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Sustainable Electricity Generation and Transmission in the Kingdom of Morocco

Including Application of Geographic Information Systems

Minnebo, P., Vuillaume, J.-F., Ardelean, M.

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Joint Research Centre

EUR 31517 EN

Contact information
Name: Philip Minnebo
Email: philip.minnebo@ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

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EUR 31517 EN

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Contents

Abstract

This technical report presents a concise assessment of the Moroccan power system, in relation to the country's pursued clean energy transition. It provides an introduction into the most critical factors affecting this transition, both technical and regulatory, with focus on development of generation and transmission assets of clean electricity. Morocco's general energy and climate change characteristics are discussed, giving emphasis to related engagement and international collaborations. The legal framework of the Moroccan power sector is addressed, along with basic data on electricity demand, generation and transmission. Sources for more sustainable electricity generation are discussed, i.e., primarily renewable energy (solar, wind and hydro), as well as natural gas in the energy transition, and the option of nuclear energy. Past, ongoing and future transmission system development programmes are treated. The role of geographic information systems in the planning phase of power generation and transmission installations is considered. Future investment needs are highlighted, along with the most pertinent funding organisations.

1 Introduction

Clean energy transitions, which are important enablers of ongoing green transitions, require energy sectors to transform their assets from fossil fuel-based towards zero-carbon operation. The main driver of this objective is the urgent need to reduce energy-related CO_2 emissions to limit climate change. Globally, fossil-fuel combustion accounts for about 90% of these emissions, of which electricity generation is the largest contributor, with roughly 35% (Netherlands Environmental Assessment Agency, 2022). Hence, worldwide power sectors offer significant opportunities in the combat against climate change, i.e., by minimising the use of coal, oil, natural gas, and other forms of fossil fuel for the production of electricity. Instead, the deployment of renewable energy sources (RES) should be boosted, with current energy policies generally giving emphasis to solar, wind and hydropower. The substantial increase of RES in the energy mix has a pertinent impact on another critical aspect of power systems: security of electricity supply. On the one hand, it leads to additional sources and suppliers, with an inherent positive impact on supply security. On the other hand, concerns arise from the intermittent nature of RES, potentially jeopardising supply security. Hence, advanced electricity systems are needed to effectively restore the supply-demand balance at all times. Energy storage systems and electricity interconnections are key solutions in this context, allowing for respectively storing or transferring extra power and making it available at other times or other places, with occurring shortages (Minnebo, P., Ardelean, M., 2021). Also other types of power plants have a potential role in addressing the variability, induced by RES. Innovative gas-fired facilities, with short start-up time, high ramp rate and low minimum load, are suitable to cover peak load (Ministry of Economic Affairs of the Netherlands, 2016). Although lacking political consensus, also advanced nuclear power offers opportunities, i.e., by providing both baseload capacity and built-in flexibility (International Energy Agency, 2019). Against this background, it has become technically challenging for individual countries to engage in a clean energy transition and secure electricity supply at the same time, while acting unilaterally in isolation from their neighbours (Jigang, W., Webb, P., 2020). Interconnection of national transmission systems is required, along with coupled electricity markets and streamlined regulatory frameworks, allowing for electricity trade in a regional context. The European Union (EU) is an obvious trendsetter in this respect, with its integrated electricity market, offering a cost-effective way to ensure secure and affordable supplies to its citizens, while pursuing ambitious objectives for renewable energy. Physical integration of electricity infrastructure between member states (MS) is imposed, with targets for interconnection of installed electricity production (Steinbacher, K., et al., 2019).

The North African states – Morocco, Algeria, Tunisia, Libya, and Egypt – are confronted with a variety of factors that influence their respective energy transitions. The region includes both important hydrocarbon producers and exporters (Algeria, Egypt, and Libya) and countries that are heavily dependent on imports to meet domestic energy demand (mainly Morocco and Tunisia). Additional aspects, including socio-economic and political contexts, further diversify the specific challenges and opportunities towards successful energy transitions. Nevertheless, final energy consumption in the region is still dominated by oil, with the transport and residential sectors as main contributors. Along with growing energy demand, this share has significantly increased during last two decades. With respect to electricity generation, natural gas is currently predominant, except in the case of Morocco (coal). The abundant RES are largely untapped, nevertheless with some promising developments in Morocco and Egypt. Consequently, the region represents a large share of the energy-related CO_2 emissions in Africa, a continent where emissions are relatively low, but nonetheless growing. Climate change effects are very similar across the region, especially with regard to water stress, e.g., involving detrimental implications for the important agriculture sector. Against this background, transition to more sustainable energy systems has become an increasing priority for the North African countries. All countries have established related policies and set renewable energy targets (International Energy Agency, 2020). Along with the major regional discrepancies (see above), energy security in North Africa largely depends on domestically exploited energy sources, i.e., predominantly oil and natural gas. Countries that currently rely on oil and gas imports have manifold opportunities to improve their energy security, by exploiting the abundant domestic RES, which goes hand in hand with pursued clean energy transitions. Although far from being straightforward, enhanced regional energy collaboration would be an additional enabler of both deployment of RES and energy security. Moreover, this collaboration could lead to more profitable energy trade, along with better prices for producers, merchants, and consumers. Presently, focus is on fostering trade of electricity (from RES) and natural gas, replacing oil in the energy transition. Regional trade agreements, investments in energy infrastructures, market-based prices, and a harmonised regulatory environment are required to achieve the full benefits of the envisaged trade (Pan-Arab Regional Energy Trade Conference, 2019). Although economic viability is currently under extensive discussion, massive opportunities are expected from generation and trade of green hydrogen in the North African region (Frontier Economics, 2021). In the context of the future Mediterranean Green Hydrogen Partnership, the EU has identified the North African countries as major partners for green hydrogen imports. These imports should significantly underpin the EU's energy security and climate neutrality targets (European Commission, 2022).

The Kingdom of Morocco holds a remarkable position within the ongoing North African energy transitions. On the one hand, this nation is still confronted with the region's general challenges from the past, especially the extensive dependence on fossil fuels. Given Morocco's strong economic growth, this situation shows an increasing trend, involving significant energy security threats, as Morocco imports more than 90% of its energy needs. Moreover, it goes along with rising greenhouse gas (GHG) emissions, whereas Morocco is particularly vulnerable to climate change. On the other hand, the country owns substantial opportunities for sustainable energy sector development, especially by making use of its significant potential of RES for electricity generation. Accordingly, Morocco has developed and implemented ambitious energy strategies and policies since more than one decade, which have already resulted in clear achievements, e.g., significant increase of RES deployment and almost general access to electricity (International Energy Agency, 2019).

In the context of its Green Deal, in particular for the achievement of climate neutrality by 2050, the EU needs to mobilise crucial countries in its Neighbourhood, especially for renewable energy imports. Morocco is one of the countries in the Southern Neighbourhood that offers great potential as a 'green partner', along with its substantial RES, its green hydrogen potential, and its ambitious energy policies (European Council on Foreign Relations, 2022). One of the five pillars of the EU Global Gateway Strategy, i.e., climate and energy, involves worldwide investments in smart, clean and secure energy links (European Commission, 2021). In the case of Morocco, potential investments offer opportunities for new or reinforced energy interconnections between this nation and the EU, particularly power cables and hydrogen pipelines (Morocco World News, 2021).

The main purpose of current report is to present an overall but concise picture of the Moroccan power system infrastructure in relation to the country's pursued clean energy transition. It provides an introduction into the most critical affecting factors, both technical and regulatory, without focussing on in-depth scientific analyses. Besides presenting the current status, special attention is paid to the development of infrastructures for the generation and transmission of clean electricity. In Section 2, basic energy facts and trends in Morocco are given, together with related impact on climate and air. The country's climate change response is presented, as well as examples of international collaboration efforts. Section 3 gives an overview of Morocco's power sector, by providing its legal framework, as well as basic data of electricity generation and transmission. Sections 4 and 5 present options for more sustainable electricity generation and transmission, respectively. Corresponding development programmes are discussed. Section 6 addresses the role of geographic information systems (GIS) in the planning of more sustainable power systems, considering both renewable energy plants and electricity transmission lines. Finally, Section 7 gives the overall conclusions of the report, also considering future investment needs in the Moroccan power system.

2 General energy and climate aspects

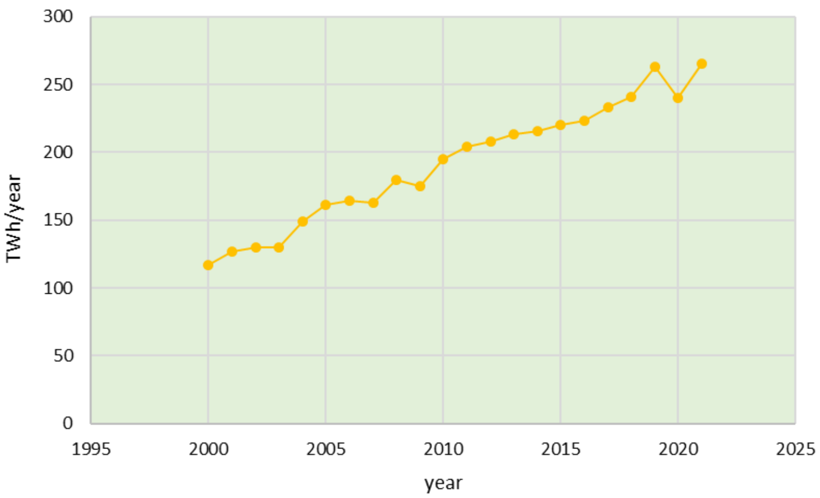
2.1 High-level energy authorities

The Moroccan energy sector falls under the authority of the Ministry of Energy Transition and Sustainable Development (MTEDD), formerly the Ministry of Energy, Mines, Water and Environment (MEMEE), which is responsible for developing and implementing policies, laws and regulations in the field of energy, including electricity and renewable energy, as well as oil and gas. The ministry underpins energy asset development and sets rules for energy markets. In addition, it is in charge of taking emergency measures to ensure security of energy supply in case of crisis. The Ministry of Economy and Finance (MEF) oversees the financial side of the energy sector, supervises all state-owned energy enterprises, and evaluates their investment plans (Popkostova, Y., 2022).

2.2 Energy sector facts

Currently, Morocco's energy sector is still highly carbon-intensive. In 2017, fossil fuels accounted for nearly 90% of its total primary energy supply (PES). Herein, oil was predominant (62%), followed by coal (22%) and natural gas (5%) (International Energy Agency, 2019). Morocco has experienced strong economic growth in recent years, with a typical annual increase of 4%, as the country has transitioned from a predominantly agriculture-based economy to one with a greater proportion of manufacturing and services (International Energy Agency, 2016). In line with this, the fossil fuel-dominated PES has shown an annual increase of 2.4% over the last decade, reaching 20.5 Mtoe already in 2017 (International Energy Agency, 2019). Similarly, Morocco's primary energy consumption (PEC) has experienced a steadily growing trend – see Figure 1 – with (equivalent) consumption values given in TWh/year.

Figure 1. Primary energy consumption trend in Morocco (2000-2021)



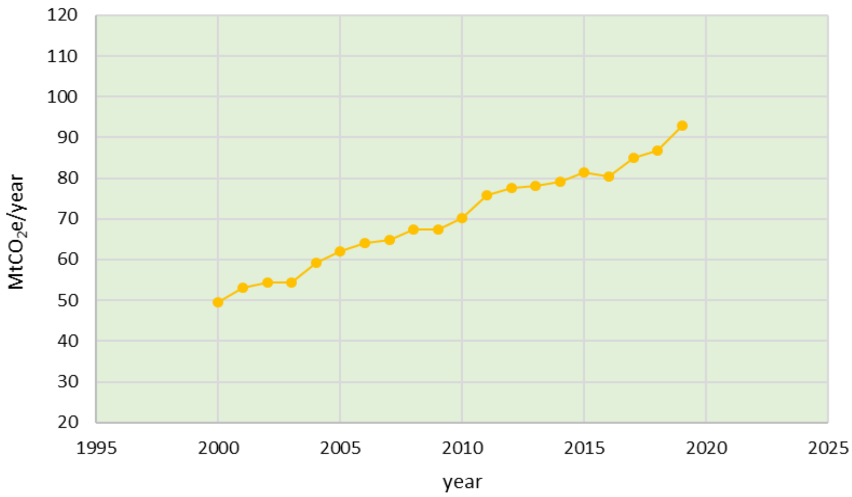
Data source: Ritchie, H., Roser M., 2020

Heavy reliance on imports of fossil fuels also has clear implications for Morocco's energy security, involving current and future threats and challenges (export.gov, 2019). Along with continuing diplomatic disputes, interruptions of natural gas supplies from Algeria clearly demonstrate this vulnerability (VOA, 2021). Morocco's increasing energy consumption will add more pressure on its energy system. The strategic dependency on energy imports implies that the Moroccan energy sector incorporates the risk of putting the national budget under a heavy financial burden in case of rising energy importation costs (Ainou, F.Z., et al., 2022).

2.3 Impact on climate and air

Following the increasing use of fossil fuel, GHG emissions in Morocco have risen substantially during the past decades – see Figure 2. In 2019, these emissions accounted for 93 $MtCO_{2}$-eq, corresponding to an increase of almost 40% with respect to 2009 (Macrotrends, 2022). The electricity and heat sector was accountable for 29 $MtCO_{2}$-eq of GHG emissions, followed by transport (19 $MtCO_{2}$-eq) and agriculture (15 $MtCO_{2}$-eq) (Ritchie, H., Roser, M., 2020). Due to its geographic conditions, Morocco is particularly vulnerable to climate change. Future climate trends in Morocco include rising temperatures of 1-1.5°C by 2050, together with a decrease in average precipitation of 10-20% across the country (United Nations Development Programme, 2022). Climate change already has important impacts on Morocco's natural, human and economic systems. Especially water resources are under increasing pressure (Climate Expert, 2022). Morocco's general economic growth occasionally declined in 2016, after it suffered a drought in 2015 (UKEssays, 2022). In line with the World Health Organization (WHO) guidelines, the general air quality in Morocco is relatively unsafe. The country's annual mean concentration of $PM_{2.5}$ is 33 μg/m^3, exceeding the recommended maximum of 10 μg/m^3 (IAMAT, 2022).

Figure 2. Greenhouse gas emissions in Morocco (2000-2019)



Data source: Macrotrends, 2022

2.4 Climate and energy engagement

In spite of above-mentioned developments, i.e., increasing fossil fuel use and GHG emissions, Morocco has shown clear engagement towards climate action during previous decades, especially in the area of overarching strategies and high-level documents. Associated policies include energy-related objectives and targets. Already in 2007, the Moroccan government established a National Committee for Climate Change (CNCC), which oversees all climate-affecting factors in the country, including energy. In 2009, Morocco adopted a National Energy Strategy (SEN), as a roadmap for the transition to a low-carbon energy system that reconciles economic development and environmental and social objectives. The 2009 National Plan to Fight against Global Warning (PNRC) included concrete targets for renewable energy, i.e. 10-12% of primary energy by 2020 and 15-20% by 2030. In 2014, Morocco developed its National Climate Change Policy (PCCM), as a coordination tool of all measures and initiatives on climate change. It provided an operational framework for the development of a medium and long-term strategy, with a vision for 2040 (Popkostova, Y., 2022). The National Sustainable Development Strategy (SNDD), which was adopted in 2017, was a low-carbon development strategy that aimed at coordinating the related objectives of all sectorial strategies and action plans. Strategic focus 9 ('Accelerate the implementation of policies on efficiency and energy transition') referred to an integrated New Energy Strategy (SER), which aimed at 42%[1] of installed electrical power, generated by renewable energy by 2020 (Kingdom of Morocco, 2017).

[1] By reaching a renewable energy capacity of 37% in 2020, this target was narrowly missed (BBC, 2023).

As a Non-Annex I Party, Morocco ratified both the Kyoto Protocol (2002) and the Paris Agreement (2016) (United Nations, 2022). In November 2016, Morocco hosted the UN Climate Change Summit in Marrakech (COP 22), which was more than a symbolic initiative of the Kingdom. The CNCC (see above) is responsible for drafting all national communications to the United Nations Framework Convention on Climate Change (UNFCCC). Accordingly, it issued the Moroccan Intended Nationally Determined Contribution (INDC) in 2015, outlining a vision of the country for 2030. Its Third National Communication to the UNFCCC (2016) included a summary of climate projections and studies, encompassing assessments of climate change impacts and vulnerabilities at national level. Also in 2016, Morocco submitted its first Nationally Determined Contribution (NDC), which was an improved version of the preceding INDC. Compared to the INDC, the level of ambition was raised for both unconditional and conditional GHG emission reduction targets. An unconditional GHG reduction target of 17% by 2030 was laid down, relative to a ‘business as usual’ scenario. Conditionally, i.e., dependent on availability of support from the international community, Morocco pledged a 42% GHG emission reduction by 2030 (Wuppertal Institute for Climate, Environment and Energy, 2018). The latter involved a decrease of 527 $MtCO_2$-eq of GHG emissions between 2020 and 2030. The budget required to reach the 42% reduction level was estimated at about USD 50 billion between 2010 and 2030, of which USD 24 billion would be conditional on international support (Kingdom of Morocco, 2016). Morocco’s Updated NDC of 2021 presented an overall GHG emission reduction of 45.5% by 2030, including an unconditional objective of 18.3% (Royaume du Maroc, 2021). The revised NDC included strategies and targets for seven sectors covered for mitigation, including energy production (NDC Partnership, 2021). At the COP21 (2015), the Kingdom announced a target of 52% for RES in the energy mix by 2030 (i.e., 20% solar, 20% wind, and 12% hydro). To meet this target, Morocco planned 10 GW of extra RES capacity between 2018 and 2030, consisting of 4560 MW of solar, 4200 MW of wind, and 1330 MW of hydropower capacity (International Energy Agency, 2019b).

2.5 International collaborations and support

Morocco’s strong climate and energy engagement has been materialised in the framework of several international cooperation schemes. Together with 27 EU MS and 14 Southern Mediterranean countries, Morocco launched the Union of the Mediterranean (UfM) in 2008. One of the fields of regional collaboration of the UfM is sustainable development, including energy and climate action. In 2021, this objective was confirmed during the third UfM ministerial meeting on energy, along with the intention to set a new clean energy transition pathway for the region, as well as priorities for strengthened regional cooperation in the energy sector (European Commission, 2021b).

Following the renewed EU European Neighbourhood Policy (ENP) of 2011, the European Neighbourhood Instrument (ENI) was the key financing instrument for bilateral cooperation with Morocco for the period 2014-2020, including funding of renewable energy projects in this country, while considering sustainable and inclusive growth, as well as cross-border cooperation. The Neighbourhood, Development and International Cooperation Instrument (NDICI – ‘Global Europe’) frames the EU’s cooperation for the period 2021-2027 (European Commission, 2022). The associated Multi-annual Indicative Programme (MIP) includes a specific objective, essentially aiming at the decarbonisation of the Moroccan economic sectors, which are responsible for important GHG emissions (including energy). The MIP also refers to the EU-Morocco Green Partnership, of which the MoU was signed in 2022 (European Commission, 2022b). The context of the MoU includes cooperation in the areas of energy transition and climate action. One of the objectives of the Partnership is to place both aspects in the centre of the bilateral relationship, together with associated commercial policies and sustainable investments. The ‘Decarbonisation of the Moroccan Economy’ field involves goals on:

- the development of renewable energy projects and related applications;
- the modernisation of electricity networks towards enhanced efficiency, stability and flexibility;
- the reinforcement of electricity interconnections between Morocco and Europe.

As part of Global Gateway, the EU mobilises – in a Team Europe approach – € 1.6 billion to finance energy transition projects in Morocco. The agreement between the EU and Moroccan authorities, which runs over five years, contributes to the country’s goal of increasing the share of renewable energy in its electricity mix to 52% by 2030 – see above (Africa Energy Portal, 2022). Morocco has officially pledged to support the EU to deploy Global Gateway, including energy connectivity between Europe and Africa (Morocco World News, 2021).

Also EU financial organisations support Morocco in its pursued energy transition. In example, the European Investment Bank (EIB) finances a feasibility study for an initial small-scale offshore wind energy pilot project in Morocco. This initiative could pave the way for intense deployment of this promising energy source (European Investment Bank, 2022). The strategic focus of the European Bank for Reconstruction and Development (EBRD) in Morocco includes a green economy transition through more sustainable energy and infrastructure. Accordingly, the bank has invested € 93 million in energy projects in the period 2015 - 2021, including for RES (European Bank for Reconstruction and Development, 2021).

Morocco has also entered in several bilateral climate and energy collaborations with individual EU MS. For instance, the German-Moroccan Energy Partnership PAREMA, which was already created in 2012, is a platform for institutionalised political dialogue on energy policy between both countries. It aims at moving forward on the energy transition, in particular by supporting Morocco's efforts in this field (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2022). Morocco and its European partners France, Germany, Portugal, and Spain have sealed the 'Sustainable Electricity Trade Roadmap' on the sidelines of the 2022 COP27 Climate Change Summit. The initiative, which aims to facilitate the mutually beneficial exchanges of renewable electricity between Morocco and the four EU countries through the gradual integration of their electricity markets, is supported by the EU and the UfM (The North Africa Post, 2022). As a final example, Finland and Morocco signed an MoU on energy cooperation in 2022. This MoU pursued the development of technical and economic cooperation between both countries in the energy sector, and promoted the access of Finnish companies to the Moroccan market (Ministry of Economic Affairs and Employment of Finland, 2022).

Also beyond the EU, the Kingdom of Morocco has engaged in energy collaborations with key partners. The US-Morocco Strategic Energy Working Group on Energy Cooperation and the Sino-Moroccan Energy and Hydrocarbon Industries Partnership are examples, including support towards deployment of renewables (U.S. Department of State, 2018) (Morocco world News, 2017). Energy cooperation with Russia is predominantly in the area of hydrocarbons and nuclear, towards the future (Morocco World News, 2019) (Morocco World News, 2022).

3 Power sector status

3.1 Authorities

In Morocco, the state-owned and vertically-integrated national power utility 'Office National de l'Électricité et de l'Eau Potable' (ONEE) is in charge of most generation activities, is the owner and operator of the transmission grid, performs the task of power dispatching, and is the largest distributor and retailer of electricity. In addition, it is responsible for electricity imports and exports. The utility is also in control of power generation and transmission master plans. ONEE is supervised technically by MTEDD and financially by MEF (Usman, Z., Amegroud, T., 2019). In 2011, ONEE was created as a merger between the 'Office National de l'Électricité' (ONE) and the 'Office National de l'Eau Potable' (ONEP) (Usman, Z., Amegroud, T., 2019).

In addition to ONEE, Morocco owns a relatively large number of electricity distribution companies that operate at regional, province or municipality level. Together with electricity, they usually take care of drinking water distribution. The public distribution companies are under the direct authority of the Directorate of Public Utilities and Concessions of the Ministry of the Interior (MdI), which also has oversight of the privatised companies. Table 1 presents an overview of these distribution companies in the Kingdom, both with public and privatised status.

Table 1. Electricity distribution companies in Morocco, in addition to 'Office National de l'Électricité et de l'Eau Potable'

Distribution Company	Legal Status	Region – Province – Municipality (or City)
AMENDIS	Privatised	Region Tangier - Tetouan
LYDEC	Privatised	Region Casablanca - Mohammedia
RADEEF	Public	Province Fez
RADEEJ	Public	Provinces El Jadida - Sidi Bennour
RADEEL	Public	Province Larache
RADEES	Public	Municipalities Safi - Jemaa Shaim - Tlet Bouguedra - Sebt Gzoula
RADEM	Public	Province Meknes
RADEEMA	Public	City Marrakech
RAK	Public	Municipalities Kénitra - Mehdya - Sidi Taibi - Haddada
REDAL	Privatised	Region Rabat - Salé - Témara - Skhirat - Bouznika - Charrat

Source: Popkostova, Y., 2022

The Moroccan Agency for Sustainable Energy (MASEN) was established in 2010, as the Moroccan Agency for Solar Energy, and leads and manages deployment of renewable energy for electricity generation. Accordingly, it develops renewable energy projects, and raises investments and funds to finance them. MASEN acts as a 'one-stop-shop': it organises tenders, signs power purchase agreements with independent power producers, while being responsible for permitting, land acquisition, and securing state guarantees for investments. MASEN also sells electricity from RES to ONEE, taking responsibility for the difference in price. Moreover, the agency conducts renewables resource assessment, and generation capacity planning in collaboration with ONEE (Usman, Z., Amegroud, T., 2019).

In 2016, Morocco introduced an independent administrative authority, the National Electricity Regulatory Agency (ANRE), with the mandate to regulate the 'open segment' of the country's power sector. Whereas ANRE was made responsible for the free electricity market, the Ministry of General Affairs (MAGG) remained in charge of tariff setting in the regulated segment. ANRE's legally determined functions include:

- regulating access to the national transmission grid;
- controlling and monitoring the efficient functioning of the open electricity market;
- setting the tariffs for the utilisation of the medium voltage (MV) grid (Bentaibi, W., et al., 2021).

Two main financial organisations have been established in Morocco, fostering investments in sustainable power system development (Popkostova, Y, 2022):

- The 'Société d'Investissement Énergétiques' (SIE), founded in 2010, is the public institution, financing and co-developping national programmes in the field of renewable energy and energy efficiency;
- The Morocco Sustainable Energy Financing Facility (MorSEFF), created in 2015, provides credits to local partner institutions towards investments in green-energy projects.

The Institute for Research into Solar and Renewable Energies (IRESEN), established in 2011, is an implementing and funding agency, which supports the SEN through applied research and fast technology transfer in the field of renewable energy. Moreover, IRESEN identifies strategic topics for future research, develops and implements joint R&D projects, and creates critical research maps. The institute links research results with industry, to develop innovative products, processes and services, which are market-oriented and create jobs (International Energy Agency, 2019).

3.2 Legal framework

Throughout previous decades, the Kingdom of Morocco has conceived and implemented ambitious power system policies, along with legal and regulatory reforms towards increased use of RES and enhanced energy efficiency. This development has been accompanied by a series of underpinning laws and decrees, of which the most relevant ones are summarised in Table 2. The Annex to the report provides more detailed information about applying Moroccan power sector laws and decrees, with focus on electricity generation and transmission.

Table 2. Principal power sector laws and decrees in Morocco

Law / Decree	Year	Subject
Decree N^{O} 1-63-226	1963	Creation of ONE.
Amendments		
Decree Law N^{O} 2-94-503	1994	Allows ONE to sign power purchase agreements with independent power producers.
Law N^{O} 28-01	2002	Authorises ONE's participation in private generation projects.
Law N^{O} 16-08	2008	Grants grid access to large renewable energy self-producers, raises the threshold for maximum self-generation capacity, and allows the sale of ONE surpluses.
Law N^{O} 54-14	2015	Allows private-to-private transactions of self-generators of electricity, and grants access to ONEE's[2] transmission grid for large self-producers.
Law N^{O} 38-16	2016	Transfers renewable energy assets of ONEE to MASEN.
Decree N^{O} 1548-02	2002	Sets rural electricity tariffs.
Law N^{O} 13-09	2010	Provides a legal framework for renewable energy projects and liberalises the renewable energy sector.
Amendments		
Law N^{O} 58-15	2015	Issues further measures, fostering private sector investment.
Decree N^{O} 2-10-578	2010	Specifies the rules and procedures for declaration and authorisation, as well as the provisions related to accessing High Voltage (HV) and Very High Voltage (VHV) networks.
Law N^{O} 57-09	2010	Establishment of MASEN as a Public Private Partnership.
Amendments		
Law N^{O} 37-16	2016	Makes MASEN a central player in the management of RES.
Law N^{O} 40-09	2011	Establishes ONEE, as merger of ONE and ONEP.
Decree N^{O} 2451-14	2014	Determines electricity tariffs and prices for the sale of electricity to distribution companies and final consumers.
Decree N^{O} 2-15-772	2015	Sets out the conditions and rules for the opening of the Medium Voltage (MV) network to renewable energy generation.
Law N^{O} 48-15	2016	Introduces ANRE as regulator of the open segment of the electricity sector.

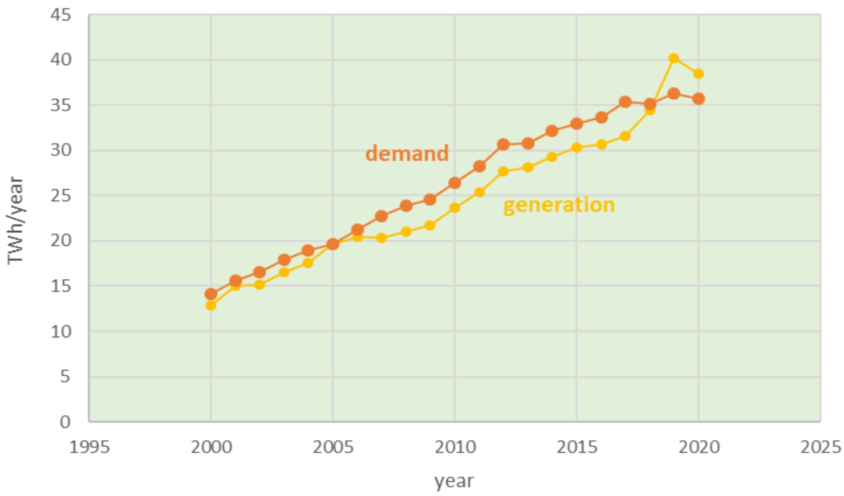
Source: Popkostova, Y., 2022

[2] ONE became ONEE in 2011.

3.3 Electricity demand and generation

Currently, access to electricity in Morocco is practically universal, whereas in 2000 only 70% of its inhabitants were connected to the grid (Ritchie, H., Roser, M., Rosado, P., 2020). Growing population and advances in socio-economic development, along with overall economic growth, have resulted in a rapidly increasing electricity demand. While large end-users have remained limited, a young and increasingly urban population has substantially contributed to this trend (Vagneur-Jones, 2021), which has been relatively well covered by the country's generation capacity – see Figure 3. During the last years, generation excess has allowed for power export towards neighbouring countries. In 2021, Morocco exported 851 GWh of electricity, worth 565 million dirhams, equivalent to about USD 60 million (The North Africa Post, 2022).

Figure 3. Electricity demand and generation in Morocco (2000-2020)



Data source: International Trade Administration, 2022

It is estimated that the annual electricity demand could further rise to either 80 TWh/year (historical data extrapolation), 115 TWh/year (national outlook), or 170 TWh/year (model based estimate) by 2050. This development would require the deployment of additional electricity generation capacities with volumes four times higher by 2030 and more than ten times higher by 2050 (Schinko, T., Bohm, S., Komendantova, N., et al., 2019).

In 2019, the total installed power capacity amounted to almost 11 GW, involving following energy sources: fossil fuels (66.4%), hydro (16.2%), wind (11.1%) and solar (6.3%) (Haidi, T., et al., 2021). Given the significant share of thermal power plants operated with fossil fuels (mainly coal), Morocco's power sector still offers significant opportunities towards reducing GHG emissions and improving air quality in the country. By boosting the use of renewable energy, substantial progress would be made in the given field. In addition, increased deployment of domestically available RES would considerably enhance energy security in the country. These energy transition objectives also require a performant electricity grid, with optimal stability and efficiency.

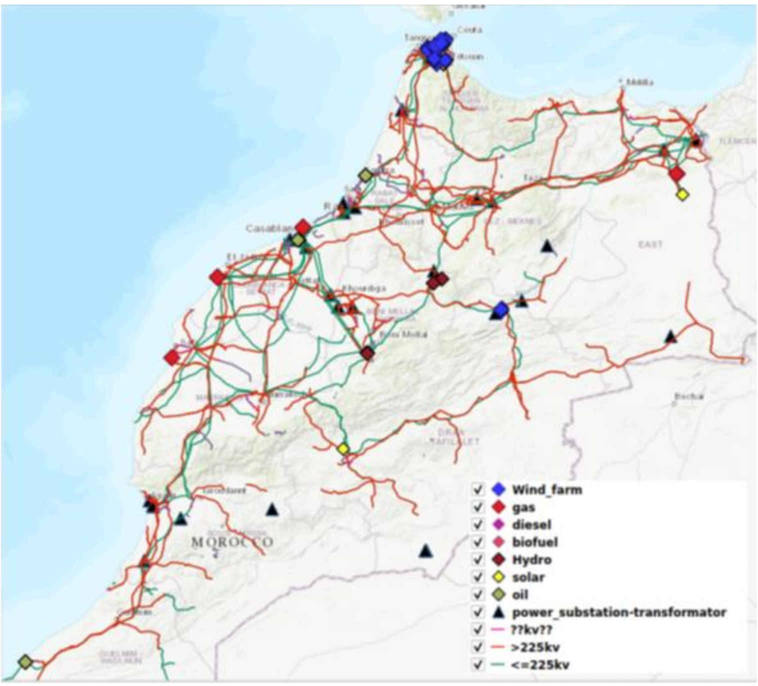
3.4 Electricity transmission grid

During previous decades, the Moroccan electricity transmission grid has been regularly upgraded, through a number of major national and regional electrification programmes, e.g.:

- Morocco's Global Rural Electrification Programme (PERG) (1995 – 2008);
- the National Development Programme Pillar 2, following the African Development Bank (AfDB) Country Strategy Paper for Morocco (2007-2011);
- the Network Development and Reinforcement Programme (2008-2013).

Primarily with the support of the AfDB, additional upgrades of the grid took place during the last ten years. By the end of 2017, the electricity transmission network of Morocco included 25885 km of HV lines: 3681 km of 400 kV lines, 9708 km of 225 kV lines, 147 km of 150 kV lines, and 12349 km of 60 kV lines (Royaume du Maroc, 2019). At the end of 2021, the total length of the transmission network had further increased to 28352 km, with an installed power transmission capacity of 27377 MVA (Office National de l'Electricité et de l'Eau Potable, 2022).

Figure 4. Morocco electricity transmission grid (and power plants) – backbone structure



Source: ENTSO-E Grid Map, 2019

The Moroccan transmission network is interconnected with the grids of Spain and Algeria, with the objective to enhance the reliability and security of supply, and to profit from beneficial electricity trade. The subsea connection between Morocco and Spain is realised via two 400 kV power cables. These cables enable net transfer capacities of 900 MW from Spain to Morocco and 600 MW from Morocco to Spain (Popkostova, Y., 2022). The 1500 MW connection with Algeria is established by two 400 kV lines and two 225 kV lines (Azeroual, M., et al., 2018). The 400 kV lines are part of a Morocco-Algeria-Tunisia transmission interconnection, which was commissioned in 2009. The resulting international 400 kV grid constitutes a synchronous system, which is connected to the Continental Europe Synchronous Area (CESA) via Spain (Popkostova, Y., 2022).

4 Energy sources for sustainable electricity generation

4.1 Great focus on renewable energy

Table 3 presents the estimated potential of Morocco's domestically available solar, wind and hydropower, of which exploitation developments are discussed below.

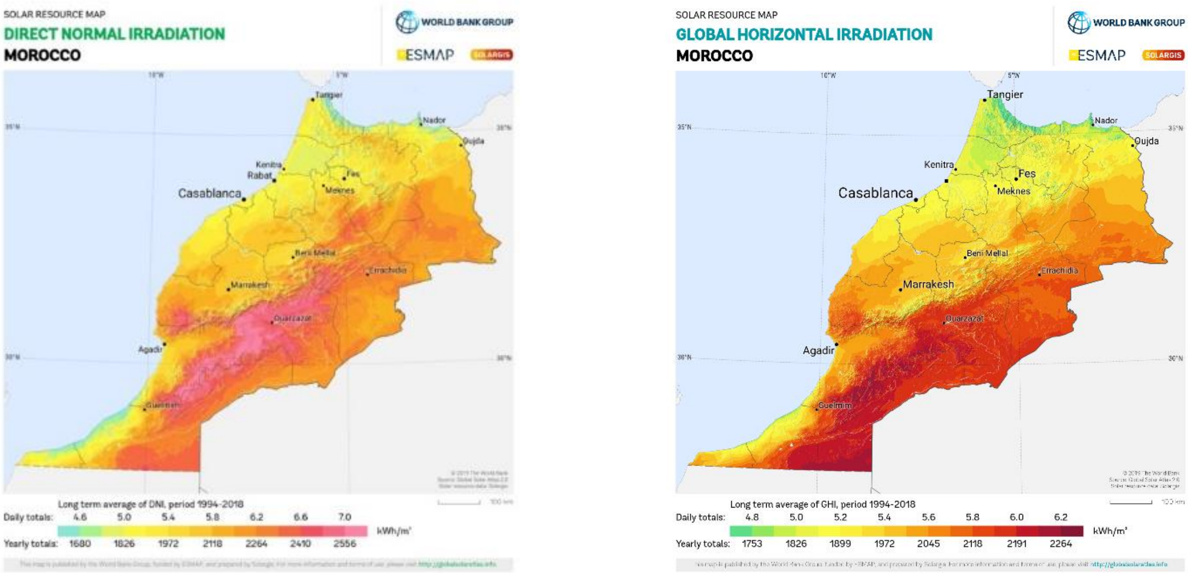
Table 3. Theoretical potential of solar, wind and hydropower in Morocco

Electric power potential (GW)		
Solar	Wind	Hydro
Concentrated solar power (CSP) 25437 Photovoltaic (PV) 31200	2645	26

Data source: United Nations Economic and Social Commission for Western Asia, 2018

Due to its favourable geographical location, the Kingdom of Morocco owns great solar energy potential. Figure 5 shows the most 'attractive' regions in the country, i.e., both in terms of direct normal irradiation (DNI) – crucial for CSP – and global horizontal irradiation (GHI) – essential for PV. Average irradiation levels are estimated well above 5 kWh/m^2/day.

Figure 5. Moroccan solar energy potential (direct normal and global horizontal irradiation)



Source: Solargis, 2022

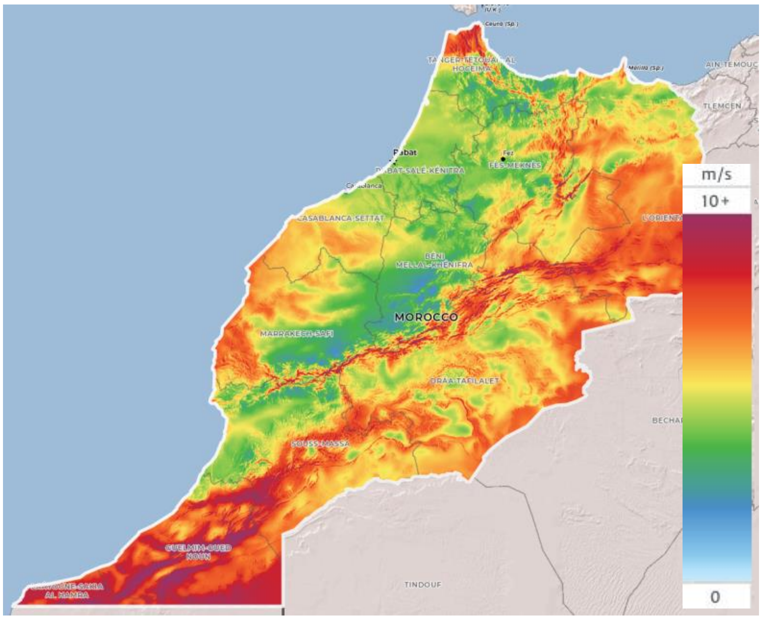
Towards increasing the capacity of renewable energy generation, the Kingdom of Morocco has set a target for solar energy of 4560 MW by 2030, representing 20% of the country's overall electricity production (Azeroual, M., et al., 2018). Currently, installed solar energy capacity in Morocco amounts to approximately 760 MW (REGLOBAL, 2022). This capacity mainly comes from the Noor Ouarzazate plant in Central Morocco, which includes the world's largest CSP facility (510 MW). The plant began operation in 2016, with the Noor Ouarzazate I facility, offering 90 MW of CSP and 70 MW of PV. In 2018, Noor Ouarzazate II, III and IV became operational, adding 200 MW, 150 MW and 70 MW of CSP, respectively. Other significant solar projects are in progress, including the Noor Midelt solar project, which will be located in the Atlas Mountains. This project will involve 800 MW of generation capacity (Oxford Business Group, 2022).

Figure 6. Noor Ouarzazate II-III concentrated solar power complex

Source: © EURACTIV, 2022

Figure 7 gives average wind speeds in Morocco (Global Wind Atlas, 2023), measured at an anemometer height of 100 m, corresponding to current wind turbine hub heights (Office of Energy Efficiency & Renewable Energy, 2022). Along Morocco's 3500 km-long coast line, annual mean wind speeds of up to 11 m/s are apparent. In the Atlantic coastal regions, wind potential is particularly significant in the South (Kousksou, T., et al., 2015).

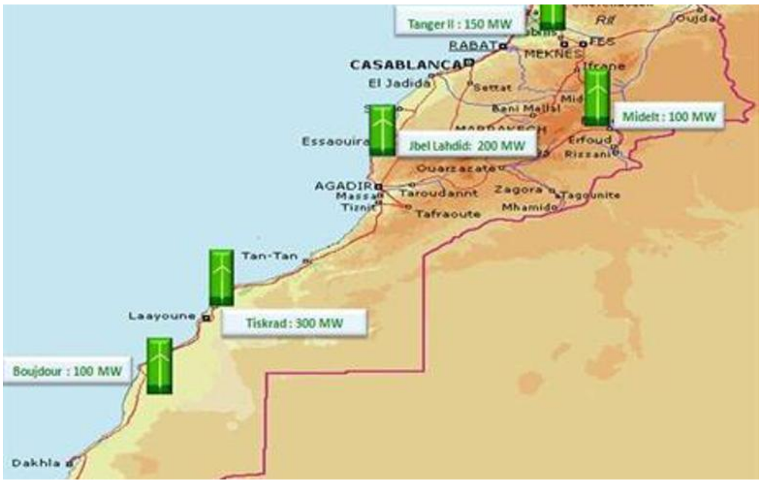
Figure 7. Morocco wind map (100 m height)



Source: Global Wind Atlas, 2023

Morocco aims at achieving 4200 MW of wind power by 2030, i.e., about 20% of its electricity production capacity – see above. A major development was ONEE's tender for 850 MW of wind power (2012) at five different sites: Tangier II (150 MW), Midelt (100 MW), Jbel Lahdid (200 MW), Tiskrad (300 MW), and Boujdour (100 MW) (Renewables Now, 2016) – see also Figure 8. This tender followed the Taza 150 MW wind farm project, which was initiated in 2011 (Azeroual, M., et al., 2018). Several of these plants are currently operational, some of them already with increased capacity (Oxford Business Group, 2022). In 2021, total wind power installed in Morocco amounted to 1350 MW (Morocco World News, 2021). This also included the 300 MW plant in the Tarfaya province (Oxford Business Group, 2022). Offshore wind development is currently limited to feasibility studies (European Investment Bank, 2022).

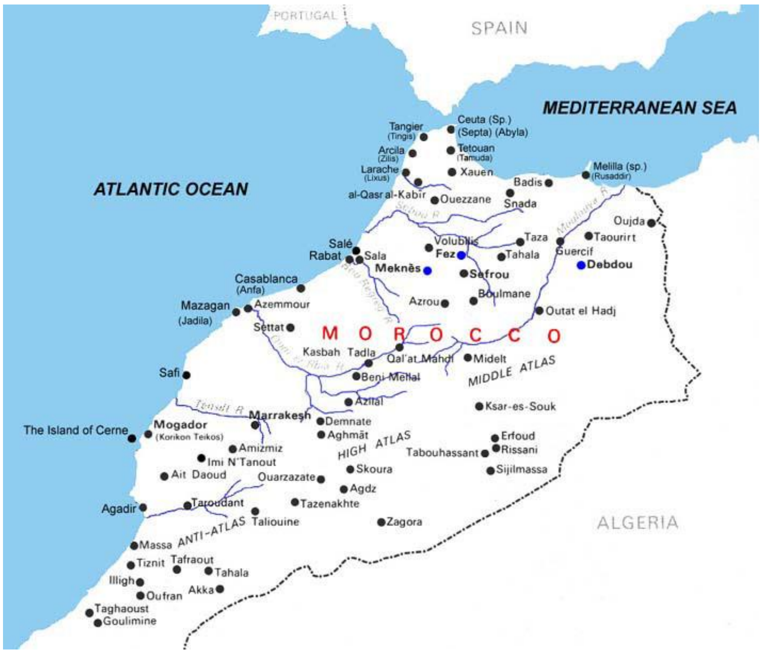
Figure 8. 850 MW wind tender projects of 'Office National de l'Électricité et de l'Eau Potable'



Source: Renewables Now, 2016

Morocco's territory includes seven major river basins. These basins are associated with following main rivers and their tributaries (from North to South): Loukkos, Moulouya, Sebou, Bou Regreg, Oum Er-Rbia, Tensift, and Souss-Massa-Drâa. Except for Loukkos, these rivers originate in the Atlas Mountains (World Atlas, 2017). These mountains, with their substantial water reserves and sufficiently high elevation range, result in significant hydropower potential. Aitchfi et al. (2022) have determined flow velocities, exceeding 1.2 m/s for the Sebou river, which originates in the Middle Atlas.

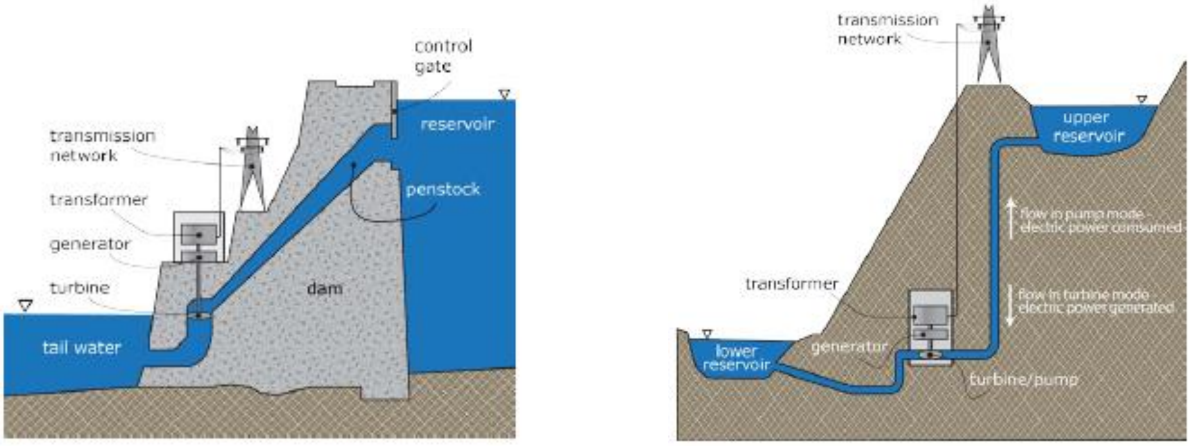
Figure 9. Main rivers of Morocco



Source: Vidiani.com, 2011

Currently, there are more than 140 large dams in operation in Morocco. While most of them are used for water supply, irrigation and flood control, the country currently owns about 1300 MW of installed hydropower, including both reservoir-based and pumped storage systems – see Figure 10. The latter is an important tool for balancing a power system, which is heavily based on RES. Opportunities for seawater-pumped storage hydropower plants are apparent. A number of hydropower facilities are currently under construction and a variety of projects are planned by 2030, including about 60 large hydropower dams (Andritz HYDRO, 2022). In 2017, ONEE announced the construction of two major pumped storage stations, with a total capacity of 600 MW: the El Menzel II facility, in the upper Sebou, and the Ifahsa plant, on the right bank of Oued Laou. Ifasha is scheduled to be completed by 2025 (International Hydropower Association, 2018).

Figure 10. Schematic of reservoir-based and pumped storage hydropower systems



Source: Viadero, R., et al., 2017

4.2 Natural gas in the energy transition

In today's energy transitions, natural gas is considered as a valuable replacement for coal and oil. Switching between consumption of fossil fuels does not provide a long-term answer to climate change, but there can nonetheless be significant CO_2 and air quality benefits in the shorter term. Accordingly, coal-to-gas switching has saved around 500 $MtCO_2$ emissions worldwide, in the period 2010-2018 (International Energy Agency, 2019c).

This option offers attractive opportunities for the Kingdom of Morocco, as electricity generation from coal is still predominant (37% in 2021) and the country owns a considerable quantity of proven gas reserves (1.44 billion cubic metres in 2021) (International Trade Administration, 2022) (CIA, 2022). Morocco continues to successfully search for gas within its borders, and significant additional discoveries have been made recently, as confirmed by Global Data (2021). Further exploiting its gas reserves would drastically decrease Morocco's dependence on Algerian gas supplies (representing 10% of the electricity generation), which are fully insecure, given the continuing deterioration of their mutual political relations. In fact, Morocco was cut off from Algerian gas in November 2021 (Reuters, 2021). Since mid-2022, Spain is supporting Morocco, by enabling the supply of natural gas through the Maghreb-Europe Gas Pipeline (GME), in the 'opposite direction' (Reuters, 2022). Morocco has concluded contracts for the purchase of liquefied natural gas (LNG) on the international market, and uses the infrastructure of Spanish operators and the GME to import the gas (Energynews, 2022). Towards the future, the Kingdom plans to make use of the subsea Nigeria-Morocco Gas Pipeline to further secure its gas supply (The North Africa Post, 2022). The utilisation of this pipeline would enable Morocco to strengthen its role as transit country for natural gas towards the EU. Along with improving security of gas supply, Morocco has already recommissioned its two main gas power plants, i.e., the 800 MW Al Wahda and the 380 MW Tahaddart stations (Energynews, 2022). These and future gas-powered plants will also be required to provide the flexibility needed for greater use of renewables.

Figure 11. The recommissioned gas power plant in Tahaddart

Source: © Embassy of the Kingdom of Morocco, New Delhi, 2021

With respect to electricity generation from fossil fuels, Moroccan plans for electricity sources foresee following developments from 2020 to 2030 (Azeroual, M., et al., 2018):

- coal – a decrease from 40 to 20%;
- fuel oil and diesel – a decrease from 11% to 3%;
- natural gas – an increase from 5 to 25%.

Accordingly, Morocco aims to add 2400 MW of combined-cycle technology to expand its gas-fuelled power generation capacity. This will be realised through two 1200 MW combined-cycle gas turbine (CCGT) power plants, to be constructed in Jorf Lasfar and Kénitra, respectively. In addition, there are plans to develop an LNG import terminal in Jorf Lasfar, an onshore regasification unit, and a pipeline to link the terminal to the GME. Further, the country will ensure that a more robust regulatory framework is in place for the use of gas by the power sector, as well as for gas transport and pricing (Oxford Business Group, 2022).

4.3 The nuclear option

The Kingdom of Morocco considers nuclear energy as a potential electricity source in the longer term (2030 – 2050). To this end, studies are being developed using International Atomic Energy Agency (IAEA) and ONEE energy planning models and tools. In addition, fuel procurement and radioactive waste management is under investigation by the 'Comité de Réflexion sur l'Électronucléaire et le Dessalement d'Eau de Mer par Voie Nucléaire' (CRED). The available amount of uranium in Moroccan phosphates is estimated at about 6.9 million tonnes. A nuclear regulatory body, the Moroccan Nuclear Safety and Security Authority (AMSSNuR), has been established, primarily to elaborate applicable laws and regulations, and to authorise and control nuclear installations (International Atomic Energy Agency, 2018).

Already in 1994, an exhaustive study led to the pre-selection of the Sidi Boulbra site, located on the Atlantic coast between Safi and Essaouira, as the most appropriate location for a nuclear power plant (NPP). This site is owned by ONEE. The implementation of the NPP project has been continuously postponed, mainly because of the non-competitiveness of nuclear energy, compared with the alternative fossil fuel option (i.e., coal). However, in the meantime a pre-selection process has been undertaken by ONEE, involving non-bidding offers, related to a NPP project, based on two units of 700 to 1000 MW, respectively (International Atomic Energy Agency, 2018). The envisaged offers encompass:

- engineering, procurement and construction;
- operation and maintenance;
- services related to nuclear fuel.

Recently, Morocco and Russia have concluded a nuclear cooperation agreement. According to the Russian News Agency TASS, the agreement encompasses at least 14 specific collaboration areas. In example, the Russian state atomic energy company Rosatom would collaborate with the Moroccan National Centre for Nuclear Energy, Sciences and Techniques (CNESTEN), by contributing to the design and construction of nuclear reactors and by sharing its expertise in the field of fuel cycle, spent nuclear fuel and waste management (Morocco World News, 2022). Following the Israel-Morocco normalisation agreement, the Kingdom has also recently entered into a partnership with Israel in the nuclear field. Although Israel has no nuclear plants, it operates nuclear research reactors and is willing to share nuclear technology expertise with various Moroccan research institutes (Atalayar, 2022).

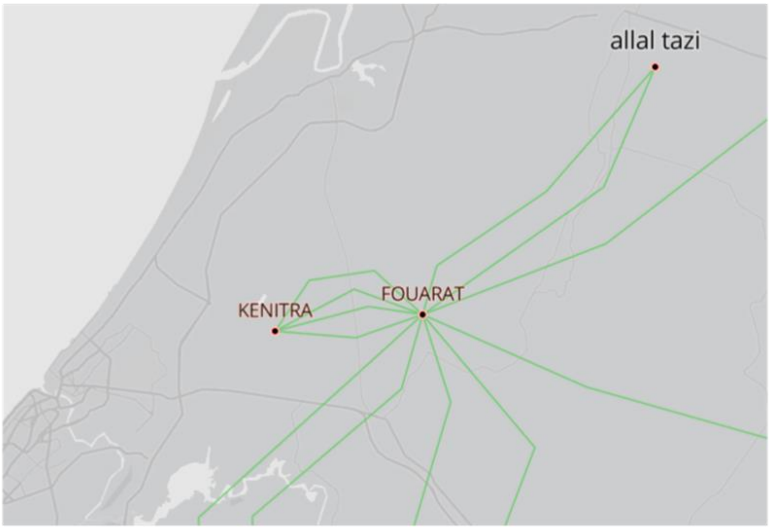
5 Electricity transmission system development

5.1 Power Transmission and Distribution Network Development Project

Along with growing electricity demand and increasing use of RES, further modernisation of the Moroccan transmission network, as well as the development of regional and international interconnections, has become increasingly needed during recent years. The upgrade of Morocco's electricity transmission grid underpins the National Sustainable Development Strategy (SNDD), as energy is an essential input to all socio-economic activities in the Kingdom. As already briefly discussed in Section 3.4, the AfDB has played a crucial funding role in associated programmes. Its Power Transmission and Distribution Network Development Project[3] (PDRTRE), which was completed in 2021, had as main target to improve security and efficiency of power supply. In particular, it aimed to decrease technical power losses in transmission lines (by reducing them from 4.7% to 3.5%), preserve grid stability, and increase the transmission capacity, with focus on the construction and extension of 400 kV and 225 kV Extra High Voltage (EHV) lines and transformer substations. This involved 881 km of 400 kV, 45 km of 225 kV lines, as well as 574 substations and transformer units (African Development Bank Group, 2020). In addition, the project envisaged the evacuation of generated electricity of supplementary power plants. Below are several examples of transmission network upgrades, illustrating the project's impact on the Maroccon electricity system (African Development Bank, 2021).

Already in 2012, a new 225 kV EHV double-circuit line (52 km) was constructed and commissioned for the evacuation of 315 MW of additional power from the new Kénitra TAG power station.

Figure 12. 225 kV power line network around the Kénitra gas power plant

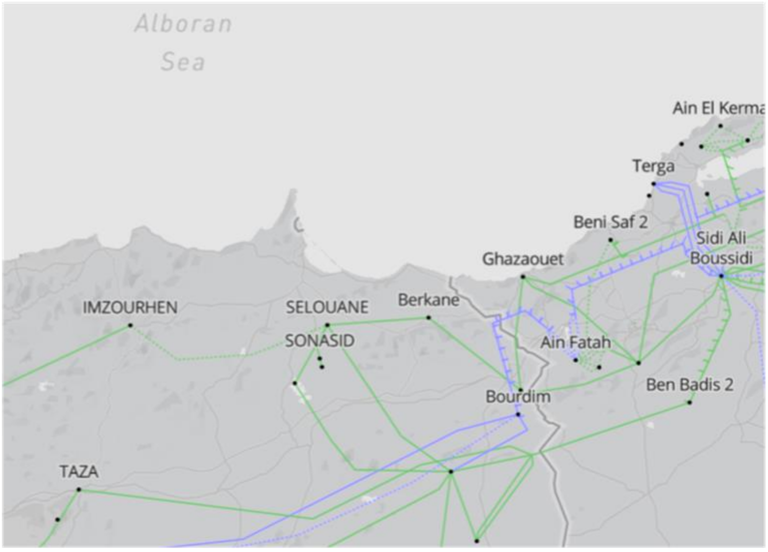


Source: ENTSO-E Grid Map, 2019

[3] Project code: P-MA-FAC-014.

The new Sélouane-Imzouren 225 kV loop line (single-circuit structure) was constructed and commissioned in 2015. This 100 km long line secured power supply to the provinces of the Oriental Region, in northern Morocco. More specifically, the line offered more reliability in the supply of electricity to the capitals of these provinces.

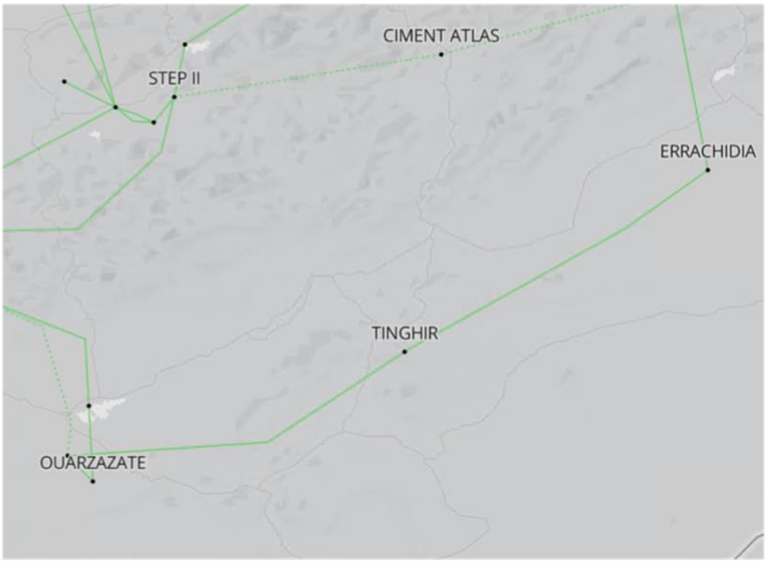
Figure 13. The Sélouane-Imzouren line within the 225 kV grid (green)



Source: ENTSO-E Grid Map, 2019

The single-circuit 225kV Errachidia-Tinghir-Ouarzazate lines (297 km long) connected the new Tinghir II 225/60 kV substation to the national electricity grid. Moreover, they better secured power supply to the regions of Ouarzazate, Tinghir and Errachidia, which were previously served by 225 kV single aerial lines, whithout backup or recovery means. Following the commissioning of the Ouarzazate solar complex (580 MW) in 2018, the lines could ensure the evacuation of a large part of the produced electrical energy.

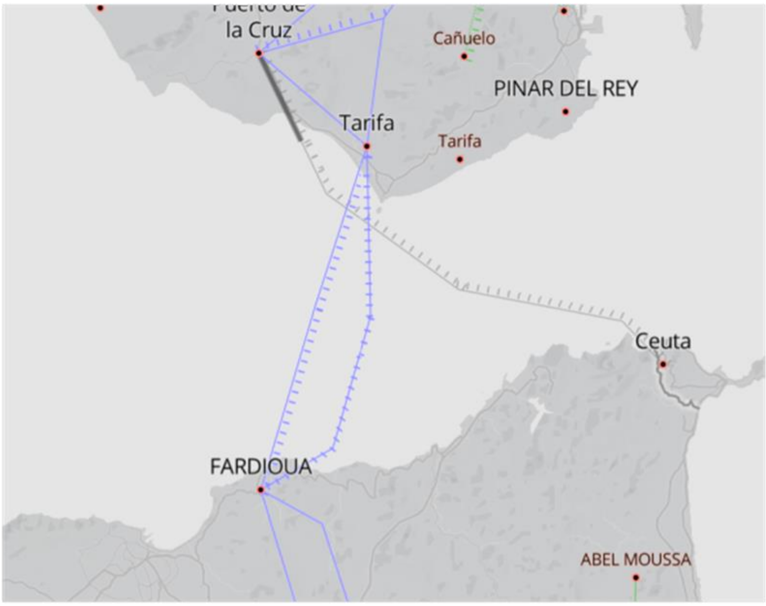
Figure 14. The Errachidia-Tinghir-Ouarzazate lines



Source: ENTSO-E Grid Map, 2019

With respect to international (submarine) power interconnections and as already suggested in Section 3.4, a second Morocco-Spain 400 kV double-circuit and double-beam link (24 km) was installed, i.e., between the Fardioua 400 kV substation (Morocco) and the Melloussa 400/225 kV substation (Spain). Commissioning took place in 2013.

Figure 15. The present subsea power cable interconnections between Fardioua and Melloussa (blue)



Source: ENTSO-E Grid Map, 2019

5.2 Ongoing and future electricity transmission programmes

The AfBD continues supporting Morocco, through its Power Transmission Network Development and Rural Electrification Programme[4] (PDRTE-ER). This programme, which will run until the end of 2024, includes following goals:

- increase the transmission capacity of the national grid, towards improving the security and efficiency of electricity supply and the overall technical performance of the national power system;
- guarantee the injection of additional power generated from RES projects (solar and wind) under development, and the transmission of this energy to consumption centres;
- contribute to increasing the share of clean energy in the national electricity mix and mitigating the climate change impacts of power generation.

In line with previous programmes, the PDRTE-ER covers the construction and extension of power lines and substations to address current transmission constraints and ensure evacuation of electricity to be generated through the development of additional production capacity, including from RES (Early Warning System, 2021).

In 2019, Morocco and Spain signed an MoU to build a third power link, connecting their electricity systems. The Spanish electricity grid operator Red Eléctrica de España (REE) and ONEE will provide the analysis for the 700 MW project, which is due to be commissioned before 2026 (Energy Reporters, 2019). From 2015 onwards, a potential interconnector between Morocco and Portugal has been under discussion by ONEE and REN (the Portuguese transmission system operator). The 400 kV High Voltage Direct Current (HVDC) interconnection would have a configuration of 2 circuits (bipolar converter) of 500 MW each. Since 2017, there have been negotiations between the governments of Morocco and Mauretania on constructing a first power interconnector. The 400 kV power line would allow Morocco to participate in the West African Power Pool. The North Africa Power Transmission Corridor is driven by the 'Comité Maghrebin de l'Électricité' (COMELEC). This project aims to ensure performant electricity transmission between Morocco, Algeria, Tunisia, Libya, and Egypt (Popkostova, Y., 2022). A 1.8 GW HVDC submarine interconnection is planned, connecting wind and solar power generated in Morocco to the United Kingdom (UK) (Electrek, 2022). Through these and additional interconnections, Morocco aims at becoming an energy crossroad between both shores of the Mediterranean Sea, contributing to a performant Euro-Mediterranean electricity market (Office National de l'Electricité et de l'Eau Potable, 2022).

[4] Project code: P-MA-FAO-008.

ONEE has announced that it will collaborate with Atos and Siemens on a large project for a smarter management of the Moroccan power grid. Both companies will deploy a smart metering platform, allowing ONEE to process data, collected by more than one hundred thousand smart meters, which will be installed across the country. The project should optimise the operation of the national grid, along with the growing electricity demand (ESI Africa, 2021).

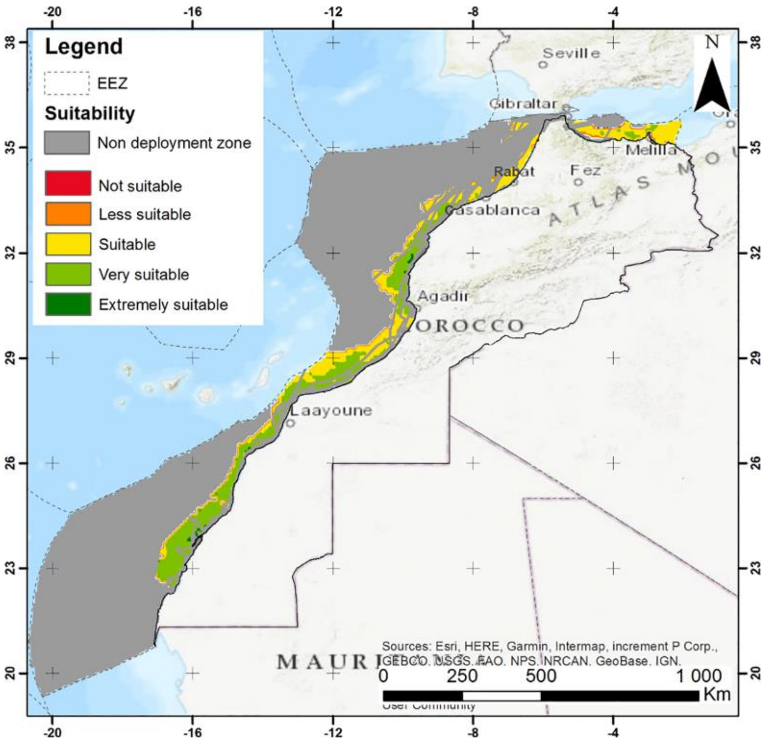
6 Geographic information systems for power system planning

6.1 Renewable energy generation

Finding most suitable sites for renewable energy plants is a pertinent task in ongoing worldwide energy transitions, with every type of plant having its specific requirements for successful performance. Geographic information systems (GIS) are useful tools for the determination of these sites. In combination with multi-criteria decision making (MCDM) techniques, favourable areas can be evaluated and shown on high-resolution maps. For this purpose, the GIS-MCDM methodologies make use of two types of criteria: restrictive criteria or constraints and weighting criteria or factors. Restrictive criteria allow to reduce the region under investigation, by discarding those areas that fully prevent the construction of renewable energy plants. In general, these criteria are linked to legislative requirements (e.g., planning regulations), disruptive infrastructure (e.g., roads and railways), protected areas, etc. On the other hand, factors are selected for the purpose of determining the areas, where renewable energy plants are most performant. They typically encompass aspects related to climate, geomorphology, environment, location, etc. Through the use of MCDM methods, the respective weights of these factors are evaluated, eventually resulting in detailed cartographic maps, which show the most suitable locations for renewable energy plants (Sánchez Lozano, J. M., et al., 2013).

In line with above approach, Taoufik and Fekri (2021) published a study, assessing the most suitable sites for the construction of offshore wind farms in the Morrocan coast territory. A GIS-MCDM methodology was employed in this investigation, along with the basic concepts, methods and applications of a Fuzzy Analytic Hierarchy Process (Fuzzy-AHP), to provide solutions to the multi-criteria challenges. A variety of GIS data sets were applied, corresponding to criteria, which influence the siting of offshore wind farms. The selection of these criteria was based on published literature and adapted to the Moroccan case. Restrictive criteria (involving 'buffer areas') related to submarine cables, shipping routes, protected areas, migratory bird's routes, etc. On the other hand, selected factors included wind speed, water depth, sediment thickness, distance to shoreline, and proximity to facilities, like the power grid and ports. The Fuzzy-AHP was implemented to obtain the weight of each factor. As expected, wind speed was found to be the most decisive factor in the selection of an offshore wind farm site. Water depth was the second rated factor, followed by proximity to the power grid and sediment thickness, respectively. Remaining parameters showed much lower weightings. Figure 16 gives the resulting suitability map for offshore wind farms in Morocco.

Figure 16. Suitability map for offshore wind farms along the Moroccan coast line



Source: Taoufik, M., Fekri, A., 2021[6]

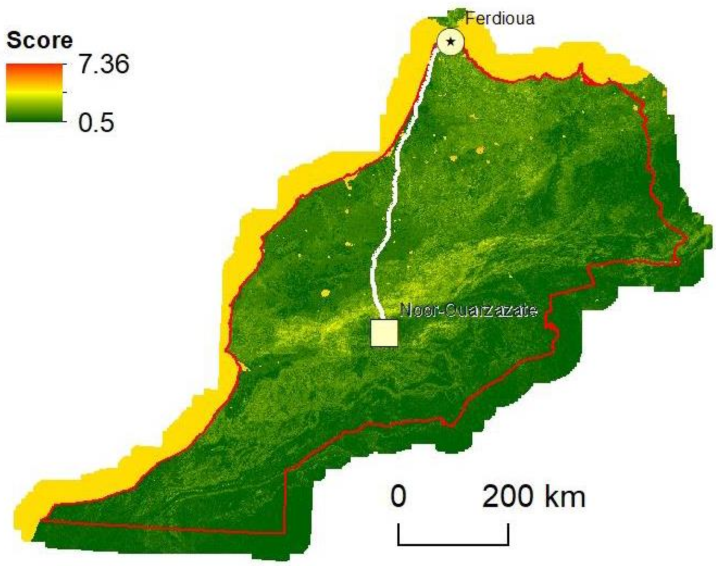
[6] Figure available under the 'Creative Commons CC-BY-NC-ND' license, permitting non-commercial use.

6.2 Electricity transmission

Massive integration of large-scale RES in the power system – as pursued by Morocco – requires substantial upgrades of the electricity transmission grid. Corresponding programmes, mainly supported by the AfDB, are presented above. Not only reinforcements, but also completely new transmission lines and cables are generally required, to provide consumer centres with green electricity and to balance the power system, given the intermittent nature of RES. Moreover, additional interconnections may be required to export and trade power surplus. Also in this context, GIS offer attractive opportunities, i.e., by assessing optimal routes for emerging transmission lines and cables. In their JRC report, Ardelean et al. (2020) presented a comprehensive methodology for calculating optimal paths for electricity interconnections between Central Asia and Europe. This methology is based on a so-called cost map, on which a 'cost' is allocated to each 'cell' or 'pixel'. This cost is composed of discrete reclassified values, corresponding to user-defined criteria, which are considered to be relevant for the construction and operation of a transmission line or cable. The reclassified values, or 'scores', range from zero to nine, with zero being the most favourable to crossing and nine the most adverse. Each criterion is associated with a data set, represented by a cartographic layer of the composite cost map. The selected criteria are grouped in five sets: terrain parameters, land use and protected areas, RES potential, barriers from natural and anthropic hazards, and proximity to power infrastructure. The criteria and sets are 'manually' weighted to allow for optimal route assessment under different scenarios, e.g., by excluding one or more criteria in the analysis. The model for assessing the optimal transmission route is developed, by using a built-in application of the GIS software. Starting and end point are user-defined, while the applied software functions allow for calculating the path with the lowest cumulative cost between these two points.

This methodology is here applied for the case of Morocco, involving a simplification, i.e., limiting the route assessment to purely geographic criteria. These criteria involve terrain parameters (elevation and slope), natural hazards (earthquakes, landslides and soil loss) and land cover (single criterion). The six weighted criteria correspond to geographic data sets, which are represented by cartographic layers, constituting the final cost map, shown in Figure 17. This combined cost map is the basis for the calculation of an optimal 'least-cost' path for an electricity transmission line between a start and an end point. As an example, the Ouarzazate Solar Power Station and the Ferdioua Submarine Cable Terminal, near the Strait of Gibraltar, are chosen here. The computed track is 626 km long, as illustrated in Figure 17.

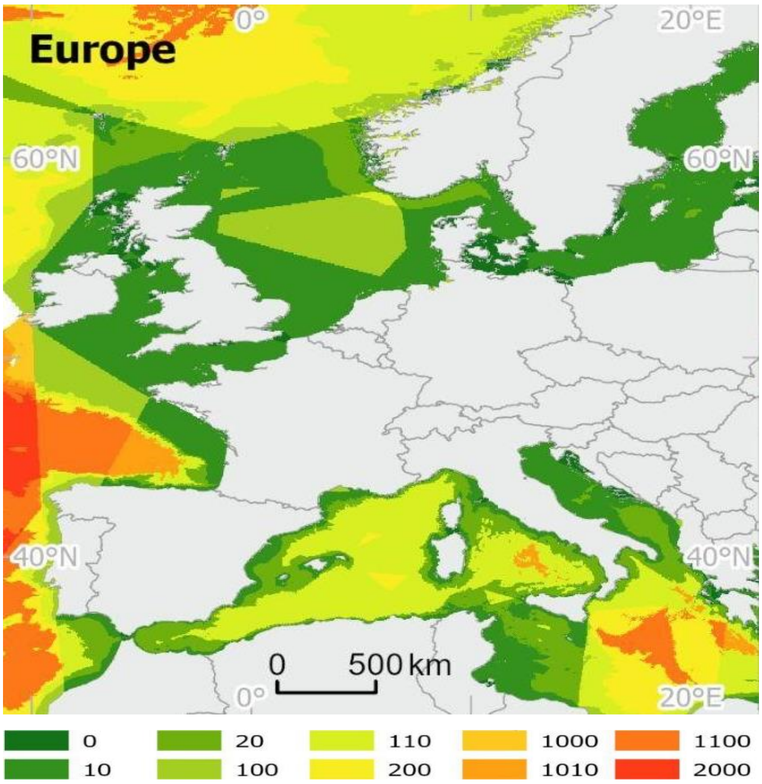
Figure 17. Combined cost map of Morocco with optimal electricity transmission route



Source: JRC analysis

GIS methodologies for electricity transmission interconnections can be extended to submarine power cables, crossing seas between national power grids, to be linked. Also for this purpose, spatial analysis may be applied by means of GIS software. The most obvious factors to assess suitability of seas for submarine power interconnections are sea depth and distance between shores. The factor values, in m and km, are subdivided into depth and distances ranges, corresponding to (discrete) scores, which are used in the spatial analysis. The scores take values from most to least favourable, e.g., 0 corresponds to most favourable, while 2000 corresponds to least favourable. By applying these values, Figure 18 shows the suitability of seas, surrounding the European continent.

Figure 18. Suitability of seas for submarine power interconnections (European region)



Source: Ardelean, M., Minnebo, P., 2023[7]

[7] Figure available under the 'Creative Commons CC-BY' license, permitting unrestricted use, distribution, and reproduction.

In the case of Morocco, submarine power interconnections with nearby countries cross seas, which are considered to be relatively suitable for this type of links (maximum score equal to 110). The planned power cable with the UK (see above) also follows a route, largely avoiding unsuitable sea regions, i.e., by staying close to the shore along its path – see Figure 19.

Figure 19. Planned cable track of the Morocco-UK interconnector

Source: The National News, 2022

7 Conclusions

Morocco is still dependent on the use of fossil fuels, which it has to import to a very large extent. As an example, more than 2 GW of electricity generation capacity from coal has been added during last decade. Nevertheless, Morocco's power sector has undergone significant transformations in recent years. Supported by concerted government strategies and policies, the country has become one of the pioneers of the energy transition in Africa. Accordingly, the share of renewable energy in the electrical capacity mix is currently approaching 40% (Ministère de la Transition Énergétique et du Développement Durable, 2019). MASEN's institutional framework, which offers opportunities for independent power producers, has been instrumental up to date, by bringing together permitting, land acquisition and financing aspects, as well as securing state guarantees for investments. Additional power sector reforms would be helpful towards reaching the 2030 renewable energy target of 52%. Further increasing the role of private power sector actors is to be seriously considered, towards enabling a genuine wholesale electricity market with cost-reflective tariffs, which would underpin additional development of renewable energy capacity (Vagneur-Jones, A., 2021).

Morocco owns substantial potential for generating extra economic income as future export and transit country of clean energy, also underpinning investments in related production and transmission infrastructures. Apart from electricity from RES, green hydrogen would offer great opportunities in this context, as its levelised production cost will significantly decrease during the coming decades (International Energy Agency, 2022). Also from this viewpoint, further boosting clean energy generation in the country is highly required, i.e., to assure Morocco's position as reliable exporter.

New energy interconnections are required to effectively underpin above ambitions, i.e., to efficiently distribute clean energy within the country, and to guarantee secure exports towards its neighbours and Europe. GIS provide useful tools, offering sufficient flexibility for the assessment of optimal paths for emerging power lines and cables, as well as hydrogen pipelines. Selection of appropriate assessment factors allow for taking into account the critical aspects of routes of particular interconnection types.

Significant investments in RES generation capacity are still required to fully enable Morocco's energy transition. The same applies for accompanying upgrades of power grids. The World Bank (WB) Group (2022) provided estimates for the economic costs of 'additional'[8] investment needs towards a decarbonisation of the Moroccan economy. For the power sector, following net present values were given:

- power generation: USD 4.79 billion until 2030, and USD 11.84 billion until 2040;
- power transmission and distribution: USD 1.34 billion until 2030, and USD 5.01 billion until 2040.

While local banks will still play an underpinning role, international investment is considered to remain the principal contributor to these important financing needs. Primarily, in line with a Team Europe approach, the EU institutions (under NDICI – 'Global Europe'), the EU financial organisations (EIB and EBRD), and several MS funding parties will continue to support Morocco, including through Global Gateway actions. Further EU investments in the Moroccan power sector are crucial, if the EU wants to safeguard Morocco's future role as key energy partner. Beyond the EU, other actors are assumed to remain active in the given field, both in an African (e.g., the AfDB) and global context (e.g., the WB).

[8] From comparing postulated 'baseline' and 'decarbonisation' scenarios.

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List of abbreviations and definitions

AfDB	African Development Bank
AMSSNuR	Agence Marocaine de Sûreté et de Sécurité Nucléaires et Radiologiques
ANRE	Autorité Nationale de Régulation de l'Électricité
BOOT	Build, Own, Operate and Transfer
CESA	Continental Europe Synchronous Area
CCGT	Combined-Cycle Gas Turbine
CNCC	Comité National sur les Changements Climatiques
CNESTEN	Centre National de l'Énergie, des Sciences et Techniques Nucléaires
COMELEC	Comité Maghrebin de l'Électricité
COP	Conference Of the Parties
CRED	Comité de Réflexion sur l'Électronucléaire et le Dessalement d'Eau de Mer par Voie Nucléaire
CSP	Concentrated Solar Power
DNI	Direct Normal Irradiation
EBRD	European Bank for Reconstruction and Development
EEM	Énergie Électrique du Maroc
EIB	European Investment Bank
EHV	Extra High Voltage
ENI	European Neighbourhood Instrument
ENP	European Neighbourhood Policy
EU	European Union
Fuzzy-AHP	Fuzzy Analytic Hierarchy Process
GHG	Greenhous Gas
GHI	Global Horizontal Irradiation
GIS	Geographic Information System
GME	Gazoduc Maghreb-Europe
HV	High Voltage
HVDC	High Voltage Direct Current
IAEA	International Atomic Energy Agency
INDC	Intended Nationally Determined Contribution
IRESEN	Institut de Recherche en Énergie Solaire et Énergies Nouvelles
LNG	Liquefied Natural Gas
LYDEC	Lyonnaise des Eaux de Casablanca
MAGG	Ministère des Affaires Générales et de la Gouvernance
MASEN	Moroccan Agency for Sustainable Energy
MCDM	Multi-Criteria Decision Making
MdI	Ministère de l'Intérieur
MEF	Ministère de l'Économie et des Finances
MEMEE	Ministère de l'Énergie, des Mines, de l'Eau et de l'Environnement
MIP	Multi-annual Indicative Programme
MorSEFF	Morocco Sustainable Energy Financing Facility

MoU	Memorandum of Understanding
MS	Member State
MTEDD	Ministère de la Transition Énergétique et du Développement Durable
MV	Medium Voltage
NDC	Nationally Determined Contribution
NDICI	Neighbourhood, Development and International Cooperation Instrument
NPP	Nuclear Power Plant
ONE	Office National de l'Électricité
ONEE	Office National de l'Électricité et de l'Eau Potable
ONEP	Office National de l'Eau Potable
PCCM	Politique du Changement Climatique au Maroc
PDRTRE	Projet de Développement du Réseau de Transport et de Répartition de l'Électricité
PDRT-ER	Programme de Développement des Réseaux de Transport d'Électricité et d'Électrification Rurale
PEC	Primary Energy Consumption
PERG	Programme d'Électrification Rurale Généralisé
PES	Primary Energy Supply
$PM_{2.5}$	Particulate Matter with diameter equal or less than 2.5 μm
PNRC	Plan National de Lutte Contre le Réchauffement Climatique
PSM	Plan Solaire Marocain
PV	Photovoltaic
RADEEF	Régie Autonome intercommunale de Distribution d'Eau et d'Électricité de la wilaya de Fes
RADEEJ	Régie Autonome intercommunale de Distribution d'Eau, d'Électricité et de gestion du reseau d'assainissement Liquide des provinces d'El Jadida et de Sidi Bennour
RADEEL	Régie Autonome intercommunale de Distribution d'Eau et d'Électricité de la province de Larache
RADEEMA	Régie Autonome de Distribution d'Eau et d'Électricité de Marrakech
RADEES	Régie Autonome intercommunale de Distribution d'Eau et d'Electricité dans la ville de Safi
RADEM	Régie Autonome de Distribution de l'Eau et de l'Électricité de Meknès
RAK	Régie Autonome de Distribution de l'Eau et de l'Électricité de Kénitra
REE	Red Eléctrica de España
REDAL	Régie de Distribution de l'Eau et de l'Électricité de Rabat-Sale
REN	Redes Energéticas Nacionais
RES	Renewable Energy Sources
SEN	Stratégie Énergétique Nationale
SER	Stratégie Énergétique Renouvelée
SIE	Société d'Investissement Energétiques
SNDD	Stratégie Nationale de Développement Durable
UfM	Union of the Mediterranean
UK	United Kingdom
US	United States
UNFCCC	United Nations Framework Convention on Climate Change

VHV	Very High Voltage
WHO	World Health Organization
WB	World Bank

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Annex – Morocco power sector laws and decrees – additional information

1963 (amended in 1994, 2002, 2008, 2015, and 2016)
Decree N° 1-63-226 - Creation of 'Office National de l'Électricité' (ONE)

ONE was created to inherit the assets of 'Énergie Électrique du Maroc' (EEM), following Morocco's independence. ONE gained monopoly in electricity generation and transmission, and became in charge of electricity distribution for most of Morocco's cities and regions (together with 11 distribution companies in large and industrialised urban centres).

In response to the recurring problems of the power system's financial sustainability and as an attempt to improve the performance of generation facilities, the amended **Decree Law N° 2-94-50** was adopted in **1994**, allowing ONE to sign power purchase agreements with independent producers. The envisaged plants included renewable energy facilities (predominantly wind), and agreements were based on BOOT (Build, Own, Operate and Transfer) schemes, i.e., ONE exploited electricity production but the investor owned the plant.

Amendment **Law N° 28-01** of **2002** authorised ONE's participation in private generation projects.

Amendment **Law N° 16-08** of **2008** provided grid access to large renewable energy self-producers, raised the threshold for the maximum allowed self-generation capacity (from 10 MW to 50 MW), and allowed the sale of occasional surpluses to ONE.

Amendment **Law N° 54-14** of **2015** allowed private-to-private transactions of self-generators of electricity (installed capacity of over 300 MW), and provided access to ONEE's transmission network for large self-producers. (ONE became ONEE in 2011 by Law N° 40-09)

Amendment **Law N° 38-16** of **2016** transferred renewable energy assets of ONEE to MASEN.

2010 (amended in 2015)
Law N° 13-09 - Renewable energy project legal framework, liberalisation of renewable energy sector

This law provided a legal framework for the development of renewable energy projects in Morocco, in particular solar, wind, hydro, geothermal, wave and tidal energy, as well as power generated through biomass, waste and biogas (except hydropower with installed capacity above 30 MW). It also liberalised the renewable energy sector, allowing private developers to generate electricity from RES, and supply individual consumers and groups of consumers. Access was allowed to VHV, HV and, under certain conditions, to MV grids.

Law N° 58-15 of **2015** amended Law N° 13-09 and encouraged private-sector investments as follows:

- Installed capacity threshold of hydro projects was decreased from 30 to 12 MW.
- Renewable electricity producers were given access to the LV grid. This measure allowed development of an industrial sector of small and medium-sized installations (especially for PV) and strengthened the labour market.
- It became possible to sell excess electricity produced from renewable sources to ONEE or directly to another distribution company.

2010 **Decree N° 2-10-578** - Procedures and rules for declaration and authorisation, as well as provisions related to accessing MV and LV networks.
This legislation required private/public distribution companies to determine their so-called 'RE envelopes', i.e., the amount of RE generation that can be integrated in the MV and LV networks in each distribution zone (between 5% and 10% of the total generation). The decree enshrined that the information from such envelopes would be further used to determine the trajectory for opening up the MV and LV networks over the next ten years.
2010 (finally adopted in 2015) **Decree N° 2-15-772** - On access to the national MV electricity network.
The decree set out conditions and rules for progressive opening of the MV network to RE generation. As in case of Decree 2-10-578, this legislation also required development of RE envelopes with a ten-year timeframe, providing for very limited trajectories of capacity expansion per electricity distribution zone, between 5% and 10% of the energy consumption of the zone.
2014 **Decree N° 2451-14** - Electricity tariffs and for the sale of electricity to distribution companies and consumers, grid access to large renewable energy self producers, thresholds for maximum self-generation capacity, sale of ONEE surpluses.
The decree established electric energy tariffs and set prices for the sale of electricity to distribution companies and to final consumers. Tariffs to distribution companies were differentiated by time peaks and by voltage levels. Tariffs to MV, HV and VHV final consumers of distribution companies were time-differentiated and consisted of a fixed (power-related) and a variable (electricity consumption-related) charge. For distribution companies, operating LV lines, tariffs consisted of variable charges and were differentiated by type of customer. For customers in administrative buildings and public lighting categories, a fixed-per-kWh tariff was introduced, regardless of consumption level. Specific tariffs for rural customers were set under a prepaid scheme.

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