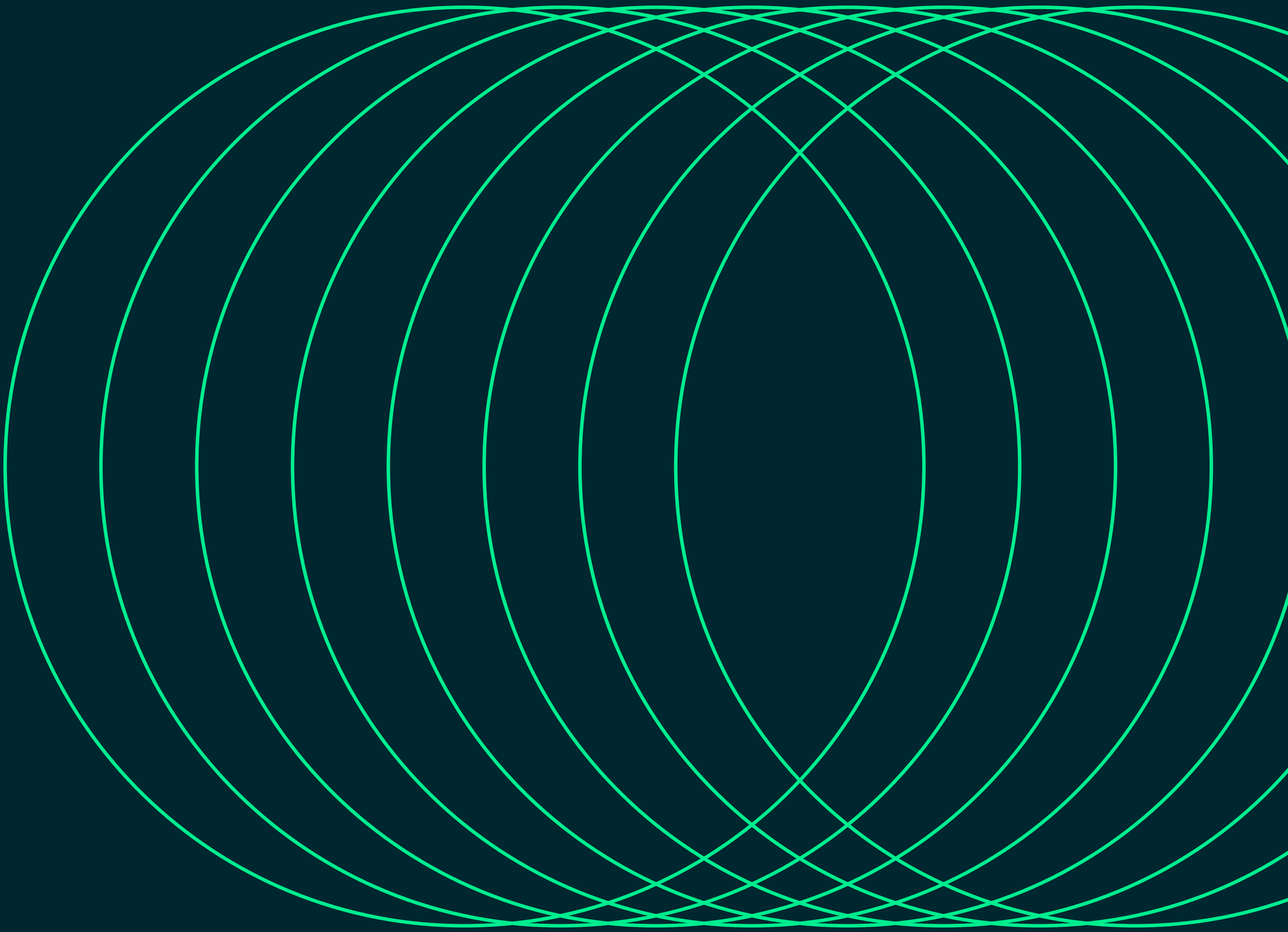
Although fuel cost predictions are subject to a great deal of uncertainty, this result makes the cost-effectiveness of electrification very clear.

Table 37: Cumulative fuel costs for heat generation under the REFERENCE and S-1.5°C scenarios in billion $US and trillion CFA

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD	[Trillion CFA]	Billion USD
Power	Total	4.8	8.2	4.8	8.2	7.5	12.7	17.1	29.1	0.6	1.0
Heat	Total	1.5	2.5	1.7	3.0	1.5	2.6	4.7	8.1	0.2	0.3
Transport	Total	1.1	1.8	1.4	2.3	1.6	2.7	4.0	6.8	0.1	0.2
Summed Costs		**7.4**	**12.5**	**7.9**	**13.5**	**10.5**	**17.9**	**25.9**	**43.9**	**0.9**	**1.5**
		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
S-1.5°C		**[Trillion CFA]**	**Billion USD**	**[Trillion CFA]**	**Billion USD**	**[Trillion CFA]**	**Billion USD**	**[Trillion CFA]**	**Billion USD**	**[Trillion CFA]**	**Billion USD**
Power	Total	0.2	0.4	0.2	0.4	0.0	0.0	0.5	0.8	0.0	0.0
Heat	Total	1.6	2.7	1.4	2.4	1.1	1.8	4.0	6.9	0.1	0.2
Transport	Total	1.0	1.7	0.7	1.2	0.4	0.7	2.1	3.6	0.1	0.1
Summed Costs		**2.8**	**4.8**	**2.4**	**4.0**	**1.5**	**2.5**	**6.6**	**11.3**	**0.2**	**0.4**
Difference REFERENCE versus S-1.5°C		**4.5**	**7.7**	**5.6**	**9.5**	**9.1**	**15.4**	**19.2**	**32.6**	**0.6**	**1.1**

6

Senegal: Power Sector Analysis



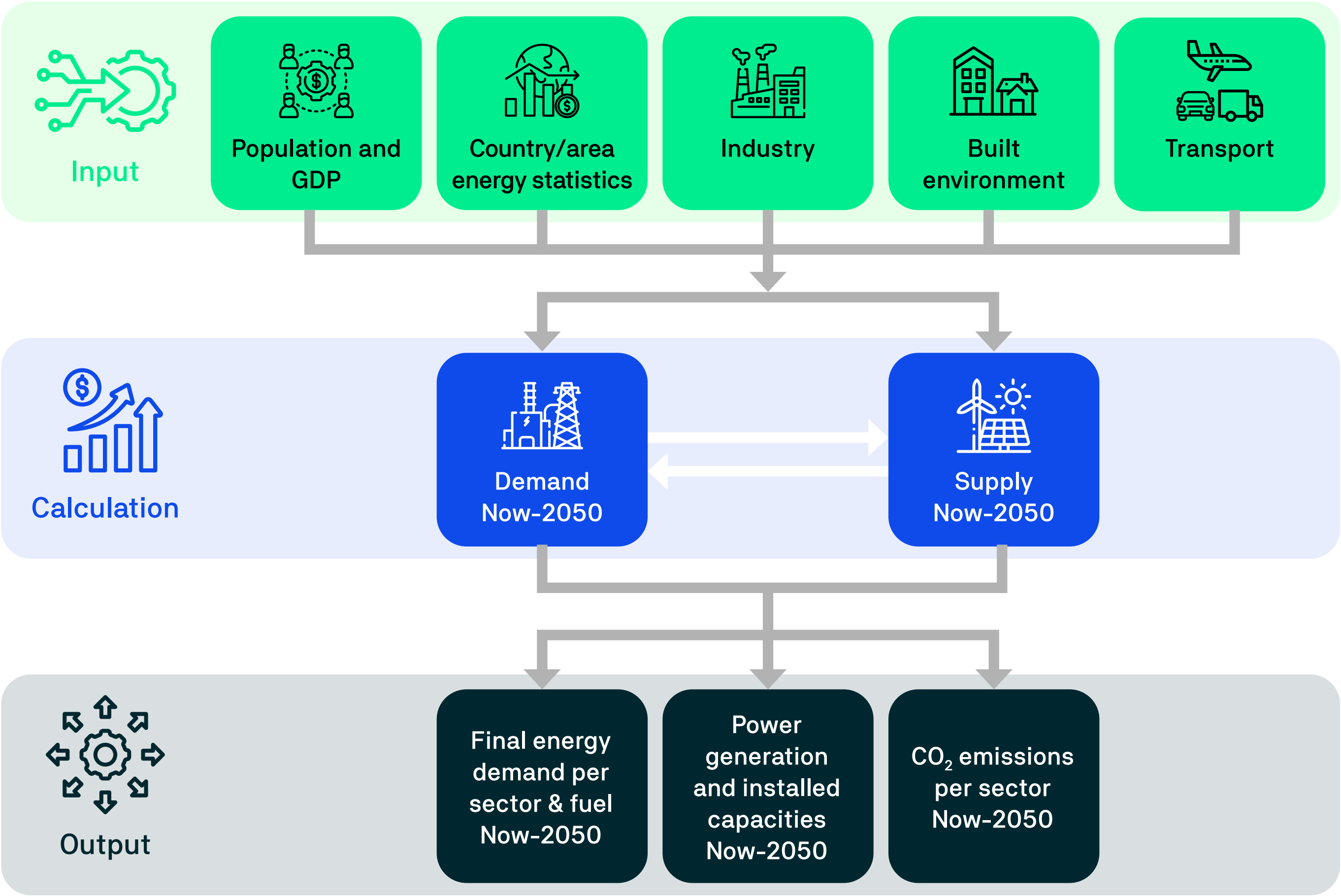
In this chapter, we summarise the results of the hourly simulations of the long-term scenarios (Chapter 5). The One Earth Climate Model (OECM) calculates demand and supply by cluster. This section provides an overview of the possible increase in electrical load under the S-1.5°C scenario, and the consequent increased demand on the power grid transmission capacities, possible new inter-provincial connections, and/or expanded energy storage facilities.

6.1 Power Sector Analysis – Methodology

After the socio-economic (Chapter 2) and geographic analyses (Chapter 3) and the development of the long-term energy pathways for Senegal (Chapter 5), the power sector was analysed with the OECM in a third step.

The energy demand projections and resulting load curve calculations are important factors, especially for power supply concepts with high shares of variable renewable power generation. Calculation of the required dispatch and storage capacities is vital for the security of supply. A detailed bottom-up projection of the future power demand, based on the applications used, the demand patterns, and the household types, will allow a detailed forecast of the demand. Understanding the infrastructure needs, such as power grids combined with storage facilities, requires an in-depth knowledge of the local loads and generation capacities. However, this model cannot simulate frequencies or ancillary services, which would be the next step in a power sector analysis.

Figure 35: Overview – energy demand and load curve calculation module



6.1.1 Meteorological data

Variable power generation technologies are dependent on the local solar radiation and wind regime. Therefore, all the installed capacities in this technology group are connected to cluster-specific time series. The data were derived from the database renewables.ninja (RE-N DB 2018)[57], which allows the hourly power output from wind and solar power plants at specific geographic positions throughout the world to be simulated. Weather data, such as temperature, precipitation, and snowfall, for the year 2019 were also available. To utilise climatisation technologies for buildings (air-conditioning, electric heating), the demand curves for households and services were connected to the cluster-specific temperature time series.

The demand for lighting was connected to the solar time series to accommodate the variability in the lighting demand across the year, especially in northern and southern global regions, which have significantly longer daylight periods in summer and very short daylight periods in winter.

For every region included in the model, hourly output traces are utilised for onshore and/or offshore wind, utility solar, and roof-top solar PV. Given the number of clusters, the geographic extent of the study, and the uncertainty associated with the prediction of the spatial distribution of future generation systems, a representative site was selected for each of the five generation types.

Once the representative sites were chosen, the hourly output values for typical solar arrays and wind farms were selected from the database of Stefan Pfenninger (ETH Zurich) and Iain Staffell (renewables.ninja, see above). The model methodology used by the renewable.ninja database is described by Pfenninger and Staffell (2016a and 2016b)[58], and is based on weather data from global re-analysis models and satellite observations (Rienecker and Suarez 2011[59]; Müller and Pfeifroth 2015[60]).

Although in practice, the utility-scale solar sites will be optimised and the tilt angle will be selected within a couple of degrees of the latitude of the representative site, an indicative system tilt of 35° was used for the generation trace for the utility systems. For the roof-top solar calculations, this was left at the default of 35° because it is likely that the panels will match the tilt of the roof.

The onshore wind outputs were calculated at a 110 m hub height to reflect the potential wind resource available in each cluster, wand is available to modern turbines with sufficiently high hub heights. It is possible that commercial hub heights will exceed this height before 2050, but 110 m was deemed appropriate because it represents the resource available to both current and future generators. A turbine model of Vestas V90 2000 was used.

Limitations

The solar and wind resources can differ within one cluster. Therefore, the potential generation output can vary within a cluster and across the model period (2020–2050).

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[57] RE-N DB (2018) Renewables.ninja, online database of hourly time series of solar and wind data for a specific geographic position, data viewed and downloaded between September and October 2022, https://www.renewables.ninja/

[58] Pfenninger S, Staffell I (2016a) Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 14:1251–1265. doi: 10.1016/j.energy.2016.08.060

Pfenninger S, Staffell I (2016b) Using bias-corrected reanalysis to simulate current and future wind power output. Energy 114:1224–1239. doi: 10.1016/j.energy.2016.08.068

[59] Rienecker M, Suarez MJ, et al. (2011) MERRA: NASA's modern-era retrospective analysis for research and applications. Journal of Climate, 24(14):3624–3648. doi: 10.1175/JCLI-D-11-00015.1

[60] Müller R, Pfeifroth U, Träger-Chatterjee C, Trentmann J, Cremer R (2015). Digging the METEOSAT treasure – 3 decades of solar surface radiation. Remote Sensing 7:8067–8101. doi: 10.3390/rs70608067

6.1.2 Power Demand Projection and Load Curve Calculation

The OECM power analysis calculates the development of the future power demand and the resulting possible load curves. The model generates annual load curves with hourly resolution and the resulting annual power demands for three different consumer sectors:

- Households
- Industry and business
- Transport.

Although each sector has its specific consumer groups and applications, the same set of parameters was used to calculate the load curves:

- Electrical applications in use
- Demand pattern (24 h)
- Meteorological data
    - Sunrise and sunset, associated with the use of lighting appliances
    - Temperature and rainfall, associated with climatisation requirements
- Efficiency progress (base year 2018 for 2020–2050, in 5-year steps
    - Possibility that the electricity intensity data for each set of appliances will change, e.g., from compact fluorescent lamp (CFL) light bulbs to light-emitting diodes (LEDs) as the main technology for lighting

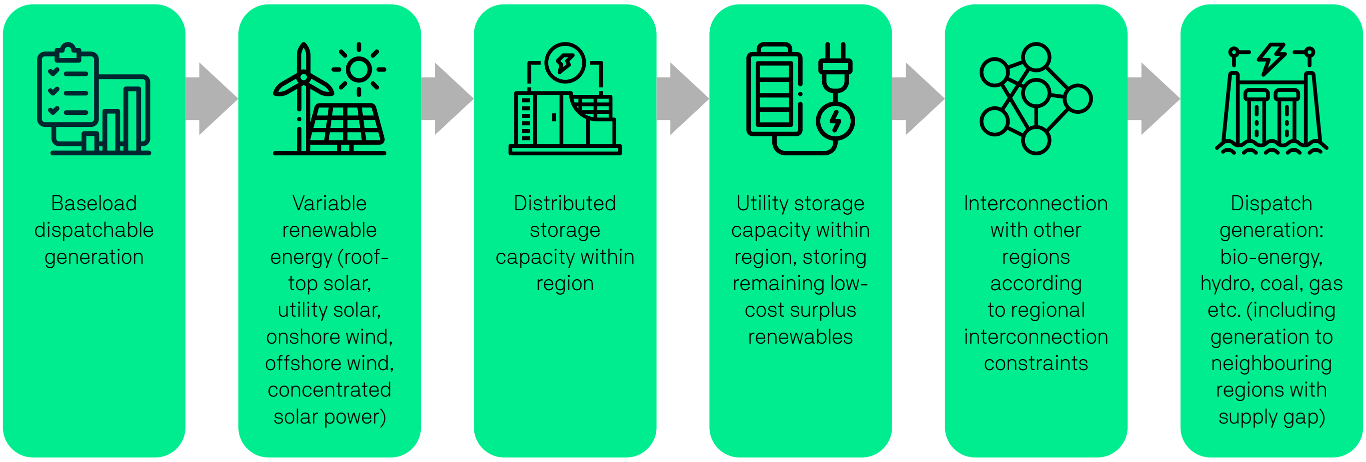
6.1.3 The OECM 24/7 Dispatch Module

The OECM 24/7 dispatch module simulates the physical electricity supply with an interchangeable cascade of different power generation technologies. The cascade starts with the calculated load in megawatts for a specific hour. The first-generation technology in the exogenous dispatch order provides all the available generation, and the remaining load is supplied by the second technology until the required load is entirely met. In the case of oversupply, the surplus variable renewable electricity can either be moved to storage, moved to other regions (including export to other countries if specified in the modelling assumptions), or – if neither option is available – curtailed. In the case of undersupply, electricity will be supplied either from available storage capacities, from neighbouring clusters, or from dispatch power plants.

The key objective of the modelling is to calculate the load development by region and modify the residual load (load minus generation), theoretical storage, and interconnection requirements for each cluster and for the whole survey region. It would be possible to produce an estimate for the additional required storage capacity required to avoid supply gaps, but in reality, the economic battery capacity is a function of the storage and curtailment costs, as well as the availability of dispatch power plants and their costs. Given Senegal's historical reliance on oil and diesel generation, which is limited in terms of its capacity, unmet generation is reported and assumed to be covered transmission connections to its five neighbouring countries (Gambia, Guinea-Bissau, Guinea, Mali, and Mauritania).

Figure 36 provides an overview of the dispatch calculation process. The model allows the dispatch order to be changed in terms of the order of renewables and the dispatch power plant, as well as in terms of the order of the generation categories: variable, dispatch generation, or storage. In this analysis, a fixed dispatch order was used: minimum baseload dispatch, variable renewables, distributed generations sources, utility storage, interconnection with other regions to allow the exchange of low-cost surplus renewables, and finally, remaining additional dispatch generation that was not dispatched as part of the minimum baseload output requirement. 'Baseload dispatch generation' represents the minimum amount of a fossil-fuel power plant capacity that must run for either economic, technical, or system requirements. For example, a coal plant may only be able to run at 30% capacity due to technical limits on its generation equipment (thermal operating windows/minimum temperature), whereas a gas plant may be asked to run at 5% or 10% capacity throughout the day because the electrical system operator requires sufficient levels of inertia in a high-renewables system (the remaining capacity is then dispatched as required as step six of the dispatch order).

Figure 36: Dispatch order within one cluster



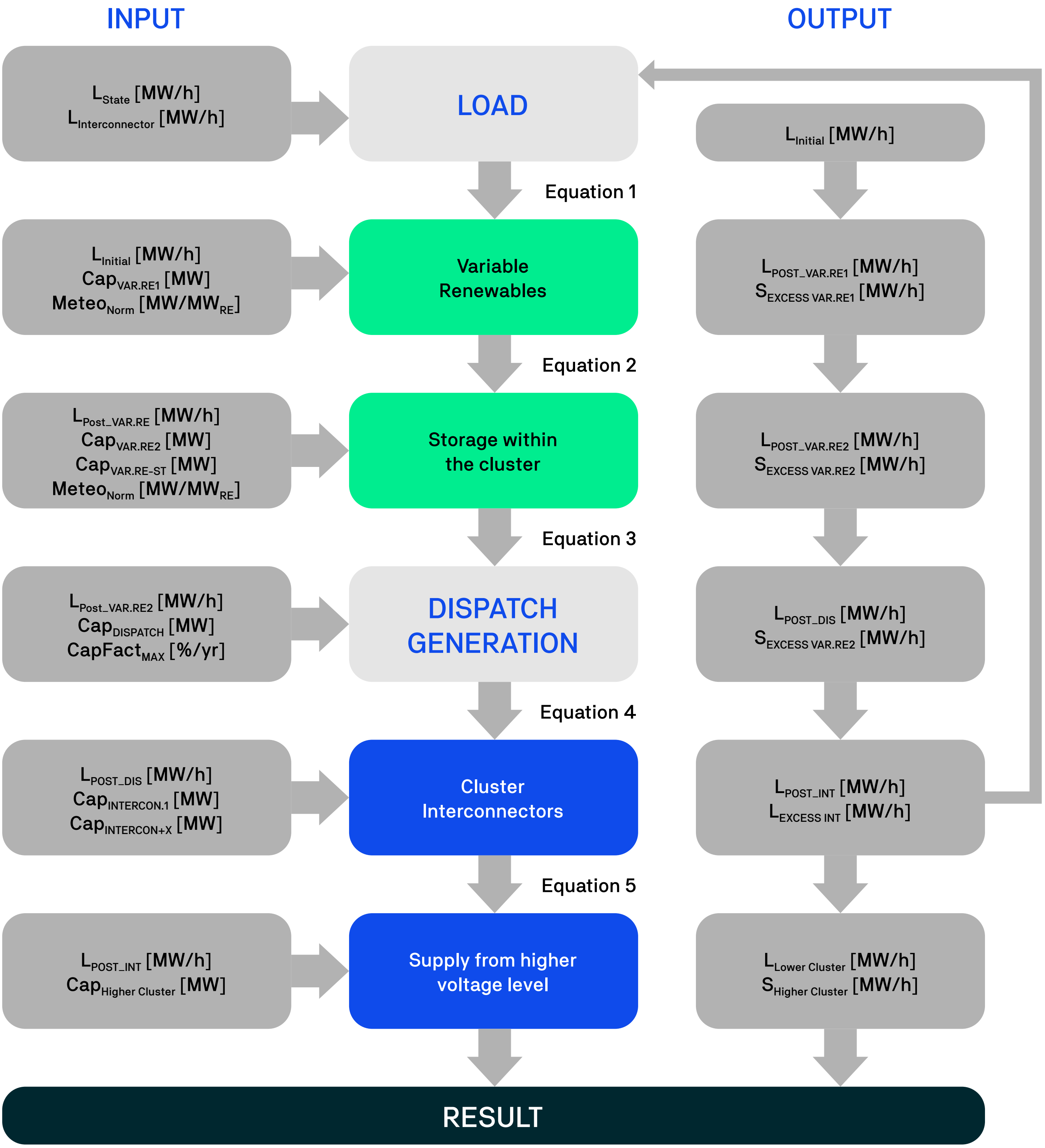
Overview: input and output – OECM 24/7 energy dispatch model

Figure 37 gives an overview of the input and output parameters and the dispatch order. Although the model allows changes in the dispatch order, a 100% renewable energy analysis always follows the same dispatch logic. The model identifies excess renewable production, which is defined as the potential wind or solar PV generation that exceeds the actual hourly demand in MW during a specific hour. To avoid curtailment, the surplus renewable electricity must be stored with some form of electrical storage technology or exported to a different cluster. Within the model, excess renewable production accumulates through the dispatch order. If storage is present, it will charge the storage within the limits of the input capacity. If no storage is included, this potential excess renewable production is reported as 'potential curtailment' (pre-storage). It is assumed that a certain number of behind-the-meter consumer batteries will be installed, independently of the system requirements.

Limitations

The calculated loads are not optimised in terms of local storage, the self-consumption of decentralised producers of solar PV electricity, or demand-side management. Therefore, the actual loads may be well below the calculated values.

Figure 37: Overview – Input, output, and dispatch order



6.2 Development of Power Plant Capacities

As discussed in Chapter 3, Senegal has substantial untapped renewable energy potential, and its renewable energy potential far exceeds the projected energy demand requirements by 2050. Despite Senegal's abundance of renewable energy resources, the nation has historically relied upon oil generation for electricity.

Under the S-1.5°C scenario, solar PV generators will expand rapidly and provide increasing electricity. Wind generation is also projected to significantly increase across Senegal. This is possible given Senegal's existing electrical infrastructure, decarbonisation policies, and sufficient areas of land with suitable resources, and is attractive from a project development perspective. Given the existing electrical infrastructure, it could be expected that the majority of PV systems installed are grid-connected, with off-grid micro-grids playing a role in remote areas of the country. In terms of Senegal's renewable electricity potential, the vast majority of future generation will be solar PV and onshore wind. Because truly sustainable sources of biomass energy are limited, it is envisioned that small amounts of offshore wind will also be developed by 2050, give that Senegal has high-quality offshore wind resources, which will be able to help fill the supply gaps when there is insufficient onshore wind and solar resources.

Therefore, the capacity for solar PV installations will increase substantially under the S-1.5°C scenario. The average solar PV market will be around 650–700 MW per year between 2026 and 2035, and then taper off thereafter as wind power begins to play a larger role in supplying energy. (Note that this relates to the assumptions made in the modelling and the fact that the PV market could continue to grow strongly if battery storage becomes more attractive, so wind power will not be required to the same extent). The installation rate of Senegal's wind power market must grow consistently throughout the modelling period, requiring an average of 115 MW installed/year until 2030, increasing to an installation rate of 550 MW/year by 2050. Senegal's renewable potential is exceptionally diverse and not limited to solar and wind power. Therefore, under the S-1.5°C scenario, the full range of renewable technologies will be utilised (Table 38).

Table 38: Senegal – average annual changes in installed power plant capacity (main technologies)

Power Generation: average annual changes in installed capacity [MW/a]							Annual Average	
	2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2035	2021–2050
Biomass	0	-3	-1	0	0	0	-1	-1
Hard coal	0	-5	0	0	0	0	-2	-1
Lignite	0	0	0	0	0	0	0	0
Fuel cell	0	3	13	22	22	13	6	12
Natural gas	-3	0	0	0	0	0	-1	-1
Oil	58	-273	-557	0	0	0	-257	-129
Diesel	0	0	0	0	0	0	0	0
Hydro	0	0	0	0	0	0	0	0
Wind onshore	1	115	241	267	471	552	119	275
Wind offshore	0	3	8	52	43	43	4	25
PV	97	652	715	260	12	-218	488	253
Geothermal	2	4	13	10	14	9	6	8
Total CHP plants	0	0	0	0	0	0	0	0
Biomass & waste	0	0	0	0	0	0	0	0
Hard coal	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Fuel cell	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0

6.3 Results: Utilisation of Power Generation Capacities

Table 39 and Table 40 show the installed capacities for roof-top and utility-scale solar PV in 2030 and 2050, respectively, under the S-1.5°C scenario. The distributions are based on the regional solar potential for utility PV and according to the population distribution for roof-top solar, with the aim of generating electricity where the demand is located. Whereas the generation of roof-top solar PV power is modular and can be installed close to the consumer or even integrated into buildings, utility-scale solar PV is usually further away from settlements and close to medium- or high-voltage power lines. Furthermore, solar power plants (= utility-scale PV) have double-digit megawatt capacities, on average. The best solar resources are located in the parts of the country above Gambia, particularly in the regions of Dakar, the Central-West, and the Central-North.

Table 39: Senegal S-1.5°C pathway – Installed photovoltaic capacities by region (2030)

S-1.5°C pathway 2030	Dakar [MW]	North-eastern [MW]	Central-North [MW]	Central-East [MW]	Central-West [MW]	South-eastern [MW]	South-western [MW]
Photovoltaic (roof-top)	277	131	77	200	289	75	148
Photovoltaic (utility-scale)	10	584	357	385	222	926	309

Table 40: Senegal S-1.5°C pathway – installed photovoltaic capacities by region (2050)

S-1.5°C pathway 2050	Dakar [MW]	North-eastern [MW]	Central-North [MW]	Central-East [MW]	Central-West [MW]	South-eastern [MW]	South-western [MW]
Photovoltaic (roof-top)	544	257	150	394	569	147	291
Photovoltaic (utility-scale)	20	1,147	702	757	437	1,819	606

In this analysis, we have assumed that 30% of the solar PV installations are roof-top and 70% are utility-scale power plants, because there is significant interest in large-scale generation capacity and a historically low capacity and economy for roof-top solar across Senegal. As discussed in previous sections, Senegal has significant wind generation potential, and this is leveraged under the S-1.5°C scenario. Offshore wind is also utilised in this scenario, so Table 42 demonstrates the percentages of variable generation and dispatchable sources of power supplied throughout the year (renewable, and fossil fuel disaggregated). The percentages shown in Table 42 are the outputs of the hourly power system modelling outlined in section 6.1, and are indicative of not only the capacity factors, but also the need for generation, which depends upon the demand in each hour. Table 41 shows the categorisation of the various generation types used in the power system modelling.

Table 41: Categorisation of generation types

Generation Type	Fuel	Technology
Limited Dispatchable	Fossil, uranium	Coal, brown coal/lignite, (including co-generation)
	Renewable	Hydro power, bio-energy, synthetic fuels, geothermal, concentrated solar power (including co-generation)
Dispatchable	Fossil	Gas, oil, diesel (including co-generation)
		Storage systems: batteries, pumped hydro power plants, hydrogen- and synthetic-fuelled power and co-generation plants
	Renewable	Bio-energy, hydro, hydrogen- and synthetic-fuelled power, and co-generation plants
Variable	Renewable	Solar photovoltaic, onshore wind

The percentages shown below in Table 42 are dependent upon multiple variables: the amount of existing fossil-fuel infrastructure, the projected solar and wind distribution (based on the regional potentials), the adoption of roof-top solar (based on population), and the installation rate for new renewable capacity.

As discussed in Chapter 3, the regions of Dakar, the Central-West, and the Central-North have some of the best solar and wind resources across the country, in terms of both resource quality and the availability of land upon which to install capacity across the region. It is interesting to contrast the changing proportions of variable renewable power in these regions, with the Central-North region expected to have a dramatic increase in renewable penetration (to more than 95%) by 2030, due to the negligible amount of existing generation assets in that region. However, regions such as Dakar and the Central-West share a substantial proportion of the existing generation assets of Senegal, and therefore will experience a different rate of uptake by 2030 from those areas with existing generators. All regions, apart from Dakar, will reach a proportion of the variable penetration supply exceeding 90% by 2050. This will occur despite Dakar's great potential due to the land constraints around the capital, so limited amounts of utility-scale solar and wind will be installed (noting the assumed levels of dispatchable renewables, which will assist in replacing the existing oil and diesel generation assets in the long term).

Table 42: Senegal – power system shares by technology group

Power Generation Structure in Percentages of Annual Supply [%/a]		S-1.5°C		
		Variable Renewable	**Dispatch Renewable**	**Dispatch Fossil**
Dakar	2020	3%	7%	90%
	2030	20%	5%	75%
	2050	66%	30%	4%
North-eastern	2020	81%	0%	18%
	2030	98%	1%	1%
	2050	100%	0%	0%
Central-North	2020	62%	1%	37%
	2030	97%	1%	2%
	2050	99%	1%	0%
Central-East	2020	13%	2%	85%
	2030	70%	2%	28%
	2050	96%	3%	1%
Central-West	2020	7%	3%	90%
	2030	44%	2%	54%
	2050	90%	9%	1%
South-eastern	2020	49%	3%	48%
	2030	92%	1%	7%
	2050	99%	1%	0%
South-western	2020	11%	2%	87%
	2030	67%	2%	30%
	2050	92%	7%	2%

Ultimately, all regions will transition towards a high variable renewable penetration supply, due to Senegal's excellent solar and wind resources. In the interim, a mix of regions with high variable renewables will exist alongside regions with more significant levels of existing gas generation assets. The significant regional differences in the power system shares – the ratio between dispatchable and non-dispatchable variable power generation – will require a combination of increased interchange, storage facilities, and demand-side management incentives to ensure that all regions maintain sufficient levels of supply security and system strength. In the long term, grid operators and market bodies must develop their systems and market arrangements to allow the functioning of Senegal's grid at very high levels of renewable penetration (> 90% of supplied energy throughout the year).

Experience in other jurisdictions indicates that the integration of large shares of variable power generation will require a more flexible market framework. Those power plants requiring high capacity factors because of their technical limitations in terms of flexibility ("base-load power plants") will not be desirable to future power system operators. Therefore, capacity factors will become more a technical characteristic than an economic necessity, and flexibility will be a commodity that increases in value over time. Future power systems must be structured to leverage the characteristics of each of the different generator categories to ensure sufficient supply and system strength. In Senegal's case, oil and diesel power plants could be operated as peaking plants to cover supply gaps when there is insufficient solar and wind resources, until sufficient levels of interconnection and storage are in place for any reliance on oil and diesel as back-up generation to be abolished.

6.4 Results: Development of Load, Generation, and Residual Load

Table 43 shows the calculated annual demand, maximum and minimum loads, and the calculated average load by region in 2020. The results are based on the S-1.5°C pathway projections. To validate the data, we compared our results with the real-time data published by the local grid operator. The statistical data for each province for 2020 were not available at the time of writing, so the values are estimates and may vary by ± 10% for each data point. However, the published online data for Senegal's power sector is within the same order of magnitude. The calculation of the maximum, minimum, and average loads for the base year (2020/21) is important to calibrate the OECM and to compare the values with future projections.

Table 43: Senegal – calculated load, generation, and residual load in 2020/21

Real Load (rounded) – measured by grid operators in 2018	Maximum Load (Domestic) [MW]	Maximum Generation [MW]	Minimum Load [MW]	Average Load [MW]
Dakar	165	233	81	107
North-eastern	97	59	39	53
Central -North	56	46	23	34
Central-East	148	148	59	91
Central-West	213	213	85	133
South-eastern	55	123	22	36
South-western	109	109	44	68
Senegal Total (non-coincident values)	**843**	**931**	**353**	**522**

The calculated load for each province depends on various factors, including the local industrial and commercial activities. A detailed analysis of the planned expansion of economic activity in each province was beyond the scope of this research and the results are therefore estimates, based on the regional distribution of GDP and population.

As discussed in the methodology above, the 24/7 model analyses both generation and load on a regional basis. Therefore, it is possible to analyse the data outputs to provide insight into the maximum hourly demand and generation values for each region. The results indicate that the peak load will increase by a factor of approximately 1.8 across each region by 2030 under the S-1.5°C pathway, with the maximum regional load increasing by a factor of ~5.5 in each by 2050. The peak load will increase to a slightly lesser extent than the overall annual electricity demand, but to an equivalent order of magnitude. The increase in load is attributable to the increase in the overall electricity demand with the electrification of cooking, heating, and cooling. Furthermore, the growth of the commercial and industrial sectors of Senegal and the electrification of transport will lead to a sharp increase in the electricity demand and therefore the overall power load.

Table 44 presents data on the levels of residual load in each region, where 'residual load' is defined as the load remaining after the local generation from variable renewable sources within the analysed region is exhausted. In general, a positive residual load implies that a region has an insufficient amount of variable supply to cover the demand in each time step, so that demand must be met through other supply sources (dispatchable renewables, dispatchable fossil fuel, storage, interconnections). The maximum residual value is the largest positive value experienced throughout the year, indicating the largest mismatch between variable renewable generation and demand to occur during the modelling period.

Table 44: Senegal – projection of load, generation, and residual load until 2050

Senegal Development of Load and Generation Maximum Load		S-1.5°C			
		Maximum Generation	Maximum Residual Load	Peak Load Increase	
		[MW]	[MW]	[MW]	[%]
Dakar	2020	165	233	163	-
	2030	324	397	893	196%
	2050	1,108	612	1,749	672%
North-eastern	2020	97	59	88	-
	2030	175	667	133	180%
	2050	556	2,333	483	573%
Central -North	2020	56	46	54	100%
	2030	103	308	83	184%
	2050	325	1,510	284	580%
Central-East	2020	148	148	144	-
	2030	268	474	743	181%
	2050	850	1,941	261	574%
Central-West	2020	213	213	210	-
	2030	387	453	743	182%
	2050	1,228	1,607	1,607	577%
South-eastern	2020	55	123	48	-
	2030	100	815	83	182%
	2050	319	3,023	261	580%
South-western	2020	109	109	106	-
	2030	198	364	379	182%
	2050	628	1,290	1,036	576%
Senegal	2020	843	931	813	-
	2030	1,555	3,478	3,057	184%
	2050	5,014	12,316	5,681	590%

In our analysis, power generation is assumed to grow proportionally to the growth in overall demand across Senegal. A more detailed assessment of the exact locations of power generation is required to optimise the required expansion of transmission grids and ensure that the generation capacity is installed appropriately to provide system security and strength, and aligned with grid operator requirements. A more detailed consideration of generation placement could lead to a reduction in the residual load to avoid over- and/or undersupply for each province, when either increased grid capacity or more storage systems will be required.

6.5 Results: Development of Inter-regional Exchange of Capacity

As discussed in section 2.2, a map of Senegal's electricity infrastructure was used as the basis for the power sector analysis. It was also used as the basis for interconnection limits, with some growth in the network interconnection infrastructure assumed to allow power flow across regions as Senegal's economy and nation grow. The growth in the transmission network follows the plans outlined '2017–2035 Power Generation and Transmission Master Plan for Senegal' report by the Power Africa Transactions and Reforms Program.[61] Conversions between interconnection line ratings in kV (source: maps), with the conversion factors provided by an industry reference partner on previous project work, were used to produce the effective power interchange constraints (Table 45).

Table 45: Industry rule-of-thumb conversion factors: line rating to exchange limit

kV Line Rating	MW
132	500
225	767
330	1,000
500	3,000

Based on the above information (regional interconnection mapping and conversion factors), the regional interconnection limits were applied in the modelling of Senegal's energy system (Table 46). The interconnection limits detailed in Table 46 factor in the upgrades mentioned previously and therefore allow for transmission across Gambia[62]. Therefore, they describe the interconnection limits used across the years modelled (2030, 2050), avoiding overly ambitious assumptions around the expansion of transmission infrastructure, but constraining the possible imports/exports into and out of regions in later years (2050).

Table 46: Interconnector capacities used in modelling Senegal's electrical system

	North-eastern	Central -North	Central-East	Central-West	South-eastern	South-western
Dakar	767	767	767	767	767	767
North-eastern		767	767	767	767	767
Central -North			767	767	767	767
Central-East				767	767	767
Central-West					767	767
South-eastern						767
South-western						

As discussed in the methodology in section 6.1, the 24/7 model distributes renewable generation capacity according to the regional potential, whereas load is distributed according to the relevant indicator (residential and demand – population distribution, whereas industrial load is distributed according to GDP. Senegal's existing oil and diesel generation assets are distributed according to their current locations based on publicly available information. In this way, an accurate reconstruction of Senegal's electricity transmission infrastructure and generation was implemented in the 24/7 MATLAB model.

The following results show the levels on annual energy exchange (TWh/a) on a regional basis for each of the years modelled, identifying the regions that can export power to surrounding regions and the regions that will be more dependent upon their neighbouring areas for import (Figure 38: note that the x-axis is not constant). Also note the dispatch order in section 6.1.3.

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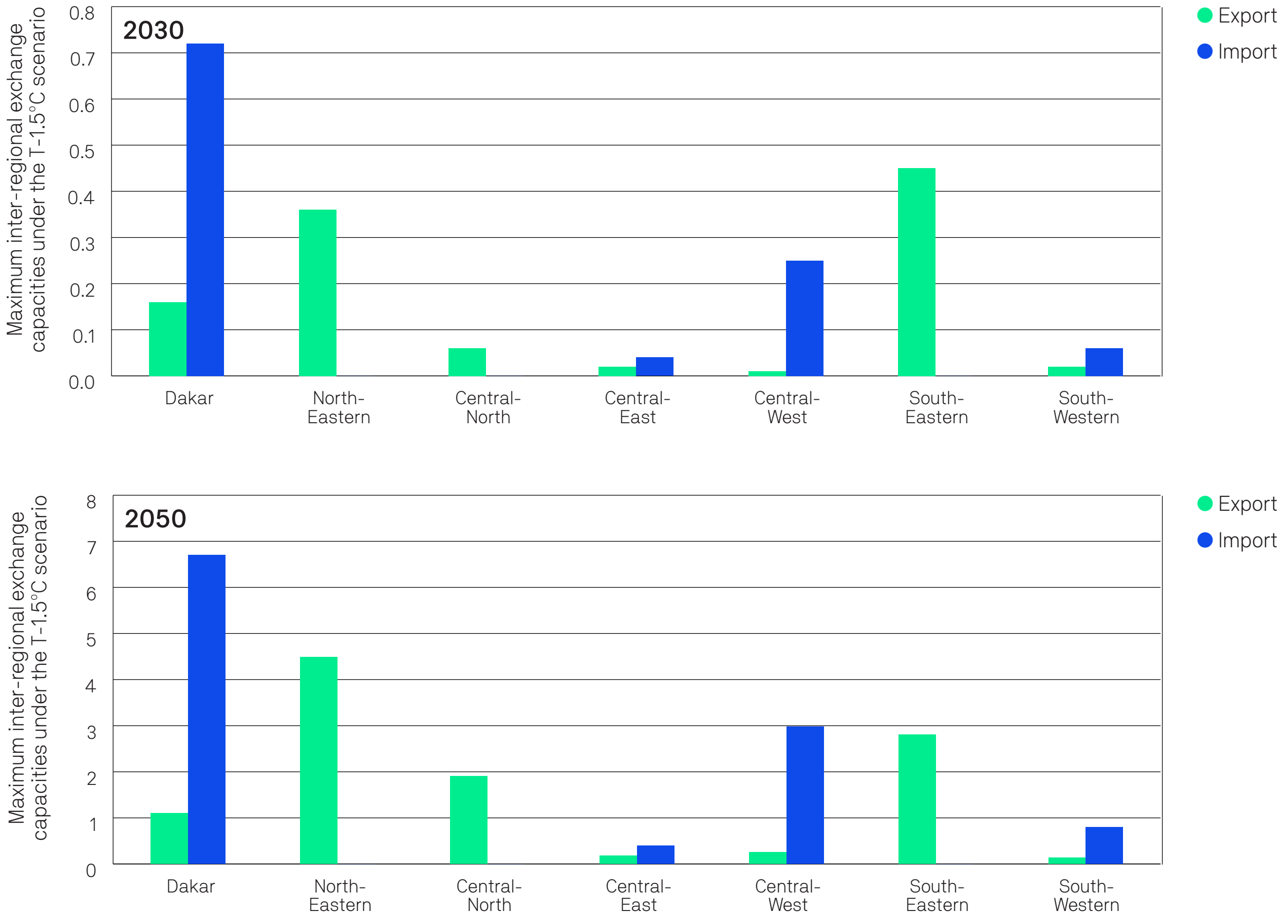
[61] Power Africa Transactions and Reforms Program, 2017–2035 Power Generation and Transmission Master Plan for Senegal, reviewed by United States Agency for International Development and prepared by Tetra Tech ES Inc., 2017

[62] Ibid.

Figure 38: Senegal – maximum inter-regional exchange capacities, additional to the required grid capacity expansion in response to load increases, under the S-1.5°C scenario



As to be expected, regions with a higher percentage of the county's population, such as Dakar and the Central-West region (23% and 24%, respectively), are net importers of energy throughout the year. This is due to the residential demand in Senegal's largest population centres, including the capital city of Dakar, and the fact that these two regions contribute a higher proportion of Senegal's GDP. Conversely, regions such as the North-eastern and South-eastern areas will be significant exporters of energy throughout the year, because generation assets are distributed according to potential, and those regions have lower population densities. In a comparison of the 2030 and 2050 results, it can be clearly seen that the energy exchange between regions increases as Senegal progresses towards a decarbonised economy, reliant on more variable generation and the consumption of electricity in lieu of fossil-fuelled energy.

To prevent the unnecessary expansion of the electricity grid, the projected increase in the regional electricity demand and additional electricity export plans should inform the expansion of the local power generation capacity. Grid operators can utilise a mixture of load management (using demand-side measures) and storage to help manage the exports and imports shown in Figure 38. Note that the interconnection values shown above are dependent upon the assumed levels of distributed and utility storage, because interconnection comes after these energy sources in the fixed dispatch order. The results described above indicate that Senegal should be able to leverage the existing transmission infrastructure to facilitate the transition pathway set out in the S-1.5°C OECM model. By appropriately managing the transition, ensuring sufficient levels of storage and load management (demand-side, electric vehicle charging), government bodies and grid-operating agencies will be leveraging the existing transmission infrastructure, while ensuring the security of supply for regions. It was beyond the scope of this project to analyse the low- and medium-voltage-level distribution systems, so the quantification of the effects of micro-grids and other such arrangements is also beyond the scope of this report.

Limitations

The calculated loads are not optimised in terms of local storage, self-consumption by decentralised producers of solar PV electricity, or demand-side management. Therefore, the calculated loads may differ from the actual values. Furthermore, the calculated export/import loads to neighbouring countries are simplified and combined into a single value. Peak load and peak generation events do not occur at the same time, so their values cannot simply be summed. Moreover, peak loads can vary across all regions and appear at different times. Therefore, to sum all the regional peak loads will only provide an indication of the peak load for the whole country. The maximum residual load[63] shows the maximum undersupply in a region and indicates the maximum load that will be imported into that region. This event may only be several hours long, so the interconnection capacity may not be as high as the maximum residual load indicates. Optimising the interconnections for all regions was beyond the scope of this analysis. To guarantee the security of supply, the residual load of a region must be supplied by one or more of the following options:

- Imports from other regions through interconnections;
- Battery storage facilities on site at solar PV installations and for electric vehicles;
- Available back-up capacities, such as gas peaking plants;
- Load and demand-side management.

In practice, security of supply will be achieved with a combination of several measures and will require the in-depth analysis of regional technical possibilities.

6.6 Results: Annual variation in renewable energy generation

Solar and wind power generation has different annual variation patterns, which are dependent upon the climate zone and to geographic location. This section provides a high-level analysis of the electricity import and/or export needs under the S-1.5°C scenario, with high shares of variable power generation. In practice, electricity demand ('load') and generation ('supply') must be balanced at all times. If local generation cannot meet demand, electricity must either be imported from other regions or taken from existing storage facilities. If generation is higher than load, either the surplus electricity can either exported to other regions or stored, the load increased, or production reduced. The term 'curtailment' is defined as the forced reduction of electricity generation, and is the energy generated by renewable resources in excess of demand that cannot be stored or transmitted within Senegal to other regions in a given time period. To determine the annual distribution of Senegal's solar and wind power generation, generation and expected load were simulated at 1-hourly resolution (8760 h/a).

Figure 39 shows the weekly values of the supply imbalances in terms of both curtailment and additional imports required. During times of high generation, generation exceeds demand (green line); the red line shows when demand exceeds generation (i.e., when additional electricity generated must be imported into Senegal). The modelling of Senegal's transmission connections to its five neighbouring countries (Gambia, Guinea-Bissau, Guinea, Mali, and Mauritania) was beyond the scope of this study, so further research must be undertaken to assess the availability of electricity imports at those times, or to identify the other measures that could be undertaken to address supply imbalances. The operation of state-of-the-art power systems and renewable-power-generation-dominated grids utilises a combination of demand- and generation-side management, export and import from neighbouring regions, and a cascade of different storage technologies, such as batteries, hydro pump storage, and at a later time, hydrogen/synthetic fuel production – which is also beyond the scope of the 24/7 modelling undertaken.

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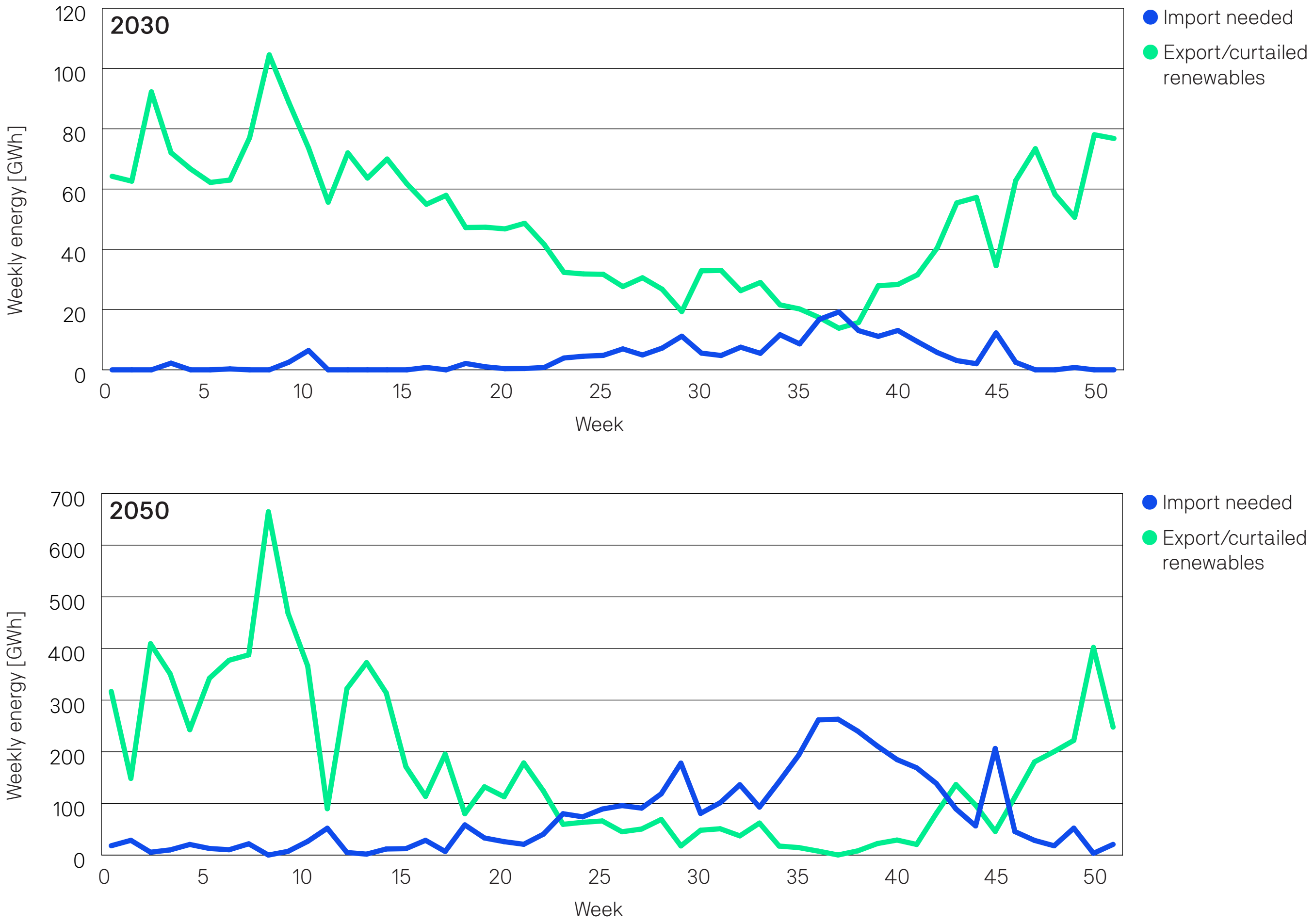
[63] Residual load is the load remaining after the local generation within the analysed region is exhausted. There could be a shortage of load supply due to the operation and maintenance of a coal power plant or reduced output from wind and/or solar power plants.

Figure 39: Senegal: weekly values for electricity imports and exports in 2050



The results shown in Figure 39 underpin the significant amount of change that is to be expected under the S-1.5°C scenario. It is noteworthy that the values on the y-axis changes by a factor of 7. In 2030, there will be increased use of renewable energy, so there will be some curtailment because this capacity supplies a decent proportion of the overall load and will increase to meet increases in load and to cover reductions in fossil-fuel consumption (excess renewables of ~17% relative to total clean production). However, by 2050, a significant build-out of capacity is required to cover the energy demand throughout the year, leading to overbuilding/excess capacity throughout the year. The combination of significant increases in demand (both peak and annual consumption will increase 5.5- and 7.5-fold, respectively) and the reliance on variable resources means that5 a consistently high level of excess power will be produced throughout the year, given the load assumptions used in the 24/7 modelling (excess renewables of ~22% in 2050 relative to total renewables production). Because both load and generation vary over time, coincidences in peak demand and peak generation are unlikely, so unmet demand will occur even in weeks with excess renewable generation. Therefore, Figure 39 highlights the importance of the 'state-of-the-art power system operation' mentioned in this chapter. Optimisation was beyond the scope of this study, so further research is required to understand the trade-offs between the oversupply of renewable generation, additional investments in storage options, additional inter-regional and inter-national electrical transmission infrastructure, and demand-side management.

Figure 40: Senegal: weekly values for inter-province transmission – 2030 and 2050

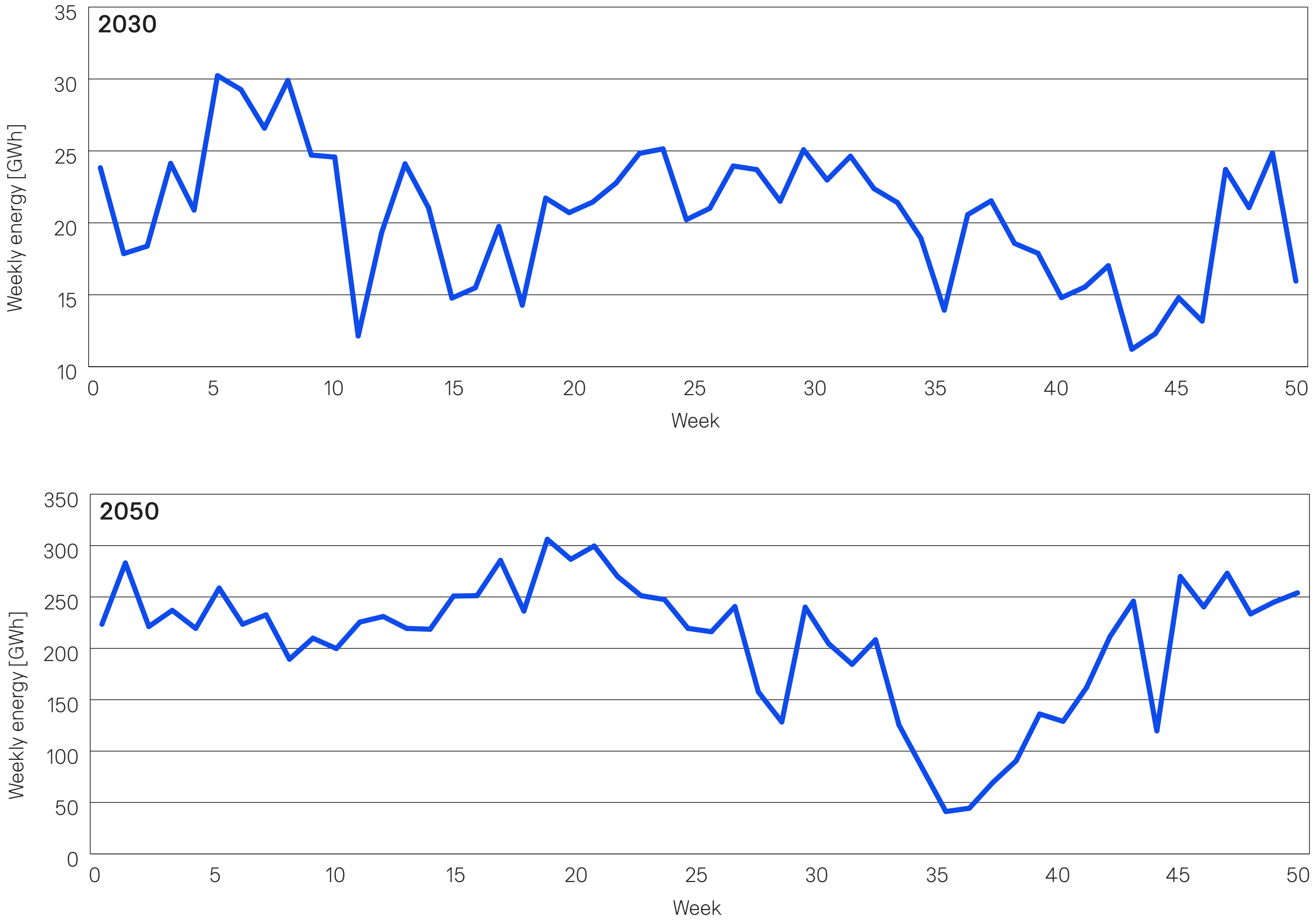
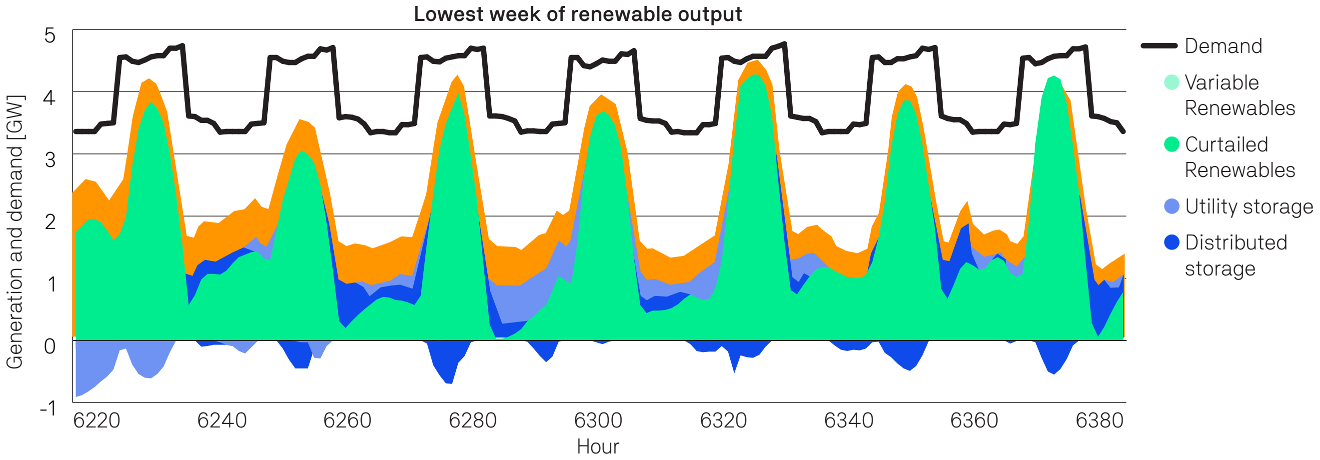


Figure 40 shows the weekly values for the inter-province transmission requirements under the S-1.5°C scenario in 2030 and 2050, which are a function of the import and export requirements on the national level. This figure shows the weekly variations in the inter-provincial energy exchanges shown in Figure 38. It can be inferred from this figure that during the period 2030–2050, the interconnection between regions will be relied upon more consistently and to a greater proportion of its maximal capacity rating (note: 10-fold growth on the y-axis). Energy exchange between regions will be important throughout the year when there is sufficient renewable generation to cover demand, noting that during the period of low wind and solar generation with excess renewables (occurring between weeks 35 and 40), the use of the transmission capacity is reduced.

The following section looks deeper into two representative weeks from the 2050 modelling, contrasting the weeks of lowest and highest renewable generation relative to demand. The purple areas in Figure 41 and Figure 42 show the charging (negative values) and discharging (positive values) of storage systems. Brown areas specify times with dispatch needs (import or export of electricity) and green areas show renewable power generation. The white areas, which indicate periods of unmet demand, are investigated further. Therefore, the analysis of the local variations in annual solar and wind power generation is the first step in determining the technical storage requirements.

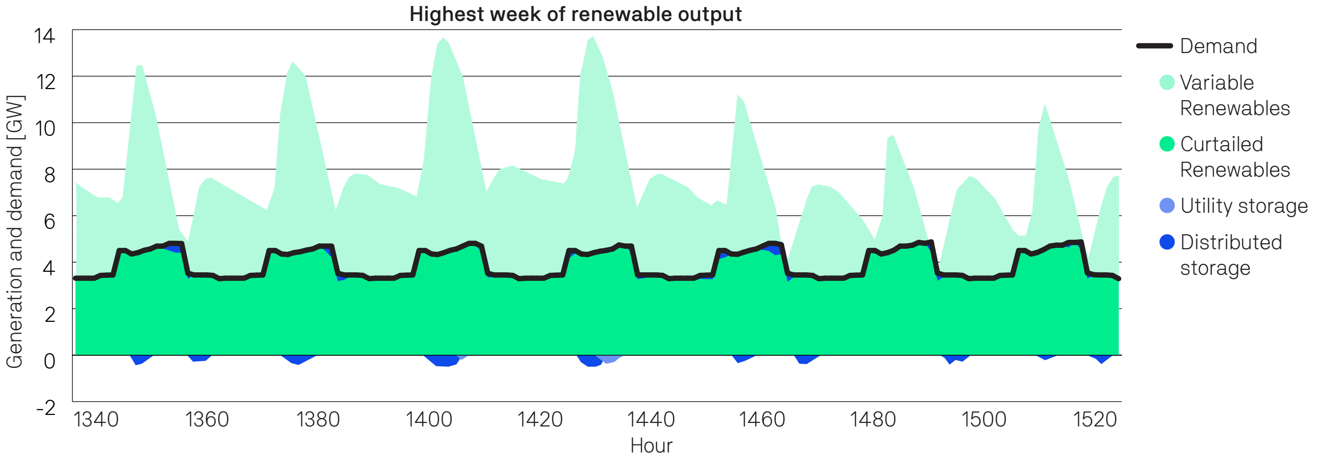
The modelling undertaken – based on historical meteorological data (section 6.1.1) – indicates that there may be cloudy periods during the year in Senegal, which are accompanied by low wind speeds, as shown in Figure 41, during which power generation from both wind and solar is at the lowest level in the entire year (occurring in late September). Energy production from onshore wind generators is consistently limited to under ~12.5% of their nominal capacity for a period of several days (due to low wind), and solar output is constrained to ~25% of its maximal output across the week. This occurrence do not seem to be an anomaly because Figure 39 shows the full utilisation of renewables between weeks 35 and 40, with negligible curtailment and noticeable levels of unmet demand. It should be noted that this period occurs during Senegal's rainy season, which occurs between June and September. Further analysis is required to examine the extent to which this may impact Senegal's security of supply, and to what extent connection with neighbouring countries (Gambia, Guinea-Bissau, Guinea, Mali, or Mauritania) can be utilised to cover possible supply gaps during the rainy season.

Figure 41: Senegal – lowest renewable electricity production under the S-1.5°C scenario in 2050



The other extreme – a period with very high power generation rates – occurs in the beginning of the year during the dry season. In this week, there are consistently high wind speeds, as can be seen by the excess generation outside hours across the entire week (Figure 42). This figure shows that having sufficient transmission to neighbouring countries will provide a significant economic benefit to Senegal through the export of excess generation. The excess generation could also be utilised for the generation of clean fuels and chemical feedstock.

Figure 42: Senegal – highest renewable electricity production under the S-1.5°C scenario in 2050



6.7 Storage Requirements

6.7.1 Introduction

The quantity of storage required will be largely dependent upon the storage costs, grid expansion possibilities, and the generation mix itself. In terms of grid expansion, the geographic situation greatly influences the construction costs. Crossing mountains, rivers, or swamps is significantly more expensive than crossing flat lands (Wei 2016)[64]. Furthermore, the length of the permission process and whether people will be displaced by grid expansions may make storage economically preferable to grid expansion, even though the current transmission costs are lower per megawatt-hour than the storage costs. Cebulla et al. (2018)[65] reported that "in general terms, photovoltaic-dominated grids directly correlate to high storage requirements, in both power capacity and energy capacity. Conversely, wind-dominated scenarios require significantly lower storage power and energy capacities, if grid expansion is unlimited or cheap". In an analysis of 400 scenarios for Europe and the USA, they also found that once the share of variable renewables exceeds 40% of the total generation, the increase in electrical energy storage power capacity is about 1–2 GW for each percentage of variable renewable power generation in wind-dominated scenarios and 4–9 GW in solar-PV-dominated scenarios.

When the share of variable power generation exceed 30%, storage requirements increase. The share of variable generation will exceed 30% between 2025 and 2030 under both scenarios in all regions. Therefore, a smart-grid integration strategy that includes demand-side management and the installation of additional decentralised and centralised storage capacities must be established.

Over the past decade, the cost of batteries, especially lithium batteries, has declined significantly. However, solar PV costs have also declined significantly. Storage is economic when the cost per kilowatt-hour is equal to or lower than the cost of generation. Therefore, if storage costs are high, curtailment could be economic. However, there are several reasons for curtailment, including transmission constraints, system balancing, and economic reasons (NREL 2014)[66]. The California Independent System Operator (CISO)[67] defines economic curtailment during times of oversupply as a market-based decision. "During times of oversupply, the bulk energy market first competitively selects the lowest cost power resources. Renewable resources can 'bid' into the market in a way to reduce production when prices begin to fall. This is a normal and healthy market outcome. Then, self-scheduled cuts are triggered and prioritised using operational and tariff considerations. Economic curtailments and self-scheduled cuts are considered 'market-based'".

6.7.2 Analysis of Storage demands

Senegal currently has a limited base of dispatchable renewable generation (such as hydro power) and negligible amounts of storage capacity. According to the Global Pumped Hydro Atlas (ANU 2022)[68], Senegal has a limited number of high-quality pumped hydro sites. Therefore, the S-1.5°C pathway does not rely heavily on the expansion of hydro power for generation or on pumped hydro storage for the development of storage capacity.

Our analysis is on an hourly basis, so the modelling of demand spikes that occur for a limited time – from minutes to hours – is at a less fine resolution, with peak demand being caused by heating/cooling loads in addition to the tendency of households to use electricity to a greater extent in the morning and evening. Therefore, our model captures peaks, but these are smoother than would occur in reality, and actual grid and storage capacity must react to those changes. In reality, 'peak-shaving' could be used to avoid peak generation events. The term 'peak-shaving' refers to the reduction in the solar or hydro

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[64] Wei W, et al. (2016) Regional study on investment for transmission infrastructure in China based on the State Grid data,10.1007/s11707-016-0581-4, Frontiers of Earth Science, June 2016.

[65] Cebulla et al. (2018) How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany, Journal of Cleaner Production, February 2018, https://www.researchgate.net/publication/322911171_How_much_electrical_energy_storage_do_we_need_A_synthesis_for_the_US_Europe_and_Germany/link/5a782bb50f7e9b41dbd26c20/download

[66] Wind and Solar Energy Curtailment: Experience and Practices in the United States; Lori Bird, Jaquelin Cochran, and Xi Wang, National Renewable Energy Laboratory (NREL), March 2014, https://www.nrel.gov/docs/fy14osti/60983.pdf

[67] Impacts of renewable energy on grid operations, factsheet, https://www.caiso.com/documents/sb350study-renewableintegrationgridreliability-fastfacts.pdf

[68] ANU (2022) Australian National University, 100% Renewable Energy Group, Global Pumped Hydro Energy Storage Atlas, https://re100.eng.anu.edu.au/global/

generation capacity in times of high production. Peak-shaving involves pro-actively managing solar generation by reducing the output – e.g., from utility-scale PV – to eliminate short-term spikes.

To build up the additional storage capacity required, we assume that a percentage of the solar PV capacity will be installed with battery storage. The suggested solar battery system must be able to store the entire peak capacity for 4 full load hours. The S-1.5°C scenario uses an ambitious growth trajectory, such that on aggregate, there is sufficient battery capacity for its nominal storage depth in GWh to be the same order of magnitude as the aforementioned ratio of aggregate solar capacity x 4 full load hours (i.e., approximately 16 GW of utility battery storage by 2050).

The estimates provided for storage requirements also presuppose that variable renewables, such as solar PV and wind, will be first in the dispatch order, ahead all other types of power generation. Priority dispatch is the economic basis for investment in utility-scale solar PV and wind projects. The curtailment rates or storage rates will be significantly higher when priority dispatch is given to, for example, hydro power plants in 'baseload' generation mode. This case has not been calculated because it would involve a lack of investment in solar in the first place. With decreasing storage costs, as projected by Bloomberg (2019)[69], interconnections may become less economically favourable than batteries. The storage estimates provided are technology neutral and do not favour any specific battery technology.

Table 47 shows the storage assumptions utilised in the S-1.5°C scenario. Given that Senegal has limited capacity for pumped hydro storage, no specific level of economic curtailment was targeted. Instead, curtailment was allowed to remain as dependent upon the modelling assumptions, and the additional generation highlights Senegal's potential to export power to neighbouring countries and also to become an important nation in the production of H_2 and other clean fuels. (Note: the H_2 value in Table 47 refers to the H_2 used for the generation of electricity and is therefore restrained to a low value).

The storage demands for micro-grids and off-grid systems must be calculated individually and are not part of this assessment. However, micro-grids always require either a storage system with a capacity large enough (in terms of both the electricity supply in kilowatt-hours and the required load in kilowatts) to bridge the gaps in times of low or no generation possibilities.

Table 47: Senegal: calculated electricity storage capacities by technology and year

Storage Capacity	Units	2020	2025	2030	2035	2040	2045	2050
Battery-distributed	[MW]	-	5	90	625	1125	2250	4375
Electric Vehicle-V2G	[MW]	-	-	-	-	-	-	-
Battery-utility scale	[MW]	-	93	1000	2591	4750	7000	9250
Hydro Pump Storage	[MW]	-	-	-	-	-	-	-
H_2	[MW]	-	5	6	7	8	10	12
Total	**[MW]**	**-**	**103**	**1096**	**3223**	**5883**	**9260**	**13637**

The outcomes of the above modelling assumptions are shown below in Figure 43 and Table 48, which demonstrate that the assumed levels of utility storage are used consistently throughout the year, dealing with the kind of supply gaps described in section 6.6. This is also indicative of the shallow nature of the storage capacity used, because without long-term storage, there is limited ability to shift energy generation from lull periods of variable power to high-demand periods.

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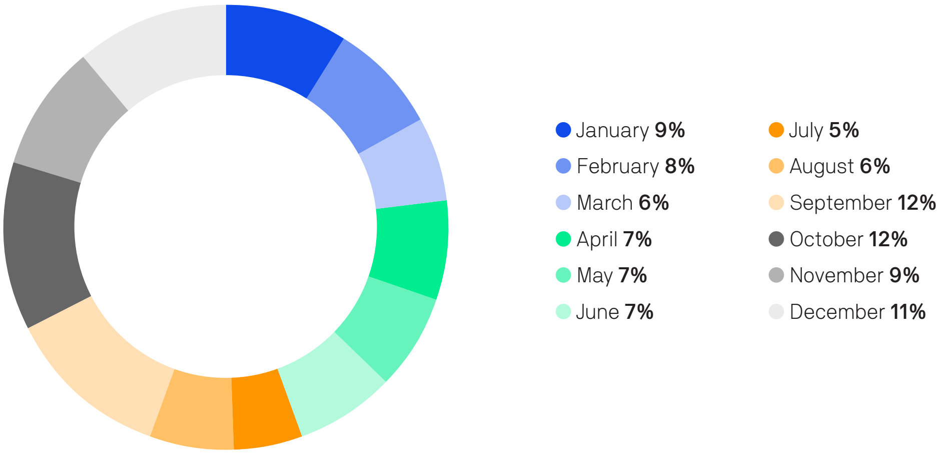
[69] Bloomberg (2019), A Behind the Scenes Take on Lithium-ion Battery Prices, Logan Goldi-Scot, Bloomberg NEF, March 5 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Figure 43: Storage usage by month in 2050



The results in Table 48 are interesting insofar as the utility battery storage capacity is distributed according to the utility solar capacity and batteries are distributed more consistently with population levels. Table 48shows that the high-density population centres, with correspondingly higher levels of GDP, are not only net importers of power from other regions but also do not utilise their storage capacity to any significant extent. This is because these regions do not experience sufficient periods of surplus renewable generation to warrant the charging of batter capacity within their regional boundaries. It is also worth noting that the Central-East and South-western areas have significant battery usage, even though they are not large exporters of surplus renewables throughout the year. This indicates that these areas have sufficient load gaps between their local generation and demand to warrant the discharging and charging of batteries throughout the year. However, other net-exporter areas will not require as much storage because they can more readily cover their load throughout the year.

Table 48: Storage usage – annual charge and discharge

	Total Charge [GWh]	Total Discharge [GWh]
Dakar	0	0
North-eastern	-209	196
Central -North	-121	112
Central-East	-420	410
Central-West	-37	37
South-eastern	-141	121
South-western	-237	230

6.7.3 Cost development – Battery storage technologies

Battery technologies have developed significantly over the past decade, and the global annual market increased from 700 MW in 2015 to close to 16,000 MW in 2021 (IEA-BAT 2024)[70]. The market is split roughly equally between grid-scale storage and ‘behind-the-meter’ storage for solar PV projects. The rapidly growing demand for electric vehicles has significantly accelerated the development of battery technologies, and manufacturing capacities have grown by double digits, with costs decreasing accordingly. The battery costs per kilowatt-hour storage capacity decreased from US$668 (CFA 405,000) in 2013 to US$137 (CFA 83,000) in 2020 – a reduction of 79% over 7 years. Bloomberg New Energy Finance estimates that battery costs will decline further to around US$58 (CFA 35,000) by 2030.

6.7.4 Further research required

A calculation of the investment costs in storage technologies that will be required after 2030 and by 2050 would entail such high uncertainty that such estimates seem meaningless. Furthermore, a more-detailed storage technology assessment for the S-1.5°C scenario based on the specific situation in Senegal – with its unique potential for a stand-alone grid that is interconnected with the expanding national grid over time between 2030 and 2050 – is required.

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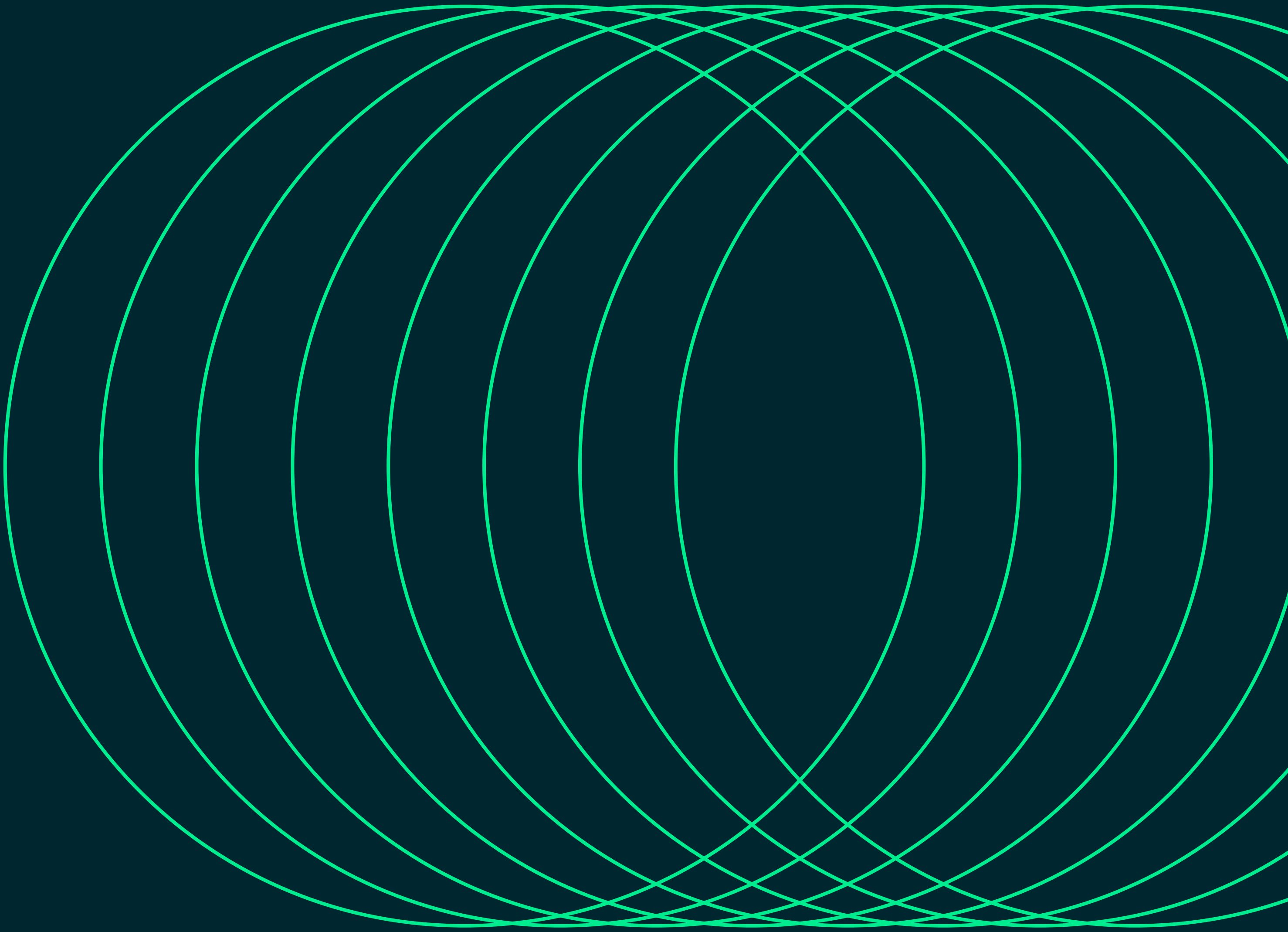
[70] IEA-BAT (2024) – website viewed April 2024. https://www.iea.org/reports/batteries-and-secure-energy-transitions

7

Senegal: Data Appendix



Senegal: Electricity generation [TWh/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Power plants	3	4	5	4	5	6	5	6	10	17	25	33	40
– Hard coal (& non-renewable waste)	0	0	0	0	0	1	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– of which from H_2	0	0	0	0	0	0	0	0	0	0	1	1	1
– Oil	3	4	4	4	4	4	4	5	3	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	0	0	2	5	9	15	23
– of which wind offshore	0	0	0	0	0	0	0	0	0	0	1	2	3
– PV	0	0	0	0	0	0	0	1	5	10	12	12	11
– Geothermal	0	0	0	0	0	0	0	0	0	1	1	2	2
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	2	2	3	4
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	1
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– of which from H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
CHP by producer													
– Main activity producers	0	0	0	0	0	0	0	0	0	0	0	0	0
– Autoproducers	0	0	0	0	0	0	0	0	0	0	0	0	0
Total generation	3	4	5	4	5	6	5	6	10	17	25	33	40
– Fossil	3	4	5	4	4	5	5	5	3	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	1	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	3	4	4	4	4	4	4	5	3	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	1	1	1
– of which renewable H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables (w/o renewable hydrogen)	0	0	0	0	0	0	1	1	8	17	25	33	40
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	0	0	2	5	9	15	23
– PV	0	0	0	0	0	0	0	1	5	10	12	12	11
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	1	1	2	2
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	2	2	3	4
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	1
Distribution losses	1	1	1	1	1	1	1	0	1	1	1	2	2
Own consumption electricity	0	0	0	0	0	0	0	0	1	1	2	2	2
Electricity for hydrogen production	0	0	0	0	0	0	0	0	0	1	2	3	3
Electricity for synfuel production	0	0	0	0	0	0	0	0	0	0	0	0	0
Final energy consumption (electricity)	3	4	4	4	4	5	5	6	10	16	22	29	34
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	1	1	7	15	21	28	34
Share of variable RES	0%	0%	0%	2%	5%	6%	10%	20%	69%	86%	84%	84%	84%

Senegal: Transport – Final Energy [PJ/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Road	27	35	38	34	37	40	37	38	36	27	26	24	27
– Fossil fuels	27	35	38	34	37	40	37	36	30	13	8	1	0
– Biofuels	0	0	0	0	0	0	0	1	2	3	4	4	5
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	1	0	1	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	3	10	14	19	22
Rail	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0
Navigation	1	2	2	2	2	3	3	3	3	3	3	3	3
– Fossil fuels	1	2	2	2	2	3	3	3	2	2	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	1	2	2	2
– Synfuels	0	0	0	0	0	0	0	0	0	0	1	1	1
Aviation	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (incl. Pipelines)	29	37	40	36	40	43	40	41	39	30	29	28	30
– Fossil fuels	29	37	40	36	40	43	40	39	33	15	9	2	0
– Biofuels (incl. Biogas)	0	0	0	0	0	0	0	1	3	4	5	6	6
– Synfuels	0	0	0	0	0	0	0	0	0	0	1	1	1
– Natural gas	0	0	0	0	0	0	0	1	0	1	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	1	1
– Electricity	0	0	0	0	0	0	0	0	3	10	14	19	22
Total RES	0	0	0	0	0	0	0	2	5	15	21	26	30
RES share	0%	0%	0%	0%	0%	0%	0%	4%	14%	49%	71%	94%	100%

Senegal: Heat supply and air conditioning [PJ/a] T – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0	8	8	9	10	10	11
– Fossil fuels	0	0	0	0	0	0	0	7	6	6	3	1	0
– Biomass	0	0	0	0	0	0	0	1	1	3	6	8	9
– Solar collectors	0	0	0	0	0	0	0	0	0	0	1	1	1
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat from CHP 1)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
Direct heating	39	48	49	37	43	44	49	50	55	57	60	63	65
– Fossil fuels	15	20	21	13	17	15	17	27	19	17	10	5	0
– Biomass	23	25	26	23	24	28	30	12	19	10	10	9	6
– Solar collectors	0	0	0	0	0	0	0	3	5	7	8	9	11
– Geothermal	0	0	0	0	0	0	0	1	2	3	4	5	7
– Heat pumps 2)	0	0	0	0	0	0	0	3	4	11	15	19	20
– Electric direct heating	2	3	2	2	2	2	2	3	3	2	2	2	2
– Hydrogen	0	0	0	0	0	0	0	0	0	0	1	2	3
Total heat supply 3)	39	48	49	37	43	44	49	58	63	66	70	73	76
– Fossil fuels	15	20	21	13	17	15	17	34	26	23	13	6	0
– Biomass	23	25	26	23	24	28	30	13	20	13	16	17	15
– Solar collectors	0	0	0	0	0	0	0	3	5	7	8	9	11
– Geothermal	0	0	0	0	0	0	0	1	2	3	5	6	8
– Heat pumps 2)	0	0	0	0	0	0	0	3	4	11	15	19	20
– Electric direct heating (incl. process heat)	2	3	2	2	2	2	2	4	7	9	11	15	19
– Hydrogen	0	0	0	0	0	0	0	0	0	0	1	2	3

Senegal: Installed Capacity [GW] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total generation	3	4	5	5	5	5	4	5	7	10	14	17	19
– Fossil	3	4	5	4	4	5	4	4	2	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas (w/o H_2)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil & Diesel	2	4	4	4	4	5	4	4	2	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen (fuel cells, gas power plants, gas CHP)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables	0	0	0	0	0	0	0	1	5	10	14	17	19
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	0	0	1	2	4	6	9
– of which wind offshore	0	0	0	0	0	0	0	0	0	0	0	1	1
– PV	0	0	0	0	0	0	0	1	4	8	9	9	8
– Biomass (& renewable waste)	0	0.0	0.0	0.0	0.0	0.0	0.022	0.022	0.006	0.000	0.000	0.0	0.0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	1	1	1	2
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	0	1	5	10	13	15	17
Share of variable RES	0%	0%	0%	2%	5%	6%	8%	17%	66%	92%	90%	89%	88%
RES share (domestic generation)	1%	0%	0%	2%	6%	7%	9%	18%	69%	99%	99%	98%	100%

Senegal: Final Energy Demand [PJ/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	80	101	107	91	101	107	123	130	141	139	155	172	191
Total Energy use 1)	78	101	107	91	101	107	111	117	128	125	139	153	170
Transport	29	37	40	36	40	43	40	41	39	30	29	28	30
– Oil products	29	37	40	36	40	43	40	39	33	15	9	2	0
– Natural gas	0	0	0	0	0	0	0	1	0	1	0	0	0
– Biofuels	0	0	0	0	0	0	0	1	3	4	5	6	6
– Synfuels	0	0	0	0	0	0	0	0	0	0	1	1	1
– Electricity	0	0	0	0	0	0	0	0	3	10	14	19	22
– RES electricity	0	0	0	0	0	0	0	0	0	1	2	2	3
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	1	1
– RES share Transport	0%	0%	0%	0%	0%	0%	0%	4%	14%	49%	71%	94%	100%
Industry	17	23	23	14	17	21	22	25	34	44	54	68	79
– Electricity	3	4	3	3	4	7	7	9	16	26	37	49	59
– RES electricity	0	0	0	0	0	1	1	2	12	26	37	49	59
– Public district heat	0	0	0	0	0	0	0	2	2	3	4	4	5
– RES district heat	0	0	0	0	0	0	0	0	0	1	2	4	5
– Hard coal & lignite	9	13	13	9	11	9	11	2	1	5	0	0	0
– Oil products	3	6	6	1	1	1	1	1	1	0	0	0	0
– Gas	0	0	0	0	0	0	0	8	7	6	6	4	0
– Solar	0	0	0	0	0	0	0	1	1	2	3	4	5
– Biomass	1	1	1	1	0	4	4	2	5	0	1	1	2
– Geothermal	0	0	0	0	0	0	0	0	0	1	2	2	3
– Hydrogen	0	0	0	0	0	0	0	0	0	1	2	4	4
– RES share Industry	9%	4%	6%	5%	5%	22%	22%	19%	58%	71%	87%	94%	100%
Other Sectors	33	41	44	41	44	44	49	51	55	51	55	58	60
– Electricity	8	9	10	11	11	10	10	12	15	21	27	35	42
– RES electricity	0	0	0	0	1	1	1	3	12	21	27	35	42
– Public district heat	0	0	0	0	0	0	0	5	5	5	5	4	4
– RES district heat	0	0	0	0	0	0	0	0	1	2	3	4	4
– Hard coal & lignite	0	0	0	0	0	0	0	2	0	0	0	0	0
– Oil products	5	5	6	5	7	7	7	4	1	0	0	0	0
– Gas	0	0	0	0	0	0	0	12	11	8	5	1	0
– Solar	0	0	0	0	0	0	0	2	3	4	5	5	5
– Biomass	20	26	28	26	26	27	33	14	18	12	11	9	5
– Geothermal	0	0	0	0	0	0	0	1	1	2	3	3	4
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– RES share Other Sectors	63%	65%	65%	63%	61%	63%	68%	39%	63%	79%	88%	97%	100%
Total RES	22	28	30	27	28	32	39	26	57	77	104	129	150
– RES share	28%	27%	28%	30%	28%	30%	35%	22%	45%	61%	75%	84%	89%
Non energy use	2	0	0	0	0	0	12	12	14	14	17	19	21
– Oil	2	0	0	0	0	0	12	12	14	14	16	19	21
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Coal	0	0	0	0	0	0	0	0	0	0	0	0	0

Senegal: Energy-Releated CO_2 Emissions [Million tons/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	1	2	3	5	5	4	5	6	4	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	1	0	1	1	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil + Diesel	1	2	2	5	4	3	5	6	4	0	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	1	2	3	5	5	4	5	6	4	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	1	0	1	1	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil + Diesel	1	2	2	5	4	3	5	6	4	0	0	0	0
CO_2 intensity (g/kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– CO_2 intensity fossil electr. generation	437	573	633	1,203	1,078	703	1,197	1,239	1,562	0	0	0	0
– CO_2 intensity total electr. generation	430	563	624	1,158	1,000	643	1,054	952	383	0	0	0	0
CO_2 emissions by sector	6	8	9	10	10	9	11	12	8	3	2	0	0
– Industry 1)	1	2	2	1	2	1	2	1	1	1	0	0	0
– Other sectors 1)	0	0	1	0	1	1	1	2	1	1	1	0	0
– Transport	2	3	3	3	3	3	3	3	2	1	1	0	0
– Power generation 2)	1	2	3	5	5	4	5	6	4	0	0	0	0
– Other conversion 3) – part of industry & transport	0	0	0	0	0	0	1	1	0	0	0	0	0
Population (Mill.)	13	15	15	15	16	16	17	15	15	15	16	16	17
CO_2 emissions per capita (t/capita)	0	1	1	1	1	1	1	1	1	0	0	0	0

Senegal: Primary Energy Demand [PJ/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	145	152	160	183	186	177	213	205	199	162	178	197	221
– Fossil (excluding on-energy use)	82	94	104	121	123	108	133	161	119	44	25	8	0
– Hard coal	12	16	19	14	18	18	12	7	2	5	0	0	0
– Lignite	0	0	0	0	0	0	0	1	0	0	0	0	0
– Natural gas	2	2	2	2	1	2	1	28	25	21	14	6	0
– Crude oil	68	77	83	105	103	88	119	126	91	19	11	1	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables	62	58	56	62	63	69	68	31	67	103	137	170	200
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	1	1	5	15	28	48	73
– Solar	0	0	0	0	1	1	1	7	29	60	76	85	87
– Biomass	62	58	56	62	62	68	66	22	30	22	23	24	23
– Geothermal	0	0	0	0	0	0	0	1	3	6	9	12	15
– Ocean energy	0	0	0	0	0	0	0	0	0	1	1	2	2

Senegal: Electricity generation [TWh/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Power plants	3	4	5	4	5	6	5	6	8	12	15	20	24
– Hard coal	0	0	0	0	0	1	0	0	0	0	0	0	1
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– of which from H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	3	4	4	4	4	4	4	5	7	10	13	16	20
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	0	0	0	0	1	1	1
– of which wind offshore	0	0	0	0	0	0	0	0	0	0	0	0	0
– PV	0	0	0	0	0	0	0	0	1	1	1	1	1
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– of which from H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
CHP by producer													
– Main activity producers	0	0	0	0	0	0	0	0	0	0	0	0	0
– Autoproducers	0	0	0	0	0	0	0	0	0	0	0	0	0
Total generation	3	4	5	4	5	6	5	6	8	12	15	20	24
– Fossil	3	4	5	4	4	5	5	6	7	10	13	17	20
– Hard coal	0	0	0	0	0	1	0	0	0	0	0	0	1
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	3	4	4	4	4	4	4	5	7	10	13	16	20
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
– of which renewable H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables (w/o renewable hydrogen)	0	0	0	0	0	0	1	1	1	1	2	3	3
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	0	0	0	0	1	1	1
– PV	0	0	0	0	0	0	0	0	1	1	1	1	1
– Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Distribution losses	1	1	1	1	1	1	1	0	0	1	1	1	1
Own consumption electricity	0	0	0	0	0	0	0	0	1	1	1	1	2
Electricity for hydrogen production	0	0	0	0	0	0	0	0	0	0	0	0	1
Electricity for synfuel production	0	0	0	0	0	0	0	0	0	0	0	0	0
Final energy consumption (electricity)	3	4	4	4	4	5	5	6	8	11	14	18	21
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	1	1	1	1	2	2	3
Share of variable RES	0%	0%	0%	2%	5%	6%	10%	10%	11%	11%	11%	11%	12%
RES share (domestic generation)	1%	2%	2%	4%	7%	8%	12%	12%	13%	13%	13%	13%	14%

Senegal: Transport – Final Energy [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Road	27	35	38	34	37	40	37	39	42	47	53	61	70
– Fossil fuels	27	35	38	34	37	40	37	37	38	43	49	56	64
– Biofuels	0	0	0	0	0	0	0	1	2	3	4	4	5
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	1	0	1	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	1	1	1	1	1
Rail	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0
Navigation	1	2	2	2	2	3	3	3	3	3	3	3	3
– Fossil fuels	1	2	2	2	2	3	3	3	2	2	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	1	2	2	2
– Synfuels	0	0	0	0	0	0	0	0	0	0	1	1	1
Aviation	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (incl. Pipelines)	29	37	40	36	40	43	40	42	45	50	57	64	73
– Fossil fuels	29	37	40	36	40	43	40	40	41	46	49	56	64
– Biofuels (incl. Biogas)	0	0	0	0	0	0	0	1	3	4	5	6	6
– Synfuels	0	0	0	0	0	0	0	0	0	0	1	1	1
– Natural gas	0	0	0	0	0	0	0	1	0	1	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	1	1
– Electricity	0	0	0	0	0	0	0	0	1	1	1	1	1
Total RES	0	0	0	0	0	0	0	2	3	4	6	7	8
RES share	0%	0%	0%	0%	0%	0%	0%	4%	7%	8%	11%	12%	11%

Senegal: Heat supply and air conditioning [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0	8	8	9	10	10	11
– Fossil fuels	0	0	0	0	0	0	0	7	7	8	9	10	10
– Biomass	0	0	0	0	0	0	0	1	1	1	1	1	1
– Solar collectors	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat from CHP 1)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
Direct heating	39	48	49	37	43	44	49	50	54	61	66	71	73
– Fossil fuels	15	20	21	13	17	15	17	27	28	29	34	38	42
– Biomass	23	25	26	23	24	28	30	12	14	18	17	17	15
– Solar collectors	0	0	0	0	0	0	0	3	4	4	4	5	4
– Geothermal	0	0	0	0	0	0	0	1	2	2	3	3	3
– Heat pumps 2)	0	0	0	0	0	0	0	3	3	4	4	4	4
– Electric direct heating	2	3	2	2	2	2	2	3	3	2	2	2	2
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
Total heat supply 3)	39	48	49	37	43	44	49	58	63	70	76	81	84
– Fossil fuels	15	20	21	13	17	15	17	34	35	38	43	48	51
– Biomass	23	25	26	23	24	28	30	13	14	18	18	18	16
– Solar collectors	0	0	0	0	0	0	0	3	4	4	5	5	5
– Geothermal	0	0	0	0	0	0	0	1	2	2	3	3	3
– Heat pumps 2)	0	0	0	0	0	0	0	3	3	4	4	4	4
– Electric direct heating (incl. process heat)	2	3	2	2	2	2	2	4	4	4	4	4	4
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
RES share (including RES electricity)	59%	52%	54%	62%	57%	63%	61%	31%	34%	37%	35%	32%	30%
Electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Senegal: Installed Capacity [GW] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total generation	3	4	5	5	5	5	4	5	7	9	13	16	19
– Fossil	3	4	5	4	4	5	4	5	6	9	11	15	17
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas (w/o H_2)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil & Diesel	2	4	4	4	4	5	4	5	6	9	11	14	17
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen (fuel cells, gas power plants, gas CHP)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables	0	0	0	0	0	0	0	0	1	1	1	1	2
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	0	0	0	0	0	0	0
– of which wind offshore	0	0	0	0	0	0	0	0	0	0	0	0	0
– PV	0	0	0	0	0	0	0	0	0	0	1	1	1
– Biomass (& renewable waste)	0	0.0	0.0	0.0	0.0	0.0	0.023	0.027	0.037	0.050	0.066	0.1	0.1
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	0	0	1	1	1	1	2
Share of variable RES	0%	0%	0%	2%	5%	6%	8%	7%	8%	8%	8%	8%	8%
RES share (domestic generation)	1%	0%	0%	2%	6%	7%	9%	8%	8%	8%	9%	8%	9%

Senegal: Final Energy Demand [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	80	101	107	91	101	107	123	131	146	172	199	228	254
Total Energy use 1)	78	101	107	91	101	107	111	118	132	156	180	207	230
Transport	29	37	40	36	40	43	40	42	45	50	57	64	73
– Oil products	29	37	40	36	40	43	40	40	41	46	49	56	64
– Natural gas	0	0	0	0	0	0	0	1	0	1	0	0	0
– Biofuels	0	0	0	0	0	0	0	1	3	4	5	6	6
– Synfuels	0	0	0	0	0	0	0	0	0	0	1	1	1
– Electricity	0	0	0	0	0	0	0	0	1	1	1	1	1
– RES electricity	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	1	1
– RES share Transport	0%	0%	0%	0%	0%	0%	0%	4%	7%	8%	11%	12%	11%
Industry	17	23	23	14	17	21	22	25	33	45	58	72	84
– Electricity	3	4	3	3	4	7	7	9	13	18	23	29	34
– RES electricity	0	0	0	0	0	1	1	1	2	2	3	4	5
– Public district heat	0	0	0	0	0	0	0	2	2	3	4	4	5
– RES district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal & lignite	9	13	13	9	11	9	11	2	3	4	5	6	7
– Oil products	3	6	6	1	1	1	1	1	1	2	2	3	3
– Gas	0	0	0	0	0	0	0	8	11	14	18	22	26
– Solar	0	0	0	0	0	0	0	1	1	1	1	2	2
– Biomass	1	1	1	1	0	4	4	2	2	3	4	5	5
– Geothermal	0	0	0	0	0	0	0	0	0	0	1	1	1
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES share Industry	9%	4%	6%	5%	5%	22%	22%	15%	16%	16%	16%	16%	16%
Other Sectors	33	41	44	41	44	44	49	51	54	61	66	71	74
– Electricity	8	9	10	11	11	10	10	12	15	21	27	35	42
– RES electricity	0	0	0	0	1	1	1	1	2	3	4	4	6
– Public district heat	0	0	0	0	0	0	0	5	5	5	5	4	4
– RES district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal & lignite	0	0	0	0	0	0	0	2	2	2	2	2	2
– Oil products	5	5	6	5	7	7	7	4	3	3	3	3	2
– Gas	0	0	0	0	0	0	0	12	11	8	7	7	6
– Solar	0	0	0	0	0	0	0	2	3	3	3	3	2
– Biomass	20	26	28	26	26	27	33	14	14	18	17	15	13
– Geothermal	0	0	0	0	0	0	0	1	1	2	3	2	2
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– RES share Other Sectors	63%	65%	65%	63%	61%	63%	69%	36%	38%	43%	40%	36%	33%
Total RES	22	28	30	27	28	32	39	24	29	37	42	44	46
RES share	28%	27%	28%	30%	28%	30%	35%	20%	22%	24%	23%	21%	20%
Non energy use	2	0	0	0	0	0	12	12	14	16	18	21	24
– Oil	2	0	0	0	0	0	12	12	14	16	18	21	23
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Coal	0	0	0	0	0	0	0	0	0	0	0	0	0

Senegal: Energy-Releated CO_2 Emissions [Million tons/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	1	2	3	5	5	4	5	7	11	16	24	33	31
– Hard coal (& non-renewable waste)	0	0	1	0	1	1	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil + Diesel	1	2	2	5	4	3	5	7	11	16	23	33	30
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	1	2	3	5	5	4	5	7	11	16	24	33	31
– Hard coal (& non-renewable waste)	0	0	1	0	1	1	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil + Diesel	1	2	2	5	4	3	5	7	11	16	23	33	30
CO_2 intensity (g/kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– CO_2 intensity fossil electr. generation	437	573	633	1,203	1,078	703	1,197	1,231	1,526	1,631	1,766	1,946	1,526
– CO_2 intensity total electr. generation	430	563	624	1,158	1,000	643	1,051	1,083	1,333	1,424	1,536	1,696	1,315
CO_2 emissions by sector	6	8	9	10	10	9	11	13	17	23	31	41	40
– Industry 1)	1	2	2	1	2	1	2	1	1	1	2	2	2
– Other sectors 1)	0	0	1	0	1	1	1	2	2	2	2	2	2
– Transport	2	3	3	3	3	3	3	3	3	3	4	4	5
– Power generation 2)	1	2	3	5	5	4	5	7	11	16	24	33	31
– Other conversion 3) - part of industry & transport	0	0	0	0	0	0	1	1	1	1	2	2	2
Population (Mill.)	13	15	15	15	16	16	17	19	21	22	22	23	23
CO_2 emissions per capita (t/capita)	0	1	1	1	1	1	1	1	1	1	1	2	2

Senegal: Primary Energy Demand [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	145	152	160	183	186	177	213	214	283	369	476	620	605
– Fossil (excluding on-energy use)	82	94	104	121	123	108	132	173	235	311	415	554	536
– Hard coal	12	16	19	14	18	18	12	7	8	10	11	13	15
– Lignite	0	0	0	0	0	0	0	1	1	1	1	1	1
– Natural gas	2	2	2	2	1	2	1	28	30	31	34	38	41
– Crude oil	68	77	83	105	103	88	119	137	197	270	369	502	479
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables	62	58	56	62	63	69	68	29	34	41	43	44	45
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0
– Wind	0	0	0	0	0	0	1	1	1	1	2	3	3
– Solar	0	0	0	0	1	1	1	4	6	7	8	8	9
– Biomass	62	58	56	62	62	68	67	22	25	31	29	29	29
– Geothermal	0	0	0	0	0	0	0	1	2	2	3	3	3
– Ocean energy	0	0	0	0	0	0	0	0	0	0	1	1	1
Total RES	72	58	56	62	63	69	68	29	34	41	42	44	44
RES share	52%	38%	35%	34%	34%	39%	34%	14%	12%	12%	9%	7%	8%

Notes

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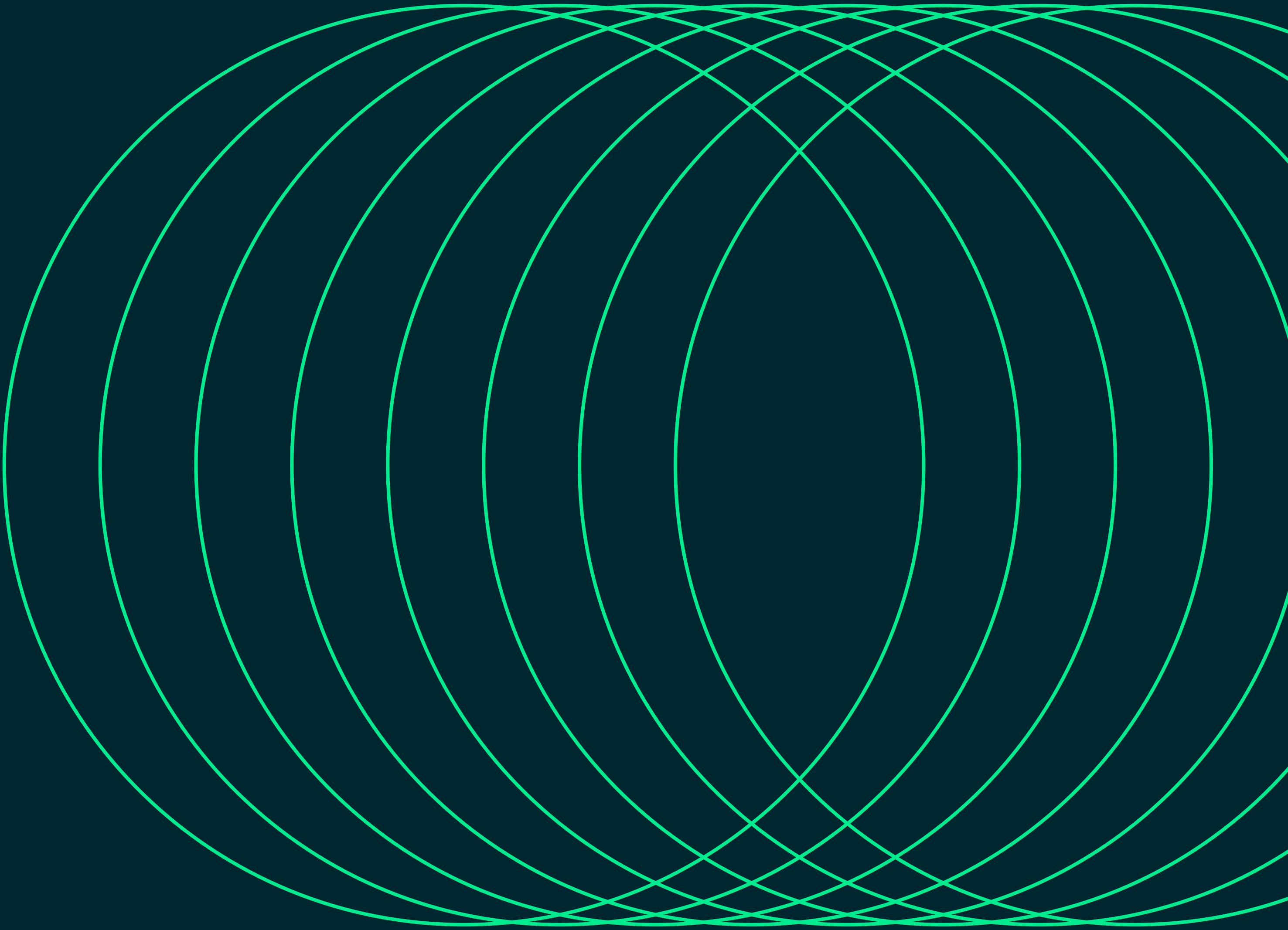

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