3 RESOURCES
3-ENERGY TRANSITION

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3.3 Energy transition in the Mediterranean

Executive summary

Current Mediterranean greenhouse gas emissions amount to a relatively low level of 6% of the global emissions, a proportion close to its proportion of the world population (7.4%). The expected impacts of climate and environmental changes necessitate an accelerated energy transition in the countries of this region to enable a secure, sustainable and inclusive development. The primary energy consumption in the Mediterranean Basin from 1980 to 2016 has steadily increased by approximate 1.7% annually. This trend is mostly related to a steady increase in the consumption of oil, gas, nuclear and renewables and is caused by changes in demographic, socioeconomic (lifestyle and consumption) and climatic conditions in the region. While the northern rim countries advance in gradually diversifying their energy mix, improving energy efficiency and increasing the fraction of renewable energy sources, the eastern and southern rim countries (SEMCs) still lack behind in these developments. The Mediterranean Basin, especially the SEMCs, has large potential for renewable energy, terrestrial as well as marine, including wind, solar, hydro, geothermal, bioenergy, waves and currents. With the increase of the share of renewables, the electricity transmission system will be more exposed to weather variations and may be threatened by specific weather conditions that are usually not considered as extremes.

The projected energy demand trajectories for the next few decades in the Mediterranean Basin are significantly different for the northern versus the eastern and southern rim countries. The energy demand in the North has decreased by 4% since 2010, due to a moderate population growth and a decreasing gross domestic product, and expected to continue to decrease until 2040. The SEMCs have experienced sustained economic and population growth over the past years, which resulted in a growth in a 6% energy demand since 2010. Towards 2040, the energy demand is expected to continue to increase. Although fossil fuels are currently expected to remain the dominant component of the energy mix until 2040, renewables will become the second most used energy source in the Mediterranean Basin and triple until 2040.

A significant gap between energy supply and demand is expected, particularly in SEMCs. It is, therefore, more than necessary to move rapidly towards a restructuring of the energy sector, particularly the more pronounced integration of renewable energies. Mitigation of greenhouse gas emissions and adaptation to climate change will require investments from households, companies and governments. Regional energy market integration and cooperation are crucial to unleashing cost-effective climate change mitigation.

3.3.1 Introduction

Despite a relatively low share in global greenhouse gas emissions (6%), close to its proportion of the world population (7.4%), the Mediterranean region is severely hit by impacts of climate change *(Section 2.2)*. The nature and magnitude of current and future impacts of climate and environmental change in the Mediterranean region, and the associated vulnerability of people, are important imperatives to accelerate the energy transition in all countries of this region in order to enable them to secure a sustainable and inclusive development trajectory.

While the energy transition raises common issues for the region as a whole, the nature and extent of these issues are expressed differently between both shores of the Mediterranean. Northern countries have achieved at least two decades of reforms that enabled them to gradually diversify their energy mix and control to some extent their energy demand due to the deceleration of their demographic growth and the gains in terms of energy efficiency. With respect to the relatively high level of CO_2 emissions from these countries, their energy transition is bound by a rationale that is different from that of Southern and Eastern Mediterranean countries (SEMCs).

The energy transition issue in the SEMCs is closely linked to the sustainability of their development model. These countries face multiple challenges related among others to the fast population growth (607 to 659 million inhabitants, depending on the scenario, by 2050 against 534 million in 2015, *Section 2.7*) which would put additional pressure on energy demand to accompany the surge of urbanization and increasing needs of various sectors of the economy. Therefore, the energy demand in the south-east Mediterranean countries is expected to rise nearly 118% by 2040. The polarization of SEMCs' energy mix on fossil fuels, mainly oil and natural gas, is another important challenge, especially for the countries

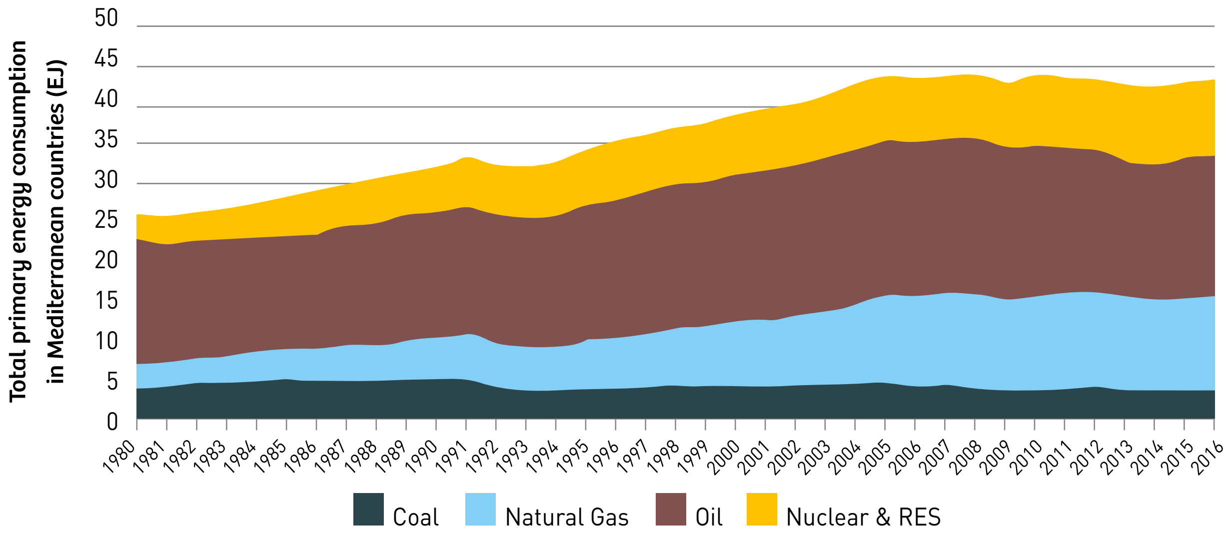

Figure 3.22 | Evolution of Primary Energy Consumption across the Mediterranean for the period 1980-2016, in exajoules EJ (10^{18} joules) RES - Renewable Energy Sources (EIA 2019).

where hydrocarbon export revenues play a central role in the macro-financial balance.

3.3.2 Past trends and current situation

3.3.2.1 Mediterranean energy situation

The Mediterranean region holds 5% of the world oil and gas reserves, of which 98% are in the countries of the southern rim (UNEP/MAP 2007; Plan Bleu 2008; UNEP/MAP-Plan Bleu 2009). There is also a significant potential of renewable energies, in particular, solar and wind energies. The Mediterranean region as a whole has been experiencing a steady increase in primary energy consumption, from about 26 exajoules (EJ) in 1980 to 34 EJ in 1995 to 43 EJ in 2016, representing an approximate annual growth rate of 1.7% as in *Fig. 3.22*. This trend concerns oil, gas, nuclear and renewables, combined with a small decline in the use of coal. In 2005 the combination of

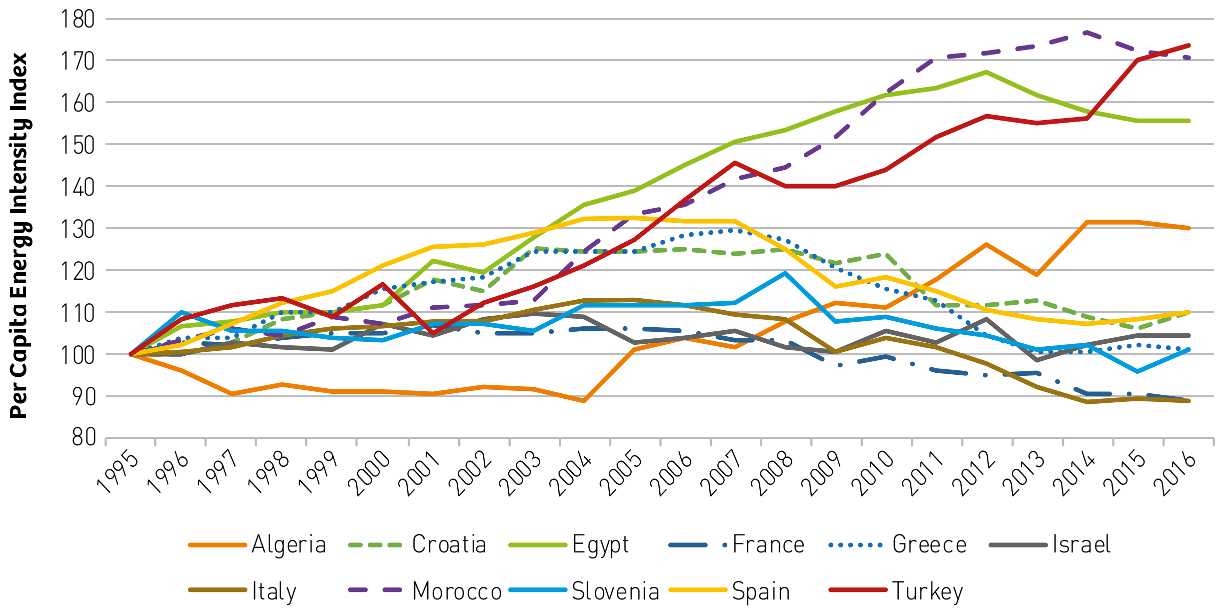

Figure 3.23 | Evolution of per capita Energy Intensity Index (energy divided by GPD) in selected Mediterranean countries; 1995 used as a year of reference (EIA 2019).

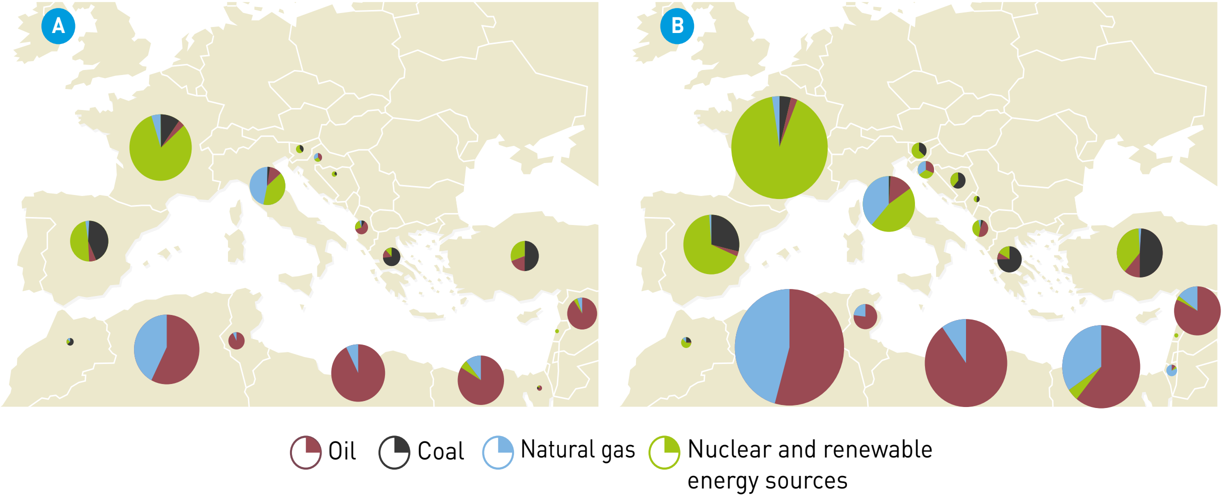

Figure 3.24 | Evolution of primary energy production across the Mediterranean between 1995 (A) and 2016 (B) (Data from the EIA 2019).

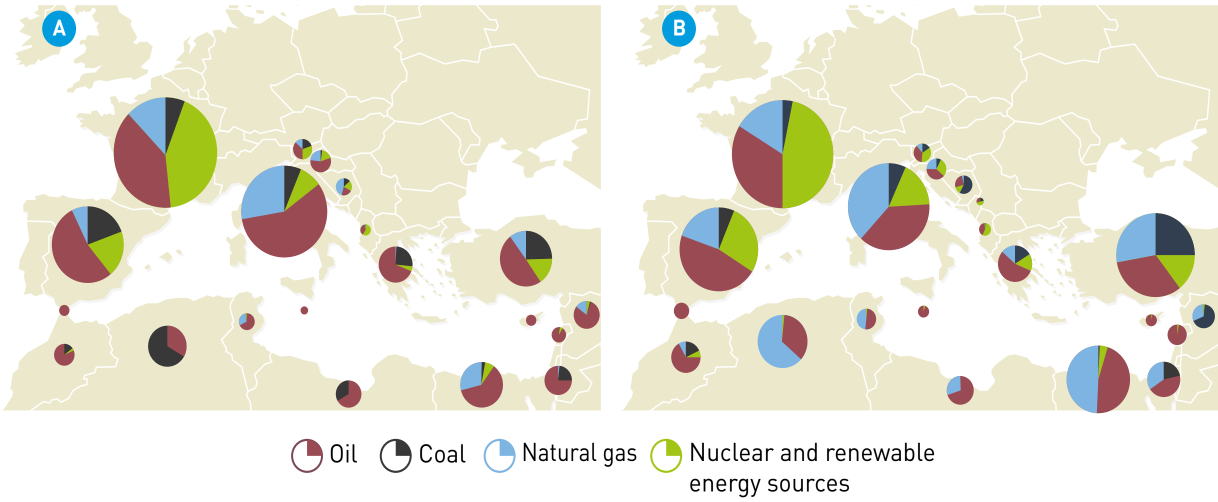

Figure 3.25 | Evolution of primary energy consumption across the Mediterranean between 1995 (A) and 2016 (B) (Data from the EIA 2019).

mechanisms that include reduced energy intensity by some large consumers, economic crises and political instability, and improved energy efficiency halted the increase in consumption.

Mediterranean countries differ in their patterns of energy use. The level of industrialization, sectoral energy profiles, prevailing climatic conditions and the level of economic growth is among the crucial aspects affecting the energy intensity of each economy. *Fig. 3.23* illustrates the evolution of the per capita energy intensity, expressed as units of energy per unit of GDP, in a selection of Mediterranean economies. Egypt, Morocco and Turkey show the highest increase in energy intensity during the period 1995-2016, driven by the economic growth. Partly hampered by the financial crisis and partly driven by energy efficiency measures, the French and Italian economies show the highest decline in energy intensity. Others, such as Greece and Spain, had experienced an increase until the mid-2000s but the subsequent financial crisis brought energy intensity back down and has stabilized in the period 2012-2016.

In terms of the energy mix, *Fig. 3.24* and *3.25* illustrate the recent evolution of primary energy production and consumption across the Mediterranean for the period 1995-2016 (EIA 2019). In absolute terms, during this period, the

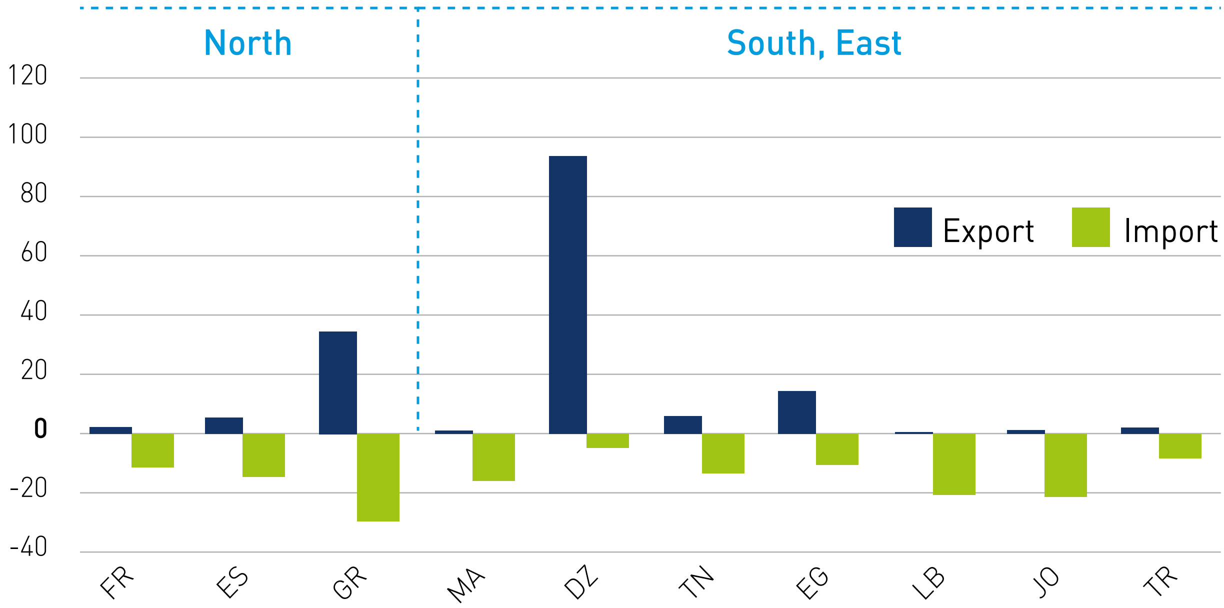

Figure 3.26 | Energy weight in trade balance (2017-2018) (MEF 2019). (Country code: Appendix D)

contribution of oil has remained stable at 17 EJ, while consumption of coal has experienced a mild gradual decrease from 4.1 to 3.7 EJ during the two reference years. Primary energy consumption of natural gas has doubled from 6 EJ in 1995 to 12 EJ in 2016, while nuclear and renewable energy sources contribution has risen from 7 to 10 EJ between 1995 and 2016.

On the national level, France has the largest energy-consuming economy in the Mediterranean. Its primary energy consumption has risen from 9.1 EJ in 1980 to 10.7 EJ in 1995, at which level it has returned by 2016 after peaking at 12.1 EJ in 2006. In both 1995 and 2016, roughly 50% of the primary energy consumed, was produced locally (EIA 2019); the vast majority of this relating to the large share of nuclear power in the country's energy mix (UN DESA 2016).

In 1995, the vast majority of Mediterranean nations were mostly dependent on oil, primarily imported, except for Algeria, Egypt, Libya, Tunisia and Syria *(Fig. 3.25)*. The importance of fossil fuels in the energy mix of most of the Mediterranean countries affects their trade balance negatively *(Fig. 3.26)* (MEF 2019). The SEMCs suffer more from this negative impact because most of them are net importers, and the energy imports can amount to, for some countries, up to 20% in the trade balance.

By 2016, oil dependence was reduced to a certain extent, as the share of natural gas and low carbon technologies has increased. Despite the increased shares of less carbon-intensive or carbon-neutral energy sources, increasing energy demand has continued to drive greenhouse gas emissions upwards in the region. An attempt to diversify and decarbonize the energy mix is underway, driven mainly by the deployment of renewable energy technologies, as well as substitution of carbon-intensive coal and oil with natural gas. The energy mix is still heavily dependent on fossil fuels.

The shift in energy carriers is a consequence of costs, constraints, regulations and new technologies, among others. The services that make use of these energy sources are, again, disparate and in various states of growth or decline depending on the country. *Fig. 3.27* shows the change in energy use in various sectors of the economy for selected Mediterranean countries. The selected countries provide a good representation of the situation in the Mediterranean as a whole, as they are the region's most significant energy users.

There are some clear-cut sectoral trends worthy of note, and some which are not easily explainable by raw data alone. All examined countries exhibit consistent growth in the transportation sector. This is in line with increases in both passenger-km and increased economic activity. This trend is mostly following an increased uptake of private vehicles in the South such as in Turkey, Israel, Egypt, Algeria and Morocco, which is also partially the case for countries in the North Mediterranean such as France, Italy, Spain and Greece, but for those countries, final consumption

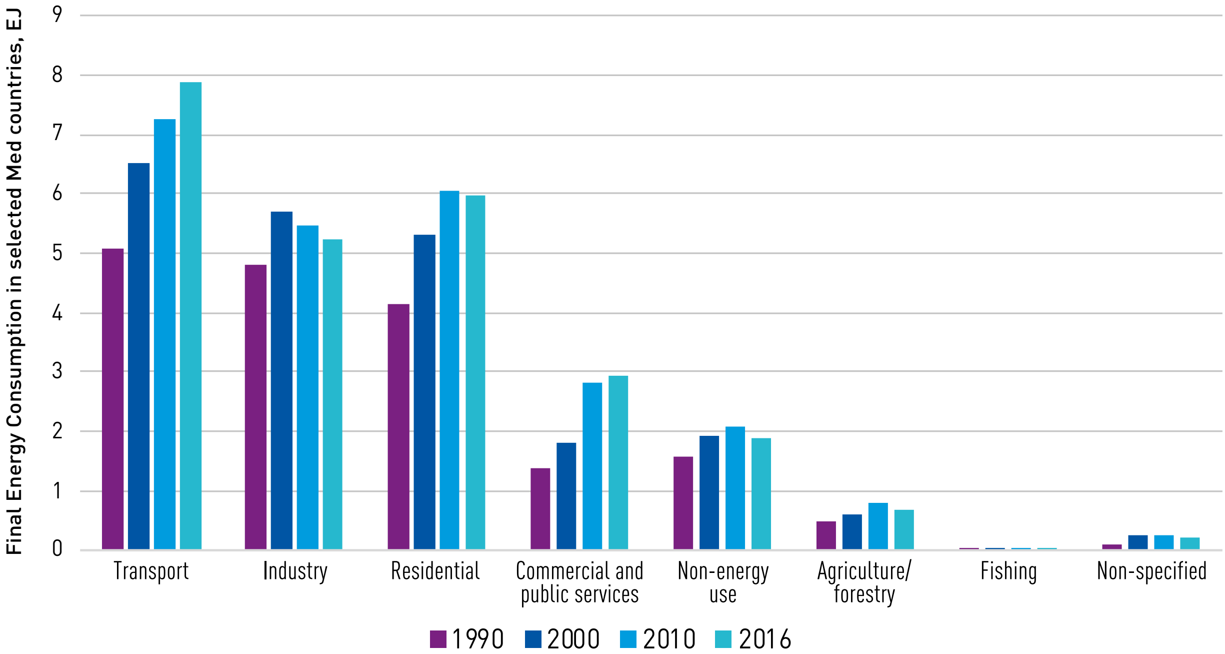

Figure 3.27 | Energy consumption in selected Mediterranean countries 1990-2016. Data for France, Italy, Spain, Greece, Turkey, Israel, Egypt, Algeria and Morocco (IEA 2018).

in transportation has been declining since 2010. This decline is attributable to a modal shift, policies and regulations that target energy savings in transportation, economic recession, increased use of more efficient vehicles and gradual electrification of transport. These characteristics are not yet strongly apparent in the countries of the South. There is evidence, that energy consumption in transportation will fall, with wider adoption of some (or all) of the above measures across the Mediterranean (OME/MEDENER 2016).

Residential energy use follows a similar upward trajectory in both North and South Mediterranean countries up to 2010, after which final energy consumption in the North is decreasing. The partial decline shown in *Fig. 3.27* is attributable to lower consumption in the four EU countries of this set. There are numerous challenges and opportunities for reducing energy demand. Improved energy efficiency measures and technologies will allow buildings to lower their energy demand per m², but the proliferation of air-conditioning due to higher living standards and increased demand due to climate change-induced higher ambient temperatures may also intensify demand in the region (OME/MEDENER 2016).

Energy use in industry differs significantly between northern and southern Mediterranean countries *(Fig. 3.27)*. While the countries of the north experience a decline due to structural change in the economy, with a shift to services and transformation industry that are less carbon-intensive (from primary industries that are more carbon-intensive), fuel switching and technical efficiency measures, the countries in the south exhibit the reverse, mainly due to new investments in industrial infrastructure and growing economies. Commercial and public service energy use is growing across all the countries examined, but at a much higher rate in the south, where the sector's registered energy use was limited in 1990. Growth in this sector's energy use reflects the changing dynamics in the economies of all countries involved.

Overall the energy consumption in the Mediterranean is increasing but tapering-off of overall consumption. There are multiple sectoral dynamics and a distinct North-South differentiation in the energy use patterns. While the total use seems to be levelling off, there are significant challenges on the horizon about increased demand for industry and services, especially in the south. The projected increase in cooling of living and working places, as caused by climate-change-induced temperature increases, represents the most significant increase in projected energy consumption in the region. The rapid growth in electricity demand is contributing most to the energy demand increase. Between 1971 and 2006 the Mediterranean region saw a fourfold increase in electricity consumption.

Transport continues to be the primary consumer compared with the other sectors in the Mediterranean. Transport electrification is set to shift the resource mix towards low carbon forms of energy but does not reduce overall energy consumption.

3.3.2.2 Renewable energy resources

The Mediterranean Basin benefits from a temperate climate with mild winters and warm and sunny summers, with a large potential for energy production from terrestrial renewable energies, as well as for the development of marine energy (Soukissian et al. 2017). These include energies drawn from wind, solar, hydro, bioenergy (crops and forests), waves and currents. Geothermal is an additional key renewable energy source in Europe that can provide low-carbon base-load power. Capacity factors of new geothermal power plants can reach 95% (Chamorro et al. 2014). In the early 2010s, a resurgent interest in geothermal power was observed after nearly a decade of only small development. A substantial number of projects have been developed throughout Europe, and geothermal energy is on its way to becoming a key player in the European energy market (Bertani 2017).

The assessment of resources for wind and solar is generally based on in-situ measurements. Long-term datasets including seasonal, yearly and decadal variability are required. These are usually available from in-situ or remote sensed measurements and gridded re-analyses. These tools have various limitations. In-situ measurements are local and may not have large measurement footprints, and homogeneity of long time series is not granted. At regional scales re-analyses are generally used but have biases, which require specific bias correction methods (Staffell and Pfenninger 2016). Remote-sensed data sets have large spatial coverage but are often short, even though several datasets are currently used for solar radiation estimate (e.g., Müller et al. 2015). Renewable energy resources should be assessed using a variety of tools combined together (Pfenninger and Staffell 2016).

Wind power

Wind power is essentially affected by wind speed in the lower part of the atmosphere, at the altitude of the hubs of wind turbines (from 50 to 150 m). Wind power production is a highly nonlinear function of hub-height wind speed, with no electricity generation below wind speeds of a few m s^{-1}, a rapid growth and a saturation at nominal wind speed (typically 10-15 m s^{-1}). To protect turbines, production is usually cut beyond a threshold of about 25 m s^{-1}. Therefore, production is extremely sensitive to low wind-speed changes as well as extreme stormy winds. Wind power production is also marginally sensitive to air density, the denser the air, the larger the production. It is sensitive to turbulence as it decreases efficiency.

A number of studies have currently assessed both the wind power potential in Europe and in Mediterranean areas, as part of the enhanced effort to develop prospective energy mix scenarios including intensive share of renewable energy sources. Beyond national assessments of wind resources in many countries, a New European Wind Atlas (NEWA)[22] (Petersen et al. 2014) is currently being developed, combining wind observations with model results. The offshore component of this atlas includes Mediterranean areas and presents regional climate model results calibrated with satellite scatterometer observations (Karagali et al. 2018).

Over the Mediterranean Sea, larger wind potentials are found in the northwestern part (the Gulf of Lions), in the Alboran Sea and in the Aegean Sea, as indicated by satellite datasets and regional climate modeling (Balog et al. 2016; Onea et al. 2016; Omrani et al. 2017; Soukissian et al. 2017; Rusu and Rusu 2019) *(Section 2.2.2.4).* Offshore installations can theoretically extract much more kinetic energy from the lower atmosphere than onshore installation in large-scale wind farms (Possner and Caldeira 2017). Currently most installed power lies onshore, with reported installed power provided in *Table 3.10.* More than 80 gigawatts (GW) are currently installed in Mediterranean countries, but the potential is much higher. Near the shorelines, wind power also benefits from regular and generally predictable land/sea breezes.

Observed near-surface winds have long-term trends (i.e., multidecadal). In Europe in general, winds have been declining for several decades (McVicar et al. 2012), a more general phenomenon called "wind stilling" (Vautard et al. 2010). In the Mediterranean region this trend was less clear. Recent observations show that the wind-stilling trend is recovering on a global scale (Zeng et al. 2019).

[22] http://www.neweuropeanwindatlas.eu/

	Installed wind power (MW)	Installed solar PV power (MWpeak) 2018
Albania	150	
Algeria	10	
Bulgaria	644	1,036 (1)
Croatia	529	61 (1)
Cyprus	188	113 (1)
Egypt	1,375	1,800 (2)
Greece	8,256	2,652 (1)
France	19,668	9,466 (4)
Israel	123	1,450 (5)
Italy	11,175	20,107 (1)
Libya	20	
Malta		131 (6)
Montenegro	118	
Morocco	1,343	
North Macedonia	37	
Portugal	5,567	671 (1)
Spain	24,664	4,751 (1)
Tunisia	242	
Turkey	9,384	5,063 (3)
Total	83,165	47,170

Table 3.10 | Reported installed wind and solar (photovoltaic, PV) power in Mediterranean countries in 2019. References are given in the footnote.

For wind power, see:

https://www.thewindpower.net/

For solar power, see:

(1) https://en.wikipedia.org/wiki/Solar_energy_in_the_European_Union

(2) https://spectrum.ieee.org/energywise/energy/renewables/egypts-massive-18gw-benban-solar-park-nears-completion

(3) https://en.wikipedia.org/wiki/Solar_power_in_Turkey

(4) https://en.wikipedia.org/wiki/Solar_power_in_France

(5) https://en.wikipedia.org/wiki/Solar_power_in_Israel

(6) https://solarfeeds.com/wiki/solar-energy-in-eu/

Solar power

Solar power production (concentrated solar power, CSP, or photovoltaic, PV) is mostly influenced by surface solar radiation *(Section 2.2.3.1)*, whose variations depend mostly on atmospheric composition (aerosols, water vapor) and clouds. The importance of aerosols has been noted in several studies for Mediterranean areas (e.g., Gutiérrez et al. 2018). Solar production is extremely sensitive to clouds and cloud types. For PV, panels efficiency also largely depends on cell temperature, which itself depends on air temperature, radiation and near-surface wind speed. Solar panels may also be sensitive to the presence of snow and ice cover or particulate matter potentially covering panels. Solar resources are of particular interest in Mediterranean countries due to the high mean solar irradiance in the region (Hadjipanayi et al. 2016). Solar radiation increases from North to South in the Mediterranean Basin, with typical yearly mean values of 150-250 W m^{-2}, and 1,300 to 2,000 kWh m^{-2} yr^{-1}.[23] On the European side weather disturbances make the resource variability higher than on the southern side.

Solar radiation has undergone varying trends in past decades, due to cloud changes and the "dimming and brightening" phenomena linked to changing aerosols atmospheric composition (Wild et al. 2005) *(Section 2.2.3.1)*. In Europe an increase of solar radiation of 2 W m^{-2} decade^{-1} was observed from 1983 to 2010 (Sánchez-Lorenzo et al. 2017), with higher values in the Mediterranean regions found in a set of ground stations (about 5 W m^{-2} decade^{-1}) (Pfeifroth et al. 2018). These trends are probably mostly attributable to changes in cloudiness but aerosol variations also affect mean solar radiation in a significant manner (Philipona et al. 2009; Nabat et al. 2015) *(Fig. 2.4)*. Such changes are also likely to affect summer temperatures. Dong et al. (2017) found that aerosols decline explain about half of the rapid rise of summertime extreme temperatures.

Hydropower and thermoelectric power

Hydropower relies on the availability of water in large reservoirs, or the streamflow intensity for run-off-the-river production. Production is sensitive to precipitation and snowpack melt, allowing to feed the reservoirs. Droughts and associated low flows are limiting the production. Bioenergy, just as agriculture and forestry, is largely dependent on climate conditions in many ways (seasonality of temperature, radiation, precipitation). Marine energies depend on currents, which have a low frequency variability, and on waves, themselves influenced by wind speed conditions.

Addressing impacts of climate variability and change on water resources, electricity supply and energy infracstructure vulnerability and resilience relies on a global hydrological-electricity coupled modelling framework. It consists of a physically based hydrological (Liang et al. 1994) and water temperature model (Yearsley 2009; van Vliet et al.

[23] https://globalsolaratlas.info/

2012a), which are linked to hydropower and thermoelectric power models (Koch and Vögele 2009; van Vliet et al. 2012b). *Fig. 3.28* shows simulated hydropower utilization rates and utilisation rates of thermoelectric power over the period 1981-2010 in the form of boxplots with the distributions of utilisation rates of all plants for the Mediterranean (van Vliet et al. 2016a). The utilization rates are fairly constant, but they may be reduced in severe drought years. During such years, hydropower utilisation rates were on average reduced by 5.2%, and thermoelectric power by 3.8% (worldwide average). This corresponds to severe streamflow drought years for hydropower and to streamflow drought and high water temperature for thermoelectric power. Overall utilisation rates of thermoelectric plants are lower than for hydropower, since usable thermoelectric power capacity may be limited by more factors (i.e., streamflow drought and high water temperature) and benefits less from storage of water in reservoirs during low flow conditions than conventional hydropower plants (van Vliet et al. 2016a).

Marine energy

The energy resource in the ocean comes from five distinct sources, each with different origins and requiring different technologies for conversion, including, (1) tidal currents that extract kinetic energy from tidal flow, (2) tidal range which captures the potential energy created by the difference in sea level between high and low tides, (3) waves which convert kinetic energy transmitted by the wind to the upper surface of the ocean, (4) ocean thermal energy conversion which exploits the temperature difference between deep and surface ocean layers, and (5) salinity gradients which exploit the chemical potential due to salinity gradients in water bodies. These resources are not uniformly distributed on the globe. Also, the degree of maturity of the technology necessary to their exploitation is different. In the Mediterranean Sea, the two ocean energy sources with the highest potential are tidal currents and waves.

The Mediterranean coastal areas experience two high tides and two low tides per day. Tidal currents are generated by horizontal movements of water, modified by seabed bathymetry, particularly near coasts or other constrictions (e.g., islands). Tidal current flows result from the rise and fall of the tide; although short-term weather fluctuations can slightly influence these flows, their timing and magnitude are highly predictable and largely insensitive to climate change influences (Lewis et al. 2011). In the Mediterranean Basin, there is no commercial development of the tidal energy sector. As tidal turbines need a stream speed of at least 1.5-2 m s^{-1} to operate effectively, the tidal energy potential of the basin sets specific constraints. Given the minimal flow needs provided above, some Mediterranean sites could be of particular interest. The Straits of Gibraltar, and particularly the Strait of Messina (where tidal stream energy resource presents its highest values in the Mediterranean) have been under consideration (Soukissian et al. 2017). The Strait of Messina is characterized by high-energy tidal currents with maximum velocities at spring peak tides ranging

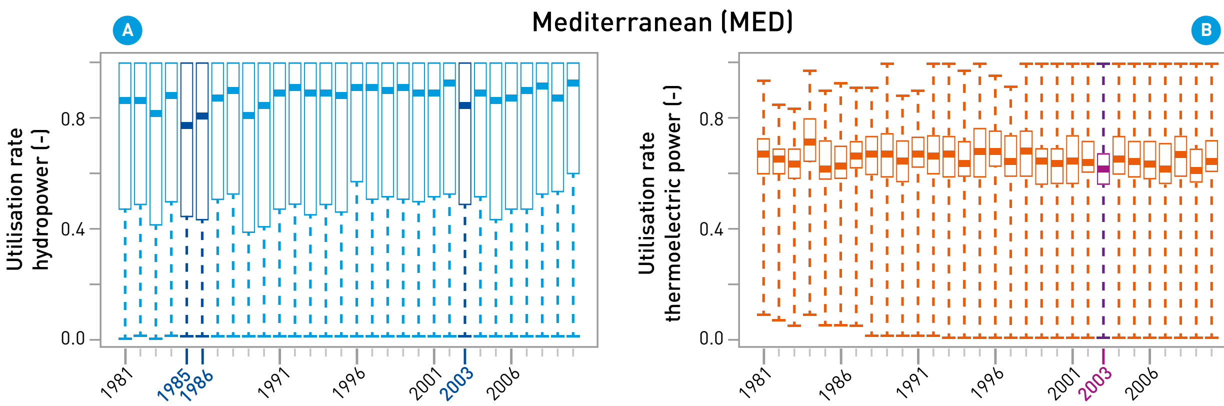

Figure 3.28 | Impacts of streamflow drought and high water temperature on utilisation rates of hydropower (A) and thermoelectric power (B) for 1981–2010. Boxplots with distributions of utilisation rates of hydropower and for thermoelectric power are presented with the largest number of plants and installed capacity. Values of 1 indicate that a power plant works at full capacity (no constraints) while for instance a value of 0.8 indicate that the plant works at 80% of the maximum capacity. Highlighted years indicate that utilisation rates were reduced significantly compared to the average over 1981–2010 (van Vliet et al. 2016a).

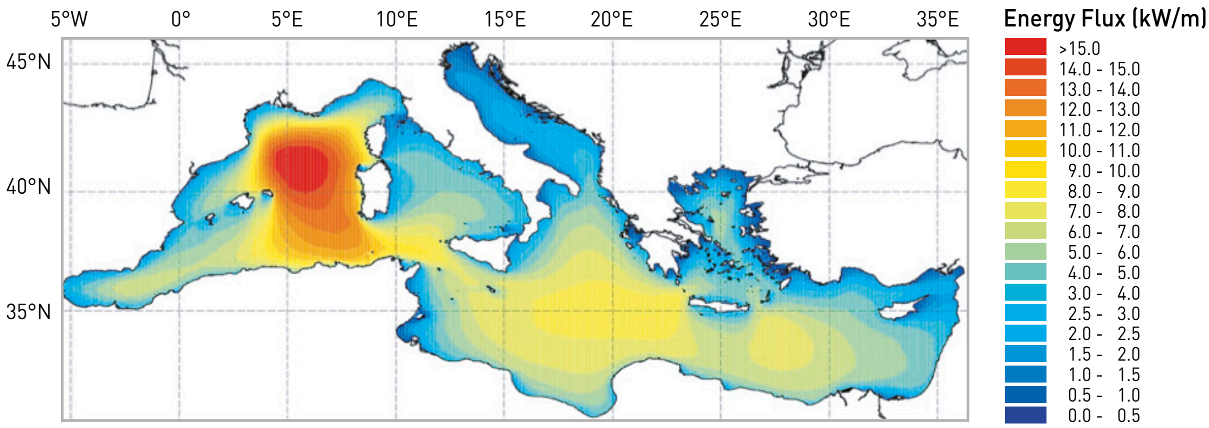

Figure 3.29 | Distribution of wave energy flux in kW m^{-1} averaged over the period 2001-2010 in the Mediterranean Sea. The energy resource was evaluated through of a numerical simulation performed using an ocean wave model. The model was forced with six-hourly wind fields obtained from European Center for Medium-Range Weather Forecast (ECMWF) operational analysis at 1/4° spatial resolution (Liberti et al. 2013).

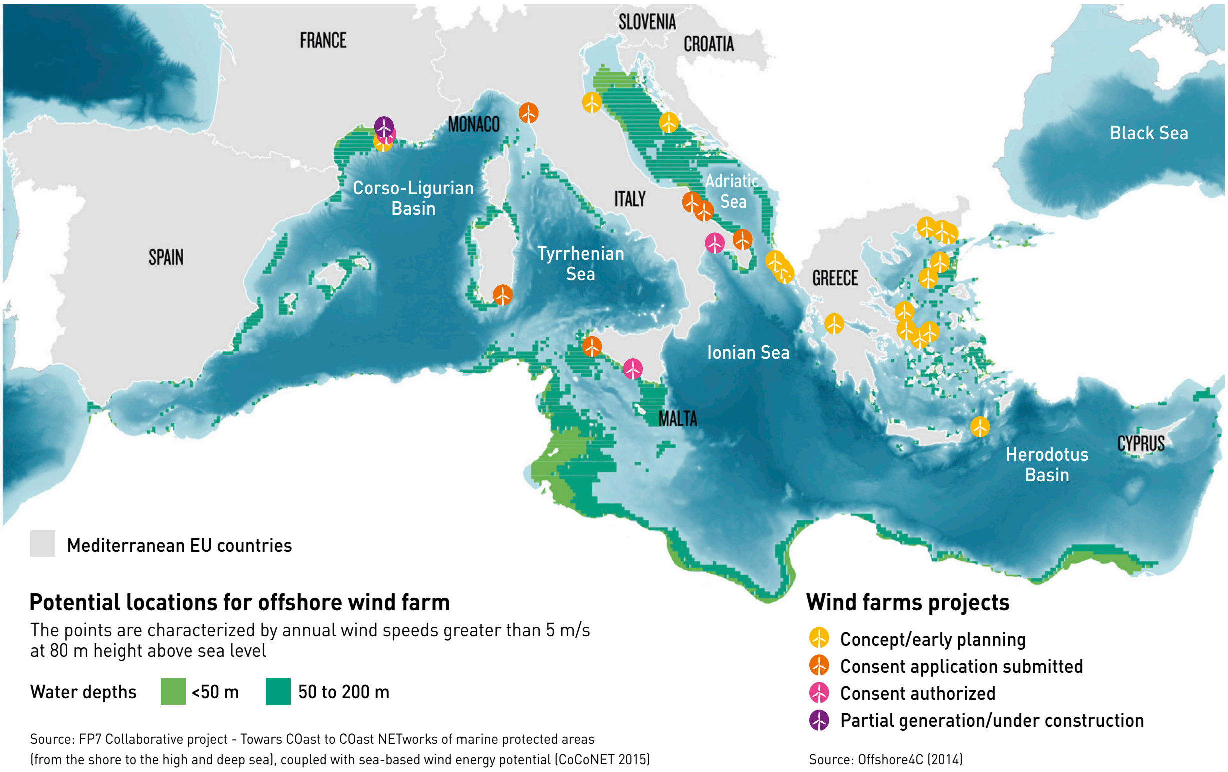

Figure 3.30 | Potential locations for offshore wind farms (Piante and Ody 2015).

from 1.8 m s^{-1} to more than 3 m s^{-1}, proving the suitability of the site for tidal energy harnessing (El-Geziry et al. 2009; Coiro et al. 2013). An estimation of the marine current energy fluxes in the Gibraltar Strait has been provided in Calero Quesada et al. (2014), revealing the suitability of two main sills (Camarinall in the middle of the Strait, and Espartell at the wester entrance of the Strait) for a power plant installation, with computed averaged fluxes in these areas that can exceed 1.8 kW m^{-2}.

Ocean wave energy is energy that has been transferred from the wind to the ocean. As the wind blows over the ocean, air-sea interaction transfers some of the wind energy to the water, forming waves, which store this energy as potential and kinetic energy. The size and period of the resulting waves depend on the amount of transferred energy, which is a function of the wind speed, the length of time the wind blows (order of days) and the length of ocean over which the wind blows (fetch). Energy availability is certainly a major factor affecting wave energy production but high energy potential usually implies exceptional wave conditions during extreme events. Such conditions pose serious engineering challenges to the design and deployment of wave energy converters increasing the costs of development, production, installation, maintenance and insurance of these devices. On the other hand, in calmer and semi-enclosed seas such as the Mediterranean, where lower amounts of wave energy are available, many technical issues related to extreme sea climate could be more easily solved, possibly making wave energy production still economically viable. From this point of view, wave energy production in the Mediterranean is particularly appealing *(Fig. 3.29)* (Liberti et al. 2013).

Offshore wind is likely the aspect of the energy transition of the Mediterranean region with the most important development potential, particularly in SEMCs. It has been introduced in other parts of the world, as it is less environmentally disturbing than on-shore alternatives (Piante and Ody 2015). So far, there is no offshore wind farm in the Mediterranean, although offshore wind production could be highly profitable *(Fig. 3.30)* (Gaudiosi and Borri 2010).

	Installed wind power (MW)	Installed solar PV power (MWpeak) 2018
Albania	150	
Algeria	10	
Bulgaria	644	1,036 (1)
Croatia	529	61 (1)
Cyprus	188	113 (1)
Egypt	1,375	1,800 (2)
Greece	8,256	2,652 (1)
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Tunisia	242	
Turkey	9,384	5,063 (3)
Total	**83,165**	**47,170**

Table 3.11 | Levels of primary solid biofuels (in terajoules (10^{12} joules, TJ) from domestic supply in Mediterranean countries for which information is available for 2017. Data downloaded from https://www.iea.org/data-and-statistics.

Bioenergy

Bioenergy is an important source of renewable energy in the Mediterranean, with an annual output from solid biofuels that dominates by far the production of electricity from solar or wind sources (*Table 3.10* and *3.11*; Bryden et al. 2013; IEA Bioenergy 2016). Traditional biomass remains a major source of renewable energy on the south side, given the low development of renewable energy in this part of the region *(Table 3.11)*. Biomass is the least promising sector for electric energy production and it is rather reserved for the production of heat or fuel. This stems from the fact that bioenergy encompasses a broad range of value-chains and end-uses, providing heat, electricity, and transportation fuels from a variety of biomass sources and conversion pathways (Sansilvestri et al. 2020).

In the Mediterranean region, the importance of bioenergy is highly variable across countries as it depends on the available biomass from forests, agriculture and organic waste. Bioenergy is difficult to characterize as it also has the advantage of producing fertilizers after the organic matter has been digested. In terms of technology, it is common to separate traditional biomass, which predominates in developing countries and involves the burning of wood fuels and agricultural residues for heating and cooking, from modern forms of bioenergy production relying on somewhat more complex biomass processing systems (Chum et al. 2011). Those include liquid biofuels for transport (e.g., bioethanol from sugar crops), pellets from forest residues or agricultural biomass, or electricity generated by dedicated power plants. Anaerobic digestion of organic waste (from cattle, agro-industry or municipal sources) to produce biogas has been growing lately throughout the Mediterranean area. Traditional biomass and modern uses of biomass are both present in the Mediterranean region, although the latter is more difficult to quantify due to a lack of statistics.

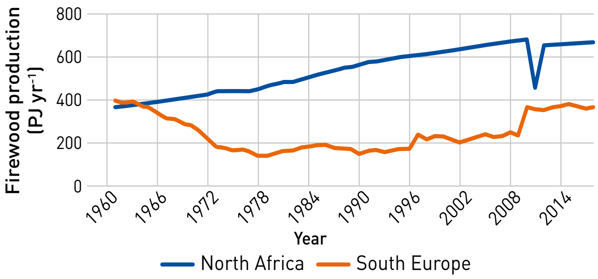


Figure 3.31 | Firewood production in the southern and northern parts of the Mediterranean Basin (FAO 2017).

Overall production of energy from solid biomass in the Mediterranean region amounts to at least 1.56 PW according to the statistics published for 2017 by the International Energy Agency[24]. Energy, including heat production from biomass, varies significantly from one country to another, being concentrated in northern Mediterranean countries *(Fig. 3.31)*. The consumption of wood, as reported by FAOSTAT includes traditional and modern usages of the biomass, presumably with a large proportion of the former when compared to other statistics available on modern value-chains relying on this feedstock. The production of firewood has increased by about 90% in North Africa over the last 60 years while it is back to its 1960's level in southern Europe after a large dip from 1973 to 2009 *(Fig. 3.32)*. The increased demand for firewood in North Africa arises from rising demographic pressure, especially in the rural areas (Schilling et al. 2012). The pressure on wood resources may be alleviated by improving the efficiency of cook stoves (thereby reduce health damages associated with open-hearth indoor fires), or switching to alternative renewable energy sources (Chum et al. 2011). In northern Europe, the competition with other end-uses for wood (e.g., for building, furniture-making or pulp and paper) explains the temporary decrease in firewood consumption.

The availability of biomass from forests is highly asymmetric between northern and southern Mediterranean countries *(Fig. 3.32)*. Considering its large area of forests, the Mediterranean Basin represents a good candidate to develop wood biomass energy for the renewable energy sector development (Gómez et al. 2010). Wood biomass

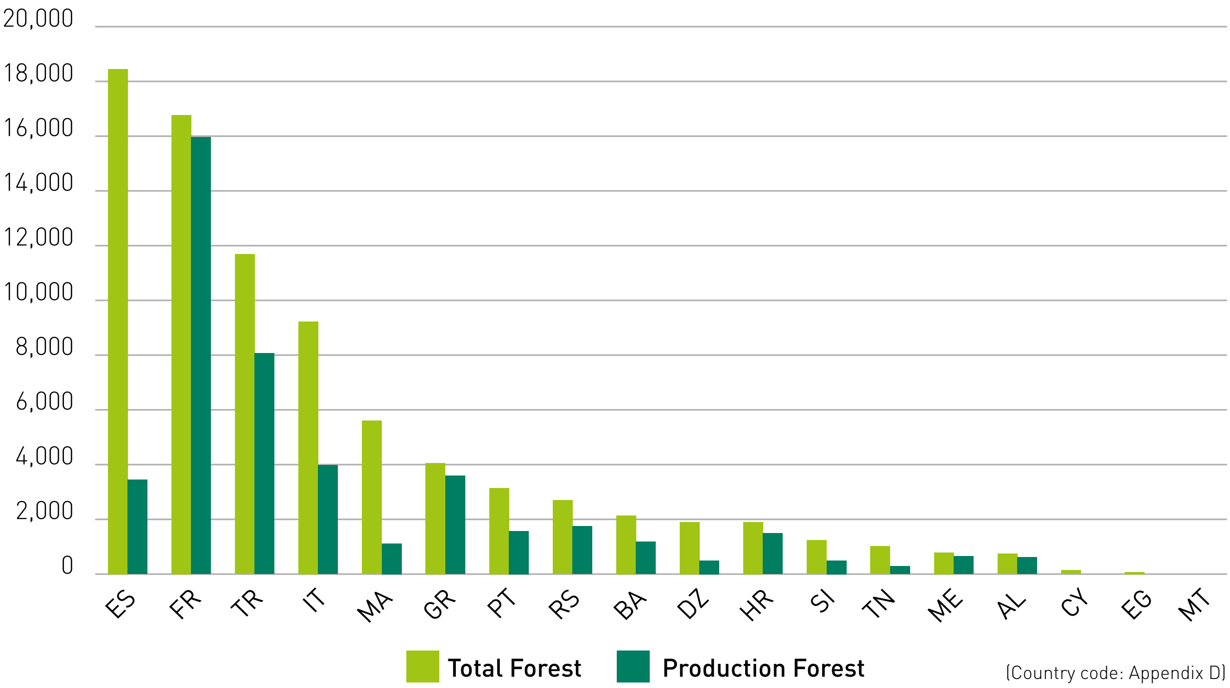


Figure 3.32 | Forest area and production forests available for industrial use including biomass for energy purposes. Values correspond to 1,000 hectares. Data obtained from the 2015 FAO Global forest Assessment[25]. Data for France obtained from official reports[26], whose classification of production forests may vary with respect to FAO guidelines.

[24] https://www.iea.org/data-and-statistics

[25] http://www.fao.org/forest-resources-assessment/en/

[26] https://inventaire-forestier.ign.fr/

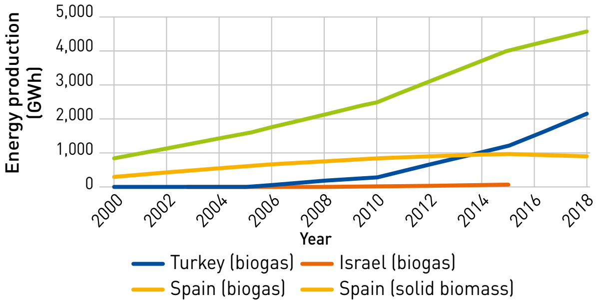


Figure 3.33 | Electricity production from biogas and solid biomass in Turkey, Israel and Spain (IEA 2018).

has low energy density and it is highly spread, two problems that increase harvesting and transportation costs (Caputo et al. 2005; Yoon et al. 2012). While forest surface may be increasing on northern Mediterranean countries, a continuous decline in northern African countries is currently occurring (see FAO forest Global Assessment[27]). Forest fragility is exacerbated in the Mediterranean area where forests have low productivity and agriculture is difficult considering regional climate conditions (González et al. 2015).

Large bioenergy facilities may constitute threats to the biodiversity and forest cover in any region, this also in the Mediterranean. Bioenergy must be ecologically sustainable, environmentally acceptable for the public, and the delivery costs need to be lower than for fossil fuels (Bilgen et al. 2015), but this is often not the case. An example can be found in the Mediterranean zone of France where the conversion of a carbon-based electric central to wood biomass-fueled power plant in 2016 caused conflict between citizens, the forestry sector and regional authorities (Sansilvestri et al. 2020). In contrast, small sized boilers using wastewood resources do not raise the same levels of concern to citizens and are more accepted.

Important efforts exist in Algeria and Morocco to scale up renewable energy sources. For instance, the Renewable Energy Development Centre in Algeria[28] has programs on the whole array of renewable energy including biomass and solar. Clearly, North African countries and other Mediterranean countries will rely more on non-forest biomass as long as there are agricultural or domestic waste as the forest biofuel supply is limited in this region.

Spain uses mainly biofuels for transports and more recently solid biomass for heating network installations (Paredes-Sánchez et al. 2016) In France, the number of heat boilers and networks increased from 30 in 2003 to 284 in 2016 (Neumuller 2015; OFME 2015). The main bioenergy potential in Portugal is domestic wastes (Ferreira et al. 2017). For Morocco wood biomass represents a real economic market with the heat demand for hammam and domestic cooking, causing continuous loss of forest surface (Zouiri and Elmessaoudi 2018).

While firewood is mostly used for heating and cooking, the recent development of more refined bioenergy systems may be captured by statistics on biogas production for the co-generation of heat and electricity in Turkey, Israel or Spain *(Fig. 3.33)*. Power plants running on solid biomass (from forestry or agriculture) are operating in Spain, Italy and Portugal, with similar outputs (2,600 - 43,000 GWh range in 2018) (IEA 2018). No estimates were found for northern Africa, but some programme targeting small-scale household digestion systems have been reported in Morocco and Tunisia (Mulinda et al. 2013). Biogas and bioelectricity production use mostly residues as feedstocks, but statistics on the amount of biomass hereby mobilized are not available. Overall, the contribution of biomass to the national energy mixes is variable in the transport sector (from 0% in the SEMCs to 9% in France), usually larger in the heating sector, and small but growing in the electricity sector.

The production of liquid biofuels (which currently relies on food crops as feedstocks) has only been reported in three southern Europe countries (France, Italy and Spain), as a result of the changes in the Common Agricultural Policy of the EU in the 1990's, and of a series of policies such as the renewable energy directive of the EU. The latter mentioned a 10% target for the share of renewables in the transport sector in 2020, most of which would be achieved with biofuels. Specific rules will be applicable for bioenergy produced from food and feed crops with a target of no more than 7%. The contribution of biofuels with a high risk of indirect land use change (i.e., mainly imported biomass such as palm oil) will be gradually reduced to 0% by 2030.

Unlike other renewables, biomass and biofuels in general may be traded across countries and con-

[27] http://www.fao.org/3/a-i4808e.pdf

[28] https://www.cder.dz/

tinents. In 2017 for instance, Italy imported large amounts of wood pellets from North America (totalling 1.8 M tons or about 32.4 PJ of energy content). This means that the lack of local biomass production potential in the Mediterranean Basin may be compensated for by imports, although its consequences in terms of overall pressure on land resources should be carefully assessed (Searchinger et al. 2008).

In general, agriculture and forestry in the Mediterranean countries are faced with a growing array of challenges (IPCC 2014): the net primary production of managed ecosystems is constrained by limited water resources, the low availability of land on which to grow crops, and soil degradation (in general from erosion, salinity or desertification in the southern Mediterranean) (Olsson et al. 2019). This clearly hinders the development of purpose-grown plants (whether biofuel crops, lignocellulosic plants such as miscanthus, or short rotation coppice), which make up a large part of biomass supply in bioenergy expansion scenarios, e.g., in the 1.5°C warming scenarios of the IPCC SR1.5 (IPCC 2018). Also, regarding agricultural land management, the emphasis in the

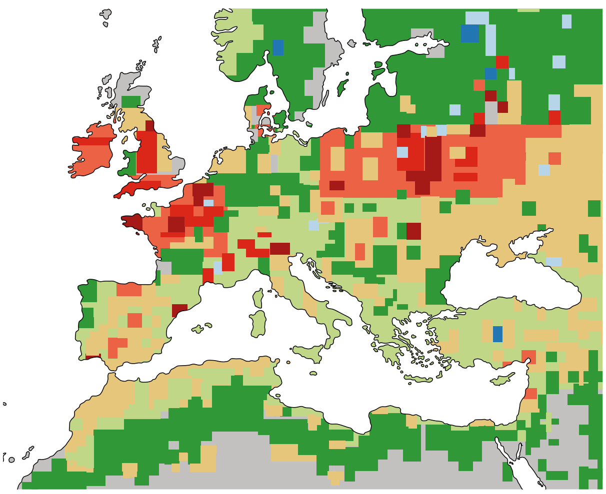


Figure 3.34 | Projected constraints to the establishment of bioenergy plantations by 2050. The "LUC emission" constraint corresponds to a loss of soil C upon converstion to bioenergy crops, which could not be paid back in less than 10 years. Adapted from Beringer et al. (2011).

SEMCs is primarily on food production since all countries rely on imports to meet the needs of their inhabitants. The food constraint is such that in the study of biomass potentials by Beringer et al. (2011), no bioenergy plantations are projected in the SEMCs area by 2050, and to a very limited extent in the northern part of the basin *(Fig. 3.34).*

Since biomass availability is the primary constraint to the development of bioenergy and is limited by a range of physical and economic factors (e.g., land availability, competition with other uses, productivity), many studies have attempted an assessment of "biomass potentials" given a set of assumptions and limitations. Sustainability has also become a major issue with bioenergy systems, arising in particular from the consequences of developing biofuels on the use of land worldwide, and the possibility that these may negate the climate benefits of substituting biofuels (Searchinger et al. 2008; El Akkari et al. 2018). In principle, "sustainable biomass potentials" would provide the most useful guidance, but are not easy to determine because the multifaceted nature of sustainability is difficult to factor in Chum et al. (2011). The trade-offs with soil quality when exporting agricultural or forest residues for bioenergy purposes can be evaluated (Saffih-Hdadi and Mary 2008). It results in a drastic reduction of removal rates (by two thirds in France, for instance).

Regarding the use of land for bioenergy plantations, an option to mitigate the competition between food production and bioenergy markets would consist in growing these plants on marginal land, i.e., land which is unsuitable for other purposes (Fritsche et al. 2017). There is still considerable debate as to the actual amount of such land worldwide, and whether it would be economically feasible to grow biomass plants on these lands. Current estimates range from 350 to 6,000 Mha worldwide (compared to a global cropland area of 1,700 Mha), and a recent study estimated an area of 69 Mha in Europe, among which 43 Mha are located in the northern Mediterranean area (Elbersen et al. 2018). Assuming an energy yield of about 60 GJ ha^{-1} on marginal land (Gelfand et al. 2013), this would translate as an output of 2,600 PJ yr^{-1} for the northern Mediterranean. This is a large amount compared to the current use of biomass in this area (for instance biomass produces 73 PJ of heat yr^{-1} in France and Italy (IEA 2018), with wood as the main feedstock). Aside from this potential opportunity on marginal land, avenues to increase biomass outputs in Europe include an intensification of forestry, the development of purpose-grown plants, which only occupy a marginal fraction of land so far (Don et al. 2011), and an increased valorization of residues and waste streams (for biogas, heat and power). Regarding energy crops, a study factoring in sustainability constraints estimated that the Northern Mediterranean countries could produce 630 PJ yr^{-1} in 2030 from less than 10 PJ yr^{-1} in 2010 (Don et al. 2011; Elbersen et al. 2012).

Regarding the SEMCs, Stecher et al. (2013) reviewed the biomass potential studies and their numbers for the African continent, concluding that the potential for energy crops could range from 0-13,900 PJ yr^{-1}, 0-5,400 PJ yr^{-1} for forestry biomass and 10-5,254 PJ yr^{-1} for residues and waste by 2020. While those numbers could not be disaggregated across regions in Africa, they point to significant potential for all three feedstock categories. From a sustainability perspective, as suggested in Chum et al. (2011), residues are particuliraly efficient at reducing GHG emissions. Their use was prioritized in the strategic energy plan of Morocco for 2030, which emphasizes the use of organic waste, agricultural residues, and algae – a medium-term technology unlikely to be commercialized before 2040 (Chum et al. 2011; Royaume du Maroc 2017).

3.3.2.3 Energy system vulnerability to climate extremes

There are a number of ways extreme weather events affect energy resources and energy systems. Individual events may threaten localized installations but large-scale events such as cold spells may threaten the electricity load balancing at a large scale. Also, with the increase of the share of renewables, the electricity transmission system will be more exposed to weather variations and may be threatened by specific weather conditions that are usually not considered as extreme.

Heat waves increase energy demand for cooling and increase rivers temperature. Long heat waves are generally associated with low flows (see bellow). Increased river temperatures reduce the permissible temperature increase in power plants, thereby inhibiting cooling the cooling water capacity and inducing plant production (Koch and Vögele 2009; van Vliet et al. 2016a). Permissible temperature increase is in particular bounded by critical biological threshold for freshwater species and strongly regulated. Excessive heat also affects power lines capacity to dissipate heat and reduces transmission capacity (Bartos et al. 2016). Heat also reduces the efficiency of solar panels and long-term thermal stress deteriorates PV cells (Chow 2010).

Long-lasting droughts may induce low flows in rivers, reducing production of run-of-the-river hydropower and stock in reservoirs for hydropower (van Vliet et al. 2016a). Droughts also increase the sensitivity of river temperature to air temperature, so that low flows combined with a heat wave can lead to a large warming of river temperatures with consequences on thermal production. The 2003 heatwave and associated drought impacted production in 30 nuclear power plants (Schewe et al. 2019). During the drought, warm year of 2003 simulated hydropower utilisation in Europe was significantly reduced by 6.6% and thermoelectric power by 4.7% compared to the average of 1981–2010 with a smaller impact in the Mediterranean than in northern Europe as Mediterranean power plants are hampered by water constraints on a more

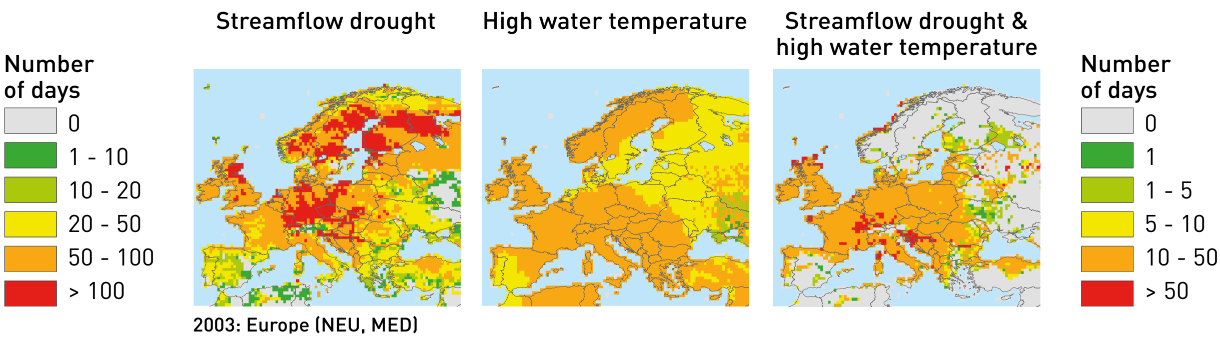


Figure 3.35 | Mediterranean patterns with number of days in the given year with streamflow drought (left), **high water temperature** (middle), **and that both events coincide** (right). Results are presented for year 2003 with both streamflow drought and high water temperature. Scale for right figure panels (streamflow drought and high water temperature) differs from the scale of the left (streamflow drought) and middle (high water temperature) panels (van Vliet et al. 2016a).

regular basis, resulting in lower absolute values of plant utilisation rates and smaller relative changes in usable capacity for 2003 compared to the long-term average for 1981–2010. In 2003, northern Europe and the Mediterranean region display large regions with streamflow drought for more than 100 days and high water temperature for more than 50 days (*Fig. 3.35*; van Vliet et al. 2016a).

Cold spells are exacerbating energy demand, due to increased heating (Thornton et al. 2016). Cold spells generally cover a large geographical extent (typically 1,000-2,000 km²) and may induce challenging conditions for the transmission system. Floods threaten all infrastructures and power devices. Storms and wind gusts also threaten infrastructures, in particular power lines, which may be damaged by falling trees. Solar panels are sensitive to several sorts of extreme weather events (floods, storms), which may threaten the infrastructure. Storms also induce halting of wind turbines for their protection. Storm surges threaten coastal infrastructures. By contrast, low winds induce a loss in wind power production. There are also a number of other hazards, which affect energy systems such as icing on wind turbines, freezing rain and heavy snowfalls endangering power lines, landslides affecting infrastructures.

3.3.3 Projections, vulnerabilities and risks

By improving energy efficiency and deploying renewables on a large scale, the Mediterranean region would enhance energy security for all countries, improve export potential for exporting ones and reduce energy costs and environmental

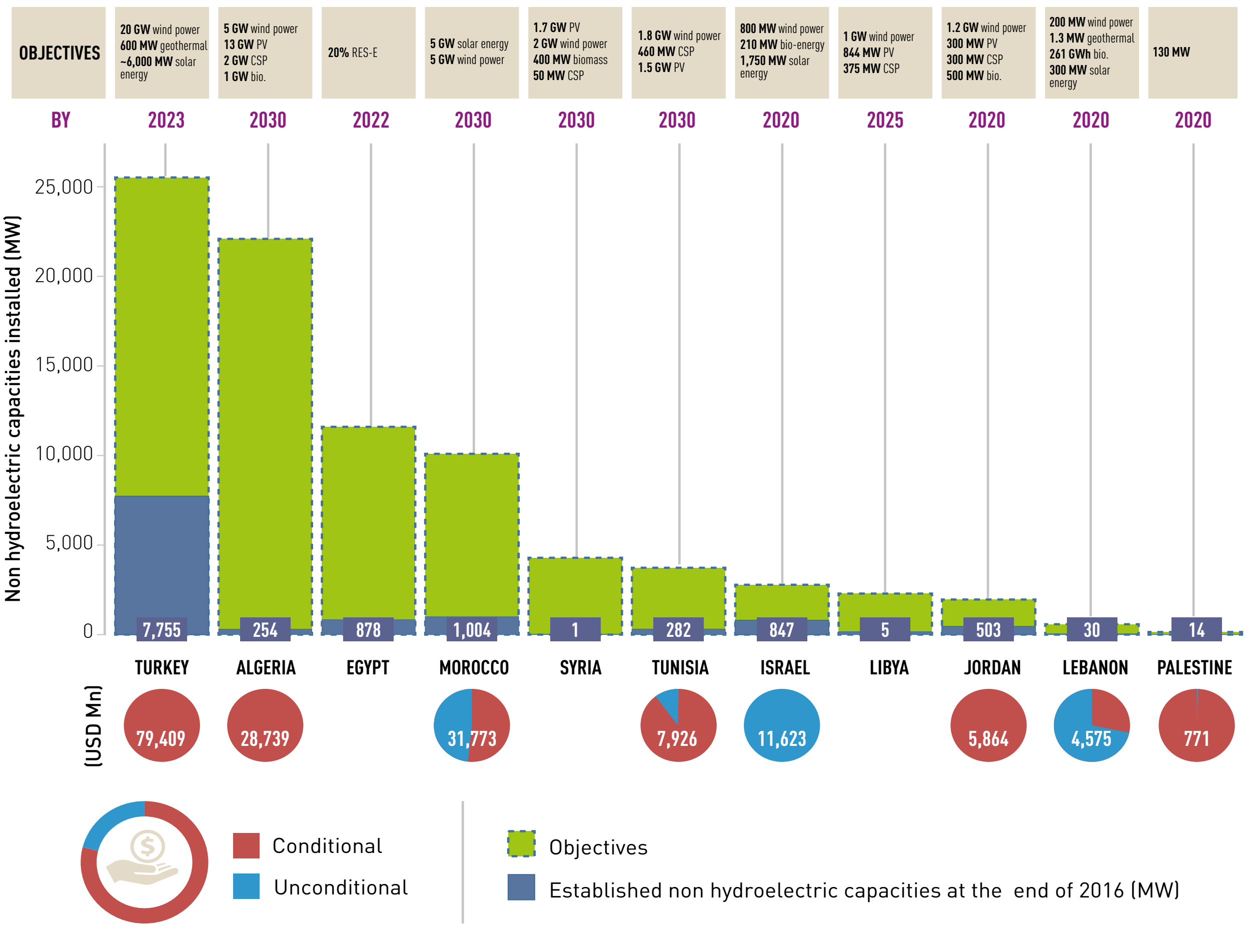


Figure 3.36 | Voluntary commitments of SEMC (Nationally Determined Contribution – NDC – and funding). The upper part shows the installed power capacity of non-hydro renewable energy technologies in 2018, and the extra effort needed to achieve the targets established by the SEMCs at the horizon 2020-2030. The lower part shows the level of funding needed to implement the measures included in the NDCs including the share covered by local vs. international climate funding (unconditional vs. conditional). Sources: OME/MEDENER (2018) - bottom part: UNFCCC[29]

[29] https://www4.unfccc.int/sites/submissions/INDC/

damages for the whole region. Embarking on an energy transition path will also help improve social welfare in the region and contribute to job creation, among other positive externalities.

Nationally Determined Contributions (NDCs) are at the heart of the Paris Agreement and the achievement of the long-term goals to keep temperatures below 2°C. They are voluntary commitments to greenhouse gas emission reduction in all sectors, among which the energy sector, which is the main responsible for greenhouse, gas emissions at global scale. The NDCs of the Mediterranean countries and their implementation have been analyzed in depth by several organisations like IPEMED (Robin 2015), OME/MEDENER (2016), the UfM (Fernández and Hertz 2019) or the European Union project ClimaSouth (Rizzo and Maro 2018) and have served for elaborating energy transition scenarios. *Fig. 3.36* shows the voluntary commitments of SEMC to the required energy transition.

3.3.3.1 Energy transition scenarios

Since 2008, OME regularly issues a Mediterranean prospective analysis to 2040, the "Mediterranean Energy Perspectives" series (MEP). The MEP analyses the trends for energy demand in the different use sectors and the implications in terms of security of supply, CO_2 emissions, and environmental impacts. Within this framework, in 2015 MEDENER and OME published a joint Mediterranean Energy Transition Scenario (TS), an ambitious scenario that goes beyond the plans and targets announced by governments and policymakers. In all scenarios, the OME follows a structural econometric approach that combines economic theory and statistical methods to produce a system of equations establishing causal relationships between energy demand and activity variables (such as GDP, population etc.). This system of equations is then used to generate medium and long-term forecasts of future energy demand. The descriptions of the model and of the energy scenarios assumptions are available in the Appendix of the OME/MEDENER report (OME/MEDENER 2016).

The Mediterranean Energy Transition Scenario (TS) assumes the implementation of those measures that are currently the most technically, economically, and politically mature for large-scale rollout of energy efficiency and renewable energies. This scenario assumes no major technology breakthrough, but the deployment of existing technologies and sound energy efficiency policies and measures across all Mediterranean countries.

According to this analysis, under a Business-As-Usual or so-called "Conservative" Scenario (CS) the situation would evolve critically on all counts over the next 25 years: doubling of energy demand and tripling of electricity consumption, soaring infrastructure and import bills (+443 GW to be installed and doubling of the fossil-fuel imports) and a critical rise in carbon emissions (+45%). Such a scenario, based essentially on fossil fuels, would put further strain on the climate and exacerbate geopolitical tensions in the region. A change of energy trajectory is therefore necessary for all Mediterranean countries to curb the trends through increasing energy efficiency and renewable energy deployment.

Based on this exercise, in 2018, a new edition of the Mediterranean Energy Perspectives was realeased by OME, which includes two scenarios: i) the Reference Scenario (RS) which considers past trends, current policies and ongoing projects and incorporates the unconditional targets of Nationally Determined Contributions (NDCs); in other terms the RS assumes that international financing and other aids will not be forthcoming. ii) The Proactive Scenario (PS) is based on the implementation of strong energy efficiency programmes and increased diversification in the energy mix based on the NDCs submitted by each country and assumes that international financing will be made readily available and that all targets of the NDCs will be met in full.

3.3.3.2 Energy demand

In the Mediterranean region, energy demand increased from 711 Mtoe in 1990 to 978 Mtoe in 2015, an average growth of 1.3% yr^{-1}. The largest share of regional energy demand is in the North Mediterranean countries, which account for over 63%. Expected trajectories for energy demand in the region are very contrasted across the two shores of the Mediterranean *(Fig. 3.37).*

The northern countries are ahead in terms of a transition path with substantial levels of renewables and effective demand-side management. The energy demand in the North has decreased by 8% since 2010. This decrease is not only due to to energy efficiency efforts but should also be seen in the light of a very moderate population growth (+0.5%) and decelerating gross domestic product growth, especially after the 2008 financial crisis (-2%). In both scenarios, by 2040, energy demand in the North Mediterranean would continue to decrease. In 2040, North Mediterranean energy demand would be 10% and 23% lower than 2015

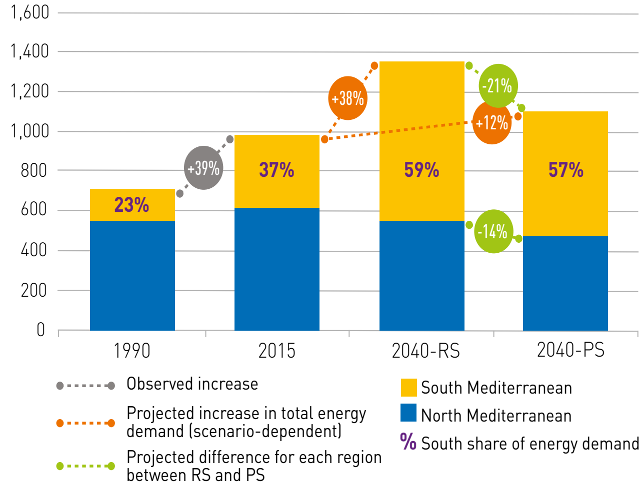


Figure 3.37 | Primary energy demand by region, in megatons of oil equivalent (Mtoe). RS = Reference Scenario; PS = Proactive Scenario (adapted from OME 2018), see *Section 3.3.3.1* for definition of the scenarios.

levels, in the Reference Scenario (RS) and Proactive Scenario (PS), respectively.

The South and East Mediterranean, on the other hand, have experienced sustained economic and population growth over the past years (+6% and +5% respectively), translating into growth in energy demand by +6% since 2010. In all scenarios, energy demand continues to increase by 118% and 72% from 2015 levels, for the Reference Scenario (RS) and Proactive Scenario (PS), respectively. Energy savings would be of 21% in the Proactive Scenario (PS) compared to the Reference Scenario energy demand forecasts.

The South and East Mediterranean would account for 61% of the energy savings with 2025 Mtoe, six times the 2015 primary energy demand of all south and East Mediterranean countries. Cumulative potential energy savings in the North Mediterranean, while less substantial than in the South and East, would still be considerable at around 1315 Mtoe over the same period – more than double current North Mediterranean primary energy demand.

The potential for energy efficiency is substantial in the Mediterranean region, particularly in the South and East. Despite some improvements, energy efficiency is still, at present, in its infancy stage in the region. Overall, energy intensity is decreasing in the region, largely related to shifts in the buildings, industry and transport sector. Globally, 45% of energy consumption (and a similar share of greenhouse gas emissions) are attributable to buildings (Butler 2008). New constructions in developing economies are numerous (Hui 2000). Building regulations aimed at energy efficiency are indispensable, especially in these developing economies, where the energy market alone, does not allow for the activation of incentive mechanisms. Substantial energy savings can be reached in the building sector (residential and tertiary sectors), especially in the South Mediterranean where over 50 million new dwellings are expected to be built over the next decades (OME/MEDENER 2015; OME, 2018). Barriers exist, including the high cost of efficient equipment, the difficulty of changing habits, the lack of adequate technology and also the ignorance of energy and climate issues by some architects in these countries (Iwaro and Mwasha 2010). Jaber and Ajib (2011) propose an assessment of the best orientation of the building, the optimal window size, the optimal thickness of thermal insulation from an energy, economic and environmental point of view for a typical residential building in the Mediterranean region. They suggest that about 28% of annual energy consumption can be saved by choosing the best orientation, optimal window size and optimal insulation thickness. The choice of new materials can also contribute to energy savings (Zabalza Bribián et al. 2011; Buoninconti and Filagrossi Ambrosino 2015).

Industry can substantially improve its efficiency of electricity consumption, but there is less scope to decrease its fossil fuel use in heavy industries, especially in the South and East Mediterranean countries. For all SEMCs, except Tunisia, the share of industry in the final energy consumption is declining. The share of industry in final energy demand is already low in Lebanon (12%) because the activity of this sector is traditionally less developed while it is high in Tunisia (35%). It fell sharply in Lebanon (-10%), after the war with Israel in 2005-2006, with the destruction of many industrial infrastructures, and to a lesser extent in Italy, France and Greece due to the economic crisis and the increasing trend of the service sector (MEDENER 2014). The transport sector would witness strong efficiency gains over the outlook period (18%) as they offer great scope for efficiency improvements in areas such as improved engines, and modal transport expansion.

3.3.3.3 Energy supply

In both OME scenarios, fossil fuels remain the dominant component of the mix. While oil alone is expected to remain the dominant fuel of the energy mix, mainly for its demand in the transport

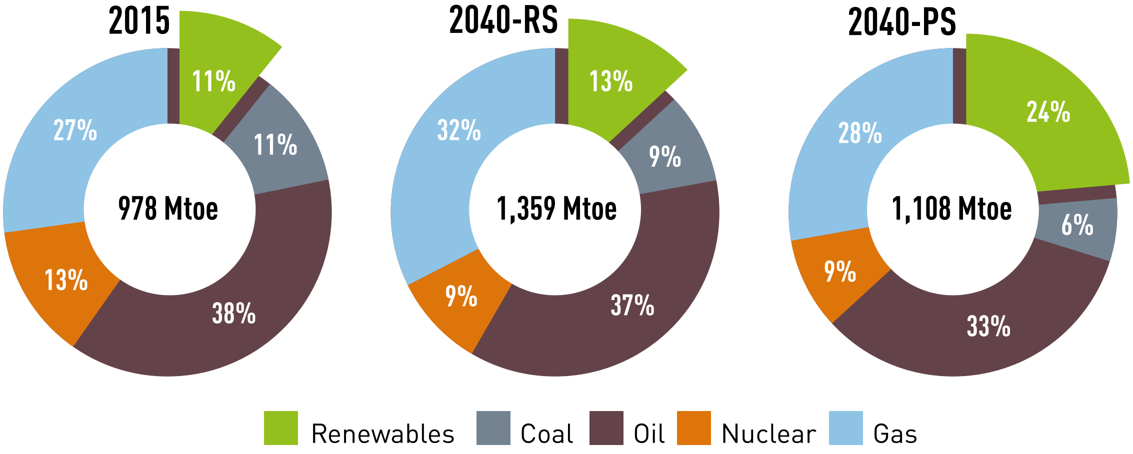


Figure 3.38 | Primary energy resources in the Mediterranean energy mix in megatonnes of oil equivalent. RS = Reference Scenario; PS = Proactive Scenario (OME 2018).

sector, a complete reshape is occurring in the electricity mix, where renewable energy sources have overtaken natural gas capacity and become the main fuel in the Mediterranean electricity mix. The Mediterranean region has abundant renewable energy resources. Yet, today renewables still account for a limited share of the region's primary energy supply (11% in 2015, *Fig. 3.38*). Traditionally the most exploited renewable energy sources have been biomass and hydropower. Geothermal energy contributes in a few countries mainly Italy, Turkey and, to a lesser extent, France, Spain and Portugal. In recent years, wind and solar, both for electricity and heat production have entered the energy mix. In 2040, the share of renewables would reach 13% in the Reference Scenario (RS) and 24% in the Proactive Scenario (PS) (OME 2018). Most of the increase is expected to come from wind and solar. Among the various renewable energy technologies, solar is expected to grow at the fastest pace in both sub-regions. End usage of solar thermal energy, in particular solar water heaters, offers great poten-

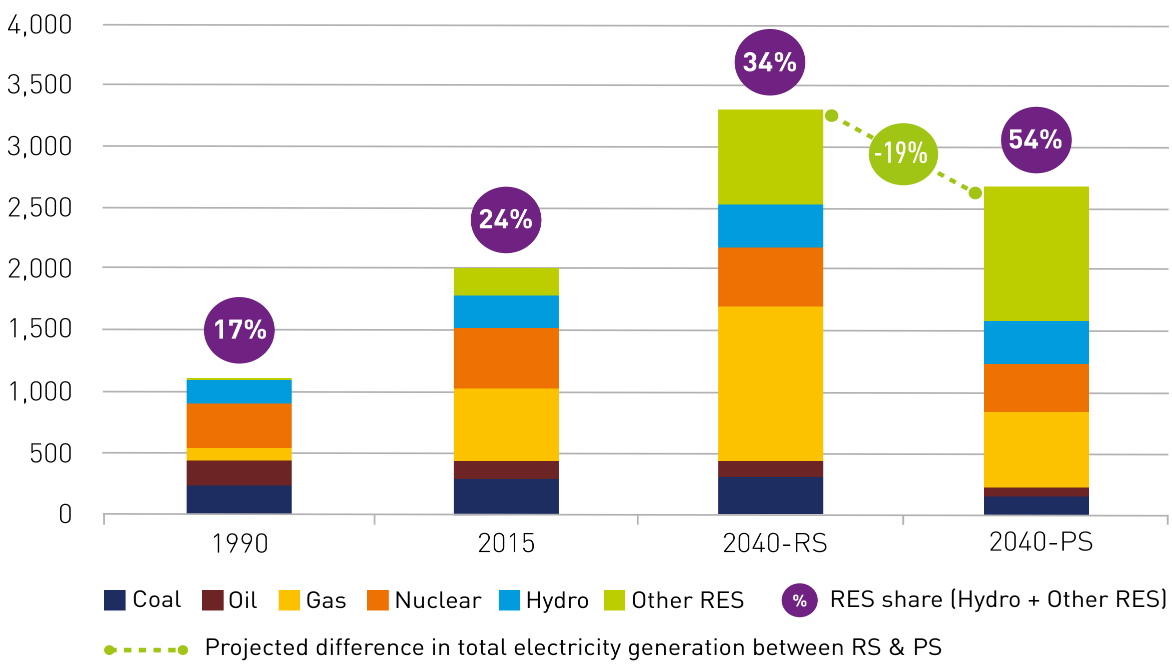


Figure 3.39 | Electricity generation mix by fuel type, in terawatt-hours (TWh). RS = Reference Scenario; PS = Proactive Scenario, RES = Renewable Energy Sources. (Adapted from OME 2018).

tial in the South and is efficient with good return on investment. Solar water heating and solar cooling demand will also increase by 2040.

The most significant change ahead is a substantial increase in the contribution of renewables to power generation *(Fig. 3.39)*. With 124 GW and 104 GW respectively, hydro and non-hydro renewable technologies covered 38% of the cumulative power capacity in the Mediterranean region in 2015. If current trends continue, renewable energy technology will dominate the Mediterranean electricity market in the next years in terms of net generation capacity additions. In 2015, the net renewable energy capacity added was almost the half of the one of natural gas, which historically represented the first-generation source in the Mediterranean electricity mix (10 GW against 5.6 GW). In particular, the net additions of non-hydro renewable electricity capacity in were larger than 8 GW yr^{-1} on average during the last 10 years.

The important growth in terms of new renewable electricity capacity expected will lead to a drastic restructuring of the power generation infrastructure. By 2040, renewables would in fact account for about 70% of total installed capacity and more than 50% of electricity generation in the PS. North Mediterranean countries are expected to add about 9 GW of new renewable capacity per year to reach a total of 410 GW by 2040 (thus more than doubling current power installed capacity). South and East Mediterranean countries will contribute some 6 GW yr^{-1}, to reach 181 GW by 2040, a five times growth in the PS compared to current levels. This would completely change the electricity market supply and demand structure in South Mediterranean countries.

In terms of electricity generation, renewables will generate 1,137 TWh in 2040 in the RS, or 34% of total electricity generation in the Mediterranean. This implies an average annual growth rate of 1.3% for hydro, which would generate 357 TWh, and 5.1% for non-hydro renewables (780 TWh) over the period 2015-2040. In the Proactive Scenario, electricity generated from renewables is expected to reach over 1,438 TWh, around 52% of total production in 2040. This trend is influenced by 20% less growth in electricity generation in the Proactive Scenario than in the reference case, the progressive phase out of oil and coal-fired electricity production plants and a further boost to renewable energy technologies, both in North Mediterranean countries, where non-hydro renewables would experience a compounded average annual growth rate (CAAGR) of over 5.5%, and in South and East Mediterranean countries, where non-hydro renewables are expected to grow at 11% CAAGR.

In terms of the outlook for the three fastest growing renewable energy technologies in the Mediterranean region, North West Mediterranean countries maintain their regional leadership in both scenarios for wind generation, with a projected electricity output of 267 TWh in the RS and 325 TWh in the PS by 2040, around 70% of wind electricity generation in the Mediterranean. The Proactive Scenario foresees a more accelerated rate of growth of wind in the South and East Mediterranean region, which would supply about one-third of the total wind-generated electricity by 2040 (over 148 TWh). The South and East Mediterranean should produce about 32% of the total solar CSP-based electricity in the region (15 TWh) by 2040 in the RS, and 43% (27 TWh) in the PS.

3.3.3.4 An NDC-based scenario for the Mediterranean region

While the energy transition raises common challenges for the entire region, the nature and scale of the challenges are different between the northern countries and SEMC. *Fig. 3.40* shows the demographic and energy projection in the Reference Scenario (RS) of OME MEP2018 which will be used as a reference in *Section 3.3.4.4* to discuss energy transition financing objectives. The countries on the northern shore have more than two decades of reforms that have gradually diversified their energy mix and controlled the growth of their energy demand, in a context of demographic stability. SEMCs are facing rapid population growth, which should lead to a significant increase in their energy demand. Their energy mix is widely relying on fossil fuels and fossil fuel export revenues which play a central role in the macro-financial balance of some countries (Algeria, Egypt, Tunisia) (MEF 2019).

Finally, compared to the RS by 2040, *Fig. 3.41* shows that the Proactive Scenario would lead to significant benefits, in terms of reduced energy dependence, energy efficiency, renewable energy growth and climate mitigation. More specifically, compared to the RS, the Proactive Scenario (PS) would reduce the energy dependency of the region by 45% (from 43% to 24%); as well energy demand and electricity generation would be reduced by 20%, each; the share of renewables in electricity production would be 57% higher in the PS compared to the RS. Finally, the PS would see a reduction of CO_2 emissions of 30%.

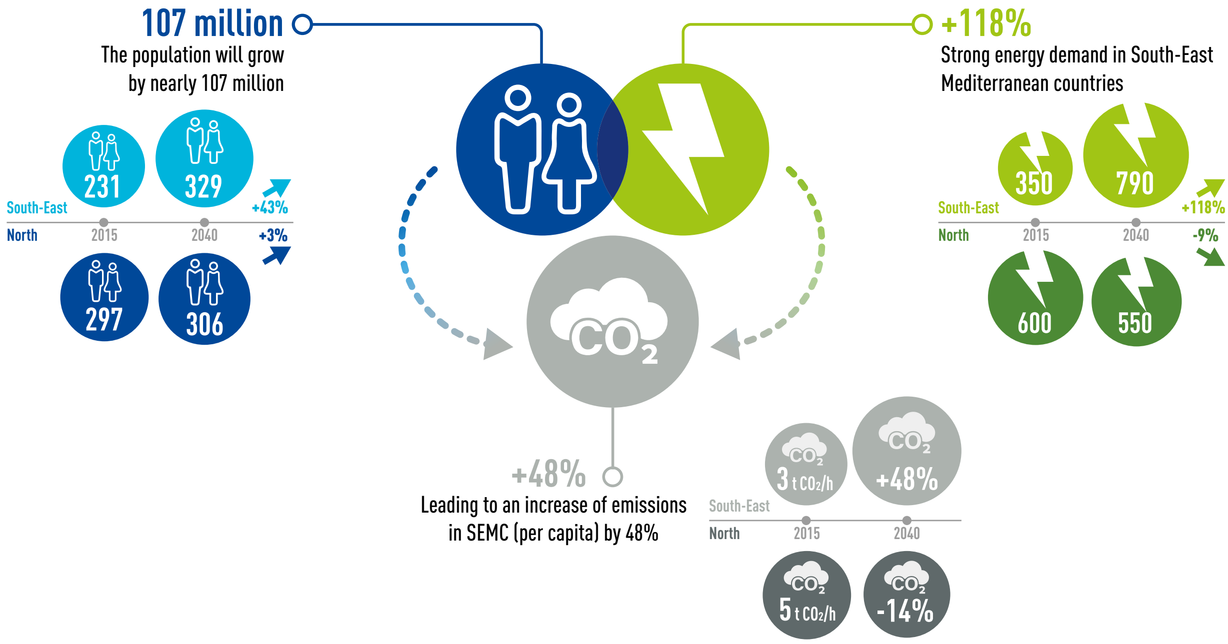


Figure 3.40 | Demographic and energy projections in the Mediterranean in 2040. Source: MEF (2019), based on OME (2018) Reference Scenario (RS).

3.3.3.5 Impact of climate change on energy resources

Although solar photovoltaics and wind power are growing rapidly, several scenario studies show that thermoelectric (fossil, nuclear, geothermal, biomass-fueled) power, together with hydropower, will most likely remain the dominant power-generating technologies during the whole of the twenty-first century (IEA 2018). Overall reduction in total power generation is projected under global

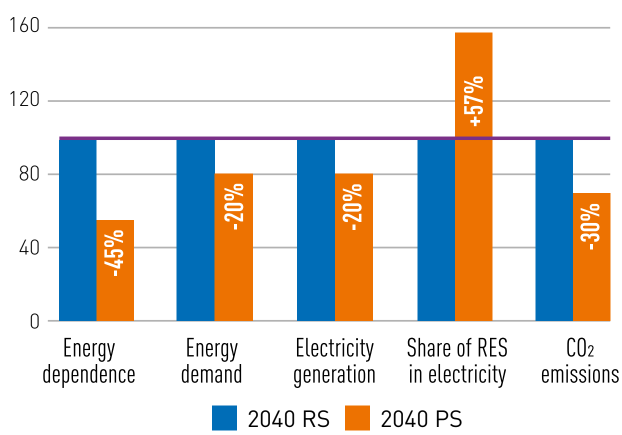
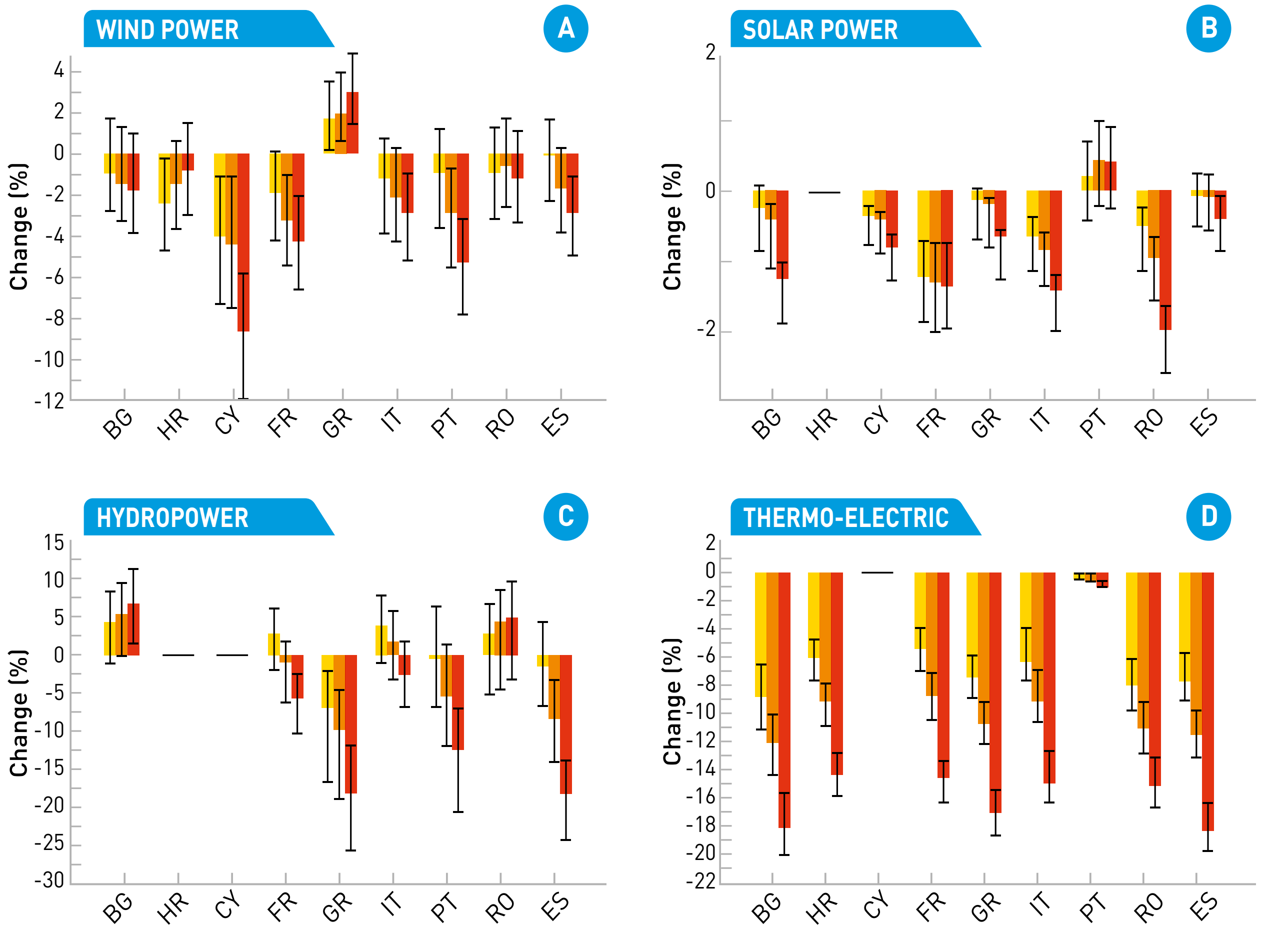


Figure 3.41 | Benefits of the implementation of the Proactive Scenario (PS) compared to the Reference Scenario (RS) at the horizon 2040 (OME 2018).

warming as highlighted in a study investigating wind, solar, hydropower and thermoelectric power generation evolution in Europe (Tobin et al. 2018).

Several studies using regional or global climate projections show that the western Mediterranean Basin is likely to undergo slightly decreasing winds in future decades (Hueging et al. 2013; Tobin et al. 2016) due to the poleward shift of the Hadley cell *(Section 2.2.2.1)*. Surface wind speed declines remain moderate by the mid-century (generally of the order of a few percent). Wind speeds usually undergo small expected changes (Solaun and Cerdá 2020). By contrast, wind speeds are consistently projected to increase in the Aegean Sea (Tobin et al. 2015, 2016) where more persistent episodes of stable wind mill production regime are found *(Section 2.2.2.4)* (Weber et al. 2018). In any case wind resource is not threatened by climate change. Overall, the magnitude of change is small (< 5%) for all countries under a 1.5°C and 2°C global warming *(Fig. 3.42; panel A)*.

For a 3°C warming, most countries undergo changes with a magnitude also below 5% except for Portugal, Ireland and Cyprus where decreases in magnitude are expected to exceed 5%, approaching 10% for Cyprus. A 2°C warming does not systematically lead to higher change magnitudes than 1.5°C, while 3°C warming leads to stronger changes in most cases. In terms of individual cli-



(Country code: Appendix D)

Figure 3.42 | Future changes in national wind power (A), solar PV power (B), hydropower (C) and thermoelectric power (D) production under +1.5°C global warming (yellow bars), 2°C (orange bars) and 3°C (red bars). Changes are relative to the reference period 1971–2000. Colored bars correspond to the ensemble mean. The black thin error bars represent ensemble-mean confidence intervals (95% level based on the Wilcoxon-Mann-Whitney test). Adapted from Tobin et al. (2018).

mate model signals, the spread among the models is limited.

Climate change also impacts solar radiation and thereby solar energy resource. For solar PV generation *(Fig. 3.42; panel B)*, projected ensemble mean impacts show moderate reductions for most countries in Europe, expect for the Mediterranean countries, i.e., Portugal, Spain, Greece and Cyprus where changes are very small (but the magnitude and direction of changes are robust since most models agree). The overall magnitude of the signals is correlated with the amount of warming. Crook et al. (2011) and Wild et al. (2015, 2017) studied the global changes on PV and CSP outputs as a result from climate change, combining solar radiation with other factors such as cell temperature and wind. They found that solar PV output is generally declining in future scenarios worldwide except over a few areas in Europe and the Mediterranean region where the expected increase in solar radiation is expected to overpass the temperature effect.

Over Mediterranean areas there is agreement among studies that radiation will increase and this will lead to an increase in solar PV output despite the temperature increase (Jerez et al. 2015; Gil et al. 2019). There is large spread in estimated amplitudes and also significant differences between regional and global climate modeling results (Bartók et al. 2017), which may be at least partly explained by the lack of aerosol changes in most regional climate models.

CSP potential is also expected to increase with climate change. North-West Africa (Morroco and North of Algeria) appears to be one of the areas of Africa where solar potential is increasing in

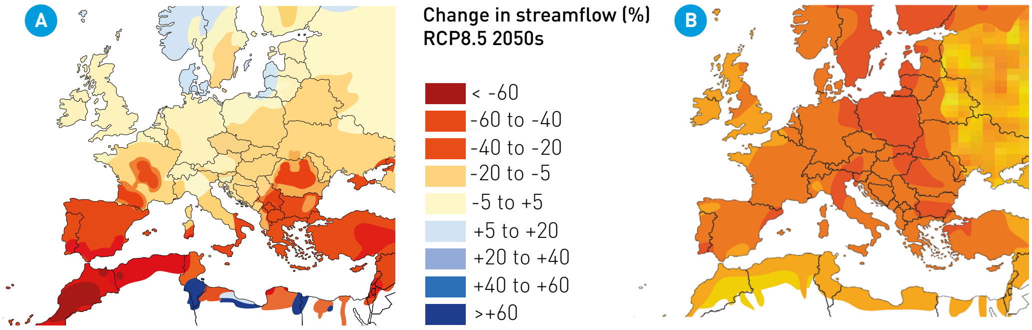


Figure 3.43 | Impacts of climate change on annual mean streamflow (A) and water temperature (B) for RCP8.5 for 2040–2069 (2050s) relative to 1971–2000 (adapted from van Vliet et al. 2016b).

climate change scenarios (Soares et al. 2019), but over the whole of North Africa projections indicate a small decrease in resource (Bichet et al. 2019).

Climate variability and the likelihood of heat waves and droughts are expected to increase in the Mediterranean (*section 2.2.4.2*; Raymond et al. 2019). This may have important impacts on water resources available for hydropower (e.g., Hamududu and Killingtveit 2012) and thermoelectric power generation (van Vliet et al. 2012b, 2016b) in Europe and Africa. Consistent decreases in streamflow are projected for the Mediterranean region (up to -30% to -50% in soth and east according to scenarios, *Fig. 3.7*). Water temperatures continue to increase during the twenty-first century for RCP8.5 (+1.0°C to +2.0°C for 2050s; van Vliet et al. 2016b; *Fig. 3.43*).

Spatial patterns of changes in hydropower usable capacities strongly correspond with the projected impacts on streamflow, showing overall decreases in hydropower usable capacity the Mediterranean, with reductions in the annual hydropower capacities of 2.5-7.0% for the 2050s (RCP2.6–RCP8.5; van Vliet et al. 2016b) (*Fig. 3.43*; panel A). Thermoelectric power usable capacities are projected to decrease for more than 60% (RCP8.5) of the power plants *(Fig. 3.43; panel B)*. Thermoelectric power plants in the Mediterranean are situated in areas with expected declines in mean annual streamflow *(Section 3.1.4.1)* combined with strong water temperature increases *(Section 2.2.4.2)*, which both amplify restrictions on cooling water use. *Fig. 3.43 (panel B)* shows considerable reductions in thermoelectric power usable capacity in the Mediterranean region of 10-15% (for the 2050s, RCP2.6–RCP8.5).

Impacts of climate change on gross hydropower potential have also been studied for Europe. Gross hydropower potential refers to "the annual energy potentially available when all natural runoff in a country is harnessed down to sea level (or to the border line of the country) without any energy losses" (Eurelectric 1997). Mean gross hydropower potential is projected to increase in northern, eastern and western Europe and to decrease in southern Europe *(Fig. 3.42; panel C)*. Overall, higher warming results in stronger changes. Results for the individual regional climate model projections show that many individual signals are not significant and the spread amongst models is substantial. The most negatively impacted countries will be Greece, Portugal, and Spain. Impacts in these southern European countries can be reduced by limiting global warming. A warming of 3°C reduces hydropower potential by 15-20% while limiting to 2°C warming would keep decreases below 10%.

The usable capacity of thermoelectric power plants using river water for cooling is expected to reduce in all European countries due to a combination of higher water temperatures and reduced summer river flows *(Fig. 3.42; panel D)*. The magnitudes of the decrease are about 5% for 1.5°C, 10% for 2°C and -15% for 3°C for most countries. Bulgaria, Greece and Spain will be the most strongly impacted (15–20% decrease). Results based on output of various climate models project significant changes and agree on the direction of changes as the spread among signals is limited. Robust and significant negative climate change effects are found, with a magnitude higher than for other power generating technologies in Europe (Tobin et al. 2018) *(Fig. 3.44)*.

Regarding bioenergy, in the long term (>2040), biomass is projected to be a key option to meet the most stringent climate targets (Clarke et al. 2014; Rose et al. 2014; Rogelj et al. 2015), because of its ability to produce negative emissions in association with carbon capture and storage *(Section 3.2.3.2)*.

Integrated assessment models involved in the IPCC 1.5°C report project that biomass will take a growing share in primary energy use in most regions of the world during the 21st century *(Fig. 3.45)*. The main driver behind this result is the need to decarbonize the energy sector (Bauer et al. 2018) and the availability of other sources of renewable energy.

Future environmental and climatic conditions of the Mediterranean Basin reinforce uncertainties related to bioenergy sector development. The Mediterranean zone is expected to have huge shifts in the distribution of agricultural and forest areas with climate change making the region vulnerable (Fernández-Manjarrés et al. 2018). The current low primary production and the fragmentation of private lands could limit the development of the bioenergy sector. Furthermore, the future increase of dry conditions and extreme natural events, reinforce tough environmental conditions for the biomass sources production especially forestry, agricultural and energy crops. Fires can be favored with increased dry conditions making many forest biomass reserves vulnerable, therefore needing adequate management (Fernández-Manjarrés et al. 2018). Also, the less pregnant decarbonisation constraint and the availability of solar energy explain why the share of biomass is not changing much in SEMCs.

Agriculture in the Mediterranean area is particularly vulnerable to climate change due to its reliance on rainfed systems and the increased water shortages, which are anticipated in this region *(Section 3.2.2.1)*. These are very likely to have a negative impact on crop yields, in particular for wheat in North Africa. A decrease in crop yields would directly affect the amount of land available to grow energy crops, which are scarce to start with, especially in the SEMCs. Herbaceous bioenergy crops (*Miscanthus, Panicum virgatum,* cardoon, *Arundo donax*) produced on marginal or abandoned land offer promising prospects in southern Europe with positive effects in terms of sustainability criteria (Pulighe et al. 2019). To ensure the feasibility of production with regard to environmental criteria, the choice of cultivars most resilient to water stress and agronomic management will play a critical role.

While there is a large body of work on the combined effects of CO_2 concentration rises and climate change on staple food crops (IPCC 2014), only few studies exist on lignocellulosic plants (Chum et al. 2011). One study on miscanthus (a perennial grass) concluded that this crop would no longer be suitable in the Mediterranean area by 2050 due to drought kill (Hastings et al. 2009). Conversely, a simulation study involving another perennial crop *(Arundo donax)* in northern Italy concluded that its

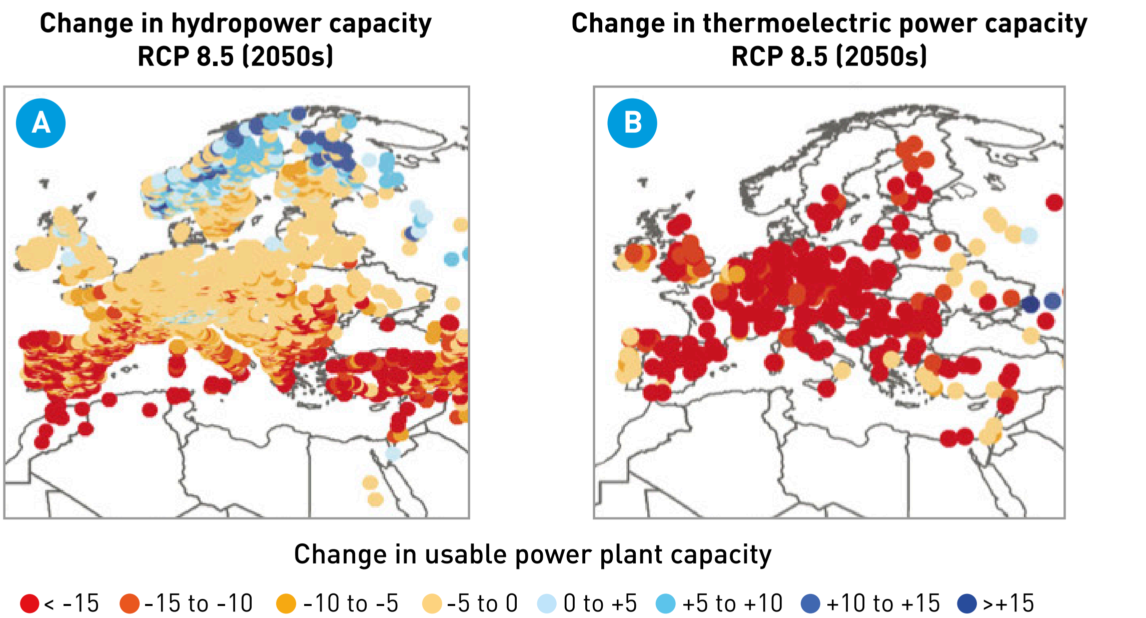


Figure 3.44 | Impacts of climate and water resources change on annual mean usable capacity of current hydropower and thermoelectric power plants. Relative changes in annual mean usable capacity of hydropower plants (A) and thermoelectric power plants (B) for RCP8.5 for 2040–2069 (2050s) relative to the control period 1971–2000 (van Vliet et al. 2016b).

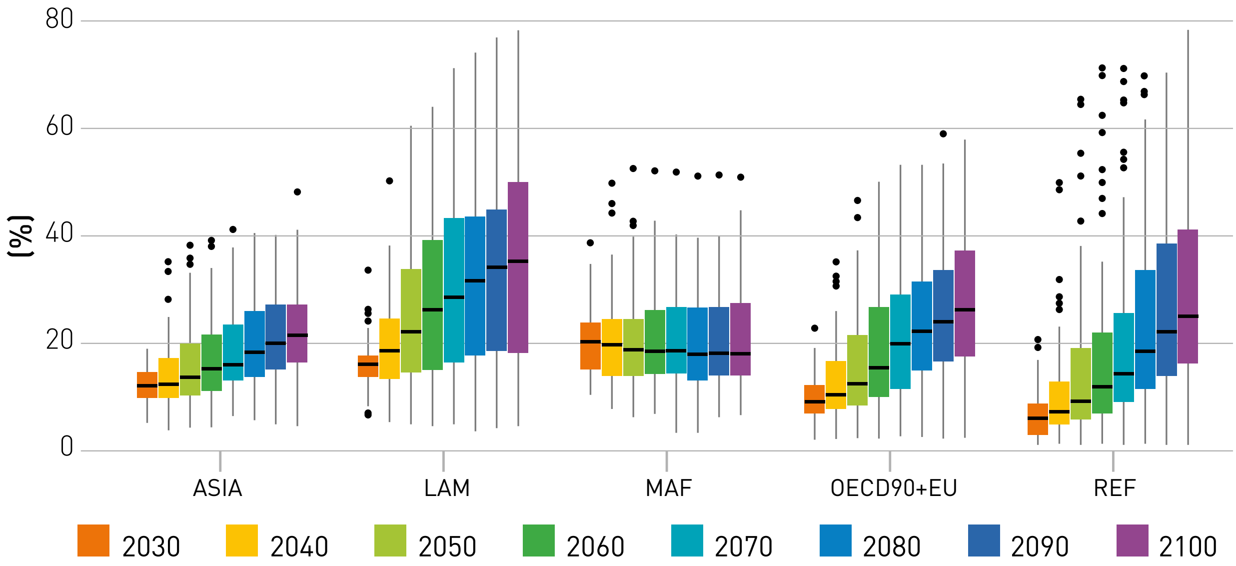


Figure 3.45 | Regional share of biomass in the primary energy use in the IPCC 1.5°C scenarios. Source: data available from the IAMC 1.5°C Scenario Explorer hosted by IIASA available at https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/#/login?redirect=%2Fworkspaces. ASIA: Asian countries except Japan, LAM: Latin America, REF: Countries from Reforming Ecomonies of the Former Soviet Union, MAF: Countries of the Middle East and Africa, OECD90+EU: OECD90 and EU (and EU candidate) countries.

yield could increase by 20% within 2050 due to an increase in water-use efficiency permitted by higher ambient CO_2 concentrations (Cappelli et al. 2015). For any bioenergy project, the selection of the most appropriate feedstocks should clearly be based on the local conditions and contexts, but while there is an increasing body of data and technical knowledge available on energy crops (Laurent et al. 2015), there is a scientific gap as far as the impact of climate change is concerned, in particular in the Mediterranean. Finally, climate change should also reduce the amount of agricultural residues available for bioenergy, which projections usually consider stable. The same applies to forest residues or waste from the agri-food sector, although the latter may import raw material from other world regions to compensate for a decrease in local supply.

Biomass production in the Mediterranean coastal regions should eventually, be limited by the lack of available land suitable for bioenergy production (Daioglou et al. 2019) and by water constraints. In a scenario projecting a warming limited to 2°C, Near East and North Africa will become major importers of biomass with, by 2100, a level of biomass imports in monetary values higher than their current fossil fuel exports (*Fig. 3.46*; Muratori et al. 2016).

Factoring in food security and bioenergy production is usually seen as a dilemma in projections and foresight studies (Tilman et al. 2009). Integrated assessment models show that the agricultural and forestry sectors can meet an increasing demand both for food and bioenergy products by various adjustments (increase in crop yields via higher input rates, expansion of cropland area) (IPCC 2018), but in the Mediterranean area it is likely that there is less room for such adjustments given the environmental and economic constraints. Overall the highest potential should come from residue and waste streams, for which there are unfortunately few estimates available, and the use of marginal land – pending a proof of concept that this strategy can be implemented at a large enough scale beyond simulation studies (Gelfand et al. 2013). In the rural areas of the southern Mediterranean Basin where the use of traditional biomass predominates, the generalization of more efficient bioenergy technologies (improved cookstoves in particular) would also reduce the pressure on biomass resources and make biomass available for more refined uses (for power and transportation fuels) (Chum et al. 2011; Mulinda et al. 2013).

3.3.3.6 Impact of climate change on energy demand

Climate change in the Mediterranean is expected to impact the energy consumption mainly as a decrease (respectively increase) in space heating

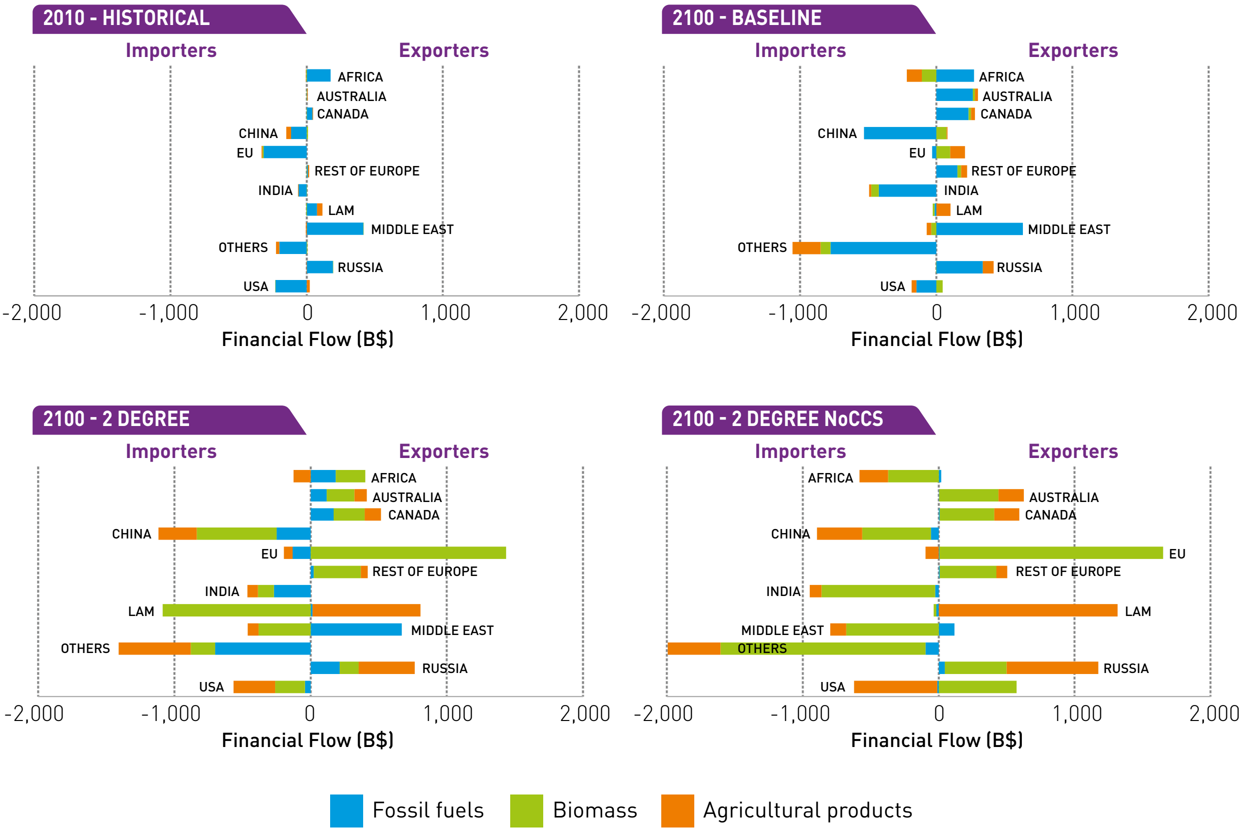


Figure 3.46 | Global fossil fuels, biomass, and agricultural products financial flows in 2010 and in 2100 (Muratori et al. 2016).

(respectively cooling) demand, all other factors remaining fixed. These results from a number of studies (see below) are derived from climate change projections from general or regional climate models reviewed by IPCC's 4th and 5th assessment reports, in combination with econometric analyses or with bottom-up energy models. The net change in the yearly energy demand for heating and cooling in the 21st century associated with climate change depends on location via both the distribution of temperatures and the thermal sensitivity of energy consumption (Wenz et al. 2017). Thermal sensitivity may be defined as the change in mean energy consumption or in peak load associated with a unit change in temperature. Thermal sensitivity is usually negative for low temperatures, due to increased energy consumption associated with heating and positive for high temperatures, due to increased energy consumption from cooling. Thus, thermal sensitivity depends on local efficiency of appliances and isolation and on consumer behavior.

Due to heating, countries historically experiencing relatively low temperatures, such as in northern Europe, are expected to see a net decrease in energy demand (Damm et al. 2017; Wenz et al. 2017) as opposed to countries which already or which will experience high temperatures, such as most Mediterranean countries (Giannakopoulos et al. 2009; Eskeland and Mideksa 2010), which are expected to see a net increase in the energy demand due to cooling. This is illustrated by the maps of *Fig. 3.47* which represent changes in average daily peak electricic load at the end of the 21st century relative to the beginning of the century estimated by Wenz et al. (2017) for the RCP4.5 (A) and RCP8.5 (B) scenarios. Differences between countries may not only be due to differences in temperature distributions, but also to varying thermal sensitivities between countries. Annual demand values do not reflect the seasonality of these changes, which may significantly impact the seasonal planning of energy resources.

Using regional climate models or statistical downscaling, case studies for specific countries such as Algeria (Ghedamsi et al. 2016), Cyprus (Zachariadis and Hadjinicolaou 2014), Slovenia (Dolinar et al. 2010), or Spain (Pérez-Andreu et al. 2018), offers

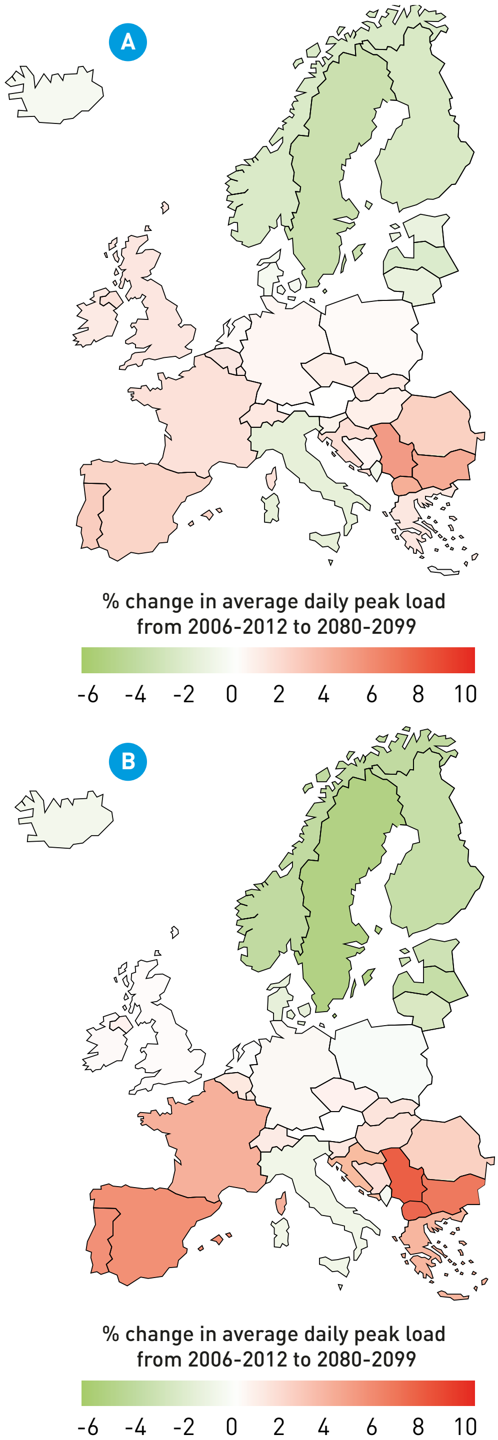


Figure 3.47 | Percentage change in average daily peak electric load from 2006–2012 to 2080–2099 for projected daily maximum temperatures under RCP4.5 (A) and RCP8.5 (B) climate change scenarios. While daily peak load decreases in northern European countries, it increases in southern and western European countries. This trend is most pronounced for a scenario of unabated climate change (RCP-8.5, B) but still holds for a scenario of mitigated climate change (RCP-4.5, A) (Wenz et al. 2017).

a more detailed picture showing that the expected distribution in demand changes may depend on local climates and that extremes in both heating and cooling demand may intensify even if the demand is reduced on average.

Energy demand may also be indirectly affected by climate change as impacts on the agricultural sector associated with reduced precipitation in North Africa may motivate replacing biomass as traditional energy source in rural areas (Schilling et al. 2012).

3.3.4 Adaptation and mitigation

3.3.4.1 Adaptation of energy systems to water constraints

Adaptation measures to mitigate the vulnerability of the electricity sector to future water constraints under changing climate have been investigated in the form of six options (van Vliet et al. 2016b). Options 1 and 2 assume increases in efficiencies of hydropower plants and thermoelectric power plants. Option 3 assumes replacement of fuel sources of thermoelectric power plants (coal- and oil-fired plants replaced by gas-fired plants). Option 4 assumes replacement of once-through cooling systems by recirculation (wet tower) cooling systems. Option 5 assumes switch to seawater cooling for thermoelectric power plants close to the coast (<100 km), and option 6 assumes decoupling from freshwater resources by switch to seawater and dry (air) cooling for 10% of the thermoelectric power plants that are most vulnerable to water constraints under climate change *(Fig. 3.48)*.

Increasing total efficiencies of hydropower plants up to 10% is able to completely offset the mean annual impacts of increased water constraints under changing climate for most regions, including the Mediterranean area (Europe and Africa) *(Fig. 3.48; panel A)*. For thermoelectric power, increased power plant efficiencies also positively contribute in reducing water demands and decreasing the vulnerability to water constraints under climate change *(Fig. 3.48; panel B)*. A strong increase in power plant efficiencies up to 20% is for most regions still insufficient to mitigate overall reductions in cooling water use potential under changing climate. This is the case for Europe, but not necessarily for Africa.

Changes in sources of fuel and switches in cooling system types (from once-through to recirculation with wet cooling towers or dry cooling) are for most regions more effective in reducing plant vulnerabilities to water constraints (Macknick et

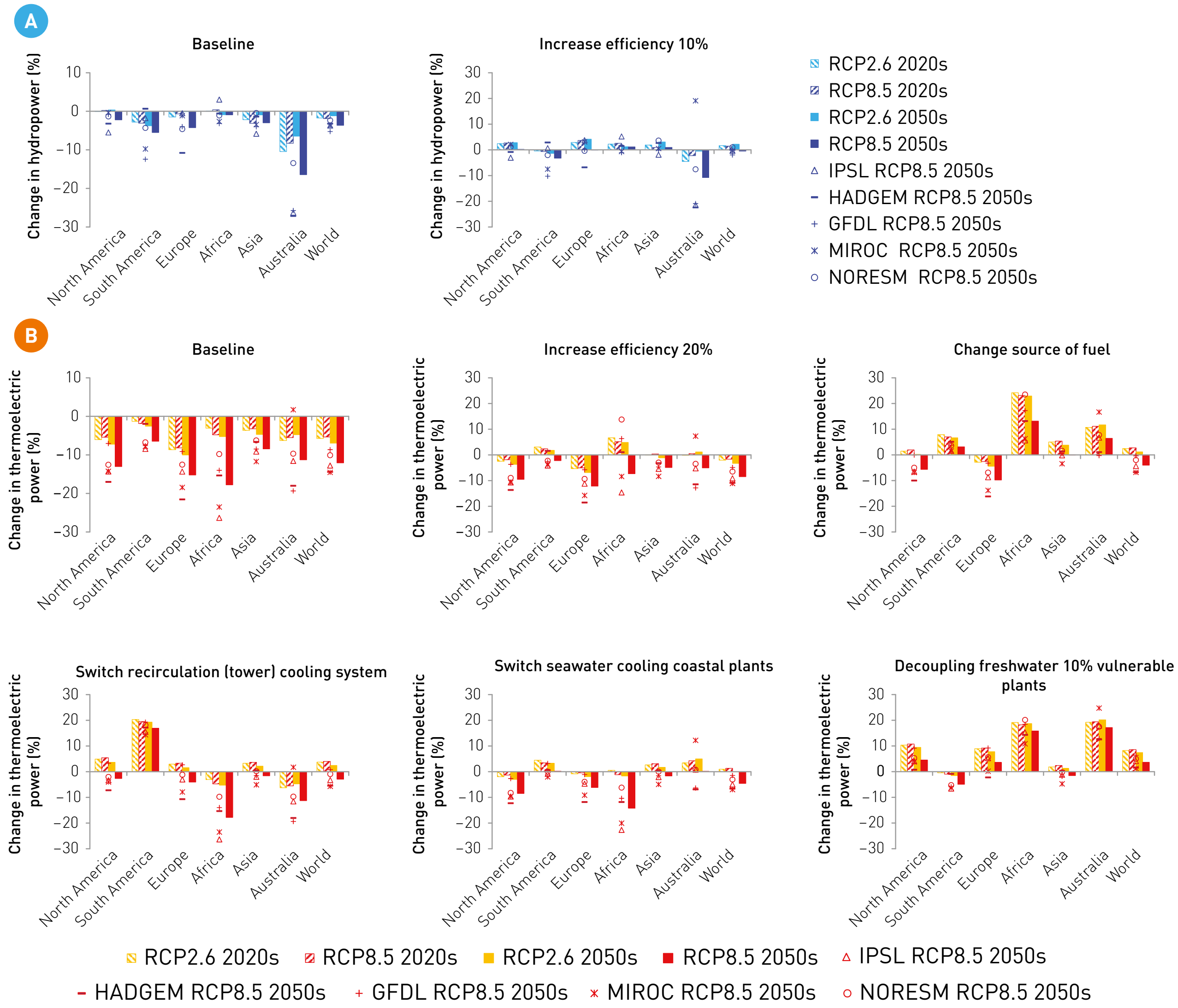


Figure 3.48 | Impacts of adaptation options on power-generation vulnerability to water constraints under climate change. Relative changes for the baseline settings and for various adaptation options of hydropower (A) and thermoelectric power (B). The GCM-ensemble mean changes are presented by the bars. In addition, changes for the five individual GCM experiments for RCP8.5 (2050s) are presented to show the range between the five different GCM experiments (van Vliet et al. 2016b).

al. 2012; van Vliet et al. 2016b). On average, fuel switching to higher efficiency gas-fired plants with lower cooling water demands can be sufficient to mitigate plant vulnerability to water constraints for the 2020s and 2050s under RCP2.6 scenario. This adaptation option will be insufficient for Europe under RCP8.5 scenario in the 2050s. The strongest positive impacts relative to the baseline settings are found for Africa, where the relative number of coal-fired plants that can be substituted by gas-fired plants is high.

A switch to recirculation (wet tower) cooling will decrease water withdrawals and reduce plant vulnerabilities to water constraints. A switch from freshwater cooling to seawater cooling for plants nearby the coast also reduces vulnerabilities to freshwater constraints. Decoupling of cooling water systems from freshwater resources (by switching to dry cooling or sea water cooling) for the 10% most severely impacted plants is a more effective adaptation option.

On top of these options, a higher share in non-water dependent power generating technologies, such as solar PV and wind power, will strongly reduce the dependency on freshwater resources. The uncertainty range is considerable and strongly depends on the relative share of different technologies within the energy transition (e.g., Mouratiadou et al. 2018).

3.3.4.2 Integration of renewables into the energy mix

In view of the current dynamics of energy supply and demand, a large gap is expected between anticipated demand and supply, particularly in SEMCs (Hawila et al. 2012). In order to address both the depletion of fossil fuels and climate change issues, it is necessary to improve rapidly the penetration of renewable energies. To this end, measures have already been taken to shift the energy mix in the SEMCs from fossile fuels to renewables. Large-scale deployment of renewable energy technologies and a necessary profound transformation of the energy sector are still lagging behind in some countries in the region (Vidican 2016).

Incentive effects of support mechanisms for renewable energy

SEMCs already consume a lot of energy and their energy demand is expected to continue to grow in the coming decades (El-Katiri 2014). As a result, energy plays an increasing role in national development policies in most of these countries. Given their climatic advantage, particularly in solar energy, the countries of the region therefore want to seize their comparative advantage. To achieve effective integration of renewable energy in these countries, a key solution would be to reform energy pricing mechanisms in the region and promote the participation of private actors in order to address the distortions of the energy market in the region. If this cannot be achieved for any reason, an alternative solution could be the introduction of tax and regulatory incentives aimed at reducing remaining cost disadvantages of renewable energies compared to fossil fuels (El-Katiri 2014). Since energy prices for the final consumer are heavily subsidized in most SEMCs renewable energy sources could also receive subsidies to make renewable energy production viable. Poudineh et al. (2018) argue that renewable energy support policy for SEMCs should meet criteria such as compatibility with the structure of the region's electricity system, harmonization with existing institutions, suitability at the project scale, coverage of economic risks and provision of efficiency.

Large-scale deployment of renewable energy could have significant positive impact on SEMCs. By examining the implications of renewable energy deployment in the SEMCs through the LEAP (Long Range Energy Alternatives Planning System) forecasting model, El Fadel et al. (2013) find that on a regional scale: (i) per capita greenhouse gas emissions could be drastically reduced, (ii) the return on investment in renewable energies promises up to 54% savings excluding positive externalities and (iii) the establishment of a CO_2 emissions trading market would provide economic incentives that make investment in renewable energies more attractive. An assessment by Timmerberg et al. (2019) of national renewable energy production targets and a diagnosis of the current energy sector in some SEMCs shows that the plans currently in place to expand renewable energy in these countries will be able to roughly meet the expected future growth in national electricity demand. Therefore, they estimate that if the targets set by the states for 2030 are met, CO_2 emissions per kWh, for example, could drop drastically to 341-514 g CO_2e kWh^{-1} compared to 396-682 g CO_2e kWh^{-1} in 2017.

Using a cost-minimizing electricity market model, Brand (2013) explores the option of optimized infrastructure for the integration of renewables into the interconnected North African electricity grids until 2030. The results show that the five countries, Morocco, Algeria, Tunisia, Libya and Egypt, could together achieve significant economic benefits of up to 3.4 billion € if they increase electricity grid integration, build interconnections and cooperate in the joint use of their power generation assets. The challenge remains to eliminate political obstacles to cooperation. Brand and Blok (2015) also assessed several studies (including Haller et al. 2012; Fragkos et al. 2013) using economic models of electricity supply and demand to assess the possible development paths of electricity systems in the North African region from today to 2030 (or even 2050). All studies agree that additional costs associated with the expansion of renewable energy in SEMCs could in most cases be offset by avoided fuel costs and avoided investments in fossil fuel power plants. Even electricity exports to Europe could become viable.

Despite the remarkable political objectives announced by SEMCs leaders to increase the deployment of renewable energy to meet growing energy demand and mitigate climate change in the region, there are still some inconsistencies between the approaches and the objectives. The deployment of renewable energy faces many obstacles in the region, namely, the state monopoly on the electricity sector, persistent fossil fuel subsidies, and weak regulatory institutions and bureaucratic issues (Lilliestam and Patt 2015). Al-Asaad (2009) notes mainly technical problems. For example, it points out that much of the region's network infrastructure (e.g., sub-stations and power lines) and network codes have long since become obsolete and therefore need to be upgraded to effectively meet the objectives of diversifying energy sources.

Finally, regarding renewable energy costs, Krupa and Poudineh (2017), using simulations, show that the levelized cost of energy (LCOE) of renewables is more sensitive to the discount rate compared to fossil energy sources in SEMCs. This is certainly due to the fact that the investment costs are very high whereas the production costs of fossils are more evenly spread over the life of the project.

The specific case of bioenergy: barriers and opportunities

There are four main barriers to develop bioenergy in Mediterranean area: financial, technological, social and institutional. Technical barriers include investment costs and lack of experience in biomass conversion technologies, and development of sustainable management of biomass sources. The regulation barrier requires new policies for bioenergy promotion, and socio-economic and environmental issues analysis. Financial decisions by funding agency adds the problem of competitiveness with other industry and energy markets. In fact, the development of bioenergy represents a new competitive sector because of the use of sources already used in industrial sectors as the paper industry or agriculture (Ferreira et al. 2017). For now, cultivation of energy crops is limited because of farmers' reluctance considering uncertainty of productivity and economic markets, and less attractive prices compared to cereal crops (Pulighe et al. 2019). In the same way, wood-biomass energy still remains low owing to the weak economic power of the forestry sector and the hard biodiversity regulation (Cavicchi et al. 2017).

The development of bioenergy implies increasing the production of local biomass sources, which raises ecological, economic and socio-political issues. Increasing biomass sources can be effective through tree plantations, forest management improvement, energy crops implementation, agricultural sources plantations, among others. Yet, these new biomass sources at large-scale production could increase greenhouse gas emissions considering the land-use changes associated (Fargione et al. 2008; Gibbs et al. 2008; Searchinger et al. 2008). In the Mediterranean Basin, tree plantations focus on *Eucalyptus* spp., *Populus* spp. and *Pinus* spp., but these species have high ecological impacts during the clearcutting and plantation operations, and soil preparation (Rodríguez-Loinaz et al. 2013). The development of agricultural energy crops would be competitive if some of the following situations happen: distinctive quality allowing competitive prices, new market opportunities that cover production costs, providing subsidies to these cultures by environmental reasons (Ferreira et al. 2017).

The development of bioenergy represents a larger opportunity than simple renewable and carbon neutral fuel source. The implementation of a holistic bioenergy sector can play a crucial role in the transition by improving Mediterranean forests management, promoting new socio-economic models and rethinking the relation between human and nature (Paredes-Sánchez et al. 2019; Sansilvestri et al. 2020). The bioenergy sector in Mediterranean Basin is an opportunity for land restoration and abandonment issues because bioenergy crops can be implanted on abandoned or polluted lands without sacrificing pastures, arable or protected lands (Pulighe et al. 2019).

It has been proposed that the evolution of the renewable energy based on biomass depends on two interacting variables: the strength of policy for centralization and the development of competitive markets for biomass-based alternatives. These two interacting axes will determine, by cascade effects, how much centralized policies will favor large industrial developments in contrast to a more widespread biomass conversion where sustainability of the resource is paramount. The development of biomass-based solutions also depends on how competitive solar and wind base solutions are *(Section 3.3.2.2).* In any case, northern Mediterranean countries have more margin of strategy evolution than southern ones, as biomass production is inherently much more restricted in the southern region.

Bioenergy has a place in a new economical organization with a clear position, rules and limits. Bioenergy can valorize residual productions from other industries, which can be upgraded in a bioeconomy sector. Pulighe et al. (2019) suggest that future support schemes and business models for mobilizing financing and attracting investors should be more aligned with greenhouse gas emissions, ecosystem services and sustainability indicators, avoiding criticism raised for the biogas sector regarding tradeoffs on land use pressure for biomass. For the time being, bioenergy is mostly based on an incentive economy, tax credits and fiscal exemptions, but to increase engagement of industry, foresters and farmers, it needs clear economic possibilities with a long-term visibility.

3.3.4.3 Energy access in developing countries of the Mediterranean region

Unlike the sub-Saharan African zone (only 45.6% electrification rate), SEMCs do not yet have major difficulties in providing electricity to their populations. The energy costs supported by households (very often subsidized) are largely lower compared to the world average. According to World Bank data, the electrification rate was almost 100% in 2017 for Algeria, Morocco, Tunisia, Egypt, Israel, Jordan and Lebanon. Libya is the only country with a lower rate (70.1%), due to the political instability (it had an electrification rate of 99.8% in 2000). Most analyses find that the energy dynamics of these countries are unsustainable in the long term, for several reasons. First, the region is experiencing strong demographic growth and prospects for strong economic growth are also expected. Therefore, energy demand is expected to grow strongly in the future for the net energy exporting countries (Algeria, Libya, Syria, Iran etc.) and for the net importing countries (Morocco, Tunisia, Egypt, Jordan and Lebanon) of the area (difficult combination of future depletion of reserves and energy subsidies). Second, the region is one of the most affected by the effects of global warming. Countries are therefore compelled to make an energy transition to renewable energy sources as quickly as possible and gradually move away from fossil energy sources. Finally, price control policies such as energy subsidies are quite widespread in the region. These policies are still costly to state budgets and quite ineffective. Energy subsidies frequently distort price signals and lead to systemic misallocation of resources (Fattouh and El-Katiri 2013). The main concerns are therefore how to produce enough renewable energy to meet the anticipated high future energy demand in the region, still considering potential political and economic barriers.

Financial, behavioral, institutional and regulatory impediments to energy access

The SEMCs are known for their oil and gas reserves, but also for their immense potential in renewable energies, particularly solar and wind energy. According to estimates, with only 0.2% of the land suitable for concentrating solar power, plants in seven countries of the region (Morocco, Tunisia, Algeria, Libya, Egypt, Jordan and Saudi Arabia) could cover 15% of the electricity demand expected in Europe in 2050 (Trieb et al. 2012). Thus, there are economic as well as environmental reasons to switch to renewable energy sources. But for those countries in the region that are highly dependent on fossil revenues (oil, natural gas), it would be very difficult to switch entirely to green forms of energy (El-Katiri 2014). The economies of these countries largely depend on the rents from hydrocarbons in the 1960s and 1970s. Also, the social contract between the government and citizens is based on the fact that energy is virtually free, making the investments into the transition difficult.

For the reasons mentioned above, the countries of the area need to make their energy transition quickly. By the end of 2013, some of them had set targets for the share of renewables in total electricity generation, in total installed power generation capacity or in total electrical and thermal energy (El-Katiri 2014). Algeria has set a target of 15% of electricity generation by 2020 and 40% by 2030, Morocco (42% of installed power generation capacity by 2020), Tunisia (25% of electricity generation by 2030), Egypt (20% of electricity generation by 2022) and Lebanon (12% of electrical and thermal energy by 2020). Despite high penetration of solar water heaters in Palestinian households (56%), solar thermal energy represents only a small fraction of the Palestinian Energy mix (8%). Transitions to renewable energy sources require huge investments, and therefore large-scale regional and international projects such as joint projects with the European Union. The realisation of large-scale energy projects between Europe and the region, such as the Mediterranean Solar Plan or Desertec, faces several barriers. Fritzsche et al. (2011) mainly refers to political constraints, such as the lack of subsidies, incentives and liberalization of the renewable energy market in the region. Authors including de Souza et al. (2018) rather refer to cultural barriers to renewable energy trade projects in the Mediterranean (between the EU and southern countries), alluding to the failures of energy cooperation projects between Europe and its former colonies.

While voices are being raised in the North of the shore to denounce what should increase Europe's energy dependence, and therefore additional diplomatic pressure (Lilliestam and Ellenbeck 2011), in the South, there is talk of a new form of resource exploitation, and therefore of the notion of solar colonialism (Marktanner and Salman 2011; Rowlinson 2015). There are three main risks to their implementation, risks that affect the cost of capital in particular: (1) the complexity and instability of national regulations, (2) low political stability and (3) terrorist threats in the region (Komendantova et al. 2011). The World Bank has repeatedly pointed out that among the constraints to investment in the renewable energy sector in the region are the narrowness of local markets (which discourages private investment in particular) and the need to consider a regional energy trading market, the weakness of public finance and the competition of energy investments with other public service and public infrastructure investments. Far from the reality of the major oil exporting countries of the region, Morocco depends heavily on its energy imports, i.e., 95% of its consumption in 2007 (Fritzsche et al. 2011), despite a rather remarkable potential in renewable energy. This energy deficit partly explains the strong pressure on traditional energy sources (wood, coal, etc.). According to Zejli et Bennouna (2009), between 30,000 and 50,000 hectares of forest disappear every year. Aware of this and aiming in particular at reducing its dependence and energy bill, the country is widely involved in projects and initiatives aimed at promoting renewable energy. With this in mind, in November 2009 the country launched the pharaonic Noor project (I, II and III) in Ouarzazate at an estimated cost of 2.5 billion US$ (9 billion US$ for the full Moroccan Solar Plan), a project that should eventually provide electricity to more than 2 million people in the country.

Regulatory framework and business models to reach universal access

According to de Souza et al. (2018), to facilitate the successful implementation of renewable energy projects, it is particularly important that the countries of the South are sufficiently integrated into the value chains of production, from distribution to transportation of energy (acceptability), put in place a plan to mitigate the environmental impacts of site operations and facilitate technology transfer. Fritzsche et al. (2011) point out that specialized agencies should be created to overcome political constraints to facilitate the establishment of renewable energy facilities in the area and multiply tax incentives to help attract foreign direct investment. They also point out that funding and technical assistance from international and regional donors and development banks are essential for the implementation of these types of projects. They also argue that technology transfer from North to South should be promoted, R&D should be encouraged and EU-SEMCs and PPP (public-private partnership) type partnerships should be implemented. Blimpo and Cosgrove-Davies (2019) argue that it would be viable to establish a regional energy exchange market between the countries in the area, since energy trade would halve the cost of kWh. As private investors are more attracted to large markets, establishing a common regional market will also allow small economies and countries that are not abundant in energy resources to benefit from cheaper electricity. As an example of an integration model, Blimpo and Cosgrove-Davies (2019) mention the example of the West African Power Pool (EEEOA), which brings together 14 countries of the zone and 27 companies. This system would have enabled many countries in the West African zone to benefit from an affordable, reliable and sustainable electricity supply (typical case of the Manantali dam on the Senegal River, which benefited from a lower investment cost to the benefit of Mali, Senegal and Mauritania). El-Katiri (2014) emphasizes the need to reform the system governing the energy price mechanism (local market prices strictly controlled by the State to its liking) at the national and regional levels and to implement a fiscal policy aimed essentially at reducing the cost disadvantage of renewable energies compared to fossil fuels.

The Green Transition in North Africa and the Middle East

With the exception of Libya, the other six states in the North African region have ratified the Paris Agreement of 2015. For countries in North Africa, the energy transition requires a profound structural transformation of the energy sector and all other sectors of the economy, but one of the major difficulties of this structural transformation is to effectively find a compromise between long-term and short-term political and economic objectives (Pye and Bataille 2016).

Another major difficulty remains the question of financing, as green projects are unfortunately still quite expensive and require large investments. To illustrate, estimates have shown that for some 28 countries on the African continent, for example, meeting national commitments for energy transition would require an overall investment of more than 240 billion US$. On the other hand, these investments would be quite beneficial for the economies of North Africa, particularly in view of their potential for renewable energy. Brand and Zingerle (2011) show that for every € spent on renewable energy, 0.15, 0.16 and 0.27 € of savings could be made in the national electricity system in Tunisia, Algeria and Morocco respectively. Also, according to Alnaser and Alnaser (2011), the costs of generating electricity from photovoltaic systems and wind turbines have been on a downward trend for several years. In some SEMCs, it is already possible to produce green power much cheaper than electricity production from fossil sources (IRENA 2018). The competitiveness of renewable energy sources depends not only on the technology used for energy production and the availability of energy resources, but depends especially on the cost of fossil fuels (substitutes for renewable energy). The costs of fossil fuels are much lower for most SEMCs compared to other regions of the world. This does not promote the competitiveness of renewable energies.

Timmerberg et al. (2019), based on an assessment of national renewable energy production targets and a diagnosis of the current energy sector in selected SEMCs (Algeria, Egypt, Morocco, Saudi Arabia and Tunisia), show that current plans for renewable energy expansion in these countries will be able to approximately meet the expected future growth in national electricity demand. They estimate that if the targets set by the States for 2030 are met, CO_2 emissions per kWh, for example, could drop drastically to 341-514 g $CO_{2}e$ kWh^{-1} (compared with 396-682 g $CO_{2}e$ kWh^{-1} in 2017).

3.3.4.4 Financing the energy transition

As discussed in the previous sections, the energy transition requires a significant transformation of the energy and economic model in the Mediterranean region. Mitigation and adaptation will require investments from households, companies and governments, which in turn require sources of financing. Policymakers in Mediterranean countries need to focus policies and public investment to achieve three main objectives: i) to bring the benefits of the new energy technologies to citizens via accelerated uptake of distributed generation, ii) incentivize the deployment of utility-scale PV parks, preferably including storage, and iii) to ease the opening of new energy technology factories in their countries. Today's low-cost solar energy and electricity storage technology, make the first objective achievable thanks to new legislation supporting distributed generation for example updating obsolete construction regulation making long and costly the permit process to functionalize buildings with solar modules. The growth potential is huge as less than 5% of the world's buildings, and even a lesser fraction of the large Mediterranean built environment, are functionalized with solar collectors. Achieving the second objective in industrialized countries such as Spain, Italy, and France is feasible by allowing renewable energy generation companies to take part not only to the day-ahead electricty market but also to the dispatching and energy services markets, so far opened to thermal production units only. Sunnier SEMCs will preferably continue with tenders to purchase clean electricity produced via utility-scale PV plants at prices

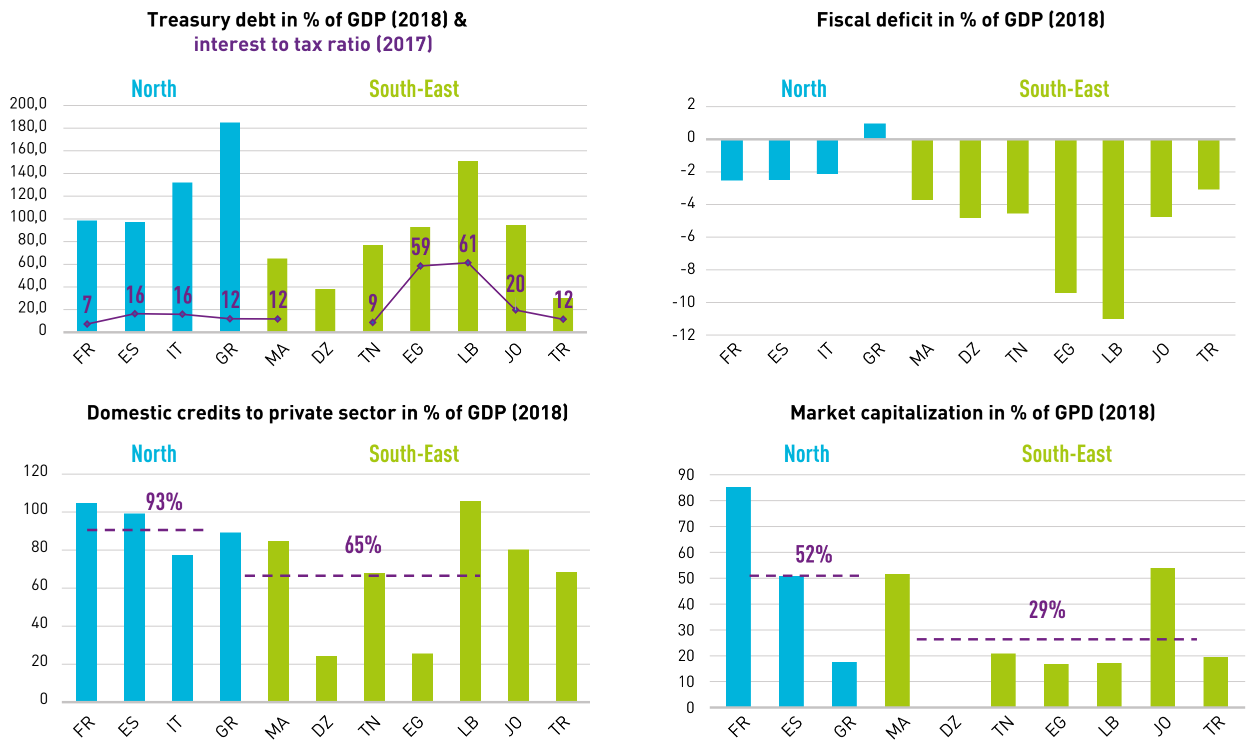


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Figure 3.49 | Economic and financial contexts around the Mediterranean (MEF 2019).

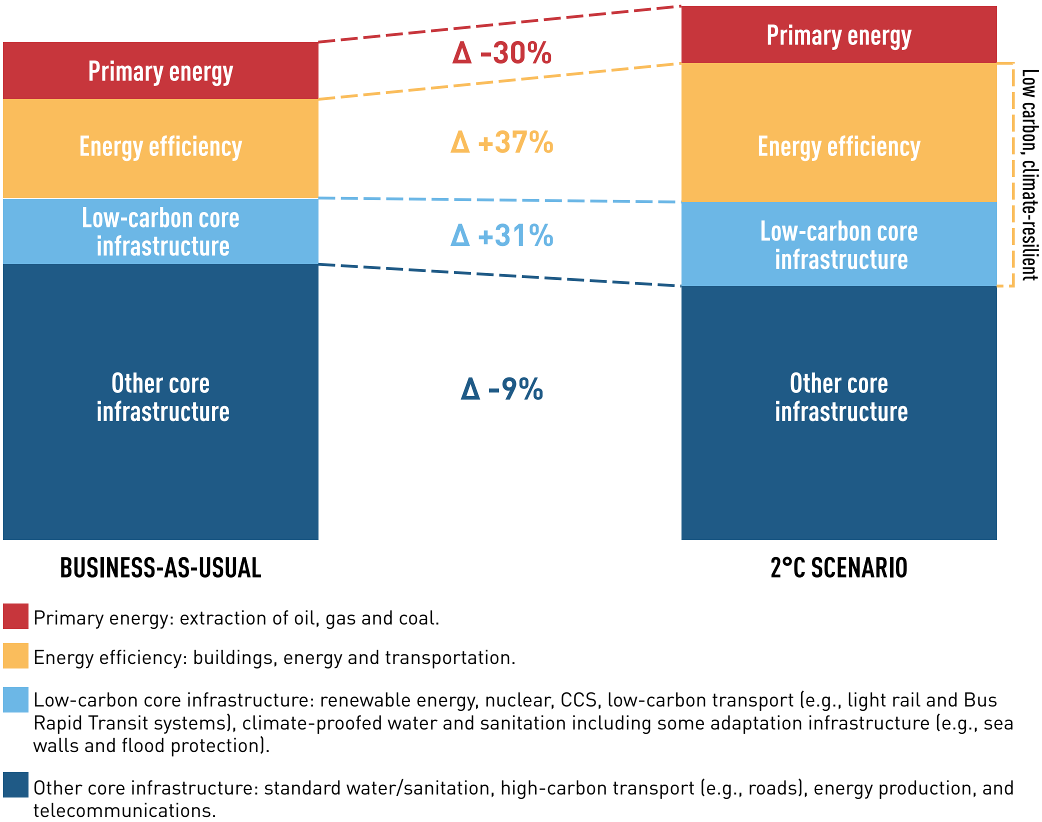


Figure 3.50 | Change in infrastructure spending for a 2°C scenario in the Mediterranean region, percentage change in expenditure over 2015-2030 compared to Business-as-usual. (MEF 2019).

that in the case of Egypt have already reached very low levels. Finally, the third goal is to make their countries home to new industrial plants of the solar economy, requires to concentrate the financial resources on establishing new partnerships with the leading renewable energy and energy storage technology manufacturers, which are not based in Mediterranean countries. There are many ways to incentivize foreign companies to invest, as shown by Morocco with their new electric vehicle plant; or by Algeria, requiring renewable energy compaies to use components made in Algeria for the utility-scale PV plants awarded the Public-Private Alliances.

Financial needs by sector and region

Beyond the economic contexts, public finance capacities of SEMCs are subject to strong tensions, with a high weight of the treasury's debt in terms of GDP. SEMCs financial systems are also characterized by a domination of banking, a weak development of financial markets and a low degree of international market openness *(Fig. 3.49).* In the Mediterranean region, financing needs for SEMCs NDC are estimated at more than 170 billion US$, of which 81% are related to conditional NDC (MEF 2019).

While there is no specific figure for the Mediterranean region, Western Europe benefited from 106 billion US$, while Middle East and North Africa benefited from 13 billion US$ during the period 2017/2018 (CBI 2019). Focusing on international public climate finance, Egypt, Turkey, and Tunisia were the top-3 recipients in 2017, altogether representing 5.6 billion US$ (of 8.1 billion US$ for the SEMCs) (UfM 2019). International public climate finance captured by the SEMCs has shown an encouraging trend since 2012, since the amounts committed have increased by an annual average of 21.5% over the 2012-2017 period (MEF 2019). In the Mediterranean region, 135 billion US$ per year in the energy sector will be needed until 2040 (approx. 1% of each country's GDP) and will have to be redirected from fossil fuels to renewables and energy efficiency (IEA 2018; IPCC 2018). Natural gas and renewables will dominate future investments in power generation across the region and close to 44 billion € per year will be needed to reach the

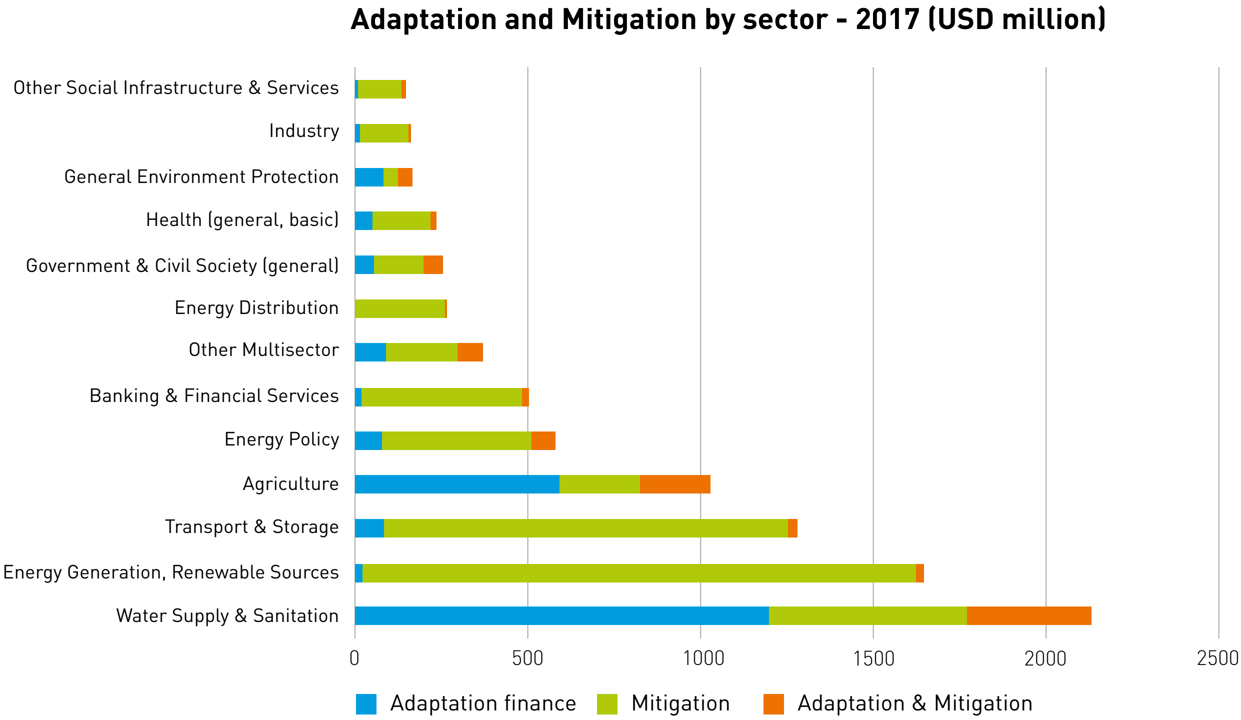


Figure 3.51 | International public climate finance by sector in SEMCs, 2017 (UfM 2019).

energy demand levels of the Reference Scenario (40% increase in demand) while energy efficiency investments will need to reach 61 billion € per year (Fig. 3.50). About 55% of these energy investments will be required on the north shore, 25% in North Africa and 20% in the South East (OME 2018).

In the 2017/2018 period, the following financial flows in SEMCs went to mitigation, and specifically to renewable energy generation (1.6 billion US$), water supply and sanitation (1.4 billion US$), transport and storage (1.2 billion US$) and agriculture (0.6 billion US$) (UfM 2019; *Fig. 3.51*).

Currently, adaptation flows account for a small percentage of total climate finance, illustrating what Abadie et al. (2013) call the 'mitigation bias'. This bias is also present in the SEMCs *(Fig. 3.51)*. Beyond investment in hard projects for mitigation and adaptation of infrastructures, financial flows are needed to push R&D capabilities in both northern and SEMCs.

Financial actors

Different actors are expected to finance climate change mitigation and adaptation. In the 2017/18 period private actors represented 326 billion US$ while public actors represented 253 billion US$ of annual flows (CBI 2019). While 75% of climate finance is invested in the same country in which it is sourced, developed countries have pledged to raise 100 billion US$ per year by 2020 for global climate action to developing countries (UNFCCC 2018), including both public and private sources.

Climate-related multilateral funds, such as the Green Climate Fund (GCF) and the Adaptation Fund (AF), remain less important (0.39 billion US$). Major bilateral donors are member countries of the Development Assistance Committee, including France (0.88 billion US$), Germany (0.75 billion US$), EU institutions (0.62 billion US$) and Japan (0.43 billion US$ in 2017 after 1 billion US$ in 2016) (UfM 2019). Since 2013, the contribution of multilateral development banks has been steadily increasing, in line with their commitment taken at COP24 in December 2018 to align their activities with the goals of the Paris Agreement. On the northern shore, EU countries committed to dedicate at least 20% of the EU budget from 2014-2020 to climate-related actions (representing around 180 billion €, threefold increase from the 6-8% share in 2007-2013[30]).

[30] Source: https://ec.europa.eu/clima/policies/international/finance_en

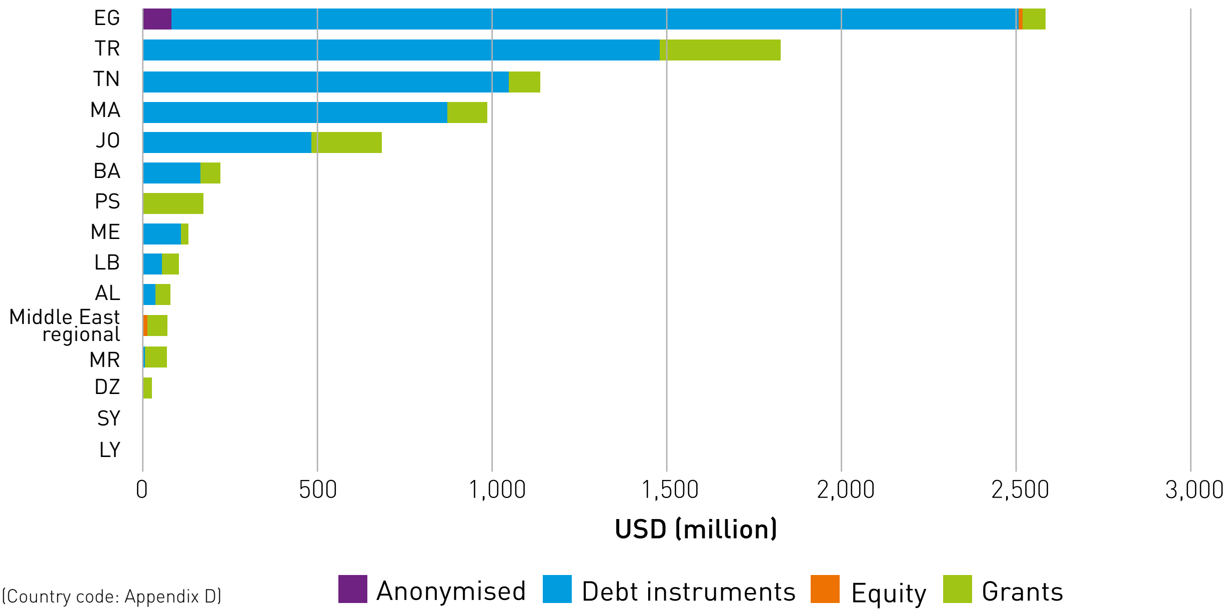


Figure 3.52 | International public climate financial isntruments by SEMCs recipient countries, 2017 (UfM 2019).

Financial instruments

Worldwide, debt is the main financial instrument of climate finance. SEMCs benefited mostly from debt instruments from international public finance *(Fig. 3.52)*. Financing the energy transition goes beyond debt, equity and grants. Above the various mitigation mechanism, putting a price on carbon with tax or quotas can encourage to consume and invest in goods and equipment that emit less greenhouse gases and generates a complementary source of financing for the energy transition. In the Mediterranean region, carbon price mechanisms are only present on the north shore. The EU Emission Trading System (EU-ETS), launched in 2005, is the world's biggest emissions trading system, accounting for 45% of total EU greenhouse gas emissions. Different countries have also applied carbon taxes (e.g., France, Portugal, Slovenia in the Mediterranean region).

Another tax measure to accelerate the energy transition and provide financing is to reduce fossil fuel subsidies. Subsidies were estimated to 130 billion US$ for SEMCs in 2015 (OECD 2018). These subsidies allocated to fossil fuels reach significantly high levels in countries such as Egypt, Lebanon and Algeria while Tunisia, Jordan or Morocco have relatively more moderate levels *(Fig. 3.53)*. In Egypt, a program was adopted in 2014 for gradually subsidy phase out taking into consideration the social impacts, with a foreseen deadline in 2021.

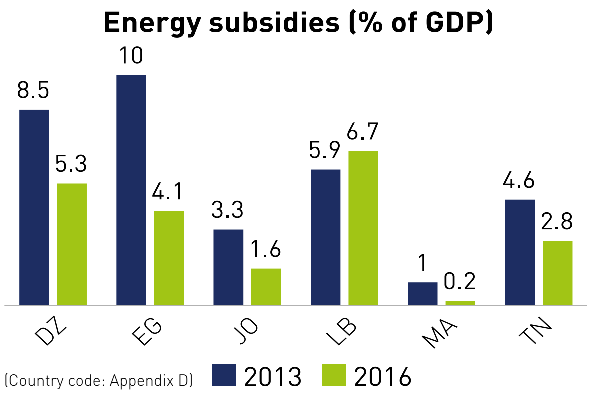


Figure 3.53 | Energy subsidies in SEMCs (World Bank 2018).

Among the new instruments of the climate finance, green bonds are bonds issued by companies, governments or local authorities on the financial markets to finance a project or activity with an environmental benefit and are subject to standards (Green Bonds Principles). Worldwide, $168 billion were issued in 2018 (40 billion US$ in 2014). Since 2007, Europe accounts for more than 36% of green bonds issued while Africa accounts for less than 0.4% (CBI 2019).

3.3.4.5 Supra-regional cooperation for energy transition

Faced with this economic, social and environmental situation, energy and climate challenges are of major importance. Accelerating the energy transition in the Mediterranean would help to control the growing demand for energy, to promote renewable resources and finally to optimize the use of fossil resources. The optimisation of the regional energy system, would pass through a better integration of markets, increased interconnection and intelligent management of networks, including the facilitation of access for renewable energy and demand side management.

Energy should be considered as part of the larger process of political shifting to a more inclusive, democratic and sustainable development paradigm (new social contract) that concentrates on a fair split of resources, opportunities and the results of growth all the while ensuring the right of all people to equitably participate in decisions that shape the future of their societies. This approach mirrors the dominant one that demands more decisive investment in renewable energies, but mainly as a tool for socio-economic development. For investments in renewable energies to have concrete value for the larger sustainable development goals of a country, projects should include technology transfers and capacity building for the population. In that regard, new initiatives for promoting renewable energies in the Mediterranean should avoid the 'Eurocentric focus' of the Mediterranean Solar Plan, which was seen as an instrument to support mostly the interests of European companies. Studies of the implementation of renewable enregy projects in the SEMCs have also alerted on their consequences in terms of reinforcing the private sector and central government at the expense of local populations. In brief, if Euro-Mediterranean energy cooperation wants to thrive, it is necessary to reconsider who matters in energy security, from market and state actors to society at large, and consider particularly marginalized sectors of the population.

The Euro-Mediterranean dialogue, under the chair of the European Commission and the Kingdom of Jordan, at the Rome conference in November 2014, decided to establish three platforms for exchange and cooperation. The ultimate goal for these platforms is to operate as permanent consultation forum on strategic objectives and measures to be implemented under the auspices of the Union for the Mediterranean. The three platforms cover: (i) the gas sector managed by the Mediterranean Observatory of Energy (OME), (ii) the electricity market with support provided by the Association of Mediterranean Regulators (MEDREG) and the Association of Mediterranean Transmission System Operators (MEDTSO) and finally (iii) the renewable energy and energy efficiency with support of MEDENER and RCREEE.

Many studies have shown that energy cooperation projects with North Africa aimed at large-scale energy production and exchange (mainly solar and wind power) would be an ideal instrument to achieve greenhouse gas reduction (Komendantova et al. 2012). Other studies have also analysed the barriers that constrain these energy projects, which Flyvbjerg et al. (2003) describe as "mega-projects" because they require huge costs. All of these studies are based on a perception of risk at two levels: regulatory and political risks, and force majeure or security risks (including, in particular, the terrorist threat in the region).

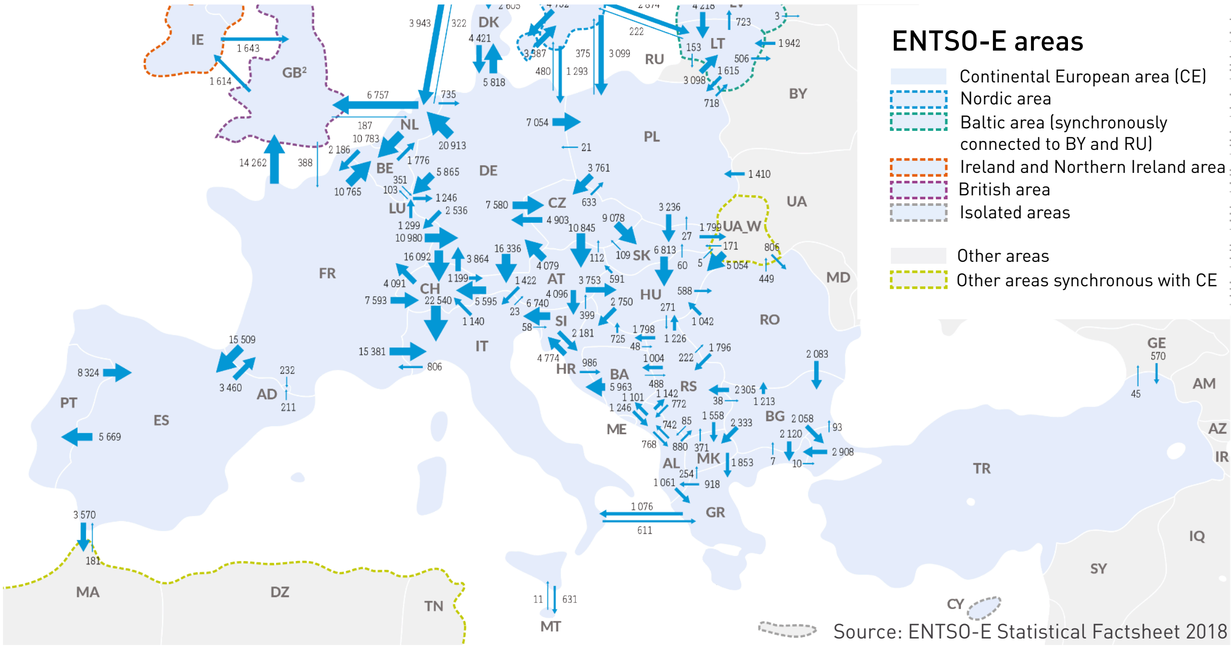
Mediterranean energy market integration

Achieving the objectives of the Paris Agreement requires a massive scale-up of renewable energy sources and regional energy market integration facilitates the large-scale development of renewable energy, as it increases the area over which electricity supply and demand must be balanced in real time, making it less likely that the resource will not be available when needed. Regional energy market integration offers numerous benefits to the power systems and the economies of participating countries: enhanced energy security and power system reliability, reduced need for back-up capacity thanks to reserve sharing, supply mix diversification, more efficient use of power plants, lower power system costs (both investment and operating) and therefore lower consumer prices (World Bank 2010; UK DECC 2013). With more ambitious climate mitigation objectives since the December 2015 Paris Agreement, the climate benefits of regional integration are increasingly acknowledged as being as important if not more than the energy and economy benefits. Some of the climate benefits result from the increased efficiency of the power system, but most of them are derived from the fact that regional integration increases power system flexibility, and therefore facilitates renewable energy scale-up.

Although several studies have estimated the costs and benefits of the integration of electricity markets, particularly in Europe (Bockers et al. 2013; Newbery et al. 2016), there is less research on the preconditions and the required policies for establishing a successfully integrated market for electricity and a truly seamless transmission system (Oseni and Pollitt 2016; Roques and Verhaeghe 2016). Newbery et al. (2016) estimate the benefits of integrating the European Union (EU)

Physical energy flows across Europe

GWh average over the year



[1] Consolidated yearly values might differ from detailed flow data from the ENTSO-E database due to ex-post consolidation taking into account national statistical resources.
[2] All data with the country code GB represents monthly statistical data as sum of England, Northern Ireland, Scotland and Wales.

	Sum of imports	Sum of exports	Balance (imp-exp)		Sum of imports	Sum of exports	Balance (imp-exp)
AL	1,771	2,683	-912	**IT**	47,169	3,268	43,902
AT	29,393	19,057	10,336	**LT**	12,850	3,219	9,631
BA	3,091	7,796	-4,605	**LU**	7,514	1,349	6,166
BE	21,650	4,313	17,338	**LV**	5,179	4,272	907
BG	2,220	10,029	-7,809	**ME**	2,760	3,011	-251
CH	30,420	31,693	-1,274	**MK**	4,144	2,224	1,921
CZ	11,562	25,453	-13,891	**NL**	26,818	18,596	8,223
DE	31,542	82,673	-51,131	**NO**	8,085	17,954	-9,869
DK	15,606	10,413	5,193	**PL**	13,839	8,121	5,718
EE	3,514	5,364	-1,850	**PT**	5,669	8,324	-2,655
ES	24,014	12,910	11,104	**RO**	2,829	5,370	-2,541
FI	23,397	3,459	19,938	**RS**	7,300	6,703	597
FR	13,466	76,020	-62,554	**SE**	14,234	31,561	-17,328
GB	22,662	2,189	20,473	**SI**	8,928	9,320	-392
GR	8,552	2,265	6,288	**SK**	12,544	8,747	3,797
HR	12,692	6,533	6,160	**TR**	2,638	3,046	-408
HU	18,613	4,265	14,348	**ENTSO-E**	**458,274**	**443,734**	**-14,540**
IE	1,614	1,643	-29	Physical flow values in GWh			

(Country code: Appendix D)

Figure 3.54 | Cross-border physical electricity flows, in gigawatt-hours (GWh) (ENTSO-E 2019).

markets at 13-40 billion € per year for the EU as a whole, depending on assumptions on fuel and carbon prices, renewable enrgy costs and penetration. If the market integration were broadened to include the whole Mediterranean region, then the savings would be even larger possibly delivering additional savings of 30 billion € per year according to studies conducted by Desert industrial energy initiative (Dii) (Zickfeld and Wieland 2012).

An integrated energy market and a cooperative approach would reduce the cost of meeting the ambitious EU CO_2 reduction and renewable energy targets (Caldés et al. 2015; Szabó et al. 2015). Associating the southern shore of the Mediterranean would further reduce the cost of decarbonization of the EU power sector, as the region is endowed with a massive renewable energy potential and a vast stock of unused land where solar panels and other renewable plants can be sited without creating a nuisance for nearby population. The Sahara Desert is a prime location for solar power generation and could potentially produce several times the level of demand for carbonless electricity in Europe, while also covering demand in the SEMCs.

The two Mediterranean shores are already inter-connected, in the West by a submarine cable of 1,400 MW under the Strait of Gibraltar connecting Spain and Morocco, and in the East with Turkey connected to Bulgaria through two 400 kV lines (for a total capacity of 2,500 MW) and to Greece through a 400-kV line with a capacity of 500 MW. Other interconnections between Europe and the southern shore of the Mediterranean are being studied, in particular, the Italy-Tunisia connection to the centre of the Mediterranean *(Fig. 3.54).* Contrary to Europe, the network in the SEMCs is sparser, and interrupted between Tunisia and Libya. In this region, renewable energy integration often needs complementary developments in generation and transmission, due to more isolated systems requiring back-up capacity.

The idea of exporting solar electricity from the Sahara is not new and dates back to the 1940s (Escribano et al. 2019), but the concept gained momentum when the first EU renewable energy Directive (EU 2009) was being prepared. The period 2008-2012 saw a flurry of initiatives such as Mediterranean Solar Plan, Desertec, Dii and MEDGRID to connect the southern and northern shores of the Mediterranean when it seemed that many EU countries would face difficulties in meeting their commitments under the Directive. Most of these initiatives went into hibernation as EU countries did not express much interest in cooperation mechanisms with southern Mediterranean countries, either because they could meet their 2020 targets from their own renewable energy resources (in part because of stagnant demand), or because they preferred to use other mechanisms such as statistical transfers or cooperation mechanisms with other EU countries. Caldés et al. (2018) and Lilliestam et al. (2016) identified the following reasons for the failures of these ambitious Mediterranean integration initiatives: (1) underdeveloped legal and regulatory frameworks, (2) weak grid infrastructures (in particular lack of interconnection between the two shores), (3) lower than expected socio-economic benefits, (4) high upfront costs and lack of financing mechanisms, (5) high fossil fuel subsidies in SEMCs and (6) energy policy giving priority to domestic renewable energy production over electricity imports and electricity surpluses in EU countries.

The EU has now set more stringent targets for 2030 and is aiming for carbon neutrality in 2050 under the European Green Deal proposed by the Commission in December 2019. Furthermore, the benefits of regional market integration in terms of investment and operating cost savings, and facilitated renewable energy grid integration, are increasingly acknowledged. Regional electricity market integration appears to be recognized as one of the most cost-effective options to increase power system flexibility.

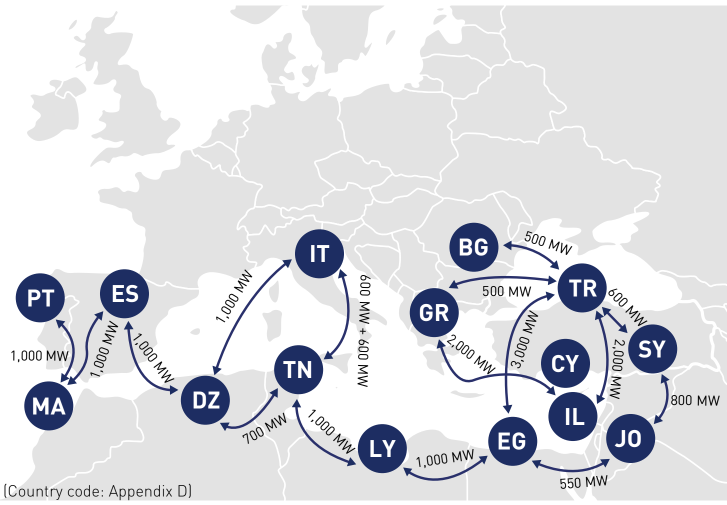
The need for supra-regional interconnections

The integration of a high-level of renewable energy requires that power systems have flexibility to cope with the stress resulting from sudden and unpredictable variations in the availability of renewable energy. Power system flexibility is defined as the ability to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to support the long-term security of supply (Taibi et al. 2018; Mohandes et al. 2019). Flexibility can be provided by dispatchable power plants, demand-side response, storage and network infrastructure, in particular, the one that supports regional market integration (Baritaud and Volk 2014) and requires a combination of regulatory, operational and investment measures (Hirth and Ziegenhagen 2015). Greater transmission interconnectivity yields substantial economic and environmental benefits and requires the strengthening of interconnectors, the hardware of regional electricity market integration (Crisan and Kuhn 2017). Ensuring that interconnectors are efficiently used and properly remunerated for their flexibility services both reduces the short-run cost of integrating renewables and increases the attractiveness of investing in additional interconnection (Newbery et al. 2016; Newbery 2017). Regional market integration through interconnectors expands the region's access to carbonless sources of energy, such as hydro reserves in the North or more predictable plentiful solar power in North Africa and reduces renewable energy sources curtailment.

The degree of interconnectivity will affect the need for new power plants and their location. Power generation and transmission planning, therefore, needs to be integrated. Successful renewable energy sources integration requires integration of power generation and transmission planning, of operational and investment decisions and of national markets into regional markets (Pariente-David 2014). A holistic approach is needed. Reaching high renewable energy shares entails "integration costs" elsewhere in the power system such as balancing services and firm back-up capacity on standby that are not reflected in traditional planning and economics approach based on the LCOE. A system-wide approach is needed that integrates all the costs and derived effects of renewable energy sources integration to determine the optimal mix of power generation plants and transmission lines to meet electricity demand at the lowest cost while satisfying the climate change and other policy objectives. This is the "total system cost" approach which focuses on the total cost of the power system, rather than trying to allocate some of the cost components to specific technologies, or part of the power system, to compare the technologies on the basis of LCOE (Pariente-David 2016).

After a period of lull, there is a revival of interest in electricity exchanges across the Mediterranean. Designed by Med-TSO between 2015 and 2018 in the framework of its Mediterranean project "the Mediterranean Master Plan plays a key role for consolidating a secure and sustainable electricity infrastructure through the development of interconnections, while facilitating the integration of Renewable Energy Sources in the Mediterranean Region" (Iliceto and Ferrante 2018). The Mediterranean Master Plan identified 14 clusters of projects for the interconnection of Mediterranean electricity grids according to a 2030 horizon scenario *(Fig. 3.55)*. The Plan targets 18 GW of new interconnection capacity, corresponding to 2,200 km of new transmission lines, requiring about 16 G billion € of additional investments.

The circumstances seem to be auspicious in 2019 to relaunch the Mediterranean Energy Union process. The EU "Clean Energy for All Europeans" (CE4ALL) Package (European Commission 2016) was fully adopted in May 2019, as the implementing instrument of the 2015 Energy Union strategy, which acknowledges that regional market integration is key in achieving EU climate change objectives at least cost and that strongly interconnected networks are required to support unhampered electricity trade and sharing of ancillary services. Cooperation, coordination (both on national policies and power system operations) as well as and regional market integration are a central part of the CE4ALL Package. Although the Package primarily aims at the European internal energy market, it recognises that the EU is not isolated and includes several cooperation mechanisms and financing instruments for joint projects with third-party countries (Held et al. 2019), so that the EU can tap into the best resources to achieve power sector decarbonisation.



NO.	INTERCONNECTION PROJECT/CLUSTER
1	Cluster MA-PT *(Morocco-Portugal)*
2	Cluster MA-ES *(Morocco-Spain)*
3	Cluster DZ-ES *(Algeria-Spain)*
4	Cluster DZ-TN *(Algeria-Tunisia)*
5	Cluster DZ-IT *(Algeria-Italy)*
6	Cluster TN-IT *(Tunisia-Italy)*
7	Cluster TN-LY-EG *(Tunisia-Lybia-Egypt)*
8	Cluster GR-TR-BG *(Greece-Turkey-Bulgaria)*
9	Cluster GR-CY-IL *(Greece-Cyprus-Israel)*
10	Cluster TR-EG *(Turkey-Egypt)*
11	Cluster TR-IL *(Turkey-Israel)*
12	Cluster EG-JO *(Egypt-Jordan)*
13	Cluster JO-SY-TR *(Jordan-Syria-Turkey)*

Figure 3.55 | Mediterranean interconnection projects (Iliceto and Ferrante 2018).

In summary, regional energy market integration and cooperation are crucial to unleashing the region's solar potential for cost-effective climate change mitigation in the Mediterranean. Many obstacles remain, including lack of the necessary transmission/interconnection infrastructure, difficulty in siting renewable energy plants in the best locations because of high up-front costs that makes financing risky, geopolitical considerations, insufficient coordination of power systems and lack of alignment of market rules. It is necessary to ensure interoperability of wholesale markets, value properly flexibility services and allocate interconnection costs to reflect the benefits accrued to the different stakeholders. This will extract value from regional market integration. The process can take years, happens in stages and requires appropriates national and regional institutions (Oseni and Pollitt 2016; Pariente-David and Jannet Allal 2019).

Strategy of transnational associations of regulators

Regulations regarding energy transmission systems and operations vary significantly among Mediterranean countries (MEDREG 2018). Transnational partnerships thus require forming a common set of

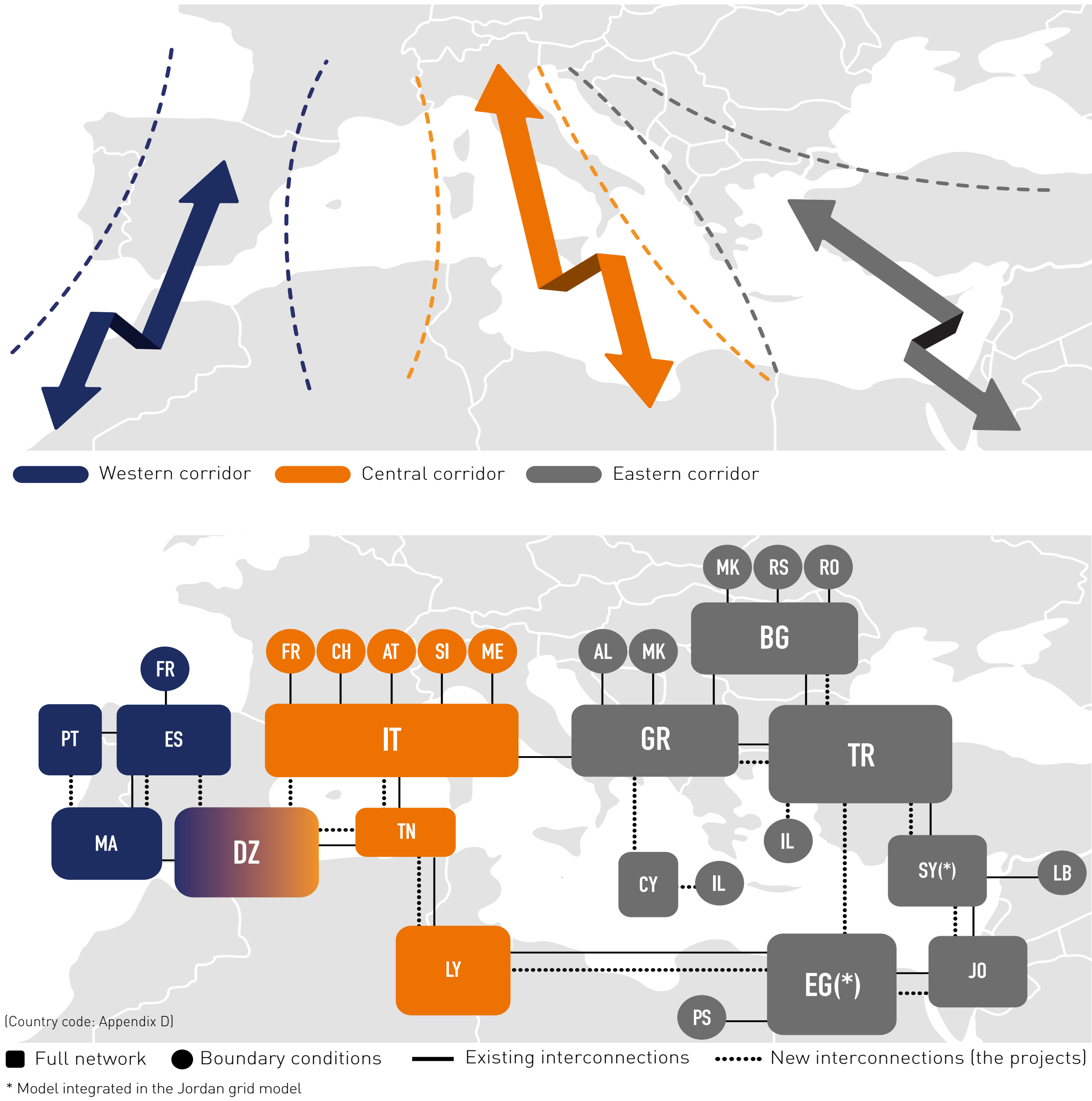


Figure 3.56 | Strategy of Mediterranean regulators for regional integration (Iliceto and Ferrante 2018).

BOX 3.3.1

Climate variability and energy planning

The variability of the renewable energies production, such as from wind and PV energy, adds to that of the energy demand and may pose challenges to the adequation and stability of networks which can translate into a decreased quality of services or into an increase in system costs (Ueckerdt et al. 2015) due to additional flexibility requirements. The variability of renewable energies production becomes critical when their penetration reaches a level, which is higher than what existing flexibility mechanisms allow the energy system to cope with (Cretì and Fontini 2019, chap. 26).

Not only the variability of meteorological conditions at single locations is relevant to energy planning, but also the relations between electricity demand and capacity factors, between capacity factors at different locations, and between capacity factors for different technologies. These correlations influence the potential smoothing of production once aggregated by interconnections, illustrated in *Fig. 3.57* for the case of wind and PV energy in Italy analyzed by Tantet et al. (2019). In panel a, points in the curves represent optimal distributions of wind and PV capacities among the six Italian electric regions for a varying trade-off between maximizing the mean and minimizing the standard deviation of the wind and PV penetration. Due to the variability of the wind and PV production, changing the weight put on each objective results in mixes with different characteristics, a higher mean penetration also leading to an increased variance. In addition, ignoring capacity-factor correlations between regions leads to sub-optimal mixes as shown by the weaker slope of the dashed lines (which corresponds to a weaker increase of the mean penetration as the variance is allowed to increase). The blue curve represents the optimal frontier with the addition of the constraint that the total wind-PV capacity be the same as in 2015. The blue dot (resp. blue diamond) on this frontier represents the optimal mix that has the same renewable energies penetration variance (resp. mean) as the actual 2015 mix (represented by the gray dot). The geographical wind-PV distribution of the capacities corresponding to the blue dot and the blue diamond are represented in panels b and c, respectively. Depending on whether more weight is put on the mean or on the variance of the renewable energy penetration, different optimal mixes are obtained.

Regarding locations for renewable energy development, the European case is studied by Pryor et al. (2006), specifically for wind energy, by Pfenninger and Staffell (2016) for photovoltaic energy and by Rodriguez et al. (2014) for both wind and PV energy with network constraints; the case of northern Spain by Marcos et al. (2012); and the case of Italy by Tantet et al. (2019). Concerning technologies, the complementarity of wind and solar energy in Europe is analyzed by Buttler et al. (2016) and Miglietta et al. (2017), in Italy by Monforti et al. (2014) and Tantet et al. (2019), and in Spain by Santos-Alamillos et al. (2012, 2017); and the case of run-of-the river hydropower and wind and PV energy with countries including France, Greece, Italy, Spain and Tunisia by François et al. (2016).

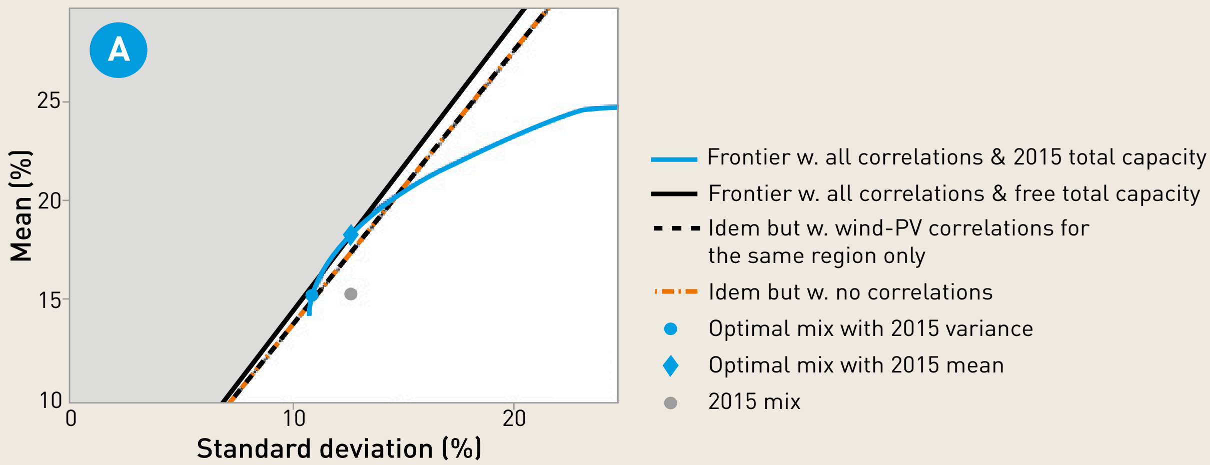
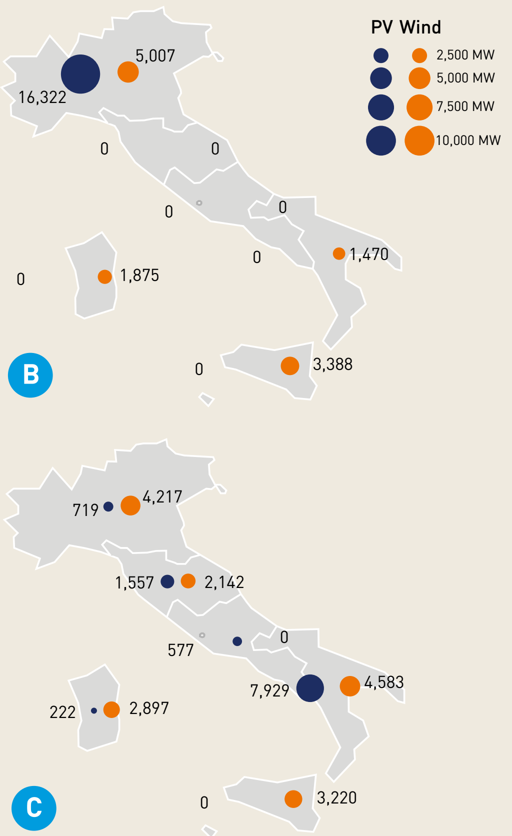


Figure 3.57 | Panel A: Illustration of the optimal, or Pareto, frontiers for two objectives – maximizing the mean (y-axis, in % of the total demand) and minimizing the standard deviation (x axis) of the total wind-PV penetration obtained by distributing wind and PV capacities among the six bidding zones (electric regions) of Italy. The gray area represents infeasible mixes. The thick line is the frontier when taking all capacity-factor correlations between regions and technologies into account in the bi-objective optimization, while the dashed line (resp. the point-dashed line) represents the frontier when only capacity-factor correlations between wind and PV energy in the same region (resp. when no correlations) are considered. The thick blue line is like the thick black line, but with the constraint that the total wind-PV capacity be the same as in 2015. The blue dot (resp. blue diamond) represents the optimal mix with the same renewable energy penetration variance (resp. mean) as in 2015. The gray dot represents the actual 2015 mix.

To our knowledge, there are no studies analyzing how past changes in climate variability has impacted energy systems and their planning, let alone in the Mediterranean. With the development of various renewable energy types, as well as with existing or new hydroelectric capacities, changes in climate variability in the Mediterranean potentially affect the variability of the energy production (Widén et al. 2015) on time scales ranging from seconds (Apt 2007) to years or more (Pryor et al. 2006; Pozo-Vazquez et al. 2011; Pfenninger and Staffell 2016; Collins et al. 2018). Only few studies analyze past changes in the variability of the wind, solar and hydroelectric resources. No clear trend is found in European wind variability over the last 140 years or so (Bett et al. 2013), but there is significant variability between decades, depending on location and specific conditions. For instance, only small changes in the occurrence of Mistral and Tramontane winds are found in regional climate simulations forced by a reanalysis over the 1950-2010 period (Obermann et al. 2018).



Panel B: PV (blue) and wind (orange) optimal capacity distribution resulting in the same variable renewable energies penetration variance as the actual 2015 mix.
Panel C: same as panel b for the same variable renewable energy penetration mean as the actual 2015 mix. (Tantet et al. 2019).

regulations so as to enable enhanced connectivity of energy markets. Setting such conditions for a future Mediterranean energy community is the aim of the Association of Mediterranean Energy Regulators (MEDREG). Gathering 27 energy regulators from 22 countries spanning the EU, the Balkans and the SEMCs, MEDREG targets the establishment of a level playing field for all Mediterranean energy actors through an adapted legal and regulatory framework.

The stability and reliability of the regulatory framework is key to provide clear rules for investors to develop their confidence and ensure technical standards compatibility, which is a prerequisite for interconnecting markets. As a result, regulators have a crucial mission in implementing a good investment climate ensuring that network developments are delivered in due time, in providing guidance to Transmission System Operators about how to use interconnections and regulatory compatibility, in articulating a sound regulatory framework and a clear strategy, in ensuring an effective coordination between regulated networks and private/competitive activities, in improving the investment planning capacity, with long term assessment of energy needs and financial charges, and in ensuring a high level of transparency and education. MEDREG recognizes the importance of developing inter-operable electricity systems at sub-regional level. This requires first working on assessing the usage and problems of current interconnections and at a second stage evaluate what added value new interconnections could bring.

In this framework, the development of renewable energy sources requires a specific focus on network regulation. At the national level, it implies the connection and integration of renewable energy sources. Cross-border regulations require convergence of national regulations to allow interconnections to work effectively. Investment regulation requires the design and develop infrastructure that will be needed for promoting international complementarities.

The framework of EU Projects of Common Interest is an example of reflection that aims to build a shared vision to ensure the security of supply and facilitate renewable energy development in a coordinated way. *Fig. 3.56* highlights the three strategic corridors regulators aim at to ensure a full integration of the Mediterranean (Iliceto and Ferrante 2018).

BOX 3.3.2

Energy issues for Mediterranean islands

Islands are physically isolated territories, a characteristic that sets specific threats, challenges and opportunities in the context of global change and energy transition. The European Union recognizes that "insular regions suffer from structural handicaps linked to their island status, the permanence of which impairs their economic and social development" (Treaty of Amsterdam 1999). Geographical and socioeconomic singularities of Mediterranean Islands put additional pressure on water and energy, leading to resource depletion and degraded environment, threatening sustainable development (Gold and Webber 2015). More than 11 million people live in Mediterranean islands (Sen Nag 2017). Except for Sicily, Sardinia and Cyprus, all Mediterranean islands are below the million permanent inhabitants, with notable cases, such as Majorca, which frequently double its population during high touristic season. Mediterranean islands suffer strong limitations due to the limited range of their accessible resources, the inability to achieve economies of scale, the strong seasonal population variation, higher infrastructure costs and particular climatic conditions (Erdinc et al. 2015).

Characteristic aspects of Mediterranean climate such as large seasonal temperature and irradiance variations, occurrence of strong winds, heavy precipitations and the impacts of a range of cyclone, interact with the islands, rendering unique climates, even at local scales (Homar et al. 2010). They also enhance Mediterranean islands vulnerability, especially in the context of global climate change. In addition to the Mediterranean specificities, the IPCC 4th and 5th assessment reports state with high confidence that, globally, coasts are undergoing adverse consequences from climate change, such as sea level rise, inundation, erosion, and ecosystem loss. The reports also state that coasts are highly vulnerable to extreme events such as cyclones, extreme waves, storm surges, altered rainfall and runoff patterns, and ocean acidification. Therefore, Mediterranean islands are essentially isolated coastal territories with double penalty from climate change impacts.

Energy production and demand in the Mediterranean islands

Climate effects on the energy transition process in Mediterranean islands are of capital importance. On the one hand, the water-energy nexus is a central aspect in islands, as pressure on water resources is exceptional and highly anticorrelated with the seasonal precipitations and the availability of fresh water depends on techniques such as dwelling, impoundment and desalination. This severe fresh water scarcity is projected to aggravate in the future, since a drying of the region is expected throughout the 21st century (Dubrovský et al. 2014) and dry spells are projected to increase in duration and increasingly affect the wet season (Raymond et al. 2019). This climate and the projected scenarios not only severely hamper the adoption of hydropower electric sources in Mediterranean islands, but also increases the projected electricity demand derived from increased use of desalination strategies. On the other hand, Mediterranean islands have an important wind power climatic resource originating from various climatic features. Larger islands develop sea breeze very in a consistent way, especially during summer, in phase with the highest seasonal electricity demand. In contrast, smaller -and usually flatter- islands do not develop relevant sea breezes, but are more exposed to the weakly dragged maritime winds. The Mediterranean is well known to have the highest concentration of cyclones across the globe (Petterssen 1956). An additional climatic resource for Mediterranean islands, that has raised some attention in recent years, is the wave energy (Franzitta and Curto 2017) and maritime underwater flows *(Section 3.3.2.2)*. Despite wave energy converters are becoming more efficient, the spatial and temporal variability of this maritime resource hampers its general implementation. Wave energy in the Mediterranean Sea is larger during the cyclogenetic cold season and over the area of influence of the most frequent cyclogenetic regions (Ponce de León et al. 2016). This resource is significantly weaker during the summer season, when energy demand steered by tourist activity is higher. This characteristic favors its use in energy transition planning as a complementary electricity generation technology to photovoltaic, which has an opposite seasonal phase (Curto and Trapanese 2018; Curto et al. 2019). Climate projections for wave energy in the western Mediterranean show that this resource will remain reliable with a reduced temporal variability and slight reduction of the annual and seasonal wave power (Sierra et al. 2017).

Regarding the demand side, islands are expected to follow the Mediterranean mainland projections of increases of 6% in demand by 2050 (Zachariadis and Hadjinicolaou 2014), even possibly amplified due to larger tourist activity in currently underexploited environments. The non-linear relation between consumed energy and total population could be explained by differences in existing economic activities, geographical site and cultural aspects (Neves et al. 2014).

Interlocking challenges of energy security and climate resilience

In addition to the effects of climate and climate change as an energy resource to consider in sustainable energy transition planning for the Mediterranean islands, climate extremes pose both energy extraction opportunities (i.e., for wave energy) but more importantly engineering and protection challenges. Strong winds and heavy precipitation are projected to decrease in frequency but become more intense *(Subchapter 2.2)*, threatening renewable energy infrastructure both in centralized plants and distributed generation topologies.

These climatic conditions add upon other economic, sociocultural and differential characteristics of Mediterranean insular territories compared to mainland, a fact that is also reflected to their power system structures and the energy transition objectives (Erdinc et al. 2015). Challenges such as the geographical limitations, protection of natural and cultural values, or the technical limitations of small size grid structures with low inertia, are all barriers to overcome in order to seize the opportunities of the energy transition for ensuring a sustainable insular power system (Andaloro et al. 2012). Nowadays, in most non-interconnected islands the electricity generation cost is extremely high due to the utilization of outdated autonomous power stations based on oil-fuel imports and diesel-electric generators, and the most frequent energy mix proposed considers solar, wind and sea wave renewable sources (Franzitta and Curto 2017; Curto et al. 2019). Interconnection with mainland is frequent although not for all cases profitable (Lobato et al. 2017). This solution may alleviate the reduced inertia challenge and externalize the dependency on fossil fuel, but does not contribute to achieve the near zero energy system proposed by some insular communities (Sanseverino et al. 2014).

For stand-alone power systems, the management of renewable energy surplus is an important concern. Hydrogen generation, commercial batteries and the deferrable load of desalinated water-production are proposed as two effective renewable energy buffering strategies for Mediterranean islands (Corsini et al. 2009; Kaldellis et al. 2012). In the absence of a single solve-all solution, hybrid solutions are hypothesized to lead to a remarkable reduction in power generation costs, although more efforts are needed for making battery/hydrogen systems technically and economically viable (Corsini et al. 2009; Beccali et al. 2018; Wang et al. 2020). Besides generation-side measures and energy storage for reserve provision, demand-side measures have also some specificities in Mediterranean insular areas which can foster their transition to a sustainable and autonomous energy system. Outdated distribution grids, impact of the lack of economy of scale on the reduced budgets for new investments and the low penetration of automation in domestic utilities prevent the widespread implementation of solutions for the automation of the end-user's electrical installations, in order to offer to the utility flexibility to be used for the improvement of the generation and distribution efficiency (Zizzo et al. 2017). In this regard, electric vehicles have ranges suitable for the great majority of Mediterranean islands sizes, also offering new grid-to-vehicle and vehicle-to-grid managing alternatives which can catalyze the solutions for the inherent reduced grid inertia problems (Groppi et al. 2019).

References

Abadie LM, Galarraga I, Rübbelke D 2013 An analysis of the causes of the mitigation bias in international climate finance. *Mitig. Adapt. Strateg. Glob. Chang.* 18, 943–955. doi: 10.1007/s11027-012-9401-7

Al-Asaad HK 2009 Electricity Power Sector Reform in the GCC Region. *Electr. J.* 22, 58–64. doi: 10.1016/j.tej.2009.08.013

Alnaser WE, Alnaser NW 2011 The status of renewable energy in the GCC countries. *Renew. Sustain. Energy Rev.* 15, 3074–3098. doi: 10.1016/j.rser.2011.03.021

Andaloro APF, Salomone R, Andaloro L, Briguglio N, Sparacia S 2012 Alternative energy scenarios for small islands: A case study from Salina Island (Aeolian Islands, Southern Italy). *Renew. Energy* 47, 135–146. doi: 10.1016/j.renene.2012.04.021

Apt J 2007 The spectrum of power from wind turbines. *J. Power Sources* 169, 369–374. doi: 10.1016/j.jpowsour.2007.02.077

Balog I, Ruti PM, Tobin I, Armenio V, Vautard R 2016 A numerical approach for planning offshore wind farms from regional to local scales over the Mediterranean. *Renew. Energy* 85, 395–405. doi: 10.1016/j.renene.2015.06.038

Baritaud M, Volk D 2014 Seamless Power Markets: Regional Integration of Electricity Markets in IEA Member Countries. Paris. https://webstore.iea.org/seamless-power-markets

Bartók B, Wild M, Folini D, Lüthi D, Kotlarski S et al. 2017 Projected changes in surface solar radiation in CMIP5 global climate models and in EURO-CORDEX regional climate models for Europe. *Clim. Dyn.* 49, 2665–2683. doi: 10.1007/s00382-016-3471-2

Bartos M, Chester M V., Johnson N, Gorman B, Eisenberg D et al. 2016 Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States. *Environ. Res. Lett.* 11, 114008. doi: 10.1088/1748-9326/11/11/114008

Bauer N, Rose SK, Fujimori S, van Vuuren DP, Weyant J et al. 2018 Global energy sector emission reductions and bioenergy use: overview of the bioenergy demand phase of the EMF-33 model comparison. *Clim. Change*, 1–16. doi: 10.1007/s10584-018-2226-y

Beccali M, Finocchiaro P, Ippolito MG, Leone G, Panno D et al. 2018 Analysis of some renewable energy uses and demand side measures for hotels on small Mediterranean islands: A case study. *Energy* 157, 106–114. doi: 10.1016/j.energy.2018.05.139

Beringer T, Lucht W, Schaphoff S 2011 Bioenergy production potential of global biomass plantations under environmental and agricultural constraints. *GCB Bioenergy* 3, 299–312. doi: 10.1111/j.1757-1707.2010.01088.x

Bertani R 2017 *Perspectives for Geothermal Energy in Europe*. World Scientific Publishing doi: 10.1142/q0069

Bett PE, Thornton HE, Clark RT 2013 European wind variability over 140 yr. *Adv. Sci. Res.* 10, 51–58. doi: 10.5194/asr-10-51-2013

Bichet A, Hingray B, Evin G, Diedhiou A, Kebe CMF et al. 2019 Potential impact of climate change on solar resource in Africa for photovoltaic energy: analyses from CORDEX-AFRICA climate experiments. *Environ. Res. Lett.* 14, 124039. doi: 10.1088/1748-9326/ab500a

Bilgen S, Keleș S, Sarikaya I, Kaygusuz K 2015 A perspective for potential and technology of bioenergy in Turkey: Present case and future view. *Renew. Sustain. Energy Rev.* 48, 228–239. doi: 10.1016/j.rser.2015.03.096

Blimpo MP, Cosgrove-Davies M 2019 Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact. World Bank Group. doi: 10.1596/978-1-4648-1361-0

Bockers V, Haucap J, Heimeshoff U 2013 Cost of Non-Europe in the Single Market for Energy: ANNEX IV Benefits of an Integrated European Electricity Market. Brussels http://publications.europa.eu/resource/cellar/99d4fd94-7619-44f4-9f4b-5541235b90d1.0001.04/DOC_1

Brand B 2013 Transmission topologies for the integration of renewable power into the electricity systems of North Africa. *Energy Policy* 60, 155–166. doi: 10.1016/j.enpol.2013.04.071

Brand B, Blok K 2015 Renewable energy perspectives for the North African electricity systems: A comparative analysis of model-based scenario studies. *Energy Strateg. Rev.* 6, 1–11. doi: 10.1016/j.esr.2014.11.002

Brand B, Zingerle J 2011 The renewable energy targets of the Maghreb countries: Impact on electricity supply and conventional power markets. *Energy Policy* 39, 4411–4419. doi: 10.1016/j.enpol.2010.10.010

Bryden J, Riahi L, Zissler R 2013 MENA Renewables Status Report. Paris, France

Buoninconti L, Filagrossi Ambrosino C 2015 Water saving assessment in residential buildings. *Sustain. Mediterr. Constr.* http://www.sustainablemediterraneanconstruction.eu/SMC/The_Magazine_n.2_files/Smc N.2_pap_10.pdf [Accessed June 30, 2019]

Butler D 2008 Architects of a low-energy future. *Nature* 452, 520–523. doi: 10.1038/452520a

Buttler A, Dinkel F, Franz S, Spliethoff H 2016 Variability of wind and solar power – An assessment of the current situation in the European Union based on the year 2014. *Energy* 106, 147–161. doi: 10.1016/j.energy.2016.03.041

Caldés N, de la Rúa C, Lechón Y, Rodríguez I, Trieb F et al. 2015 Bringing Europe and Third countries closer together through renewable energies (BETTER): Summary Report. http://better-project.net/sites/default/files/BETTER_Summary Report_0.pdf [Accessed June 29, 2019]

Caldés N, del Río P, Lechón Y, Gerbeti A 2018 Renewable Energy Cooperation in Europe: What Next? Drivers and Barriers to the Use of Cooperation Mechanisms. *Energies* 12, 70. doi: 10.3390/en12010070
Calero Quesada MC, García Lafuente J, Sánchez Garrido JC, Sammartino S, Delgado J 2014 Energy of marine currents in the Strait of Gibraltar and its potential as a renewable energy resource. *Renew. Sustain. Energy Rev.* 34, 98–109. doi: 10.1016/j.rser.2014.02.038
Cappelli G, Yamaç SS, Stella T, Francone C, Paleari L et al. 2015 Are advantages from the partial replacement of corn with second-generation energy crops undermined by climate change? A case study for giant reed in northern Italy. *Biomass and Bioenergy* 80, 85–93. doi: 10.1016/j.biombioe.2015.04.038
Caputo AC, Palumbo M, Pelagagge PM, Scacchia F 2005 Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. *Biomass and Bioenergy* 28, 35–51. doi: 10.1016/j.biombioe.2004.04.009
Cavicchi B, Palmieri S, Odaldi M 2017 The Influence of Local Governance: Effects on the Sustainability of Bioenergy Innovation. *Sustainability* 9, 406. doi: 10.3390/su9030406
CBI 2019 Green Bonds: The State of the Market 2018. Climate Bonds Initiative. https://www.climatebonds.net/files/reports/cbi_gbm_final_032019_web.pdf
Chamorro CR, García-Cuesta JL, Mondéjar ME, Pérez-Madrazo A 2014 Enhanced geothermal systems in Europe: An estimation and comparison of the technical and sustainable potentials. *Energy* 65, 250–263. doi: 10.1016/j.energy.2013.11.078
Chow TT 2010 A review on photovoltaic/thermal hybrid solar technology. *Appl. Energy* 87, 365–379. doi: 10.1016/j.apenergy.2009.06.037
Chum H, Faaij A, Moreira J, Berndes G, Dhamija P et al. 2011 Bioenergy, in *Renewable Energy Sources and Climate Change Mitigation - Special Report of the Intergovernmental Panel on Climate Change*, eds. Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P et al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press), 209–332. doi: 10.1017/cbo9781139151153.006
Clarke L, Jiang K, Akimoto K, Babiker M, Blanford G et al. 2014 Assessing Transformation Pathways, in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S et al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press).
Coiro DP, Troise G, Ciuffardi T, Sannino G 2013 Tidal current energy resource assessment: The Strait of Messina test case. in *International Conference on Clean Electrical Power (ICCEP), Alghero, Italy* (IEEE). doi: 10.1109/iccep.2013.6586992
Collins S, Deane P, Ó Gallachóir B, Pfenninger S, Staffell I 2018 Impacts of Inter-annual Wind and Solar Variations on the European Power System. *Joule* 2, 2076–2090. doi: 10.1016/j.joule.2018.06.020
Corsini A, Rispoli F, Gamberale M, Tortora E 2009 Assessment of H_2- and H_2O-based renewable energy-buffering systems in minor islands. *Renew. Energy* 34, 279–288. doi: 10.1016/j.renene.2008.03.005
Cretì A, Fontini F 2019 *Economics of Electricity: Markets, Competition and Rules*. Cambridge University Press doi: 10.1017/9781316884614
Crisan A, Kuhn M 2017 The Energy Network: Infrastructure as the Hardware of the Energy Union, in *Energy Union: Europe's New Liberal Mercantilism?* International Political Economy Series., eds. Andersen SS, Goldthau A, Sitter N (London: Palgrave Macmillan UK), 165–182. doi: 10.1057/978-1-137-59104-3_10
Crook JA, Jones LA, Forster PM, Crook R 2011 Climate change impacts on future photovoltaic and concentrated solar power energy output. *Energy Environ. Sci.* 4, 3101–3109. doi: 10.1039/c1ee01495a
Curto D, Franzitta V, Viola A, Cirrincione M, Mohammadi A et al. 2019 A renewable energy mix to supply small islands. A comparative study applied to Balearic Islands and Fiji. *J. Clean. Prod.* 241, 118356. doi: 10.1016/j.jclepro.2019.118356
Curto D, Trapanese M 2018 A Renewable Energy mix to Supply the Balearic Islands: Sea Wave, Wind and Solar. in *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)* (IEEE). doi: 10.1109/eeeic.2018.8493876
Daioglou V, Doelman JC, Wicke B, Faaij A, van Vuuren DP 2019 Integrated assessment of biomass supply and demand in climate change mitigation scenarios. *Glob. Environ. Chang.* 54, 88–101. doi: 10.1016/j.gloenvcha.2018.11.012
Damm A, Köberl J, Prettenthaler F, Rogler N, Töglhofer C 2017 Impacts of +2 °C global warming on electricity demand in Europe. *Clim. Serv.* 7, 12–30. doi: 10.1016/j.cliser.2016.07.001
de Souza LEV, Bosco EMGRL, Cavalcante AG, Da Costa Ferreira L 2018 Postcolonial theories meet energy studies: "Institutional orientalism" as a barrier for renewable electricity trade in the Mediterranean region. *Energy Res. Soc. Sci.* 40, 91–100. doi: 10.1016/j.erss.2017.12.001
Dolinar M, Vidrih B, Kajfež-Bogataj L, Medved S 2010 Predicted changes in energy demands for heating and cooling due to climate change. *Phys. Chem. Earth, Parts A/B/C* 35, 100–106. doi: 10.1016/j.pce.2010.03.003
Don A, Osborne B, Hastings A, Skiba U, Carter MS et al. 2011 Land-use change to bioenergy production in

Europe: implications for the greenhouse gas balance and soil carbon. *GCB Bioenergy* 4, 372–391. doi: 10.1111/j.1757-1707.2011.01116.x

Dong L, McPhaden MJ 2017 The Effects of External Forcing and Internal Variability on the Formation of Interhemispheric Sea Surface Temperature Gradient Trends in the Indian Ocean. *J. Clim.* 30, 9077–9095. doi: 10.1175/JCLI-D-17-0138.1

Dubrovský M, Hayes M, Duce P, Trnka M, Svoboda M et al. 2014 Multi-GCM projections of future drought and climate variability indicators for the Mediterranean region. *Reg. Environ. Chang.* 14, 1907–1919. doi: 10.1007/s10113-013-0562-z

EIA 2019 International Energy Statistics. *US Energy Inf. Adm.* https://www.eia.gov/beta/international/data/browser/#/?pa=004000001000000000000000000000000000000000000000000000fu&c=3g2uq069sp7mlt16pro0a7t42skkemdcgg2004lrtapvc1j800fk&ct=0&vs=INTL.44-1-ALB-QB-TU.A&vo=0&v=T&end=2016 [Accessed June 30, 2019].

El-Geziry TM, Bryden IG, Couch SJ 2009 Environmental impact assessment for tidal energy schemes: an exemplar case study of the Strait of Messina. *J. Mar. Eng. Technol.* 8, 39–48. doi: 10.1080/20464177.2009.11020217

El-Katiri L 2014 A Roadmap for Renewable Energy in the Middle East and North Africa. Oxford Institute for Energy Studies doi: 10.26889/9781907555909

El Akkari M, Réchauchère O, Bispo A, Gabrielle B, Makowski D 2018 A meta-analysis of the greenhouse gas abatement of bioenergy factoring in land use changes. *Sci. Rep.* 8, 8563. doi: 10.1038/s41598-018-26712-x

El Fadel M, Rachid G, El-Samra R, Bou Boutros G, Hashisho J 2013 Emissions reduction and economic implications of renewable energy market penetration of power generation for residential consumption in the MENA region. *Energy Policy* 52, 618–627. doi: 10.1016/j.enpol.2012.10.015

Elbersen B, Van Verzandvoort M, Boogaard S, Mucher S, Cicarelli T et al. 2018 Definition and classification of marginal lands suitable for industrial crops in Europe. EU Deliverable 2.1. Wageningen, The Netherlands.

Elbersen BS, Startisky I, Hengeveld G, Schelhaas M-J, Naeff H 2012 Atlas of EU biomass potentials. Deliverable 3.3: Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources. Brussels.

ENTSO-E 2019 Power facts Europe. https://eepublicdownloads.entsoe.eu/clean-documents/Publications/ENTSO-E general publications/191113_Powerfacts.pdf

Erdinc O, Paterakis NG, Catalão JPS 2015 Overview of insular power systems under increasing penetration of renewable energy sources: Opportunities and challenges. *Renew. Sustain. Energy Rev.* 52, 333–346. doi: 10.1016/j.rser.2015.07.104

Escribano G, Lázaro L, Lechón Y, Oltra C, Sala R 2019 Geopolitical Context for CSP in Europe. Deliverable 6.4. MUSTEC project. Madrid http://mustec.eu/sites/default/files/reports/MUSTEC_ D6.4 Geopol_context_for_CSP_in_EU.pdf

Eskeland GS, Mideksa TK 2010 Electricity demand in a changing climate. *Mitig. Adapt. Strateg. Glob. Chang.* 15, 877–897. doi: 10.1007/s11027-010-9246-x

EU 2009 Directive 2009/28/EC of the European Parliament and of teh Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. 757–759. doi: 10.1007/978-1-137-54507-7_21

Eurelectric 1997 Study on the Importance of Harnessing the Hydropower Resources of the World. Brussels

European Commission 2016 Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee, the Committee of the Regions and the European Investment Bank: Clean Energy For All Europeans. Brussels. https://eur-lex.europa.eu/resource.html?uri=-cellar:fa6ea15b-b7b0-11e6-9e3c-01aa75ed71a1.0001.02/DOC_1&format=PDF [Accessed June 29, 2019] FAO 2017 FAOSTAT.

Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P 2008 Land Clearing and the Biofuel Carbon Debt. *Science (80-.).* 319, 1235–1238. doi: 10.1126/science.1152747

Fattouh B, El-Katiri L 2013 Energy subsidies in the Middle East and North Africa. *Energy Strateg. Rev.* 2, 108–115. doi: 10.1016/j.esr.2012.11.004

Fernández-Manjarrés J, Ruiz-Benito P, Zavala M, Camarero JJ, Pulido F et al. 2018 Forest Adaptation to Climate Change along Steep Ecological Gradients: The Case of the Mediterranean-Temperate Transition in South-Western Europe. *Sustainability* 10, 3065. doi: 10.3390/su10093065

Fernández JD, Hertz A 2019 Final Report. Regional Analysis of (I)NDCs in the SEMed Region. https://ufmsecretariat.org/wp-content/uploads/2019/12/Regional-analysis-on-NDCs-in-the-SEMed-region.pdf

Ferreira S, Monteiro E, Brito P, Vilarinho C 2017 Biomass resources in Portugal: Current status and prospects. *Renew. Sustain. Energy Rev.* 78, 1221–1235. doi: 10.1016/j.rser.2017.03.140

Flyvbjerg B, Bruzelius N, Rothengatter W 2003 *Megaprojects and risk: An anatomy of ambition*. Cambridge University Press. doi: 10.1017/cbo9781107050891

Fragkos P, Kouvaritakis N, Capros P 2013 Model-based analysis of the future strategies for the MENA energy system. *Energy Strateg. Rev.* 2, 59–70. doi: 10.1016/j.esr.2012.12.009

François B, Borga M, Creutin J-D, Hingray B, Raynaud D et al. 2016 Complementarity between solar and hydro power: Sensitivity study to climate characteristics in Northern-Italy. *Renew. Energy* 86, 543–553. doi: 10.1016/j.renene.2015.08.044

Franzitta V, Curto D 2017 Sustainability of the Renewable Energy Extraction Close to the Mediterranean Islands. *Energies* 10, 283. doi: 10.3390/en10030283

Fritsche UR, Berndes G, Cowie AL, Dale VH, Kline KL et al. 2017 Energy and Land-Use. https://knowledge.unccd.int/sites/default/files/2018-06/2. Fritsche%2Bet%2Bal%2B%282017%29%2BEnergy%2Band%2BLand%2BUse%2B-%2BGLO%2Bpaper-corr.pdf

Fritzsche K, Zejli D, Tänzler D 2011 The relevance of global energy governance for Arab countries: The case of Morocco. *Energy Policy* 39, 4497–4506. doi: 10.1016/j.enpol.2010.11.042

Gaudiosi G, Borri C 2010 Offshore wind energy in the mediterranean countries. *Rev. des Energies Renouvelables SMEE'10 Bou Ismail Tipaza*, 173 – 188. https://www.cder.dz/download/smee2010_19.pdf

Gelfand I, Sahajpal R, Zhang X, Izaurralde RC, Gross KL et al. 2013 Sustainable bioenergy production from marginal lands in the US Midwest. *Nature* 493, 514–517. doi: 10.1038/nature11811

Ghedamsi R, Settou N, Gouareh A, Khamouli A, Saifi N et al. 2016 Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach. *Energy Build.* 121, 309–317. doi: 10.1016/j.enbuild.2015.12.030

Giannakopoulos C, Hadjinicolaou P, Zerefos CS, Demosthenous G 2009 Changing energy requirements in the Mediterranean under changing climatic conditions. *Energies* 2, 805–815. doi: 10.3390/en20400805

Gibbs HK, Johnston M, Foley JA, Holloway T, Monfreda C et al. 2008 Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. *Environ. Res. Lett.* 3, 34001. doi: 10.1088/1748-9326/3/3/034001

Gil V, Gaertner MA, Gutiérrez C, Losada T 2019 Impact of climate change on solar irradiation and variability over the Iberian Peninsula using regional climate models. *Int. J. Climatol.* 39, 1733–1747. doi: 10.1002/joc.5916

Gold G, Webber M 2015 The Energy-Water Nexus: An Analysis and Comparison of Various Configurations Integrating Desalination with Renewable Power. *Resources* 4, 227–276. doi: 10.3390/resources4020227

Gómez A, Rodrigues M, Montañés C, Dopazo C, Fueyo N 2010 The potential for electricity generation from crop and forestry residues in Spain. *Biomass and Bioenergy* 34, 703–719. doi: 10.1016/j.biombioe.2010.01.013

González A, Riba JR, Puig R, Navarro P 2015 Review of micro- and small-scale technologies to produce electricity and heat from Mediterranean forests' wood chips. *Renew. Sustain. Energy Rev.* 43, 143–155. doi: 10.1016/j.rser.2014.11.013

Groppi D, Astiaso Garcia D, Lo Basso G, de Santoli L 2019 Synergy between smart energy systems simulation tools for greening small Mediterranean islands. *Renew. Energy* 135, 515–524. doi: 10.1016/j.renene.2018.12.043

Gutiérrez C, Somot S, Nabat P, Mallet M, Gaertner MÁ et al. 2018 Impact of aerosols on the spatiotemporal variability of photovoltaic energy production in the Euro-Mediterranean area. *Sol. Energy* 174, 1142–1152. doi: 10.1016/j.solener.2018.09.085

Hadjipanayi M, Koumparou I, Philippou N, Paraskeva V, Phinikarides A et al. 2016 Prospects of photovoltaics in southern European, Mediterranean and Middle East regions. *Renew. Energy* 92, 58–74. doi: 10.1016/j.renene.2016.01.096

Haller M, Ludig S, Bauer N 2012 Decarbonization scenarios for the EU and MENA power system: Considering spatial distribution and short term dynamics of renewable generation. *Energy Policy* 47, 282–290. doi: 10.1016/j.enpol.2012.04.069

Hamududu B, Killingtveit A 2012 Assessing climate change impacts on global hydropower. *Energies* 5, 305–322. doi: 10.3390/en5020305

Hastings A, Clifton-Brown J, Wattenbach M, Mitchell CP, Stampfl P et al. 2009 Future energy potential of *Miscanthus* in Europe. *GCB Bioenergy* 1, 180–196. doi: 10.1111/j.1757-1707.2009.01012.x

Hawila D, Mezher T, Kennedy SW, Mondal A 2012 Renewable energy readiness assessment for North African countries. *Proc. PICMET '12 Technol. Manag. Emerg. Technol.*, 2970–2982. doi: 10.1016/j.rser.2014.01.066

Held A, Ragwitz M, Winkler J 2019 "Clean energy for all Europeans" package: Implications and opportunities for the Mediterranean. https://www.cmimarseille.org/sites/default/files/newsite/english_version_online.pdf

Hirth L, Ziegenhagen I 2015 Balancing power and variable renewables: Three links. *Renew. Sustain. Energy Rev.* 50, 1035–1051. doi: 10.1016/j.rser.2015.04.180

Homar V, Ramis C, Romero R, Alonso S 2010 Recent trends in temperature and precipitation over the Balearic Islands (Spain). *Clim. Change* 98, 199. doi: 10.1007/s10584-009-9664-5

Hueging H, Haas R, Born K, Jacob D, Pinto JG 2013 Regional changes in wind energy potential over Europe using regional climate model ensemble projections. *J. Appl. Meteorol. Climatol.* 52, 903–917. doi: 10.1175/JAMC-D-12-086.1

Hui SCM 2000 Building energy efficiency standards in Hong Kong and mainland China. in *2000 ACEEE Summer Study on Energy Efficiency in Buildings, 20-25 August 2000, Pacific Grove, California.*

IEA 2018 Data and Statistics. *Int. Energy Agency*. https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy supply&indicator=Total primary energy supply (TPES) by source [Accessed June 30, 2019].
IEA Bioenergy 2016 IEA Bioenergy Countries' Report: Bioenergy policies and status of implementation.
Iliceto A, Ferrante A 2018 Consolidating a Secure and Sustainable Electricity Infrastructure in the Mediterranean Region : The Mediterranean Project of Med-TSO. in *2018 AEIT International Annual Conference* (IEEE). doi: 10.23919/AEIT.2018.8577419
IPCC 2014 *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. , eds. Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ et al. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. doi: 10.1017/CBO9781107415386
IPCC 2018 *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,*. , eds. Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J et al. In press
IRENA 2018 Renewable power generation costs in 2014. https://www.irena.org/documentdownloads/publications/irena_re_power_costs_2014_report.pdf
Iwaro J, Mwasha A 2010 A review of building energy regulation and policy for energy conservation in developing countries. *Energy Policy* 38, 7744–7755. doi: 10.1016/j.enpol.2010.08.027
Jaber S, Ajib S 2011 Optimum, technical and energy efficiency design of residential building in Mediterranean region. *Energy Build.* 43, 1829–1834. doi: 10.1016/j.enbuild.2011.03.024
Jerez S, Tobin I, Vautard R, Montávez JP, López-Romero JM et al. 2015 The impact of climate change on photovoltaic power generation in Europe. *Nat. Commun.* 6, 10014. doi: 10.1038/ncomms10014
Kaldellis JK, Gkikaki A, Kaldelli E, Kapsali M 2012 Investigating the energy autonomy of very small non-interconnected islands. *Energy Sustain. Dev.* 16, 476–485. doi: 10.1016/j.esd.2012.08.002
Karagali I, Mann J, Dellwik E, Vasiljević N 2018 New European Wind Atlas: The Østerild balconies experiment. *J. Phys. Conf. Ser.* 1037, 52029. doi: 10.1088/1742-6596/1037/5/052029
Koch H, Vögele S 2009 Dynamic modelling of water demand, water availability and adaptation strategies for power plants to global change. *Ecol. Econ.* 68, 2031–2039. doi: 10.1016/j.ecolecon.2009.02.015
Komendantova N, Patt A, Barras L, Battaglini A 2012 Perception of risks in renewable energy projects: The case of concentrated solar power in North Africa. *Energy Policy* 40, 103–109. doi: 10.1016/j.enpol.2009.12.008
Komendantova N, Patt A, Williges K 2011 Solar power investment in North Africa: Reducing perceived risks. *Renew. Sustain. Energy Rev.* 15, 4829–4835. doi: 10.1016/j.rser.2011.07.068
Krupa J, Poudineh R 2017 Financing renewable electricity in the resource-rich countries of the Middle East and North Africa: a review. Oxford Institute for Energy Studies. doi: 10.26889/9781784670788
Laurent A, Pelzer E, Loyce C, Makowski D 2015 Ranking yields of energy crops: A meta-analysis using direct and indirect comparisons. *Renew. Sustain. Energy Rev.* 46, 41–50. doi: 10.1016/j.rser.2015.02.023
Lewis A, Estefen S, Huckerby J, Musial W, Pontes T et al. 2011 Ocean Energy, in *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, eds. Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P et al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press).
Liang X, Lettenmaier DP, Wood EF, Burges SJ 1994 A simple hydrologically based model of land surface water and energy fluxes for general circulation models. *J. Geophys. Res.* 99, 14415–14428. doi: 10.1029/94jd00483
Liberti L, Carillo A, Sannino G 2013 Wave energy resource assessment in the Mediterranean, the Italian perspective. *Renew. Energy* 50, 938–949. doi: 10.1016/j.renene.2012.08.023
Lilliestam J, Ellenbeck S 2011 Energy security and renewable electricity trade—Will Desertec make Europe vulnerable to the "energy weapon"? *Energy Policy* 39, 3380–3391. doi: 10.1016/j.enpol.2011.03.035
Lilliestam J, Ellenbeck S, Karakosta C, Caldés N 2016 Understanding the absence of renewable electricity imports to the European Union. *Int. J. Energy Sect. Manag.* 10, 291–311. doi: 10.1108/IJESM-10-2014-0002
Lilliestam J, Patt A 2015 Barriers, risks and policies for renewables in the Gulf States. *Energies* 8, 8263–8285. doi: 10.3390/en8088263
Lobato E, Sigrist L, Rouco L 2017 Value of electric interconnection links in remote island power systems: The Spanish Canary and Balearic archipelago cases. *Int. J. Electr. Power Energy Syst.* 91, 192–200. doi: 10.1016/j.ijepes.2017.03.014
Macknick J, Newmark R, Heath G, Hallett KC 2012 Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. *Environ. Res. Lett.* 7, 45802. doi: 10.1088/1748-9326/7/4/045802
Marcos J, Marroyo L, Lorenzo E, García M 2012 Smoothing of PV power fluctuations by geographical dispersion. *Prog. Photovoltaics Res. Appl.* 20, 226–237. doi: 10.1002/pip.1127

Marktanner M, Salman L 2011 Economic and geopolitical dimensions of renewable vs. nuclear energy in North Africa. *Energy Policy* 39, 4479–4489. doi: 10.1016/j.enpol.2010.12.047

McVicar TR, Roderick ML, Donohue RJ, Li LT, Van Niel TG et al. 2012 Global review and synthesis of trends in observed terrestrial near-surface wind speeds: Implications for evaporation. *J. Hydrol.* 416–417, 182–205. doi: 10.1016/j.jhydrol.2011.10.024

MEDENER 2014 Trends in energy efficiency in countries of the Mediterranean rim.

MEDREG 2018 Mediterranean Energy Regulatory Outlook 2017.

MEF 2019 Financing energy transition in the Mediterranean: Issues, challenges and key responses.

Miglietta MM, Huld T, Monforti-Ferrario F 2017 Local Complementarity of Wind and Solar Energy Resources over Europe: An Assessment Study from a Meteorological Perspective. *J. Appl. Meteorol. Climatol.* 56, 217–234. doi: 10.1175/jamc-d-16-0031.1

Mohandes B, Moursi MS El, Hatziargyriou N, Khatib S El 2019 A Review of Power System Flexibility With High Penetration of Renewables. *IEEE Trans. Power Syst.* 34, 3140–3155. doi: 10.1109/TPWRS.2019.2897727

Monforti F, Huld T, Bódis K, Vitali L, D'Isidoro M et al. 2014 Assessing complementarity of wind and solar resources for energy production in Italy. A Monte Carlo approach. *Renew. Energy* 63, 576–586. doi: 10.1016/j.renene.2013.10.028

Mouratiadou I, Bevione M, Bijl DL, Drouet L, Hejazi M et al. 2018 Water demand for electricity in deep decarbonisation scenarios: a multi-model assessment. *Clim. Change* 147, 91–106. doi: 10.1007/s10584-017-2117-7

Mulinda C, Hu Q, Pan K 2013 Dissemination and Problems of African Biogas Technology. *Energy Power Eng.* 05, 506–512. doi: 10.4236/epe.2013.58055

Müller R, Pfeifroth U, Träger-Chatterjee C, Cremer R, Trentmann J et al. 2015 Surface Solar Radiation Data Set - Heliosat (SARAH) - Edition 1, Satellite Application Facility on Climate Monitoring. doi: 10.5676/EUM_SAF_CM/SARAH/V001

Muratori M, Calvin K V., Wise M, Kyle P, Edmonds JE 2016 Global economic consequences of deploying bioenergy with carbon capture and storage (BECCS). *Environ. Res. Lett.* 11, 95004. doi: 10.1088/1748-9326/11/9/095004

Nabat P, Somot S, Mallet M, Sevault F, Chiacchio M et al. 2015 Direct and semi-direct aerosol radiative effect on the Mediterranean climate variability using a coupled regional climate system model. *Clim. Dyn.* 44, 1127–1155. doi: 10.1007/s00382-014-2205-6

Neumuller M 2015 Retour à l'équilibre du marché des bois provençaux. *Econostrum*.

Neves D, Silva CA, Connors S 2014 Design and implementation of hybrid renewable energy systems on micro-communities: A review on case studies. *Renew. Sustain. Energy Rev.* 31, 935–946. doi: 10.1016/j.rser.2013.12.047

Newbery D 2017 Tales of two islands – Lessons for EU energy policy from electricity market reforms in Britain and Ireland. *Energy Policy* 105, 597–607. doi: 10.1016/j.enpol.2016.10.015

Newbery D, Strbac G, Viehoff I 2016 The benefits of integrating European electricity markets. *Energy Policy* 94, 253–263. doi: 10.1016/j.enpol.2016.03.047

Obermann A, Bastin S, Belamari S, Conte D, Gaertner MÁ et al. 2018 Mistral and Tramontane wind speed and wind direction patterns in regional climate simulations. *Clim. Dyn.* 51, 1059–1076. doi: 10.1007/s00382-016-3053-3

OECD 2018 Climate-related Development Finance Data. *OECD, Dev. Assist. Comm.* https://www.oecd.org/dac/financing-sustainable-development/development-finance-topics/Climate-related-development-finance-in-2018.pdf

OFME 2015 Données et chiffres clés de la forêt Méditerranéenne. Marseille https://www.ofme.org/documents/Chiffres-cles/Chiffres-cles-2015_pl_web.pdf

Olsson L, Barbosa H, Bhadwal S, Cowie AL, Delusca K et al. 2019 Land Degradation, in *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, eds. Shukla PR, Skea J, Buendia EC, Masson-Delmotte V, Pörtner H-O et al. (In press).

OME/MEDENER 2016 Executive Summary. Mediterranean Energy Transition: 2040 Scenario. Paris https://www.medener.org/wp-content/uploads/2015/05/Transition-énergétique-en-Méditerranée-scénario-2040-en.pdf [Accessed June 30, 2019].

OME/MEDENER 2018 Les Energies Renouvelables en Méditerranée : Tendances, Perspectives et Bonnes Pratiques. Paris.

OME 2018 Mediterranean Energy Perspectives 2018. Paris.

Omrani H, Drobinski P, Arsouze T, Bastin S, Lebeaupin-Brossier C et al. 2017 Spatial and temporal variability of wind energy resource and production over the North Western Mediterranean Sea: Sensitivity to air-sea interactions. *Renew. Energy* 101, 680–689. doi: 10.1016/j.renene.2016.09.028

Onea F, Deleanu L, Rusu L, Georgescu C 2016 Evaluation of the wind energy potential along the Mediterranean Sea coasts. *Energy Explor. Exploit.* 34, 766–792. doi: 10.1177/0144598716659592

Oseni MO, Pollitt MG 2016 The promotion of regional integration of electricity markets: Lessons for developing countries. *Energy Policy* 88, 628–638. doi: 10.1016/j.enpol.2015.09.007

Paredes-Sánchez JP, López-Ochoa LM, López-González LM, Las-Heras-Casas J, Xiberta-Bernat J 2019

Evolution and perspectives of the bioenergy applications in Spain. *J. Clean. Prod.* 213, 553–568. doi: 10.1016/j.jclepro.2018.12.112

Paredes-Sánchez JP, López-Ochoa LM, López-González LM, Xiberta-Bernat J 2016 Bioenergy for District Bioheating System (DBS) from eucalyptus residues in a European coal-producing region. *Energy Convers. Manag.* 126, 960–970. doi: 10.1016/j.enconman.2016.08.084

Pariente-David S 2014 Successful Grid Integration of Renewable Energy: Integration is the Name of the Game. *Int. Assoc. Energy Econ.*, 29–30. https://www.iaee.org/newsletter/issue/29

Pariente-David S 2016 The Cost and Value of Renewable Energy: Revisiting Electricity Economics. *Int. Assoc. Energy Econ. IAEE Energy Forum*, 21–23.

Pariente-David S, Jannet Allal H Ben 2019 North Africa. An energy bridge between the African and European Continents, in *Empowering Africa: Access to power in the African continent*, eds. Colantoni L, Montesano G, Sartori N (Peter Lang), 199–231. doi: 10.3726/b15292/20

Pérez-Andreu V, Aparicio-Fernández C, Martínez-Ibernón A, Vivancos J-L 2018 Impact of climate change on heating and cooling energy demand in a residential building in a Mediterranean climate. *Energy* 165, 63–74. doi: 10.1016/j.energy.2018.09.015

Petersen LE, Troen I, Ejsing Jørgensen H, Mann J 2014 The new European wind atlas. *Energy Bull.* 17, 34–39.

Petterssen S 1956 *Weather Analysis and Forecasting*. McGraw-Hill.

Pfeifroth U, Sánchez-Lorenzo A, Manara V, Trentmann J, Hollmann R 2018 Trends and variability of surface solar radiation in Europe based on surface- and satellite-based data records. *JGR Atmos.* 123, 1735–1754. doi: 10.1002/2017JD027418

Pfenninger S, Staffell I 2016 Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. *Energy* 114, 1251–1265. doi: 10.1016/j.energy.2016.08.060

Philipona R, Behrens K, Ruckstuhl C 2009 How declining aerosols and rising greenhouse gases forced rapid warming in Europe since the 1980s. *Geophys. Res. Lett.* 36. doi: 10.1029/2008gl036350

Piante C, Ody D 2015 Blue Growth in the Mediterranean Sea: The Challenge of Good Environmental Status. http://www.developpement-durable.gouv.fr/

Plan Bleu 2008 Climate Change and Energy in the Mediterranean. Sophia Antipolis http://www.eib.org/attachments/country/climate_change_energy_mediterranean_en.pdf.

Ponce de León S, Orfila A, Simarro G 2016 Wave energy in the Balearic Sea. Evolution from a 29 year spectral wave hindcast. *Renew. Energy* 85, 1192–1200. doi: 10.1016/j.renene.2015.07.076

Possner A, Caldeira K 2017 Geophysical potential for wind energy over the open oceans. *Proc. Natl. Acad. Sci. U. S. A.* 114, 11338–11343. doi: 10.1073/pnas.1705710114

Poudineh R, Sen A, Fattouh B 2018 Advancing renewable energy in resource-rich economies of the MENA. *Renew. Energy* 123, 135–149. doi: 10.1016/j.renene.2018.02.015

Pozo-Vazquez D, Santos-Alamillos FJ, Lara-Fanego V, Ruiz-Arias JA, Tovar-Pescador J 2011 The Impact of the NAO on the Solar and Wind Energy Resources in the Mediterranean Area, in *Hydrological Socio-economic and Ecological Impacts of the North Atlantic Oscillation in the Mediterranean Region, Advances in Global Change Research*, eds. Vicente-Serrano SM, Trigo RM (Springer Netherlands), 213–231. doi: 10.1007/978-94-007-1372-7_15

Pryor SC, Barthelmie RJ, Schoof JT 2006 Inter-annual variability of wind indices across Europe. *Wind Energy* 9, 27–38. doi: 10.1002/we.178

Pulighe G, Bonati G, Colangeli M, Morese MM, Traverso L et al. 2019 Ongoing and emerging issues for sustainable bioenergy production on marginal lands in the Mediterranean regions. *Renew. Sustain. Energy Rev.* 103, 58–70. doi: 10.1016/J.RSER.2018.12.043

Pye S, Bataille C 2016 Improving deep decarbonization modelling capacity for developed and developing country contexts. *Clim. Policy* 16, S27–S46. doi: 10.1080/14693062.2016.1173004

Raymond F, Ullmann A, Tramblay Y, Drobinski P, Camberlin P 2019 Evolution of Mediterranean extreme dry spells during the wet season under climate change. *Reg. Environ. Chang.* 19, 2339–2351. doi: 10.1007/s10113-019-01526-3

Rizzo A, Maro P 2018 Implementing Nationally Determined Contributions (NDCs) in the South Mediterranean region. Perspectives on climate action from eight countries.

Robin K 2015 Climate - What did Mediterranean countries commit to in view of the COP21?

Rodríguez-Loinaz G, Amezaga I, Onaindia M 2013 Use of native species to improve carbon sequestration and contribute towards solving the environmental problems of the timberlands in Biscay, northern Spain. *J. Environ. Manage.* 120, 18–26. doi: 10.1016/j.jenvman.2013.01.032

Rogelj J, Luderer G, Pietzcker RC, Kriegler E, Schaeffer M et al. 2015 Energy system transformations for limiting end-of-century warming to below 1.5 °C. *Nat. Clim. Chang.* 5, 519–527. doi: 10.1038/nclimate2572

Roques F, Verhaeghe C 2016 Options for the future of Power System Regional Coordination. Paris https://docstore.entsoe.eu/Documents/Publications/Position papers and reports/entsoe_fti_161207.pdf

Rose SK, Kriegler E, Bibas R, Calvin K V., Popp A et al. 2014 Bioenergy in energy transformation and climate management. *Clim. Change* 123, 477–493.

doi: 10.1007/s10584-013-0965-3
Rowlinson ET 2015 À Qui le Soleil: How Morocco's Developing Solar Capacities Have Altered Urban Infrastructural Provisions. https://repositories.lib.utexas.edu/bitstream/handle/2152/35485/ROWLINSON-THESIS-2015.pdf?sequence=1&isAllowed=y
Royaume du Maroc 2017 Stratégie nationale énergétique – horizon 2030.
Rusu E, Rusu L 2019 Evaluation of the wind power potential in the European nearshore of the Mediterranean Sea. *E3S Web Conf.* 103, 1003. doi: 10.1051/e3sconf/201910301003
Saffih-Hdadi K, Mary B 2008 Modeling consequences of straw residues export on soil organic carbon. *Soil Biol. Biochem.* 40, 594–607. doi: 10.1016/j.soilbio.2007.08.022
Sánchez-Lorenzo A, Enriquez-Alonso A, Wild M, Trentmann J, Vicente-Serrano SM et al. 2017 Trends in downward surface solar radiation from satellites and ground observations over Europe during 1983–2010. *Remote Sens. Environ.* 189, 108–117. doi: 10.1016/J.RSE.2016.11.018
Sanseverino ER, Sanseverino RR, Favuzza S, Vaccaro V 2014 Near zero energy islands in the Mediterranean: Supporting policies and local obstacles. *Energy Policy* 66, 592–602. doi: 10.1016/j.enpol.2013.11.007
Sansilvestri R, Cuccarollo M, Frascaria-Lacoste N, Benito-Garzon M, Fernandez-Manjarrés J 2020 Evaluating climate change adaptation pathways through capital assessment: five case studies of forest social-ecological systems in France. *Sustain. Sci.* 15, 539–553. doi: 10.1007/s11625-019-00731-7
Santos-Alamillos FJ, Pozo-Vázquez D, Ruiz-Arias JA, Lara-Fanego V, Tovar-Pescador J 2012 Analysis of Spatiotemporal Balancing between Wind and Solar Energy Resources in the Southern Iberian Peninsula. *J. Appl. Meteorol. Climatol.* 51, 2005–2024. doi: 10.1175/jamc-d-11-0189.1
Santos-Alamillos FJ, Thomaidis NS, Usaola-García J, Ruiz-Arias JA, Pozo-Vázquez D 2017 Exploring the mean-variance portfolio optimization approach for planning wind repowering actions in Spain. *Renew. Energy* 106, 335–342. doi: 10.1016/j.renene.2017.01.041
Schewe J, Gosling SN, Reyer C, Zhao F, Ciais P et al. 2019 State-of-the-art global models underestimate impacts from climate extremes. *Nat. Commun.* 10, 1005. doi: 10.1038/s41467-019-08745-6
Schilling J, Freier KP, Hertig E, Scheffran J 2012 Climate change, vulnerability and adaptation in North Africa with focus on Morocco. *Agric. Ecosyst. Environ.* 156, 12–26. doi: 10.1016/J.AGEE.2012.04.021
Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A et al. 2008 Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. *Science (80-.).* 319, 1238–1240. doi: 10.1126/science.1151861
Sen Nag O 2017 The Most Populated Islands In The Mediterranean Sea. https://www.worldatlas.com/articles/the-most-populated-islands-in-the-mediterranean-sea.html
Sierra JP, Casas-Prat M, Campins E 2017 Impact of climate change on wave energy resource: The case of Menorca (Spain). *Renew. Energy* 101, 275–285. doi: 10.1016/j.renene.2016.08.060
Soares PMM, Brito MC, Careto JAM 2019 Persistence of the high solar potential in Africa in a changing climate. *Environ. Res. Lett.* 14, 124036. doi: 10.1088/1748-9326/ab51a1
Solaun K, Cerdá E 2020 Impacts of climate change on wind energy power – Four wind farms in Spain. *Renew. Energy* 145, 1306–1316. doi: 10.1016/j.renene.2019.06.129
Soukissian TH, Denaxa D, Karathanasi F, Prospathopoulos A, Sarantakos K et al. 2017 Marine renewable energy in the Mediterranean Sea: Status and perspectives. *Energies* 10, 1512. doi: 10.3390/en10101512
Staffell I, Pfenninger S 2016 Using bias-corrected reanalysis to simulate current and future wind power output. *Energy* 114, 1224–1239. doi: 10.1016/j.energy.2016.08.068
Stecher K, Brosowski A, Thrän D 2013 Biomass potential in Africa. Abu Dhabi.
Szabó L, Mezősi A, Törőcsik Á, Kotek P, Kácsor E et al. 2015 Dialogue on a RES policy Framework for 2030. D3.1a Renewable Based District Heating in Europe - Policy Assessment of Selected Member States.
Taibi E, Nikolakakis T, Gutierrez L, Fernandez C, Kiviluoma J et al. 2018 Power system flexibility for the energy transition. Part 1: Overview for policy makers. Abu Dhabi https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Nov/IRENA_Power_system_flexibility_1_2018.pdf?la=en&hash=72EC26336F127C7D51DF798CE19F477557CE9A82
Tantet A, Stéfanon M, Drobinski P, Badosa J, Concettini S et al. 2019 E4Clim 1.0: The Energy for a Climate Integrated Model: Description and Application to Italy. *Energies* 12, 4299. doi: 10.3390/en12224299
Thornton HE, Hoskins BJ, Scaife AA 2016 The role of temperature in the variability and extremes of electricity and gas demand in Great Britain. *Environ. Res. Lett.* 11, 114015. doi: 10.1088/1748-9326/11/11/114015
Tilman D, Socolow R, Foley JA, Hill J, Larson E et al. 2009 Beneficial Biofuels--The Food, Energy, and Environment Trilemma. *Science (80-.).* 325, 270–271. doi: 10.1126/science.1177970
Timmerberg S, Sanna A, Kaltschmitt M, Finkbeiner M 2019 Renewable electricity targets in selected MENA countries – Assessment of available resources, generation costs and GHG emissions. *Energy Re-*

ports 5, 1470–1487. doi: 10.1016/j.egyr.2019.10.003
Tobin I, Greuell W, Jerez S, Ludwig F, Vautard R et al. 2018 Vulnerabilities and resilience of European power generation to 1.5°C, 2°C and 3°C warming. *Environ. Res. Lett.* 13, 44024. doi: 10.1088/1748-9326/aab211
Tobin I, Jerez S, Vautard R, Thais F, van Meijgaard E et al. 2016 Climate change impacts on the power generation potential of a European mid-century wind farms scenario. *Environ. Res. Lett.* 11, 34013. doi: 10.1088/1748-9326/11/3/034013
Tobin I, Vautard R, Balog I, Bréon F-M, Jerez S et al. 2015 Assessing climate change impacts on European wind energy from ENSEMBLES high-resolution climate projections. *Clim. Change* 128, 99–112. doi: 10.1007/s10584-014-1291-0
Trieb F, Schillings C, Pregger T, O'Sullivan M 2012 Solar electricity imports from the Middle East and North Africa to Europe. *Energy Policy* 42, 341–353. doi: 10.1016/j.enpol.2011.11.091
Ueckerdt F, Brecha R, Luderer G 2015 Analyzing major challenges of wind and solar variability in power systems. *Renew. Energy* 81, 1–10. doi: 10.1016/j.renene.2015.03.002
UfM 2019 Tracking and enhancing international private climate finance in the Southern-Mediterranean Region. https://ufmsecretariat.org/wp-content/uploads/2019/09/Private-Climate-Finance-Tracking-and-enhancing-international-private-climate-finance-in-the-Southern-Mediterranean-Region.pdf
UK DECC 2013 More interconnection: improving energy security and lowering bills. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/266460/More_interconnection_-_improving_energy_security_and_lowering_bills.pdf [Accessed June 29, 2019]
UN DESA 2016 Energy Balances. https://unstats.un.org/unsd/energy/balance/default.htm
UNEP/MAP-Plan Bleu 2009 State of the Environment and Development in the Mediterranean. Athens, Greece.
UNEP/MAP 2007 MAP Mediteranean Action Plan. Energy and sustainable development in the Mediterranean: in *Proceedings of the Regional Workshop, Monaco* (Monaco). https://wedocs.unep.org/bitstream/handle/20.500.11822/516/mts167.pdf?sequence=2&isAllowed=y [Accessed June 30, 2019].
UNFCCC 2018 Biennial Assessment and Overview of Climate Finance Flows. Technical Report. https://unfccc.int/sites/default/files/resource/2018 BA Technical Report Final Feb 2019.pdf
van Vliet MTH, Sheffield J, Wiberg D, Wood EF 2016a Impacts of recent drought and warm years on water resources and electricity supply worldwide. *Environ. Res. Lett.* 11, 124021. doi: 10.1088/1748-9326/11/12/124021
van Vliet MTH, Wiberg D, Leduc S, Riahi K 2016b Power-generation system vulnerability and adaptation to changes in climate and water resources. *Nat. Clim. Chang.* 6, 375–380. doi: 10.1038/nclimate2903
van Vliet MTH, Yearsley JR, Franssen WHP, Ludwig F, Haddeland I et al. 2012a Coupled daily streamflow and water temperature modelling in large river basins. *Hydrol. Earth Syst. Sci.* 16, 4303–4321. doi: 10.5194/hess-16-4303-2012
van Vliet MTH, Yearsley JR, Ludwig F, Vögele S, Lettenmaier DP et al. 2012b Vulnerability of US and European electricity supply to climate change. *Nat. Clim. Chang.* 2, 676–681. doi: 10.1038/nclimate1546
Vautard R, Cattiaux J, Yiou P, Thépaut J-N, Ciais P 2010 Northern Hemisphere atmospheric stilling partly attributed to an increase in surface roughness. *Nat. Geosci.* 3, 756–761. doi: 10.1038/ngeo979
Vidican G 2016 Scaling Up Renewable Energy Deployment in North Africa. *Regul. Investments Energy Mark.*, 73–87. doi: 10.1016/b978-0-12-804436-0.00004-7
Wang Z, Lin X, Tong N, Li Z, Sun S et al. 2020 Optimal planning of a 100% renewable energy island supply system based on the integration of a concentrating solar power plant and desalination units. *Int. J. Electr. Power Energy Syst.* 117, 105707. doi: 10.1016/j.ijepes.2019.105707
Weber J, Gotzens F, Witthaut D 2018 Impact of strong climate change on the statistics of wind power generation in Europe. *Energy Procedia* 153, 22–28. doi: 10.1016/j.egypro.2018.10.004
Wenz L, Levermann A, Auffhammer M 2017 North-south polarization of European electricity consumption under future warming. *Proc. Natl. Acad. Sci. U. S. A.* 114, E7910–E7918. doi: 10.1073/pnas.1704339114
Widén J, Carpman N, Castellucci V, Lingfors D, Olauson J et al. 2015 Variability assessment and forecasting of renewables: A review for solar, wind, wave and tidal resources. *Renew. Sustain. Energy Rev.* 44, 356–375. doi: 10.1016/j.rser.2014.12.019
Wild M, Folini D, Henschel F 2017 Impact of climate change on future concentrated solar power (CSP) production. *AIP Conf. Proc.* 1810, 100007. doi: 10.1063/1.4975562
Wild M, Folini D, Henschel F, Fischer N, Müller B 2015 Projections of long-term changes in solar radiation based on CMIP5 climate models and their influence on energy yields of photovoltaic systems. *Sol. Energy* 116, 12–24. doi: 10.1016/j.solener.2015.03.039
Wild M, Gilgen H, Roesch A, Ohmura A, Long CN et al. 2005 From dimming to brightening: Decadal changes in solar radiation at Earth's surface. *Science (80-.).* 308, 847–850. doi: 10.1126/science.1103215
World Bank 2010 2010 Annual Report. Washington, DC. http://documents.worldbank.org/curated/en/408911468331735129/2010-annual-report
World Bank 2018 Energy Subsidies in Mediterranean

developing countries and their reform. https://www.cape4financeministry.org/sites/cape/files/inline-files/Session 1-3. Thomas Flochel_M

Yearsley JR 2009 A semi-Lagrangian water temperature model for advection-dominated river systems. *Water Resour. Res.* 45. doi: 10.1029/2008wr007629

Yoon SJ, Son Y-I, Kim Y-K, Lee J-G 2012 Gasification and power generation characteristics of rice husk and rice husk pellet using a downdraft fixed-bed gasifier. *Renew. Energy* 42, 163–167. doi: 10.1016/j.renene.2011.08.028

Zabalza Bribián I, Valero Capilla A, Aranda Usón A 2011 Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Build. Environ.* 46, 1133–1140. doi: 10.1016/j.buildenv.2010.12.002

Zachariadis T, Hadjinicolaou P 2014 The effect of climate change on electricity needs - A case study from Mediterranean Europe. *Energy* 76, 899–910. doi: 10.1016/j.energy.2014.09.001

Zejli D, Bennouna A 2009 Wind Energy in Morocco: Which Strategy for Which Development?, in (Springer, Dordrecht), 151–173. doi: 10.1007/978-1-4020-9892-5_9

Zeng Z, Ziegler AD, Searchinger T, Yang L, Chen A et al. 2019 A reversal in global terrestrial stilling and its implications for wind energy production. *Nat. Clim. Chang.* 9, 979–985. doi: 10.1038/s41558-019-0622-6

Zickfeld F, Wieland A 2012 Desert Power 2050: Perspectives on a Sustainable Power System for EUMENA. Germany http://mait.camins.cat/ET2050_library/docs/tech/energy/2012_2050_Desert_Power.pdf [Accessed June 29, 2019]

Zizzo G, Beccali M, Bonomolo M, di Pietra B, Ippolito MG et al. 2017 A feasibility study of some DSM enabling solutions in small islands: The case of Lampedusa. *Energy* 140, 1030–1046. doi: 10.1016/j.energy.2017.09.069

Zouiri H, Elmessaoudi H 2018 Energies renouvelables et développment durable au Maroc. *Rev. Estud. Front. del Estrecho Gibraltar* REFEG 6/20, 1–29.

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