Study on the offshore grid potential in the Mediterranean region

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Final Report

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Advisory Board contribution

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Executive summary

The Mediterranean Sea region is becoming increasingly interested in the application of clean energy technologies, both on- and offshore. Therefore, there is a need to identify the potential for a joint regional effort in developing offshore energy and supporting grid infrastructure, following similar studies for the North and Baltic Seas.

Guidehouse (previously Navigant Netherlands B.V.)[1] provided technical assistance to the European Commission (EC) on the topic of offshore grid potential in the Mediterranean region (request for services no, ENER/B1/2019-508 under framework contract MOVE/ENER/SRD/2016-498 Lot 2). The geographical scope of this study includes nine European Union (EU) member states in the Mediterranean region:

- Croatia
- Cyprus
- France
- Greece
- Italy
- Malta
- Slovenia
- Spain
- Portugal

The analysis covered five energy technologies: offshore wind (bottom-fixed and floating technologies), wave and tidal energy, onshore wind, and solar technologies in islands. This final study presents the results of the analysis followed by a broad stakeholder consultation.

Potential for offshore power generation

The deployment of offshore technologies for electricity generation in the Mediterranean Sea has been relatively slow so far, consisting of floating offshore wind, wave, and tidal pilot projects. Onshore wind and solar PV are widely spread across the Mediterranean islands. Most of the countries in the region have set targets per technology for the coming decade as part of their National Energy and Climate Plans (NECPs). The highest targets are set for offshore bottom-fixed wind (France, Italy, Portugal) and onshore PV. Some other countries (Greece, Malta, Cyprus) are also actively developing analyses of the renewable energy sources (RES) potential so one may hope for even more ambitious developments in future policy targets.

In terms of forecasting, this study presents estimates for the technical and the economic potential for offshore renewable energy and renewable energy on islands in the Mediterranean region for the years 2030 and 2050. We have analysed the natural potential, limited by the spatial constraints, nature protection areas, maritime and (partly) military use, and technology-specific exclusions such as water depth and visual impact.

The assessment shows that floating offshore wind is the most suitable technology due to large available areas with favourable wind speeds, suitable water depths, and relatively high capacity factors, resulting in a technical potential of approximately 4,600 TWh/aby 2030 and 4,700 TWh/a by 2050. The technology is not fully mature, but it is promising as costs are expected to fall. Onshore technologies on islands, such as onshore wind and rooftop and utility-scale solar PV, are promising technologies due to their maturity level, regulatory readiness, projected cost levels, and social acceptance (in the case of solar). The technical potential is 60 TWh/a for onshore wind on islands in 2050 and 207 TWh/a for solar PV on islands in 2050. Wave energy has a good technical potential at 4,500 TWh/a) by 2050, comparable to floating offshore wind. However, this technology is still less mature and more expensive than the aforementioned offshore and onshore technologies, and further research, development, and innovation (RDI) investments are required to overcome these barriers. Bottom-fixed offshore wind technical potential is rather limited due to water depth constraints in the Mediterranean Sea and is estimated at 60 TWh/a in 2050. However, bottom-fixed offshore wind is a mature technology, making it suitable for deployment in specific parts of the Mediterranean region. The role for tidal energy will be more limited due to its limited technical resource potential (22 TWh/a in 2050), technology immaturity and high cost levels.

[1] Guidehouse LLP completed its acquisition of Navigant Consulting, Inc. and its operating subsidiaries on October 11, 2019. For more information, see: https://guidehouse.com/news/corporate-news/2019/guidehouse-completes-acquisition-of-navigant.

This study also presents the economic potential for renewable power production by estimating the levelized cost of electricity (LCOE) for each of the technologies and countries analysed for 2030 and 2050. Among offshore technologies, LCOE values for bottom-fixed offshore wind are lower than for floating offshore; however, the difference is expected to decrease through 2050. For wave and tidal technologies, LCOE values are significantly higher, but they are also on a decreasing trend. LCOE levels for onshore technologies (i.e., wind and solar PV on islands) are generally much lower than those for offshore technologies.

Selected technology mix areas

Based on the results of the technical potential and the LCOE analysis, this study identified 10 technology mix areas (TMAs) with the greatest cost-effective potential for various technologies or combinations thereof.

Some areas are prioritised above other regions for more practical reasons, such as the availability of resources that can be utilised with more mature technologies or the possibility of including the connection hub within a meshed grid. The final selection of TMAs covers a wide range of the Mediterranean Sea from the Spanish Gulf of Cádiz to the Greek Aegean Sea, presented in Figure ES-1.

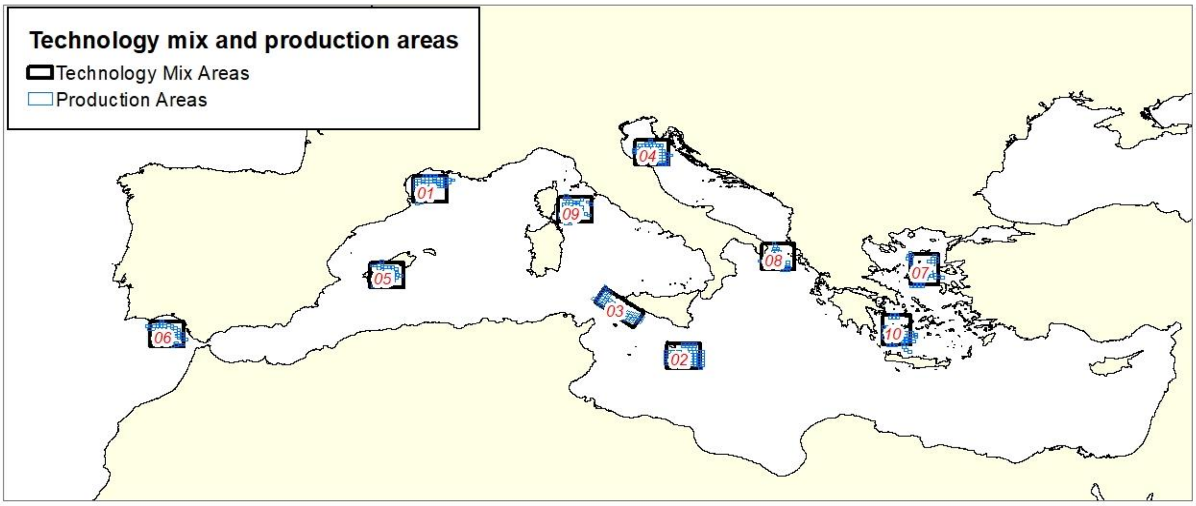

Figure ES-1: Most interesting identified TMAs

(Source: Guidehouse)

The 10 TMAs proposed in the study do not cover the entire potential in the region. They simply ranked highest in this study’s modelling, as presented in Table ES-1.

Table ES-1: TMA rankings

TMA Label	Description	Ranking	Remarks
01	Gulf of Lion	1	Low LCOE Close to load centre
07	North Aegean Sea	2	Low LCOE
03	Sicily	3	Low LCOE Large potential of onshore technologies on nearby islands Close to planned grid connection Sicily-Tunisia
04	Gulf of Venice	4	Substantial bottom-fixed offshore wind with relatively low LCOE in 2030 Close to load centre
08	Italy–Ionian Sea	5	
09	Corsica–Sardinia	6	Large potential of onshore technologies on nearby islands Close to planned grid connection
10	South Aegean Sea	7	Close to load centre
06	Gulf of Cádiz	8	Far from load centre
02	Malta	9	High LCOE Far from load centre
05	Baleares	10	High LCOE Far from load centre

(Source: Guidehouse)

Therefore, a higher resolution analysis of the potentials is needed to fully understand RES potential for each country in the region.

Production scenarios

Based on the identified economic offshore energy potential, this study develops two realistic production scenarios for each of the selected countries for 2030 and 2050, focusing on the 10 selected TMAs. The scenarios differ regarding the ambition level (the amount of installed offshore power generation capacity). The NECP scenario is less ambitious (2.4 GW offshore wind in 2030 and 32.7 GW offshore wind in 2050) than the ambitious scenario (13.3 GW offshore wind in 2030, about 76.0 GW offshore wind in 2050). Beyond these installations, there is additional offshore capacity in France, Portugal, and Spain since not all of their coastline is defined as Mediterranean.

Both scenarios are designed to reach or exceed the respective national renewables target for 2030. **The ambitious scenarios add between 2% and 22% in RES share for 2030 for each of the Mediterranean member states**. This increase contributes to a higher RES share in Europe and faster decarbonization.

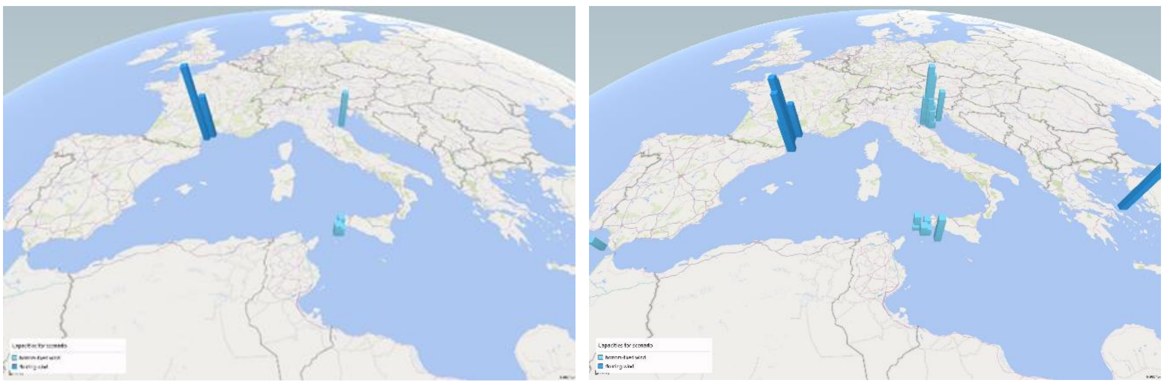

Figure ES-2: Regional distribution of offshore generation capacity, NECP scenario: 2030 (left), and regional distribution of offshore generation capacity, ambitious scenario: 2030 (right)

(Source: Sweco)

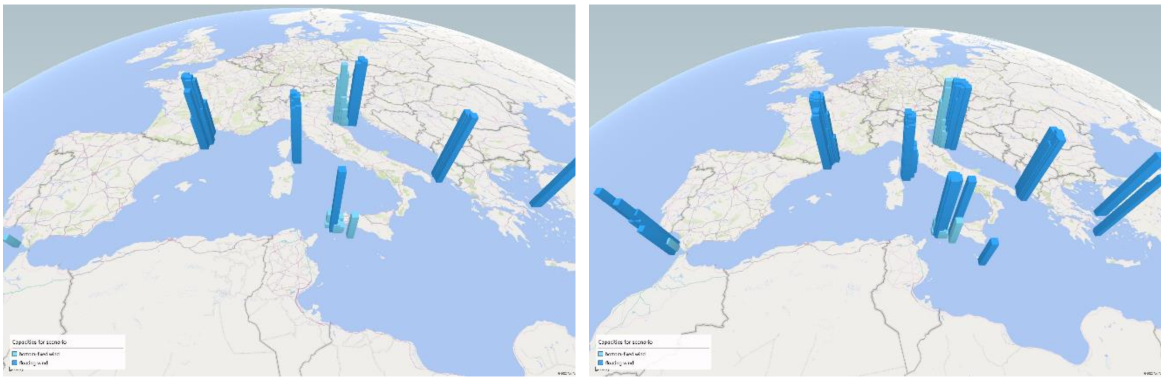

Figure ES-3: Regional distribution of offshore generation capacity, NECP scenario: 2050 (left), and regional distribution of offshore generation capacity, ambitious scenario: 2050 (right)

(Source: Sweco)

Impact on CO_2 emissions

The analysis of this study also shows that CO_2 emissions fall significantly in most Mediterranean countries between 2020 and 2030, most significantly in Portugal, Spain, Italy, and Greece. Substantial additional gains can be made in almost all Mediterranean countries by introducing more offshore generation, as presented in Figure ES-5.

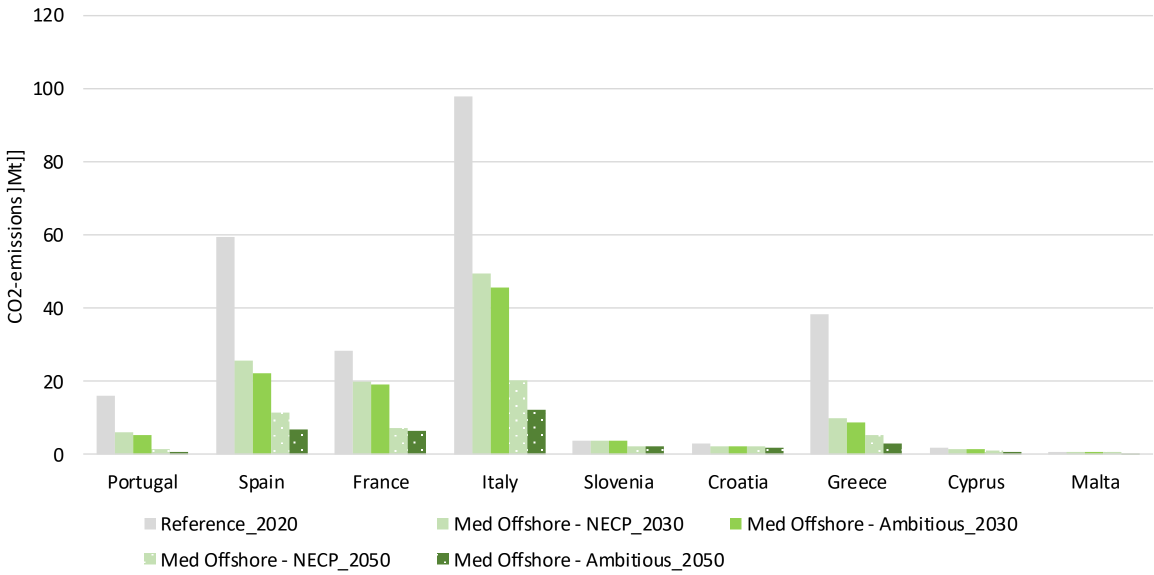

Figure ES-4: CO_2 emissions from power production 2020, 2030, and 2050 in the different production scenarios

(Source: Sweco)

Grid options

This study concludes that the region does not require one meshed grid solution covering the entire region. On the contrary, this study's recommendation is considering several sub regional hubs linking offshore installations with interconnectors.

This study develops two grid connection alternatives for connecting the identified production blocks within the TMAs to the onshore transmission grid and to each other, if feasible: radial and hub connections. For two of the TMAs, a cross-country interconnection was also investigated as a third option.

The hub connection requires lower capital investment costs than the radial connection alternatives because the hub connection utilizes a common interconnection for several production blocks in a given area, thereby limiting the construction and material costs. On the downside, this interconnection means a limited decrease in security of supply, as the outage of a cable could mean loss of the output from more than one production block. Another difference between the radial connection and the hub connection is that the former does not require coordination of the different production blocks, whereas the latter assumes that the whole group of production blocks is realized as a common project. A common hub project is more difficult to achieve with a step-by-step approach and generally requires a bigger commitment in terms of investments and policies. Thus, a comparison between the two options needs to consider not only the summary costs but also the strategic choices involved.

A third option is feasible cross-country interconnectors based on the hub grid connection alternative. This study found that the cross-country interconnection from Italy to Croatia in the Gulf of Venice was not economically beneficial, whereas the interconnection from France to Spain in the Gulf of Lion was economically beneficial.

Socioeconomic benefits

For 2030, this study concludes that the ambitious scenario with 13 GW RES integration yields more benefits than the NECP scenario with 2 GW installed offshore capacity by lowering power prices. The analysis disregards the cost for onshore grid reinforcement, which was not quantified in this study. However, both scenarios require considerable investments in offshore power generation, its connection to the land, and the onshore grid, in addition to considerable reinforcement of the onshore grid itself.

To reach the RES integration of about 76 GW of offshore wind power capacity in the Mediterranean in the ambitious scenario for 2050, about €120-130 billion of accumulated investments is needed until 2050. These investments include investments in offshore production assets and their grid connection to land but exclude onshore grid reinforcements and other production assets or energy storage. However, opportunities for substantial socioeconomic gains exist with the modelled investments in RES, as presented in Figure ES-5.

Figure ES-5: Summary of CAPEX, RES integration, change in socioeconomic welfare, and CO_2 savings in the various 2030 and 2050 scenarios

(Source: Sweco)

Key barriers

This study identifies a list of barriers and implementation challenges for offshore grid and renewable development and groups them into 10 broader categories. Next, these barriers and implementation challenges were ranked based on their impact on offshore grid and renewable development in the Mediterranean.

The categories of barriers with the highest priority at a regional level are:

- Offshore grid and renewable generation technologies: grid connection and technology maturity
- Offshore RES generation related to support schemes
- Administrative/governance processes
- Social and environmental constraints

The study proposes a series of measures to overcome these hurdles, presented below.

Key recommendations

Regional cooperation in energy, grid, and spatial planning is key for cost optimisation of the deployment of offshore RES technologies in the region. Following the analysis and the achieved result of the study, the study's authors propose the following recommendations.

This study recommends the following activities on the member state level:

- Execute a more detailed analysis of potential for economically viable variable renewable energy sources (vRES)- offshore and on islands, including detailed environmental and spatial analyses.
- Consider increasing the national level of ambition.
- Revisit grid development plans, including development of sub regional hubs and linking them to planned interconnectors the entire Mediterranean region.
- Perform detailed analysis of RES costs.
- Discuss ways of aligning support schemes/balancing and grid services within the specific subregions.
- Initiate programs promoting sustainable tourism.
- Develop RES education programs to create more RES skills capacity in the job market and expand the RES job skill base in the region across the entire value chain.

The EC plays a crucial role in facilitating sub regional and regional coordination of efforts also in the Mediterranean region. Therefore, this study proposes that the EC prioritize the following:

- RES potential and development
  - Consistent methodology for analysis of RES potentials for offshore energy and the energy in islands
  - Structured guidance on the regional/cross-border coordination of maritime spatial planning and energy planning in the region
  - Discussion on support scheme designs and balancing and grid services solutions in the subregions and across the region
- Grid developments
  - Coordination of offshore, onshore, and cross-border grid development and operational standards via Med-TSO and ENTSO-E for a dedicated regional RES growth strategy
  - Development of models via Med-TSO/ENTSO-E
  - Minimal requirements for grid/onshore delivery models for Projects of Common Interest (both infrastructure and cross-border RES projects)
  - Rules for cross-border capacity allocation and a regional grid maintenance strategy with active participation of the Mediterranean countries, Med-TSO, MEDREG, ENTSO-E, and ACER
  - Development of aligned rules for onshore grid infrastructure development, serving offshore energy sources
- Market design
  - Market coupling efforts coordination
  - Regional bidding zone arrangements with active participation of the Mediterranean countries, Med-TSO, MEDREG, ENTSO-E, and ACER

  - Cross-border cost allocation (CBCA) framework for cost sharing supporting the ongoing efforts of Med-TSO.
  - Coordination of CBCA principles via leading a dialogue with member states or even developing the methodology
- Financing
  - Providing measures to reduce the risks for projects in south and south eastern Europe via an EU Renewable Energy Cost Reduction Facility or other facilitating programs supported by EIB or EBRD
- RDI
  - Supporting RDI for less mature technologies, such as wave, tidal, and floating offshore
  - Optimization of grid planning on a regional level
  - Impact of various bidding zone configurations in the offshore area

This study identified and ranked 10 TMAs and identified technology production blocks for each TMA. The most interesting ones are:

- Gulf of Lion has high floating offshore wind and wave potential, combined with the interconnection between Spain and France.
- Gulf of Venice possesses a very interesting opportunity in bottom-fixed offshore wind, which could be connected to the shore with a hub connection and Italy-Croatia.
- North Aegean Sea has substantial floating offshore wind and wave potential, with the possibility of linking these offshore resources with the extended submarine grid for interconnection of major islands in the Aegean Sea.
- The TMA southwest of Sicily offers floating and bottom-fixed offshore wind opportunities, large wave potential, and large onshore technology opportunities in Sicily and nearby islands; it is possible to envisage technical solutions where the connection of the production blocks is realised in parallel with the HVDC link in Italy-Tunisia or the two projects being integrated as a single multipole HVDC link.
- TMA Corsica-Sardinia, similarly to Sicily, offers large offshore floating wind energy potential and potential for onshore technologies in the nearby islands. These offshore resources could be connected to Italy, but it is possible to consider connecting it to an HVDC interconnection between northern Italy and Tunisia, in parallel with the connection of the production blocks, or being integrated as a single multipole HVDC link.

Further recommended work includes:

- Analysis of the offshore RES potential for the whole region, including the non-EU countries, in coordination with institutional partners such as Med-TSO, MEDREG or (partly) the Energy Community, along with its potential impact on the environment and potential interference with other economic activities in the sea
- Bottom-fixed offshore wind potential around the Greek and Croatian islands as well as in the Gulf of Venice
- Onshore vRES potential in islands
- Analyse the potential for novel technologies, such as floating PV, CSP, and P2X solutions (green hydrogen generation) and (green) gas transmission.
- Analyse flexibility potential including storage and demand response options
- Further onshore grid reinforcement analysis for the whole region, taking into consideration the RES potential and EU 2030 target realisation for interconnectivity, is needed to understand the trade-offs between the lower cost of energy, a decrease in CO_2 emissions, and the cost of new infrastructure.

1.0 Potential for Offshore Power Generation

Task 1 identified areas in the Mediterranean region with the greatest cost-effective offshore energy potential with a performance ranking for use in Task 2 and Task 3. This task used a spatial constraint analysis to determine suitable locations for renewable power generation in the Mediterranean Sea. Following identification of these locations, their technical energy potential was determined by using a raw resource map for each technology under investigation. Technology cost figures then helped determine economic potential. The study collated the locations within a (flexible) spatial grid (120x120 km) to identify potential technology mix areas (TMAs). Then, the study ranked these areas according to their levelized cost of electricity (LCOE) and selected 10 TMAs for further assessment. At a representative location of each selected area, hourly production time series data were extracted to inform Task 2 and Task 3 for each relevant renewable energy technology.

The geographic scope of this study includes nine European Union (EU) member states in the Mediterranean region: Croatia, Cyprus, France, Greece, Italy, Malta, Slovenia, Spain, and Portugal. This report provides an assessment of four technology categories:

1. Offshore wind (bottom-fixed and floating technologies)
2. Solar on the region’s islands (interconnected and non-interconnected)
3. Wind on the region’s islands (interconnected and non-interconnected)
4. Wave and tidal energy (floating technology)

Figure 1-1 presents the approach to Task 1.

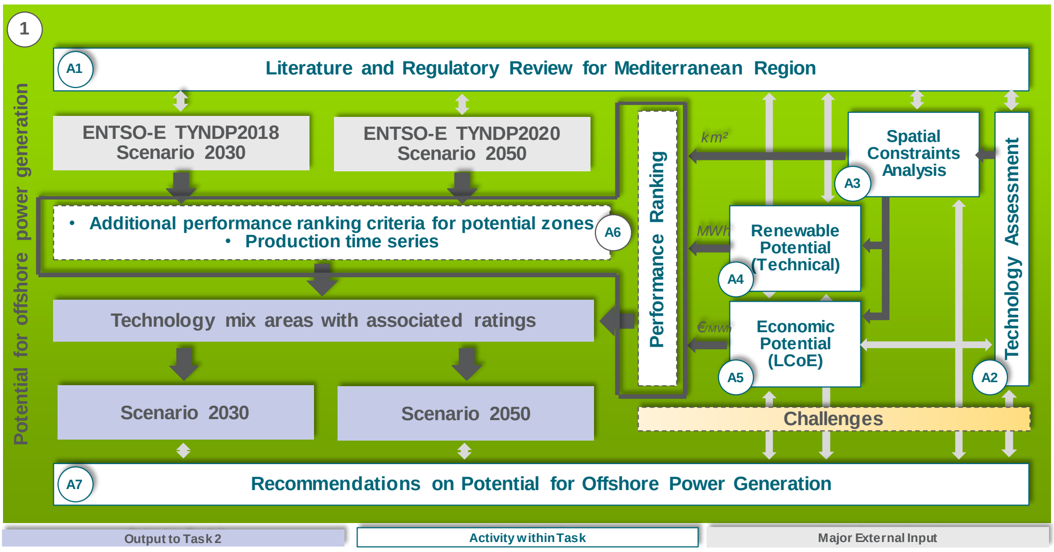

Figure 1-1: Approach to Task 1[2]

(Source: Guidehouse)

Tasks 1 and 2 investigated the current level of renewable energy sources (RES) development and included performing a technology assessment. Task 3 used publicly available geographic information system layers to limit potential offshore renewable areas in the Mediterranean with key exclusion variables. Based on the available areas found, Tasks 4 and 5 calculated the available resource potential in those areas and the LCOE, representing economic potential. Task 6 took a detailed look at selected high potential areas in the Mediterranean and determined performance

[2] This task used TYNDP 2018 (ENTSO-E, 2018d) as the TYNDP 2020 is not finalized yet. Although scenarios and market studies are available for TYNDP 2020, specific projects of European relevance and their cost-benefit analyses will only become available later in 2020.

ranking cost curves. The detailed methodology and key findings are presented in the following section.

1.1 Current RES development in the Mediterranean region

The deployment of offshore technologies in the Mediterranean region is currently very limited. Existing installed offshore capacities consist of mainly floating offshore wind located off the Atlantic coast of Portugal and wave and tidal pilot projects located mainly in Italy and Greece. The projects are rather small and in a precommercial phase in the case of floating wind or a R&D stage in the case of wave and tidal.

Although Portugal does not have a Mediterranean Sea shore, it is involved in offshore developments taking place in the south of Europe and could be interested in offshore grid connections directly related to other Mediterranean offshore grid links. Portugal is in the process of commissioning the first precommercial floating offshore wind project in the region (PrinciplePower, 2020). Meanwhile, the Spanish Canary Islands and the northern region touched by the Cantabrian Sea have positioned themselves as two innovation hubs in southern Europe. These regions have seen interesting developments with existing and future deployments of various floating structures on different test sites: Oceanic Platform of the Canary Islands (PLOCAN) and Biscay Marine Energy Platform (BiMEP) (Recharge News, 2020a; Recharge News, 2020b). In both of these regions, several developers have recently expressed interest in deploying precommercial (50-60 MW) and full-scale floating offshore wind farms (200 MW) that could become live as early as 2021 and 2024, respectively (Recharge News, 2019a; Recharge News, 2019b; The Olive press, 2020). If these developments take place, the Canary Islands would be close to achieving its target of 310 MW by 2025 (AEE, 2019.). Although these regions are out of the geographical scope of this study, ongoing prototype testing developments are directly linked to the future potential of floating wind technology in Spanish Mediterranean waters, where no projects are currently in place.

Italy is well advanced in research studies for several wave energy prototype devices (Soukissian et al., 2017). Spain and Portugal had installed a few wave prototype devices between 2008 and 2010 but decommissioned them shortly afterward (Soukissian et al., 2017). Since 2015, Greece has also started testing and developing wave energy modules, and additional research activities have been ongoing since 2017 (SINN Power Projects, 2020). Notably, the ongoing projects are still focused on analysing the technical requirements of such technologies for further expansion to other areas in the Mediterranean (WindPlus, 2017; Coiro, Troise, & Bizzarini, 2018).

Bottom-fixed offshore wind is the most mature technology among the considered offshore technologies but has not seen any developments in the Mediterranean region (Soukissian et al., 2017). This fact is primarily due to the characteristic bathymetry of the Mediterranean Sea and its waters that are generally too deep (beyond 50 meters) to deploy this technology cost-effectively. Due in part to the latter, regional policymakers have not focused on bottom-fixed offshore wind (Soukissian et al., 2017). This trend partly explains the absence of an incentive to develop large-scale offshore wind farms in the Mediterranean Sea. Table 1-1 gives a country overview of the current state of deployment of offshore technologies in the Mediterranean region.

Table 1-1: Current state of deployment of offshore technologies in the Mediterranean region (MW)

Location	Total offshore wind	Bottom-fixed offshore wind	Floating offshore wind	Tidal energy	Wave energy
Croatia	0[3]	0[3]	0[3]	0[3]	0[3]
Cyprus	0[4]	0[4]	0[4]	0[4]	0[4]
France	0[5]	0[5]	0[6]	0[7]	0[7]
Greece	0[5]	0[5]	0[6]	0[7]	0.05[8] [7]
Italy	0[5]	0[5]	0[6]	0.55[9]	2.85[10] [7] [11] [12]
Malta	0[5]	0[5]	0[6]	0[13]	0[13]
Portugal	8.40[5] [14]	0[5]	8.40[15] [6] [14]	0[12]	0.35[9]
Slovenia	0[16]	0[16]	0[16]	0[16]	0[16]
Spain	0[5]	0[5]	0[6]	0[17] [18]	0[17] [18]

(Source: Guidehouse)

Portugal has set the precedent for floating offshore wind in the region within the scope of the study, and the country has concrete plans to reach 200 MW of installed capacity in the medium term after the precommercial phase of the project is complete (Direção-Geral de Energia e Geologia, 2019). Italy and Portugal are the frontrunners with respect to wave R&D projects, while Greece has also reported some pilot activities in wave energy. Currently, no commercial tidal projects exist, and development projects for tidal energy in the region are very scarce. A few coastal locations in Croatia, Gibraltar, and the Strait of Messina (Italy) have caught the attention of ocean energy experts to further assess the available wave and tidal resources (Soukissian et al., 2017). Slovenia has limited offshore potential that is not yet fully recognised.

Onshore technologies on Mediterranean islands have seen a considerably greater deployment, though it remains rather modest compared to the deployment of these technologies on the mainland. Clean Energy for European Islands—a program designed to implement decarbonisation

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[3] (Ministry of Environment and Energy, 2019)
[4] (Department of Environment Cyprus, 2020)
[5] (WindEurope, 2019b)
[6] (WindEurope, 2019a)
[7] (Collombet, 2018)
[8] (SINN Power Projects, 2020)
[9] (Ocean Energy Europe, 2017)
[10] (Pisacane, Sannino, Carillo, Struglia, & Bastianoni, 2018)
[1111] (Ocean Energy Europe, 2017)
[12] (Ocean Energy Systems, 2020)
[13] (Government of Malta, 2019)
[14] (Direção-Geral de Energia e Geologia, 2019)
[1515] (Soukissian et al., 2017)
[16] (Ministrstvo za infrastrukturo, 2020)
[17] (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a)
[18] (Curto & Trapanese, 2018)

of energy islands—may facilitate the process substantially and reduce the cost of renewable energy in island communities (European Commission, 2020).

Some regional differences are worth noting in the relative deployment and renewable energy resource penetration rates on the islands' gross final electricity generation compared with the mainland. This development is mainly driven by countries' island-specific regulatory schemes put in place in the past few years. Corsica (France) exceeds the national share of renewable electricity generated, mainly thanks to hydropower (77% of renewable generation) and solar PV (18% of renewable generation).[23] The largest Italian islands, Sicily (32%) and Sardinia (32%), have similar shares as the national averages.[23] However, the smaller Italian and Greek islands have significantly lower RES shares but have policies in place to change that, which will be discussed in Section 1.1.2. On the other hand, the renewable electricity share is especially low in the Spanish Balearic Islands compared with the national average at less than 10%.[23] Similarly, Malta and Cyprus have low shares of renewable electricity generation, around 5% and 8%, respectively.[23] For Croatian islands, it was not possible to establish the share of gross final renewable electricity in relation to the national average.[23] Slovenia has no islands, and therefore no onshore renewable potential in the scope of this study.

Table 1-2 shows an overview of the deployed capacities solar PV and onshore wind on islands. Solar PV capacities include both large-scale utility solar plants and rooftop solar PV systems.

Table 1-2: Current state of onshore technologies in Mediterranean islands (MW)

Location	Solar PV	Onshore wind
Croatia	2 MW (Vis)[19] 6.5 MW (Cres)[19]	0[20]
Cyprus	360 MW (Island Vis)[19] 6.5 MW (Island Cres)[19]	157.5 MW
France	152 MW (Corsica)[21]	18 MW (Corsica)[21]
Greece	100.03 MW (Crete)[22] 56.87 MW (NII besides Crete)[22]	200.29 MW (Crete)[22] 105.86 MW (NII besides Crete)[22]
Italy	2,077 MW (Italian islands)[23] 1400 MW (Sicily)[23] 787 MW (Sardinia)[23] 0.45 MW (Pantelleria)[23] 2.78 MW (Elba)[23] 0.3 MW (Lipari)[23] 0.09 MW (Ventotene)[23] 0.04 MW (Ustica)[23] 0.11 MW (Ponza)[23] 0.01 MW (Capri)[23] 21.72 MW (Capraia) [23] 34.74 MW (Giglio) [23] 18.4 MW (Tremiti) [23] 232.5 MW (Favignana) [23] 24 MW (Levanzo) [23] 11 MW (Marettimo) [23] 3 MW (Panarea) [23] 119.6 MW (Vulcano) [23] 69.12 MW (Lampedusa) [23] 4.5 MW (Linosa) [23]	2,823 MW (Italian islands)[23] 1,892 MW (Sicily)[23] 1,055 MW (Sardinia)[23] 0.032 MW (Pantelleira)[23]
Malta	178 MW	0
Portugal	N/A	N/A

[19] (HEP Group)

[20] (Institute of Public Finance, 2018)

[21] (French Ministry for the Energy Transition, 2019)

[22] Email correspondence with Permanent Representation of Greece to the European Union on March 9, 2020.

[23] (Navigant & E3 Modelling, 2017), Working communication from the Italian Permanent Representation, 31.07.2020, based on GSE Communication 31/12/2018 and Atlaimpianti GSE.

Location	Solar PV	Onshore wind
Slovenia	N/A	N/A
Spain	78 MW (Balearic Islands)	11 MW (Balearic Islands)

(Source: Guidehouse)

Overall, large islands such as Cyprus, Corsica, Malta, Crete, Sicily, and Sardinia have already installed a significant amount of wind and solar capacity. Solar PV technology is more abundant in Cyprus, Corsica, and Malta, whereas onshore wind prevails more in Crete, Sicily, and Sardinia. Smaller islands in Croatia, Italy, and Greece have installed rather modest capacities, but the Spanish islands are lagging compared with other islands in terms of current RES capacity installed.

For example, the regulation in Spain did not incentivize the development of rooftop solar PV systems until very recently. In 2018, Spain’s new administration abolished a set of fees that were charged to behind-the-meter distributed generation and storage assets (unofficially referred to as the sun tax) and a set of burdensome administrative requirements for new residential PV systems that were enacted in 2015 (Spain's Ministry of Industry, Energy and Tourism, 2015). The new regulation encourages collective self-consumption of energy and established frameworks to distinguish compensation of self-produced and unconsumed energy (Valdivia, 2019; Spain's Ministry for Ecological Transition and Demographic Challenge, 2019). Different types of self-consumption are defined within the new framework. The novelty lies in the collective self-consumption concept by which multiple consumers are associated with one PV generation system that is not necessarily located on one’s own building. Also, the payment mechanism corresponding to any surplus energy injected into the grid has been simplified. Consumers are now paid monthly for systems up to 100 kW, and compensation amounts can go up to 100% of the value of the energy consumed. In addition, administrative procedures have been simplified to a single-step process for installations of up to 15 kW with surplus or 100 kW without surplus (Molina, 2019). Therefore, solar PV deployment is expected to massively increase in Spain in the coming years. More importantly, this new regulation will allow for lower energy system costs and prices, especially on the islands (Navigant & E3 Modelling, 2017).

In Greece and Italy, however, onshore wind and rooftop solar PV are in a relatively advanced stage of deployment. In addition, Greece enacted a new legislative framework for energy communities in 2018 with the goal of opening the energy market to new civil cooperatives. This framework would enable civil cooperatives to address the energy transition, increase the penetration of RES and its local acceptance, and combat energy poverty (Ministry of Environment & Energy of Greece, 2018). More recently, in May 2020, Greece enacted a new environmental law (Law No. 4685/2020) that modernises the environmental regulation and establishes a simplified, efficient, and fast licensing process for RES projects (Government of Greece, 2020). With this new law, photovoltaic projects under 1 MW are exempt from obtaining a license. This law also harmonises Greek law with EU Directives 2018/844/EU and 2019/692/EU and is anticipated to accelerate the deployment of RES projects in the country even more. Already in 2016, the average total RES integration in Greek islands amounted to 18.7%, reaching a 60% hourly penetration in Crete (HEDNO, 2016).Overall, multiple factors explain the still limited development of onshore wind farms and utility solar PV plants in the Mediterranean region:

- Limited space availability in islands (Government of Malta, 2019) and competition for other land uses such as agricultural activities (RSE S.p.A., n.d.)
- A strong commitment to preserve the islands’ natural protected areas (RSE S.p.A., n.d.) and safeguard the region’s key industry, tourism (Government of Malta, 2019; Conseil Insular de Menorca)
- Policy frameworks that still incentivize the use of fossil fuels in the islands’ power systems (Navigant & E3 Modelling, 2017)
- Lack of interconnections between islands and the mainland, which could provide additional flexibility to manage RES fluctuations efficiently and further increase RES development (The need for interconnections is emphasized by the high yearly load variability due to the influx and outflux of tourists.) (Soukissian et al., 2017; RSE S.p.A., n.d.)
- Lack of adequate regulations and financial incentives, which is not encouraging the installation of hybrid stations and storage that would significantly increase the deployment and management of RES

1.1.1 Capacity targets up to 2030 and beyond

Most of the countries in the Mediterranean region have elaborated and submitted their final NECPs with an outline of their climate strategy and set targets per technology for the coming decade. Targets for offshore wind are clearly set in France's draft NECP, which plans to hold several bottom-fixed and floating offshore wind tenders in the coming years up to 2028 (French Ministry for the Energy Transition, 2019). In 2022, a call for tenders for floating offshore wind is planned for Mediterranean sites. The French government aims to organize an additional auction between 2024-2028 for two new projects in the Mediterranean Sea of around 500 MW each (2x40 turbines), in addition to the first two projects of 250 MW that call for tenders, which is planned for 2022 (2x20 turbines). The total installed capacity for offshore wind in the Mediterranean Sea is estimated to be 1,500 MW by 2040.[28]

Portugal and Italy aim to install significant offshore wind capacity by 2030. However, Portugal has not yet specified how that goal will be achieved (Direção-Geral de Energia e Geologia, 2019), and Italy has not finalized the split between bottom-fixed and floating technologies at the time of preparing this report (Ministry of Economic Development (Italy), 2019).

Other countries display interest in and commitments to offshore wind but lack specific offshore wind targets. Malta, for example, confirmed the current technological and economic infeasibility of developing offshore wind farms in Maltese waters but is continuing to monitor further developments in the technology (Government of Malta, 2019). Malta also considers floating solar as a potential technological solution to the country's specific context.

In its target scenario, Spain outlines a total joint onshore and offshore wind installed capacity of approximately 40 GW in 2025 and 50 GW in 2030 (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a). Spain's NECP shows commitment to enabling public mechanisms that will support the technologies that are not yet mature, such as offshore wind and ocean energies; at the same time, it emphasizes addressing the peculiarities of the island territories (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a).

The NECP also proposes specific recurring tenders with adaptable pre-arranged volumes of capacity tendered for offshore wind and ocean energy technologies as a means of delivering flagship projects. In the case of floating offshore wind, Spain already sees increasing potential within the 2030 horizon. Therefore, it will adapt its support mechanisms and the capacity volumes tendered in renewable energy auction rounds due to the technology's increasing competitiveness and synergy with other strategic economic sectors (electro-intensive and naval industries). Public financing will be made available subject to the needs of each specific renewable energy tender (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a).

Meanwhile, Spain's Ministry for the Ecological Transition and the Demographic Challenge is working on the roadmap for the development of offshore wind and marine energy and recently launched the public consultation for these technologies. (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020b; The Institute for Diversification and Energy Saving, 2020). In parallel, the ministry is working on an update of Directive 2014/89 that has a twofold objective: identification and analysis of sites that could provide the greatest offshore wind energy potential. This update would also provide the time window for projects and identification of new testing sites that can foster the sector's development, especially around the islands' waters (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020c). This marine spatial planning (MSP) update is expected to be ready no later than April 2021. While no specific target for offshore wind is defined in Spain's NECP today, this spatial planning update exercise could result in the addition of concrete capacity targets in periodical NECP reviews (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020b). On the other hand, Cyprus, Croatia, and Slovenia have no plans for offshore wind development in their NECPs (Ministry of Environment and Energy, 2019; Department of Environment Cyprus, 2020; Ministrstvo za infrastrukturo, 2020).

Wave and tidal technologies remain outside of the scope of many countries' NECPs. For example, Malta expresses interest in monitoring the still immature technology (Government of Malta, 2019), and Spain refers to enabling public mechanisms to support demonstration projects of ocean energy technologies (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a).

Table 1-3 gives a country overview of the 2030 targets and 2040 long-term outlooks for offshore technologies in the Mediterranean region.

Table 1-3: 2030 targets and long-term outlook for offshore technologies in the Mediterranean region (MW)[24]

Location/target	Total offshore wind	Bottom-fixed offshore wind	Floating offshore wind	Tidal energy	Wave energy
Croatia 2030	No target	No target	No target	No target	No target
Croatia 2040[25]	No target	No target	No target	No target	No target
Cyprus 2030	No target	No target	No target	No target	No target
Cyprus 2040[26]	No target	No target	No target	No target	No target
France 2030	500[27]	0[27]	500[27]	No target	No target
France 2040[27]	1,500[28]	0[28]	1,500[28]		
Greece 2030	No target	No target	No target	No target	No target
Greece 2040[22]					
Italy 2030	900[29]	No target[30]	No target	No target	12[31]
Italy 2040[32]	No target				
Malta 2030	No target	No target	No target	No target	No target
Malta 2040[33]	No target	No target	No target	No target	No target
Portugal 2030	300	No target	300	No target	70 MW
Portugal 2040[34]	No target		No target		No target
Slovenia 2030	No potential[35]	No potential[35]	No potential[35]	No potential[35]	No potential[35]
Slovenia 2040					
Spain 2030	No target	No target	No target	*50*	
Spain 2040[36]				No target	No target

(Source: Guidehouse)

Among all countries, France is by far the most ambitious in setting targets with respect to offshore wind technologies. Between 2020 and 2028, the total installed capacity in France should increase

[24] Capacity targets for Spain refer to all coastal regions, including non-Mediterranean sites. These targets are shown in italics in the table.
[25] (Ministry of Environment and Energy, 2019)
[26] (Department of Environment Cyprus, 2020)
[27] (French Ministry for the Energy Transition, 2019)
[28] Email correspondence with France's permanent representation to the European Union on 21 July 2020.
[29] (International Energy Agency, 2019)
[30] the Italian target capacity of 900 MW by 2030 can be supposed completely bottom-fixed. Elaborations based on a RSE study (RSE report 10000251, 2010, http://www.rse-web.it/documenti/documento/2906) were made, based on the information provided by the Italian Permanent Representation in the working communication, 31.07.2020
[31] The 2025 target for industrial plants based on ISWEC device could be 12 MW, Working communication from the Italian Permanent Representation, 31.07.2020
[32] (Ministry of Economic Development (Italy), 2019)
[33] (Government of Malta, 2019)
[34] (Direção-Geral de Energia e Geologia, 2019)
[35] Email correspondence with Slovenia's permanent representation to the European Union on February 19th, 2020.
[36] (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a)

from 0 MW to between 5.2-6.2 MW, including 500 MW in the Mediterranean Sea. By 2040, a total capacity of 1,500 MW of floating offshore wind should at least be in service in the Mediterranean Sea. However, this forecast will greatly depend upon the decisions on new tenders made in the second half of the French energy plan in 2024-2028 and upon the length of administrative procedures.

Italy and Portugal also stand out with relatively high 2030 offshore wind targets in the region. Italy’s general offshore wind target amounts to 900 MW while Portugal aims to reach 300 MW of floating offshore wind capacity by 2030. The wind conditions off the western and northern shores of Portugal, Spain, and France are generally more suitable for offshore wind generation than wind conditions off the Mediterranean shores, so the Mediterranean will likely play a smaller part in these three countries’ ambitious targets.

Only Portugal and Spain have defined targets for wave and tidal technologies in 2030. In general, the Atlantic waters represent better wave and tidal resources than the Mediterranean Sea. It can therefore be expected that a large share of the Spanish and Portuguese target will be located off the Atlantic coast. These targets are, nevertheless, relatively smaller in size compared to the other technologies in scope with set targets: 50 MW in Spain (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a) and 70 MW in Portugal (Direção-Geral de Energia e Geologia, 2019).

Both onshore wind and solar PV national capacity targets will play a key role in achieving countries’ renewable goals. For Italy, France and Spain in particular, national targets in the NECPs count solar PV technology as the main contributor to meeting the renewable energy targets of the countries’ power systems. This technology is anticipated to experience the highest increase in terms of installed capacity in the coming years on a national level. France, Italy, and Spain are expected see their solar installed capacity increase by 34 GW,[37] 33 GW, and 33 GW, respectively, by 2030 (French Ministry for the Energy Transition, 2019; Ministry of Economic Development (Italy), 2019; Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a).

However, many of the countries’ NECPs do not give a detailed explanation of specific targets or a roadmap for islands to achieve sustainability goals by 2030 and beyond. Specific targets for islands are mostly defined in Island Sustainable Energy Action Plans (ISEAPs), an initiative launched by the EC to engage local authorities in implementing sustainable energy policies on islands. Municipalities on islands in Croatia, Cyprus, Greece, Italy, Malta, and Spain submitted action plans with differing ambition levels for 2020. Greek islands represented the highest level of ambition overall (Navigant & E3 Modelling, 2017). However, only a few islands have submitted updated targets and plans for 2030.

Except for some specific cases, overall NECPs and the data gathered from countries’ permanent representations to the EU give an incomplete outlook on regional energy plans for Mediterranean islands for the coming decade. Corsica in France and Menorca in Spain are two examples where updated sustainability plans beyond 2020 have been made available. Therefore, determining how ambitious the targets towards 2030 and beyond are in the Mediterranean region and substantial differences within the region is not possible at this point.

Table 1-4 gives a country overview of the 2030 targets and 2040 long-term projections for onshore technologies on Mediterranean islands.

Although little data is available on capacity rollout plans for onshore wind on islands, a very limited increase in onshore wind deployment is expected in cases where 2030 island capacity targets are known. This limited increase is mostly due to land use constraints on islands, including high population density, and strong commitments to protect natural areas (Government of Malta, 2019). Corsica is an exception since it plans to increase its onshore wind capacity fivefold compared to current 2020 deployments.

According to Cyprus and Malta 2030 targets, solar PV capacities will increase significantly compared with onshore wind. However, according to a model-based projection of planned policies, Malta’s 2040 solar PV projected capacity shows that its solar PV capacity deployment would

[37] France is expected to reach 34 GW of additional solar capacity by 2028.

decrease from a total installed capacity of 266 MWp to 88 MWp from 2030 to 2040; meanwhile, the estimated generated electricity from conventional sources and interconnections is expected to increase in the same time period (Government of Malta, 2019).

Table 1-4: Targets and long-term outlook for onshore technologies in the Mediterranean region (MW)[38]

Location/target	Solar PV	Onshore wind
Croatia 2030	*768*	*1,364*
Croatia 2040[39]	*1,245*	*1,684*
Cyprus 2030	804 50 for concentrated solar power (CSP) technology	198
Cyprus 2040[40,41]	1,892 500 for CSP technology	198
France 2028	*35,600-44,500*	100
France 2040[42,43]	No target	No target
Greece 2030	No target	No target
Greece 2040[22]	No target	No target
Italy 2030	*52,000 of which CSP: 880*	*19,300*
Italy 2040[44]	No target	No target
Malta 2030	266	0
Malta 2040[45]	88	No target
Portugal 2030	N/A	N/A
Portugal 2040	N/A	N/A
Slovenia 2030	N/A	N/A
Slovenia 2040	N/A	N/A
Spain 2030	330 (Menorca)	10 (Menorca)
Spain 2040[46,47,48]	No target	No target

(Source: Guidehouse)

[38] Capacity targets for Croatia, France and Italy refer to national targets, including the mainland. These targets are shown in italics in the table.
[39] (Ministry of Environment and Energy, 2019)
[40] (Department of Environment Cyprus, 2020)
[41] Email correspondence with Cyprus' permanent representation to the European Union on March 6th, 2020.
[42] (French Ministry for the Energy Transition, 2019)
[43] (Dodd, 2019)
[44] (Ministry of Economic Development (Italy), 2019)
[45] (Government of Malta, 2019)
[46] (Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a)
[47] (Regional Government of the Balearic Islands, 2019)
[48] (Conseil Insular de Menorca)

Menorca remains one of the most ambitious Mediterranean islands in Spain with a full decarbonisation plan prepared through 2030. Compared to its peers Mallorca and Ibiza, Menorca announced that it aims to meet 85% of its electricity demand with renewable sources by 2030. Additionally, Menorca plans to ramp up its deployment of rooftop PV systems (Conseil Insular de Menorca). Similarly, the Croatian island Krk started its energy transition in 2011 with the development of its ISEAP. Krk is now the frontrunner island in Croatia, and it plans to reach 100% decarbonization by 2030 (Ministry of Environment and Energy, 2019). The ambitious trends set by Menorca, Krk, and other islands could set an example for other islands to follow.

CSP technology, though not considered in the scope of this study, stands out in some islands' energy plans. Due to this technology and others, Cyprus is expected to see an increase from 0 MW in 2020 to 50 MW in 2030 and to 500 MW in 2040 (Biscay Marine Energy Platform (BiMEP)).

Technology capacity targets for the year 2050 are non-existent on a national level, let alone a regional level. Only a few scenario estimates for onshore technologies have been provided in an interview with Cyprus' EC permanent representative. Table 1-5 shows a 2050 scenario estimate for Cyprus. Given the significant increase in CSP capacity in Cyprus, other countries that include CSP in their future energy mix might also see a significant rise in CSP installed capacity.

Table 1-5: 2050 scenario estimate for onshore technologies in Cyprus

Location/target	Solar PV	Onshore wind
Cyprus 2050	1,686 MW 1,050 MW for CSP technology	198 MW

(Source: Guidehouse)

1.1.2 Pathways to meet capacity targets

The pathways to reach to 2030 targets and beyond differ substantially per country. Some countries have plans in place to carry out recurring tenders in the short and medium terms. France plans to hold two floating offshore wind tenders in 2022 and annual offshore wind tenders from 2024 until 2028 (French Ministry for the Energy Transition, 2019). For wave and tidal technologies, however, no plan yet exists to launch competitive tenders in any of the countries in the Mediterranean region. However, most countries are willing to support wave and tidal projects, and many count on ocean technologies to some extent in their future energy mix (Direção-Geral de Energia e Geologia, 2019; Spain's Ministry for Ecological Transition and Demographic Challenge, 2020a).

On the other hand, France, Greece, Italy, and Spain[49] have plans to schedule island-specific competitive tenders for onshore wind and solar technologies (Navigant & E3 Modelling, 2017; Tsagas, 2018; GlobalData Energy, 2020; Bellini, Spain's Balearic Islands assign 362 MW of solar in auction, 2019). Corsica (France) already held island-specific tenders in 2016 and 2017 for solar-plus-storage projects. After the successful 2018 and 2019 tenders in the Canary Islands, Spain has now held its first RES tender in the Balearic Islands (Navigant & E3 Modelling, 2017; Tsagas, 2018). Cyprus, Croatia, and Slovenia have no plans for offshore wind development in their NECPs as indicated in Section 1.1.

Greece aims to reach RES penetration levels in excess of 60% in the non-interconnected islands (NIIs). For this goal, the Greek Regulatory Authority for Energy (RAE) has issued competitive tenders for smart islands, focusing especially on hybrid plants that include storage (Government of Greece, 2019). More specifically, the issued competitive tenders concern the islands of Antipole, Semi, and Merits, which are pending the relevant Ministerial Decision.[50] In addition to these tenders, Greece grants higher feed-in tariffs to projects on NIIs compared with projects on the mainland (Navigant & E3 Modelling, 2017). Greece holds technology-specific auctions for projects on the mainland and on islands that are interconnected to the mainland. The last two solar PV

[49] The Spanish Wind Association (AEE) calls for at least 3 GW of offshore (from the 50 GW), source: WindEurope, 16.07.2020

[50] Email correspondence with Greece's permanent representation to the European Union on 7th August, 2020

auctions took place in 2018. Projects on NIIs are excluded from participating in the auctions (Government of Greece, 2019).

Table 1-6 and Table 1-7 summarize the approach taken by countries to reach their 2030 targets. Only France's offshore wind roadmap is known in detail according to NECPs. Other member states have no clear strategy defined and are therefore excluded from the overview. Regarding onshore technologies, some countries choose a support scheme based on competitive auctions and others choose a feed-in tariff scheme.

Table 1-6: Offshore energy deployment strategy in countries in the Mediterranean region: 2020-2030[51]

Country	Offshore wind	Tidal energy	Wave energy
France	• 2x250 MW floating wind tenders planned in 2022 • Annual 1 GW offshore wind tenders from 2024-2028, no precise location, Mediterranean or North Sea, is currently specified • At least two additional projects of 500 MW each should be tendered between 2024 and 2028 in the Mediterranean Sea (extensions of the first two projects)	No tender planned	No tender planned

(Source: Guidehouse)

[51] (French Ministry for the Energy Transition, 2019)

Table 1-7: Onshore energy deployment strategy in countries in the Mediterranean region: 2020-2030[52,53,54,55]

<table>
<tr><th>Country</th><th>Solar PV</th><th>Onshore wind</th></tr>
<tr><td>Croatia</td><td colspan="2">No island-specific RES support
Pilot programmes
Krk is frontrunner
PRISMI project involves six Croatian islands: Korčula and Vis, among others</td></tr>
<tr><td>Cyprus</td><td>Capacity-based subsidy for PV systems
Net metering scheme for PV systems up to 10 kW connected to the grid for all consumers (residential and nonresidential)
Self-consumption systems with compensation on energy surplus for capacities ranging 10 kW-10 MW for commercial and industrial consumers</td><td>N/A</td></tr>
<tr><td>France</td><td>Island-specific support with solar-plus-storage auctions</td><td>Onshore wind tenders as in the mainland: tenders for projects of wind turbines or more</td></tr>
<tr><td>Greece</td><td colspan="2">Technology-specific auctions for islands connected to mainland with feed-in premium
Feed-in tariffs for projects on NIIs</td></tr>
<tr><td>Italy</td><td colspan="2">Island-specific support for projects on the 20 smaller non-interconnected islands
Competitive tender with investment subsidy (financing 60% of CAPEX for the realization of 2-3 innovative and integrated projects)
Technology-neutral auctions for projects > 1MW in larger islands, competing with projects on the mainland, with a Contract for Difference scheme
3 auctions in 2020
3 auctions in 2021</td></tr>
<tr><td>Malta</td><td colspan="2">Feed-in tariff for solar PV projects</td></tr>
<tr><td>Portugal</td><td colspan="2">N/A</td></tr>
<tr><td>Slovenia</td><td colspan="2">N/A</td></tr>
<tr><td>Spain</td><td colspan="2">Technology-specific auctions on Balearic Islands</td></tr>
</table>

(Source: Guidehouse)

For Malta and the NIIs in Greece, a feed-in tariff scheme is in place to support the development of solar PV projects in Malta and onshore wind and solar PV projects in Greece. For its part, Cyprus has a net metering arrangement in place mainly for solar PV operating under the scheme Solar Energy for All, launched by the Ministry of Energy in 2016. The scheme provides capacity-based grants for the installation of PV systems in combination with a net metering billing scheme. Prosumers will be liable to pay for the net electricity used (energy consumed minus energy produced onsite). This scheme is aimed at small-scale residential and non-residential prosumers with a capacity of up to 10 kW (In-Cyprus, 2019). Commercial and industrial consumers with capacities ranging from 10 kW up to 10 MW are eligible to opt into the net billing scheme. Under this scheme, the prosumer can sell any excess energy produced to the grid at cost, further reducing the initial solar investment cost. Islands in Croatia, however, do not have any island-specific support scheme in place. Renewable projects taking place mainly in Krk, Vis, and Korčula are results of pilot programmes. An example is the PRISMI project of the Interreg MED Programme that was financed by the European Regional Development Fund until 2018 (Navigant & E3 Modelling, 2017). As reported by Slovenia's permanent representation to the European Union, no offshore or onshore potential is available in Slovenia since it has no islands.

[52] (Navigant & E3 Modelling, 2017)
[53] (Martín, 2020)
[54] (Bellini, Spain's Balearic Islands assign 362 MW of solar in auction, 2019)
[55] (Dodd, 2019)

1.1.3 Existing and future offshore projects

Several offshore projects are currently in place in the Mediterranean region. Until now, the most remarkable floating offshore wind developments in the region have taken place in Portugal and France. In Portugal, the two remaining floating platforms of the WindFloat Atlantic (Phase 1) offshore wind farm of 25.2 MW were commissioned in June 2020. Phase 1 of the project is expected to be completed in 2020.

Best practise example

Name	Country	Key technology	Type of project	Status
Eoliennes Flottantes du Gulf of Lion	**France**	**Floating offshore wind**	**Pilot project**	**Under development**

The French government has set out to build a pilot floating wind farm in the Gulf of Lion in the Mediterranean Sea. The commissioning of the wind farm is expected in 2022. It is anticipated to be one of the first floating wind farms in the Mediterranean Sea.

Figure 1-2. Schematic of EFGL floating wind. *Source: https://info-efgl.fr/le-projet/le-parc/*

Project details

- The project received consent after a call for projects by the French government in 2016.
- The consortium consists of three project partners: ENGIE Green, EDPR Renewables Europe, and Caisse des Dépôts.
- The wind farm will consist of three turbines of 10 MW each (MHI Vestas V164-10.0 MW turbines) located in the "Leucate" offshore zone about 16 km off the coastal towns of Leucate and Barcarès.
- In 2022 and 2023, France is expected to auction two 25 MW floating offshore wind sites, which will further increase the floating wind generation capacity in the Mediterranean.

Project findings

- This project is one of the first floating offshore wind projects in the Mediterranean Sea. This pilot project can enable the development of larger floating offshore wind farms in the Mediterranean Sea.

More information: https://info-efgl.fr/

In France, ADEME launched a call for tenders in 2017 for which winners have been designated; three out of four pilot projects between 24 MW and 30 MW each were assigned in the Mediterranean and are expected to be commissioned by 2021 (French Ministry for the Energy Transition, 2019)

Best practise example				
Name	**Country**	**Key technology**	**Type of project**	**Status**
Taranto Wind farm	**Italy**	**Bottom-fixed offshore wind**	**Commercial project**	**Planned**

The first offshore wind farm of the Mediterranean Sea is expected to be built in 2020 off the coast of the Italian city Taranto. The offshore wind farm will consist of bottom-fixed wind turbines with a total capacity of 30 MW.

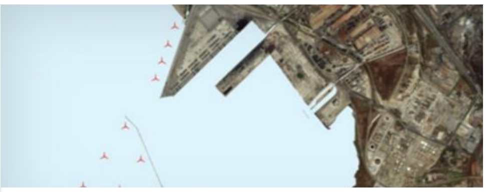

Figure 1-3. Schematic of Taranto fixed-bottom wind farm.

Source: http://www.belenergia.com/english-belenergia-developpements-eolien-italie.php

Project details

- The project reached financial close early 2019, and development was expected to start at the end of 2019.
- The project is being developed by Italian developer Renexia.
- The wind turbines will be located nearshore and close to the port of Taranto.
- The Taranto project gained the right for 25 years of support at a level of €161.70 ($184.20) per megawatt-hour through an Italian renewable energy auction in December 2016 that mostly allocated support to onshore wind projects.
- The supplier of the turbines is the Germany-based company Senvion. The company has developed a new offshore version of its 3.0M122 wind turbine for the project.

Project findings

- This project is the first bottom-fixed offshore wind project in the Mediterranean Sea. Lessons learned from the deployment of this project can be used for further bottom-fixed projects.
- The nearshore wind farm will only consist of bottom-fixed wind turbines.

More information: https://www.rechargenews.com/wind/italy-on-pole-in-race-for-first-mediterranean-offshore-wind/2-1-552007

Wave and tidal renewable energy technologies are still relatively immature in terms of the technology development and the available potential in the Mediterranean (see Section 1.4). However, Italy has been experimenting with these technologies, and some growth potential exists, given that the technology develops further, and costs decrease substantially.

Best practise example

Name	Country	Key technology	Type of project	Status
GEMSTAR	Italy	Tidal	Pilot project	Operational

A tidal energy system called Gemstar is deployed in the Strait of Messina in Italy and has been operational since 2012.

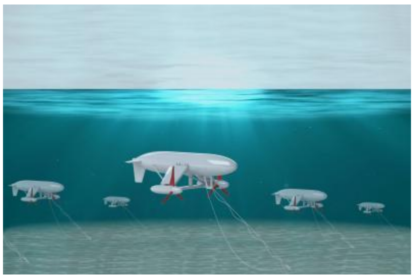

Figure 1-4. Illustration of GEMSTAR.
Source: https://tethys.pnnl.gov/project-sites/seapower-gemstar-system

Project details

- GEMSTAR is one of the products of Seapower SCRL, a consortium with the University of Naples Federico II.
- The system has a capacity of 300 kW.
- The turbine was built by a consortium of Venetian companies.
- One key characteristic of the turbine is its ability to align itself along the current direction, which allows for a higher yield.

Project findings

- This project explores the potential of tidal energy in the Mediterranean Sea and shows lessons applicable to similar projects in the future.

More information: http://www.seapowerscrl.com/ocean-and-river-system/gem#slide_6

Table 1-8 gives an overview of offshore projects in the pipeline, which are mostly in the planned and permitting development stages. For many of these projects, the delivery date is still unknown. Most offshore wind pipeline activity concerns France, Greece, Italy, and Portugal. Italy also has existing and planned wave prototype projects.

Table 1-8: Existing and future offshore projects in the Mediterranean region[56,57,58,59,60,61,62,63]

Project	Country	Region	Status	Technology	Commercial Operation Date (COD)	Total capacity [MW]
GEMSTAR full-scale prototype	Italy	Venice Lagoon	Development	Wave	Existing[64]	0.02
PIVOT WEC prototype	Italy	Civitavecchia harbour	Development	Wave	Existing	Unknown
Beleolico	Italy	Mediterranean	With permits	Bottom-fixed	2020	30.0
WindFloat Atlantic Phase 1	Portugal	Atlantic Ocean	Commissioned	Floating	2020	25.2
SINN POWER Floating WEC array	Greece	Crete	Development	Wave	2021	0.75
EolMed (Gruissan)	France	Gulf of Lion	Permitting	Floating	2022-2023	28.5
Les éoliennes flottantes du Golfe du Lion (EFGL) (Leucate)	France	Gulf of Lion	Permitting	Floating	2022-2023	30
Provence Grand Large (PGL) (Faraman)	France	Gulf of Lion	Permitting	Floating	2022-2023	24.0
2022 Tender zone I	France	Gulf of Lion	Tender Zone	Floating	Unknown	250.0
2022 Tender zone II	France	Gulf of Lion	Tender Zone	Floating	Unknown	250.0
2024-2028 Tender zone	France	Unspecified	Tender Zone	Bottom-fixed	Unknown	1,000
Pleiades Aioliki SA	Greece	Gulf of Petalioi	Development	Bottom-fixed	Unknown	450
TERNA ENERGY and Aioliki Povata Trainoupole Os partnership	Greece	Thracian Sea	Development	Bottom-fixed	Unknown	585

[56] (WindEurope, 2019a)
[57] (Hogan Lovells, 2020)
[58] (French Ministry for the Energy Transition, 2019)
[59] (4C Offshore, 2020)
[60] (Ocean Energy Systems, 2020)
[61] (Coiro, Troise, & Bizzarini, 2018)
[62] (SINN Power Projects, 2020)
[63] (Greek Regulatory Authority (RAE), 2020)
[64] Existing wave prototype projects are undergoing further research and development, hence their status is still under "development"

Project	Country	Region	Status	Technology	Commercial Operation Date (COD)	Total capacity [MW]
Thrakiki Aioliki 1 SA	Greece	Sea Area South of Alexandrou-polis	With permits	Bottom-fixed	Unknown	216
Kyon	Greece	Sea Area of Municipality of Kymi and Avlonas	With permits	Bottom-fixed	Unknown	300
City Electric SA	Greece	Plaka	Development	Bottom-fixed	Unknown	498
TERNA ENERGY	Greece	Methones-Keros	Development	Bottom-fixed	Unknown	320
Rokas Aioliki North Greece	Greece	Plaka-Keros-Agia Eirini	Development	Bottom-fixed	Unknown	486
Banco di Pantelleria e Banchi di Avventura	Italy	Adventure Bank	Early Development	Floating	Unknown	228.0
Golfo di Gela	Italy	Sicily/ Mediterranean	Planned	Bottom-fixed	Unknown	136.8
WindFloat Atlantic Phase 2	Portugal	Atlantic Ocean	Planned	Floating	Unknown	125.0
Kobold I	Italy	Mediterranean	Operational	Tidal	Unknown	0.05
GEM Demonstrator	Italy	Mediterranean	Consent Authorized	Tidal	Unknown	0.5

(Source: Guidehouse)

In terms of onshore technologies on islands, solar PV capacity is increasingly coming online, specifically in urban areas. This increase is especially the case for islands in France, Greece, Italy, and Spain, where a significant growth in PV capacity is expected for small and large rooftops (Rollet, 2019; Stavropopoulou, 2019). To a lesser extent, large-scale solar projects are expected to increase. This is mainly driven by the new Spanish self-generation energy policy and the scheduled auctions for French and Greek islands (Valdivia, 2019; Navigant & E3 Modelling, 2017). Also, Greece and Cyprus are realising projects that may be developed under the following three policy schemes: net metering; government-set feed-in tariffs; and feed-in tariffs via competitive tenders (Balkan Green Energy News, 2019). In Croatia, solar projects can be developed under the premium tariff support scheme allocated through tenders (Balkan Green Energy News, 2019). Many of these projects are rather small in size; therefore, providing an exhaustive list of all individual developments in the region within this project is not possible. Table 1-9 presents a list of selected projects across the Mediterranean region.

Table 1-9: Selection of planned and ongoing onshore wind and solar PV projects on Mediterranean islands[65,66,67,68,69,70,71,72]

Project	Country	Region	Status	Technology	Commercial Operation Date	Total Capacity (MW)
Pissouri project	Cyprus	Cyprus	Under construction	Solar PV	2019	4.5
Solar project	Cyprus	Cyprus	Advanced development	Solar PV	2019	4.0
Solar project	Cyprus	Cyprus	Advanced development	Solar PV	2019	4.0
Solar project	Croatia	Vis	Operations	Solar PV	2020	3.5
Solar project	Croatia	Cres	Advanced development	Solar PV	Unknown	6.5
Solar project	Croatia	Krk	Advanced development	Solar PV	2020	5.0
Rooftop solar PV systems	Croatia	Krk	Planning	Solar PV	Unknown	36.8
Utility-scale solar project	Croatia	Krk	Planning	Solar PV	Unknown	4.0
Wind project	Croatia	Krk	Planning	Wind	Unknown	25.2
Tenesa	France	Corsica	Advanced development	Wind	2020	12.0
Ersa-Rogliano (repowering)	France	Corsica	Unknown	Wind	Unknown	12.0
Giuncaccio project	France	Corsica	Planning	Solar PV and storage	2019	2.0
Pancheraccia project	France	Corsica	Planning	Solar PV and storage	2019	1.5
Giurone project	France	Corsica	Planning	Solar PV and storage	2018	4.8
Solar PV and storage project	France	Corsica	Planning	Solar PV and storage	2020	1.5
Green Island	Greece	Agios Efstratios	Under study	Wind, solar PV, and storage	Unknown	0.9 (Wind) 0.2 (PV)

[65] (Balkan Green Energy News, 2019)
[66] (Todovoric, 2019)
[67] (Rollet, 2019)
[68] (Stavropopoulou, 2019)
[69] (Dodd, 2019)
[70] (Rogulj, 2020)
[71] (Reve, 2020)
[72] (DEM - Energy, 2017)

Project	Country	Region	Status	Technology	Commercial Operation Date	Total Capacity (MW)
Smart Island Pilot 1	Greece	Symi	Planning	Wind, solar PV, and storage	2021	Unknown
Smart Island Pilot 2	Greece	Astypalea	Under study	Wind, solar PV, and storage	Unknown	Unknown
Smart Island Pilot 3	Greece	Megisti / Kastelori-zo	Under study	Wind, solar PV, storage	Unknown	Unknown
Hybrid station project	Greece	Ikaria	Operation	Wind and hydro	Unknown	2.7
TILOS project	Greece	Tilos	Operation	Wind, solar PV, and storage	Unknown	0.8 (Wind) 0.2 (PV)
Solar project, RES auction	Italy	Sardinia	Early development	Solar PV	2022	5.0
Wind project	Italy	Sicily	Advanced development	Wind	2021	20.0
Son Salomó (ext.)	Spain	Menorca	Advanced development	Solar PV	Unknown	49.8
Son Angladó	Spain	Menorca	Early development	Wind	Unknown	20.7
46 projects, RES auction I	Spain	Mallorca	Early development	Solar	2022	206.0
6 projects, RES auction I	Spain	Menorca	Early development	Solar	2022	62.0
1 project, RES auction I	Spain	Ibiza	Early development	Solar	2022	6.0
1 project, RES auction I	Spain	Forment-era	Early development	Solar	2022	2.0

(Source: Guidehouse)

Best practice example				
Name	**Country**	**Key technology**	**Type of project**	**Status**
TILOS	**Greece**	**Energy island**	**Commercial project**	**Operational**

Project TILOS concerns the development of a hybrid energy system (smart microgrid) on the island of Tilos solely based on renewable energy sources. The project's goal is to reduce dependency on imported, fossil-fuel based electricity from the island of Kos, improve system reliability, and potentially turn Tilos in an exporter of renewable energy to Kos.

Figure 1-5. the Tilos project *Source: https://www.tiloshorizon.eu/*

Project details

- The project is an EU Horizon 2020 (Grant Agreement No 646529) demonstration and research project with 13 project partners from seven European states.
- Project TILOS develops solutions for reaching the goal of the European Agenda 2020 (Local / small-scale storage-LCE-08-2014). The total cost of the project is around 15M€ for a European grant of 11 M€. TILOS started in February 2015 and ran for 4 years.
- TILOS is coordinated by the Technological Educational Institute of Piraeus (TEIP) from Athens in Greece.
- The island has a total of 500 inhabitants. In the summer, the population on the island grows to 3,000 people as a result of tourism.
- On Tilos an 800-kW wind turbine was installed together with a 160 kW PV park, a new type of NaNiCl2 FIAMM battery (2.4MWh/800kW), an energy management system and smart meters.

Project findings

- Besides the Danish island Samsø, Tilos is the first island that is fully running on locally generated renewable electricity.
- As a frontrunner, this project can be an example for the development of fully renewable electricity systems for other islands in the Mediterranean Sea.

More information and source picture: https://www.tiloshorizon.eu/

1.2 Technology assessment

Task 1.2 assessed the potential suitable generation technologies in the Mediterranean region. The technology assessment was conducted for the categories and criteria detailed in Table 1-10.

Table 1-10: Framework for assessment of potential generation technologies

Assessment category	Assessment criteria	Criteria description
Technical	Renewable energy resource	Feasibility of the technology due to resource and environmental conditions: water depth, distance from shore, wind speeds, wave energy, insolation, tides, and other uses of the sea such as fishing, shipping, etc.
	Potential production per installed capacity	Capacity factors of technologies for 2030 and 2050
	Scalability	Degree to which the technology is easily scalable and the impacts of other factors such as land availability, population density, economic activity, maritime transport, and environmental restrictions
	Grid interconnectivity in the region	Degree to which RES technology can easily be connected to and integrated in the power system
Economic	Current investment and operational cost levels	CAPEX and OPEX levels in 2020
	Projected investment and operational cost levels	CAPEX and OPEX levels in 2030 and 2050
	Demand matching production profile	Extent to which power production occurs at times of high demand in bidding zones where it can be transported easily to the grid
Environmental impact	Impact on environment	Impacts of the technology such as noise on the environment, including wildlife and vegetation
Social acceptance	Social acceptance	Degree of acceptance by society due to visual impact from shore and impact on tourism
Regulatory	Support schemes for RES technology	Policy support in the form of RES auctions, financial incentives (premium tariffs), or other initiatives (pilot programmes)
	Permitting procedures for RES technologies, regulatory quantity limits	Extent to which the current regulatory frameworks allow for development of projects and whether caps on deployment exist

(Source: Guidehouse)

A metric or key performance indicator (KPI) is defined to measure each assessment criterion. Each RES technology is scored for each criterion based on the KPIs laid out in Table 1-10.

Table 1-11: Scoring methodology for assessment criteria

Indicator	Description
○	Indicates that the RES technology has a poor performance with respect to the criterion
◐	Indicates that the RES technology has a moderate performance with respect to the criterion
●	Indicates that the RES technology has a good performance with respect to the criterion

(Source: Guidehouse)

Table 1-12 gives an overview of the outcome of the qualitative technology assessment. Sections 1.2.1 through 1.2.5 show a qualitative analysis conducted per assessment criterion to explain the KPI scoring presented in Table 1-12.

Table 1-12: Outcome of the qualitative technology assessment

Assessment criteria	Bottom-fixed offshore wind	Floating offshore wind	Wave & tidal energy	Utility-scale solar PV	Rooftop solar PV	Onshore wind
Technical						
Renewable energy resource	◑	●	○	●	●	●
Potential production per installed capacity	●	●	○	◑	◑	●
Scalability	◑	◑	◑	◑	●	◑
Grid interconnectivity in the region	○	○	○	◑	●	◑
Economic						
Current investment and operational cost levels	◑	○	○	●	●	●
Projected investment and operational cost levels	●	◑	○	●	●	●
Demand matching production profile	◑	◑	◑	●	●	◑
Environmental impact						
Impact on environment	◑	◑	◑	◑	●	◑
Social acceptance						
Social acceptance	○	◑	◑	○	●	○
Regulatory						
Support schemes for RES technology	○	◑	○	●	●	●
Permitting procedures for RES technologies, regulatory quantity limits	○	○	○	●	●	●

(Source: Guidehouse)

1.2.1 Technical assessment

Many sites in the Mediterranean region are available for the development of floating offshore wind farms (Soukissian et al., 2017), given the area available with a water depth up to 1,000 m within 200 km from shore (see Section 1.3 for the spatial constraint analysis). Floating offshore wind technology has less stringent requirements for soil conditions and geotechnical studies, shorter weather windows, and fewer, simpler, and less-costly operations during installation than bottom-fixed offshore wind technology (WindPlus, 2017). Bottom-fixed offshore wind is limited mostly due to the great water depths that characterize the Mediterranean Sea. However, a few sites exist in the northern Adriatic Sea where bottom-fixed technology would be feasible (Soukissian et al., 2017).

From a scalability perspective, floating offshore wind has the highest potential to scale up offshore technologies. However, the current no existing offshore wind industry’s supply chain in the Mediterranean region hinders its scoring compared to onshore wind and solar PV technologies, which are already established.

Wave and tidal energy resources are rather low in the Mediterranean Sea compared to other areas where the ocean energy sector is growing, such as in the UK. Tidal turbines require a minimum current speed, and experts have been considering only a few sites such as Gibraltar and the Strait of Messina. The lack of tides that meet these minimum requirements could limit the feasibility and scalability of wave and tidal technologies in the Mediterranean region. All offshore technologies could face scalability constraints in specific sites, such as nearshore coastal areas, due to competing economic activity, including tourism, fishing, maritime, and shipping activities that take place in the Mediterranean Sea (Government of Malta, 2019) as it is one of the busiest seas in the world.

The lack of a sufficiently developed power grid in the region is another aspect that could slow down the deployment of large-scale offshore technologies such as offshore wind. This situation would impact wave and tidal technologies to a lesser extent since project capacities are generally lower. The existing power grid around the islands would not be capable of integrating very large amounts of variable renewable energy (Soukissian et al., 2017). To a lesser extent, increased penetration of onshore wind, utility solar, and rooftop solar PV on islands may require upgrading the existing low voltage and medium voltage distribution networks on islands. For onshore wind projects, grid interconnectivity may become an important issue since wind sites tend to be located further away from the grid.

Solar irradiation is possibly the most homogenous resource across the region. Mediterranean islands have a relatively high wind resource potential (explored in Section 1.4) that is currently largely untapped.[23] However, large-scale solar PV and onshore wind encounter significant barriers to their development. Mediterranean islands are highly populated (Navigant & E3 Modelling, 2017), thereby limiting scalability due to land use restrictions. Rooftop solar PV, however, has a better technical outlook as it can be deployed easily on small, medium, and large domestic and industrial roofs.

In terms of potential production per installed capacity, all wind technologies benefit from reaching the highest capacity of the technologies considered. The capacity factor for onshore and offshore wind is approximately 40% based on the analysis in Section 1.4.1. Utility-scale and rooftop solar PV have an estimated capacity factor per solar module of 19% in 2030 and 23% in 2050. The capacity factor for wave energy is 14% while tidal energy reaches 6% in Italy and 10% in Spain.

1.2.2 Economic assessment

This section assesses the investment and operational costs of the RES technologies discussed in this report. Note that the LCOE for each technology is assessed specifically in Section 1.5 based on current and future cost levels and yield. Less mature technologies such as floating offshore wind, wave, and tidal have higher CAPEX and OPEX levels compared to bottom-fixed offshore wind and onshore technologies. Figure 1-26 gives an overview of the specific cost levels used for 2030 and 2050 per technology. The cost reduction potentials in the case of the less mature technologies will determine the technology’s economic attractiveness and scalability in the mid to long term. Floating offshore wind, for example, shares a large part of the cost base with bottom-fixed offshore wind technology, especially in relation to turbine technology. The floating wind industry can therefore already benefit from and build on the lessons learned from the traditional offshore wind industry. The focus on cost reduction opportunities will naturally shift to the foundational technologies. Cost reductions could be achieved in large part through industrialising the value chain to optimise substructure and mooring designs, which would reduce the unitary cost per tonne, and through identifying more efficient methods for installation, operations and maintenance (O&M). However, uncertainty still exists regarding the lift off and subsequent cost developments of this novel technology and industry, though some already expect cost parity with bottom-fixed offshore wind by 2030 (Irena, 2016; Utility Week, 2020).

The production profile of each technology is evaluated by the extent to which power is produced during periods of high demand. Despite competition from mainland onshore solar energy, relatively high value of Mediterranean offshore energy is expected in the summer season due to tourism and during daytime hours due to demand for air-conditioning. Solar PV technologies therefore have a natural fit with periods of relatively high demand in the Mediterranean area according to country-specific load patterns (ENTSO-E, 2019b). Other technologies such as offshore and onshore wind, wave, and tidal have production patterns that do not necessarily coincide with high demand periods as they also see high production occurring at night. Although wind and wave power complement solar power on a seasonal level since they typically produce most power during the winter months, they do not necessarily produce at the hour when the demand or value of power is highest. For a more detailed and quantitative assessment, production profiles of all technologies will be used in the power market modelling analysis in Tasks 2 and 3.

1.2.3 Environmental assessment

The Mediterranean Sea is home to very rich ecosystems with high levels of biodiversity and autochthonous species. Many protected areas and natural reserves have been established by the EU member states and the EU Natura 2000 network, which provides an overview of the number and size of terrestrial and marine sites designated under the Birds and the Habitats Directives (European Environment Agency, 2018). Conservation areas of high priority and ecological relevance can be found in all Mediterranean marine subregions. The average size of Marine Protected Areas (MPAs) located within the range of 1-12 nautical miles varies per subregion: ~350 km2 in the western Mediterranean Sea, ~30 km2 in the Ionian and central Mediterranean Seas, ~20 km2 in the Adriatic Sea, and ~100 km2 in the Aegean-Levantine Sea. For MPAs beyond 12 nautical miles, the western Mediterranean Sea hosts the largest MPAs with an average size larger than 1,000 km2. In addition, approximately 70-80% of the MPAs within each Mediterranean subregion have sizes of around 15 km2 (Environment European Agency, 2015).

Environmental impact assessments for offshore wind, wave, and tidal projects could face issues in some locations, thereby limiting their potential deployment area. In Malta, for example, an environmental impact assessment for the development of the Sikka l-Bajda wind farm determined negative impacts on marine geology and marine life in the area (Government of Malta, 2019). Consequently, the development of the wind farm was abandoned.

Large-scale onshore wind and solar PV plants could also negatively affect flora and fauna onshore by influencing migrating birds (Zwart, Mckenzie, Minderman, & Withingham, 2016). For example, in France, bird migration towards Africa through the Gulf of Lion is an essential environmental constraint that must be taken into account when identifying the right zones for floating offshore wind farms. Also, islands are rest areas for migrating birds. However, this impact can be mitigated with proper monitoring prior to the investment. Rooftop solar PV systems generally do not interfere with nature since many of these systems are located in urban or industrial areas.

1.2.4 Social acceptance assessment

Mediterranean economies rely heavily on tourism, as it represents more than 70% of production value added in the region. The dependency on tourism has affected many offshore wind farm developments along the coasts of France, Spain, Italy, and Greece. Many of the projects are now cancelled or dormant, such as the Parco eolico Marino Gargano Sud project in Italy (Soukissian et al., 2017; Foggia Today, 2013). Local authorities in coastal regions expressed strong opposition to the realization of these projects, arguing that the visual impact could adversely affect tourism. Due to their lower visual impact, wave and tidal technologies may attract less opposition from local authorities and other stakeholders and, consequently, may be more suitable in areas with abundant tourism and economic activities. Solar PV is mainly opposed on a utility scale, e.g. due to competition with agricultural land (Bellini, Is solar eroding too much land? The EU thinks not, 2019). Project sizes for utility-scale solar PV on Mediterranean islands range 1.5-7.5 MW, with a few cases reaching capacities of up to 50 MW. However, relatively small standalone PV projects of 0.1 MW or less would probably benefit from greater social acceptance since these could be developed by individual investors such as local farmers. For similar reasons as utility-scale solar PV, utility-scale onshore wind projects face opposition from multiple stakeholders.

The introduction of Multiuse Platforms at Sea (MUPs) could help overcome strong opposition from local stakeholders. For example, in 2018, Sicily’s regional government decided to revoke licenses that had been granted to new solar PV and onshore wind projects. The regional government's aim was to assess the impact on the landscape and develop new regional spatial planning.23 Projects like MERMAID (Stuiver, et al., 2016) focus on the technical perspective to assess the feasibility of combining different activities at sea and the visionary perspective to facilitate social acceptance that will ensure the required support for future sustainable activities in European seas. Another MUP project worth mentioning is the TROPOS project (European Commission, 2015). Its objective was the development of a floating modular multiuse platform system for use in deep waters. The TROPOS approach focuses on the modular development in a way that ensures that the multiuse platform system can integrate a range of functions from the transport, energy, aquaculture, and leisure sectors in a greater number of geographical areas than if it was a set platform design.

1.2.5 Regulatory assessment

The NECPs of different member states demonstrate an overall lack of adequate policies that could constitute a solid regulatory framework favourable to the development and scalability of offshore wind in the Mediterranean region and the implementation of more wave and tidal flagship projects. A few countries have set targets for offshore wind towards 2030 and long-term, model-based projections for 2040. Italy has expressed willingness to enhance regional cooperation with neighbouring countries based on sharing project developments at sea (Direção-Geral de Energia e Geologia, 2019; French Ministry for the Energy Transition, 2019; Ministry of Economic Development (Italy), 2019). Spain has proposed introducing tenders aimed at boosting offshore wind and ocean energy technologies by providing public financing if required. However, no further calendar details are yet known. More certainty about potential volumes and timelines is expected after the ongoing marine spatial planning in Spanish waters is finalized. At the time of this report's publication, only France is increasing certainty in the project pipeline by scheduling two upcoming floating offshore wind tenders (French Ministry for the Energy Transition, 2019). Therefore, the regulatory framework for offshore technologies does not yet sufficiently support concrete project development of offshore energy projects in most parts of the region, as addressed in Section 1.1.2.

In terms of permitting procedures, countries such as Portugal have adapted the consenting procedures to better suit wave energy developments. The deployment duration and the capacity installed drive the need to issue either a license or a concession. A license is required for wave energy devices that are deployed for less than 1 year and have an installed capacity below or equal to 25 MW. For lengthier deployment periods and installed capacities higher than 25 MW, a concession is mandatory (Simas, 2015). France has introduced a new set of rules gathered in three different codes: the Energy Code, the Environment Code, and the Code of Public Property. These new laws contribute to a clear governance of the steps in the process of offshore developments and a simplification of permitting procedures (Hogan Lovells, 2020). In Spain, Royal Decree 1028/2007 established two authorization processes for the development of offshore energy generation plants: a simplified version for capacities lower than 50 MW and a regular process for capacities above 50 MW. Currently, Spain's marine spatial planning framework is under review, and the authorization process may also undergo changes in the short term (The Institute for Diversification and Energy Saving, 2020). From experience in the North Sea, marine spatial planning highly influences the consenting process for proposed ocean energy and offshore wind projects (Simas, 2015). Overall, this is currently lacking in Mediterranean member state countries. In addition, limited, burdensome legal frameworks or lack thereof for offshore energy projects creates further uncertainty among developers (WindPlus, 2017).

In contrast, the amount of existing island-specific policies with varying characteristics demonstrates that islands' energy challenges are high on the political agenda, as presented in Section 1.1.2. As outlined in Table 1-7, support schemes for onshore wind and solar PV technologies appear favourable across the region, especially for solar PV. Existing island-specific RES support policies, including auction schemes, feed-in tariffs, and pilot programmes, aim to achieve a reduction in energy system costs. This common issue is shared by many member states in the Mediterranean region (Navigant & E3 Modelling, 2017).

1.3 Spatial constraint analysis

Task 1 aimed to identify the areas and sites in the Mediterranean region with the greatest cost-effective potential and performance ranking, used in Task 2 and Task 3. Task 4 analyses challenges and barriers in detail and provides part of the input to Task 1.

This task narrows down the Mediterranean Sea to suitable boundaries for applicable renewable energy technologies. A spatial constraint analysis is employed to determine locations available for power generation. Following identification of those locations, the technical energy potential is determined by using a raw resource map for each technology under investigation. Economic potential determination will follow by using technology cost figures.

1.3.1 Starting point geographical analysis

The scope of this study is limited to the European Mediterranean countries of Croatia, Cyprus, France, Greece, Italy, Malta, Portugal, Slovenia, and Spain. The Exclusive Economic Zones (EEZ) define the geographical regions allotted to different countries for resource potential calculation. The countries have jurisdiction only on the EEZ seabed, and the sea surface is international waters. Installing offshore technologies, even floating ones, requires use of the seabed. In practice, international agreements are expected to form, giving the exploration right to the country that controls the seabed with high probability; therefore, this report's approach should be a good approximation. In the spatial constraint analysis, no legal aspects were considered that could limit using the EEZ zones for developing offshore renewables. Legal barriers will be discussed later in Task 4.

The EEZ areas are the first exclusion criterion within the Mediterranean Sea for the geographical and resource analysis. Note that some EEZs, though located within the European Mediterranean Sea, belong to countries that are not members of the EU. These zones are also excluded from the analysis.

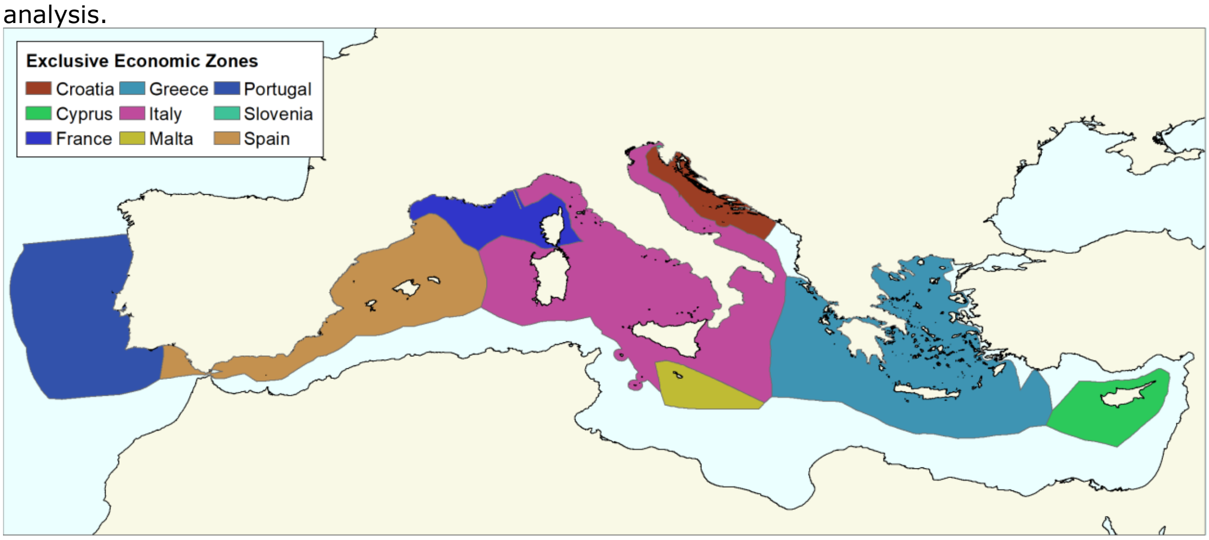

Figure 1-6 shows the EEZs of EU countries in the Mediterranean Sea. The next section presents the exclusion factors applied in the analysis.

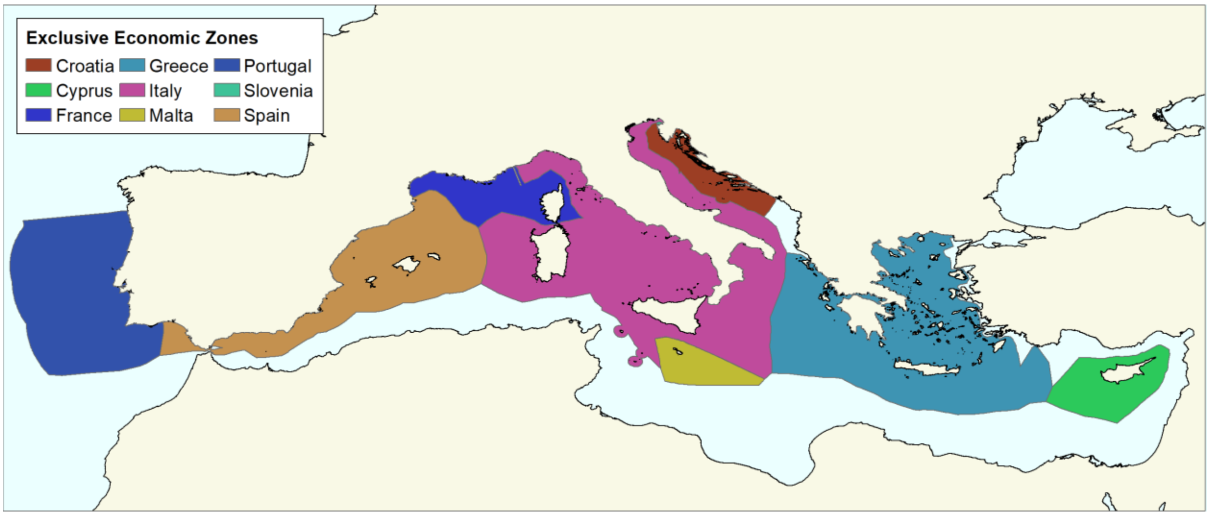

Figure 1-6: EEZs of EU countries in the Mediterranean Sea[73]

(Source: (Vlaams Instituut voor de Zee (VLIZ), n.d.))

1.3.2 Natural exclusion zones and conservation areas

Offshore wind farms have the potential to act as a new type of habitat for marine wildlife, leading to an increased biodiversity of benthic organisms, marine mammals, and some bird species (Lindeboom et al., 2011). However, in the development phase of a new offshore project, the installation of and the presence of large vessels can lead to disturbances of the marine environment and existing species. For this offshore energy potential analysis of the Mediterranean Sea, existing nature protection zones are excluded. The analysis considered three distinct datasets: Natura 2000, rocky reefs, and CoCoNet. It also investigated the influence of bird migration routes.

Natura 2000 is a European network of protected areas, offering a haven to Europe's most valuable and threatened species and habitats. It covers 8% of the European marine territory, including the Mediterranean Sea. The objective of these Natura 2000 sites is to ensure long-term survival of Europe's most valuable and threatened species and habitats (European Commission, 2020c). Therefore, these protected sites are generally assumed to be not viable for the development of offshore energy systems, so all Natura 2000 sites are classified as exclusion zones for this study.

Rocky reefs offer shelter to diverse marine wildlife species as well as corals (Sala et al., 2011) and are therefore also classified as exclusion zones. The CoCoNet study is published by the European Maritime Spatial Planning Platform and identifies groups of MPAs in the Mediterranean and Black Seas. Figure 1-7 presents the exclusion of Natura 2000 sites and rocky reef areas.

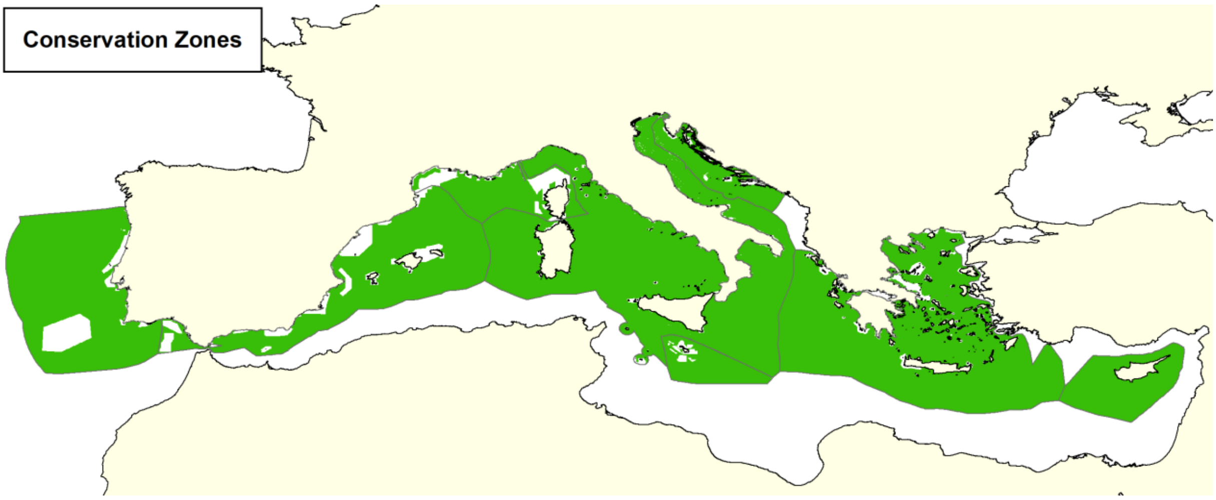

Figure 1-7: Exclusion of Natura 2000 sites[74] and rocky reef areas[75]

(Source: (European Environment Agency, n.d.), (National Center for Ecological Analysis and Synthesis (NCEAS), 2008) National Center for Ecological Analysis and Synthesis (NCEAS), retrieved from [https://knb.ecoinformatics.org/view/doi:10.5063/F1JW8C4R)](https://knb.ecoinformatics.org/view/doi:10.5063/F1JW8C4R)

Total exclusion of Natura2000 sites would result in dismissal of high development areas in terms of resource potential and economic potential for floating wind turbines. The most important affected area is in the Gulf of Lion, which has a high resource potential with one of the highest wind speeds in the Mediterranean as shown in Figure 1-15. The location of the proposed production areas in the Gulf of Lion are shown Section 1.6 in Figure 1-38 and are within the area labelled 01.

[73] The EEZ areas are defined as the geographical regions allotted to the different countries for resource potential calculation.

[74] (European Environment Agency, n.d.)

[75] (National Center for Ecological Analysis and Synthesis (NCEAS), 2008)

Figure 1-8 shows the impact of the Natura 2000 sites on the selected production areas. As this specific Natura 2000 area in the Gulf of Lion is designated for sea bottom conservation, the effect of floating wind turbines should be relatively insignificant as turbines are only anchored in the sea bottom (compared with the immersive foundations of bottom-fixed wind turbines). Another reason for the expected low impact is the assumed offshore wind resource density of 7 MW/km^2 (see Section 1.4.1). Combined with increasing wind turbine sizes (already up to 7 MW), spatial impact is expected to be mitigated easily. Furthermore, some projects are already developed in this area in the Gulf of Lion, so this area is assumed to be available for development of floating technologies with careful regard for restrictions.[76]

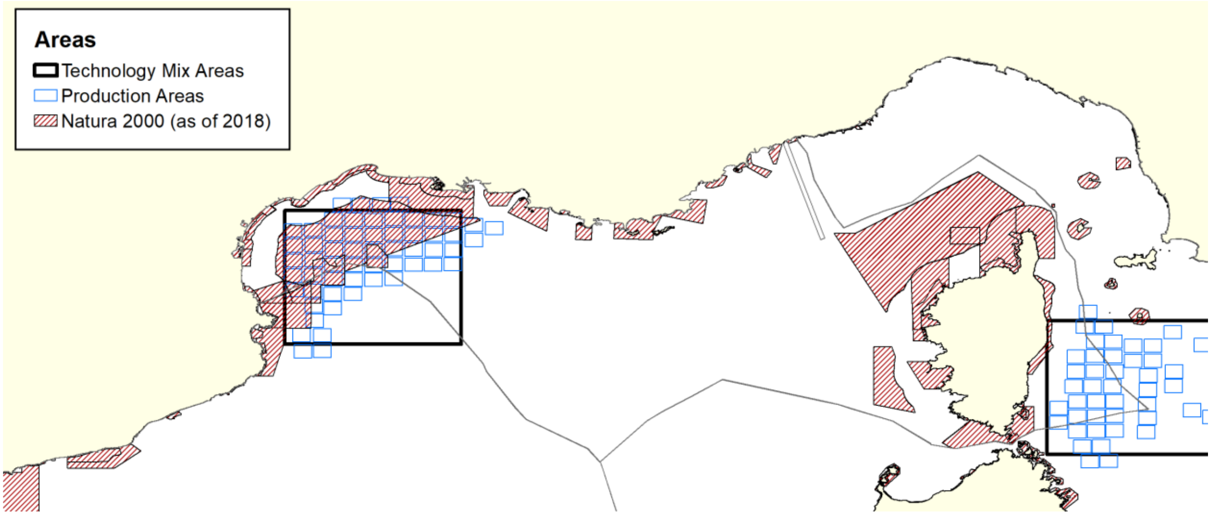

Figure 1-8: TMAs and production areas proposed in Section 1.6 overlap with Natura 2000 areas in the Gulf of Lion

(Source: Guidehouse)

This report also considered protection areas identified in the CoCoNet study. Published by the European Maritime Spatial Planning Platform, this study identifies groups of MPAs in the Mediterranean and Black Seas (Grande & Foglini, 2016). This report investigated the extent to which these MPAs will cause additional spatial exclusions other than those already identified in other protection datasets. The most notable area identified is the Pelagos Sanctuary for Mediterranean Marine Mammals. The Pelagos Sanctuary is the blue hatched area north of Corsica shown in Figure 1-9. While this area is large and overlaps with one of the selected technology mix and production areas, activity in the sanctuary is not restricted. The sanctuary seeks to ensure that human activities are compatible with the presence of native species (Pelagos, 2012). Therefore, the area is assumed to be available for development with careful regard for restrictions.

[76] The area is too deep for bottom-fixed technologies.

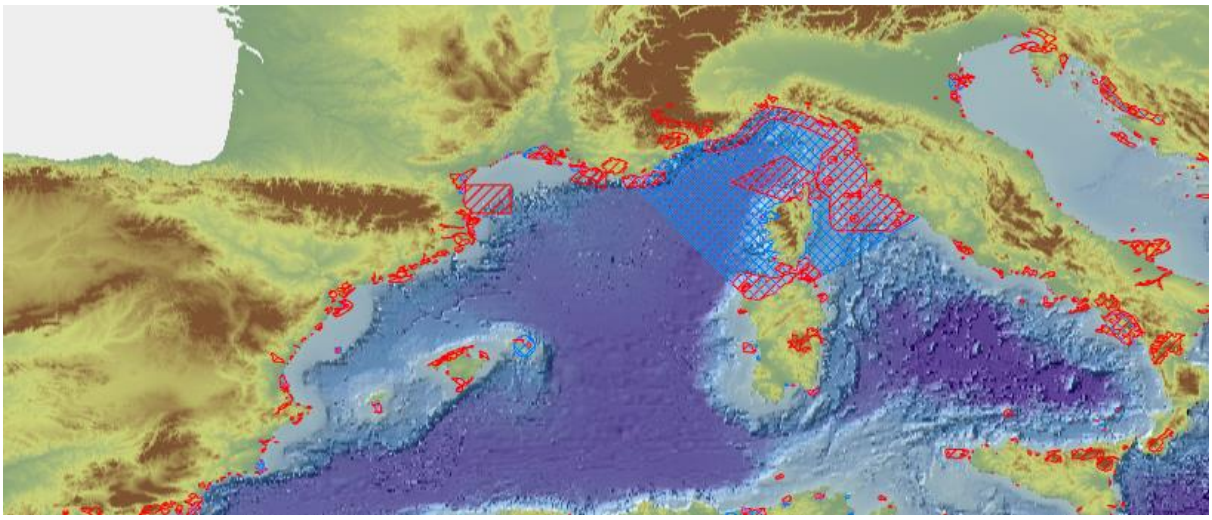

Figure 1-9: National and international protected sites identified by CoCoNet

(Source: CoCoNet)

Bird migration routes in the Mediterranean Sea area are concentrated on the shortest stretches of sea between Europe and Africa. These stretches are the Strait of Gibraltar and the crossing between western Sicily and Tunisia. In the Strait of Gibraltar, migration routes should have little impact because project development is not expected to occur there due to exclusion by high intensity shipping lanes. However, a proposed development area remains between Sicily and Tunisia that can potentially effect bird migration. This area southwest of Sicily is the area labelled 03 in Figure 1-38, and it overlaps with bird migration routes between Europe and Africa.

Several measures can mitigate the effects of offshore development on birds, including shutdown, attraction avoidance, luring, and deterrence. This study considers shutdown. To reduce the bird mortality rate, avian radars are available on a commercial level to detect migrating flocks and shut down a wind farm's production for brief periods of time. One manufacturer reports that these shutdown periods are few (less than 4 hours during springtime) and have a very limited effect on the availability of a wind farm (STRIX, 2017). Studies have shown that wind farm shutdowns can lead to a 50% reduction in the bird mortality rate with only a 0.07% loss in energy production (Lucas, 2012). The effects on bird migration can be mitigated, and this study includes the area between Sicily and Tunisia with only a negligible decrease in resource potential.

1.3.3 Maritime use

The maritime use constraints considered in this study include:

- Artisanal fishing
- High intensity shipping lanes
- Munition dump areas
- Production platforms for oil & gas

Commercial and artisanal fishing are very important activities in the Mediterranean Sea. Artisanal fishing refers to fishing practices undertaken by small-scale, low technology, individual fishing households as opposed to commercial companies. These activities mostly take place close to shore and have limited flexibility with displacement. Therefore, high intensity artisanal fishing areas have been excluded from the available areas for offshore energy production.

Maritime transport is a traditionally strong economic sector in the Mediterranean Sea. The Mediterranean Sea is among the world's busiest waterways, accounting for 15% of global shipping activity by number of calls.[77] Therefore, high intensity shipping lanes are excluded from the available area for offshore energy production. High traffic shipping lanes will most likely not be identified as a potential offshore wind zone. A low traffic shipping lane might be willing to accommodate a wind park.

Military activity in the Mediterranean Sea can form another obstacle for the development of offshore energy development, but information on the location of military activities is very difficult to come by. However, concerns do exist regarding dumped munitions. This is especially relevant in the Adriatic-Ionian Sea (European Commission, 2019). The known munition dump areas are excluded from the analysis in this study. While probably not all dump areas would exclude renewable energy generation, their exclusion acts as a proxy for the unavailable military activity area.

A standard 500-meter safety zone exists around offshore production platforms for oil & gas. This zone requires that vessels keep a minimum distance of 500 m from a production platform. Therefore, an exclusion zone with a 500-meter radius is defined around each production platform in the European Mediterranean Sea in this study. Only existing oil & gas facilities are considered. Figure 1-10 shows the available area after exclusion of artisanal fishing areas, high intensity shipping lanes, military munition dump sites, and offshore production platforms.

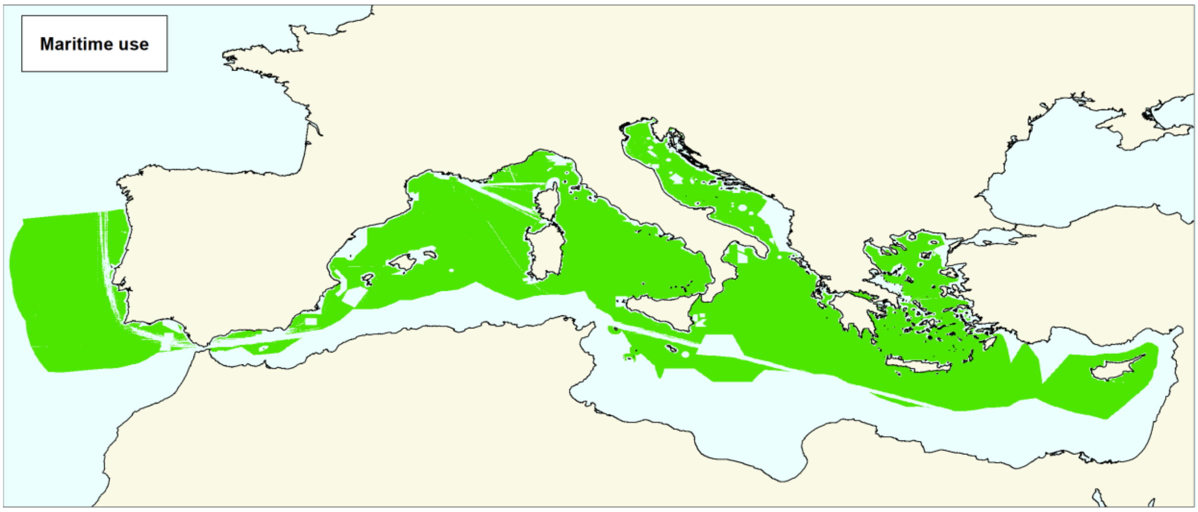

Figure 1-10: Exclusion of artisanal fishing areas,[78] main shipping routes,[78] military munition dump sites,[79] and offshore production platforms[79]

1.3.4 Technology-specific exclusions

The technologies considered have specific zonal exclusion criteria based on geographical constraints. For reasons related to visibility from shore, in the Northern Seas, wind turbines are generally built outside of the coastal region, defined by 12 nautical miles from shore. This holds true for bottom-fixed and floating bottom wind turbines. This report did not consider hub heights of offshore wind turbines to trigger any change in this spatial constraint.

Installation, operation, and maintenance costs are proportional to the distance to shore. From 200 km onwards, it is generally not economically viable to build and maintain offshore wind farms and wave energy installations. Offshore hubs might allow for larger distances, but this option is not considered here. Also, deep water hubs are difficult to develop. It turns out that 200 km is not a

[77] Unique identifier of a ship or boat

[78] (National Center for Ecological Analysis and Synthesis (NCEAS), 2008)

[79] (EMODNET, 2020)

limiting factor anywhere because of the large depth and steep slope of the Mediterranean seafloor. There were no other technical or legal reasons for the 200 km limit.

In addition to the distance to shore, depth is another determining factor (National Centers for Environmental Information, n.d.).[80] Bottom-fixed wind turbines are generally built in locations with a maximum depth of 50 m (International Energy Agency, 2019). A 1000-meter maximum limit exists for floating wind and wave energy installations. Table 1-13 summarises the distance and depth limitations. The remaining areas available for the development of bottom-fixed wind, floating wind, and wave energy installations are presented in

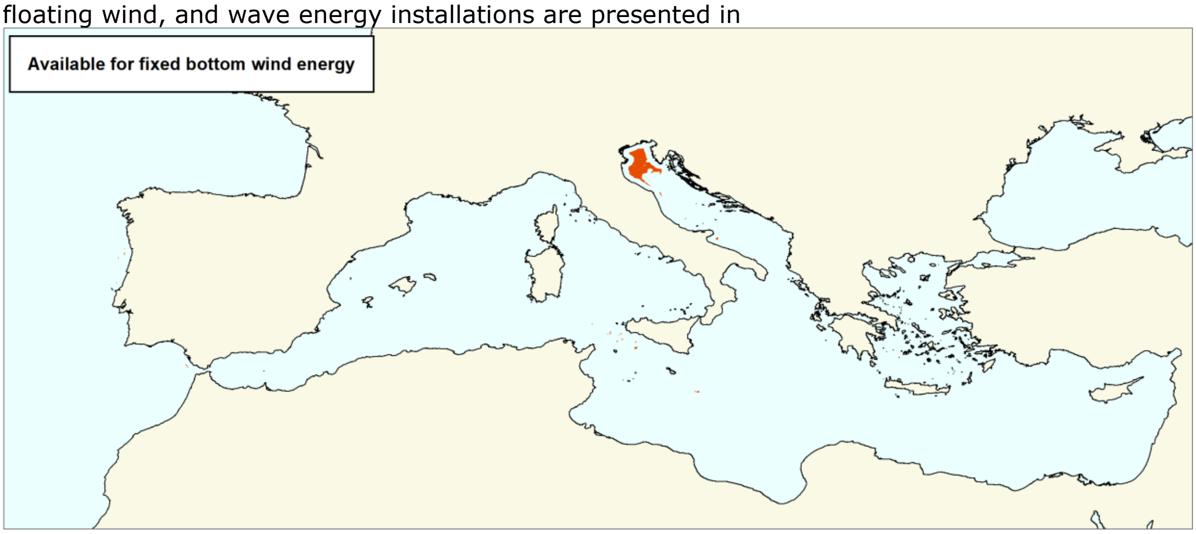

Figure 1-11, Figure 1-12, and Figure 1-13, respectively.

Table 1-13: Specific limitations of offshore energy production technologies

Limitation	Bottom-fixed wind turbines	Floating bottom wind turbines	Wave energy
Minimum distance to shore (km)	22.2[81]	22.2	0
Maximum distance to shore (km)	200	200	200
Maximum depth (m)	50	1,000[82]	100,085

(Source: Guidehouse)

Figure 1-11 shows the available area for bottom-fixed wind turbines after applying additional technology-specific exclusions, depth, and distance to shore. This figure shows the area available for technology development with all geographic constraints considered.

[80] This report uses the global ETOPO1 relief dataset from NOAA (https://www.ngdc.noaa.gov/mgg/global/global.html). This dataset includes bathymetric data. The dataset is checked and in accordance with the bathymetry from EMODNET (https://portal.emodnet-bathymetry.eu/).

[81] 22.2 kilometres corresponds to 12 nautical miles, a customary minimal distance in offshore wind development in the North and Baltic Seas.

[82] Connection to installations at these depths is possible: Today a relevant number of cables running below 1,000 m sea depth. TERNA ENERGY's cable SAPEI, interconnecting Sardinia with continental Italy, runs at 1,600 m depth.

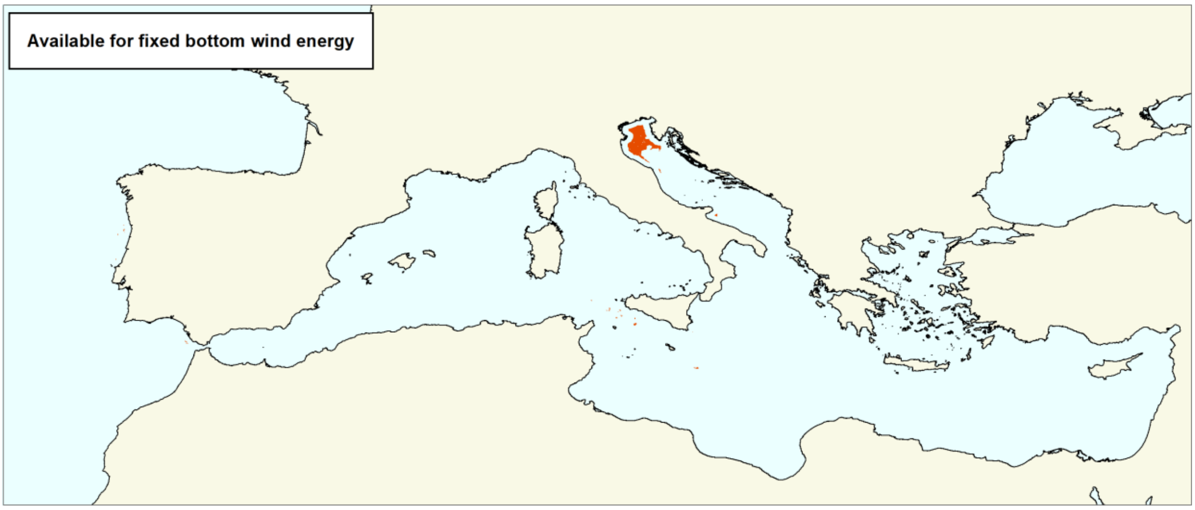

Figure 1-11: Available area for bottom-fixed wind turbines based on geographical constraints

(Source: Guidehouse)

Figure 1-12 shows the available area for floating wind after applying additional technology-specific exclusions, depth, and distance to shore. This figure shows the area available for technology development with all geographic constraints considered.

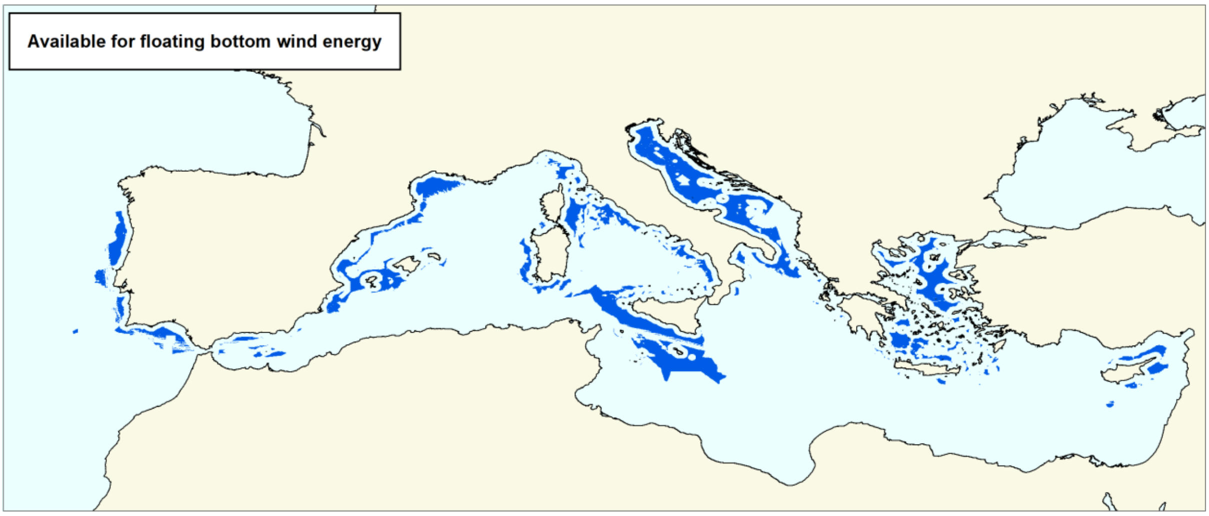

Figure 1-12: Available area for floating wind turbines based on geographical constraints

(Source: Guidehouse)

Figure 1-13 shows the available area for wave energy installations after applying additional technology-specific exclusions, depth, and distance to shore. This figure shows the area available for technology development with all geographic constraints considered.

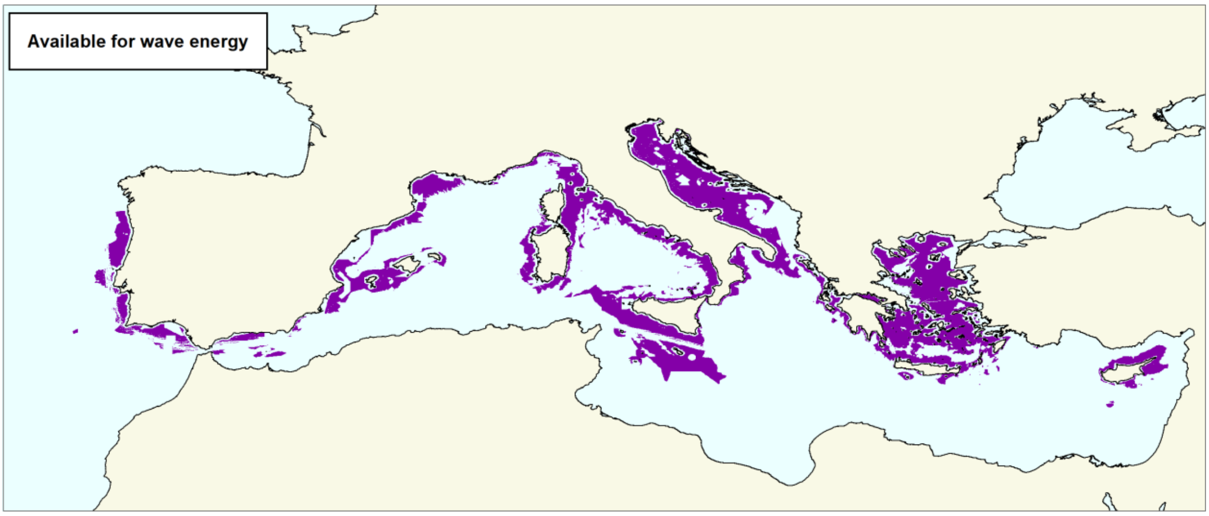

Figure 1-13: Available area for wave energy installations based on geographical constraints

(Source: Guidehouse)

1.3.5 Technology-specific resource exclusions

To determine locations with suitable renewable resource potential, annual average resource values are needed for all locations in the Mediterranean. The solar energy resource information was obtained from NASA SSE in the form of solar irradiation given in kWh/m2/day (NASA SSE, n.d.). Figure 1-14 shows the geographical variation of the solar irradiation.

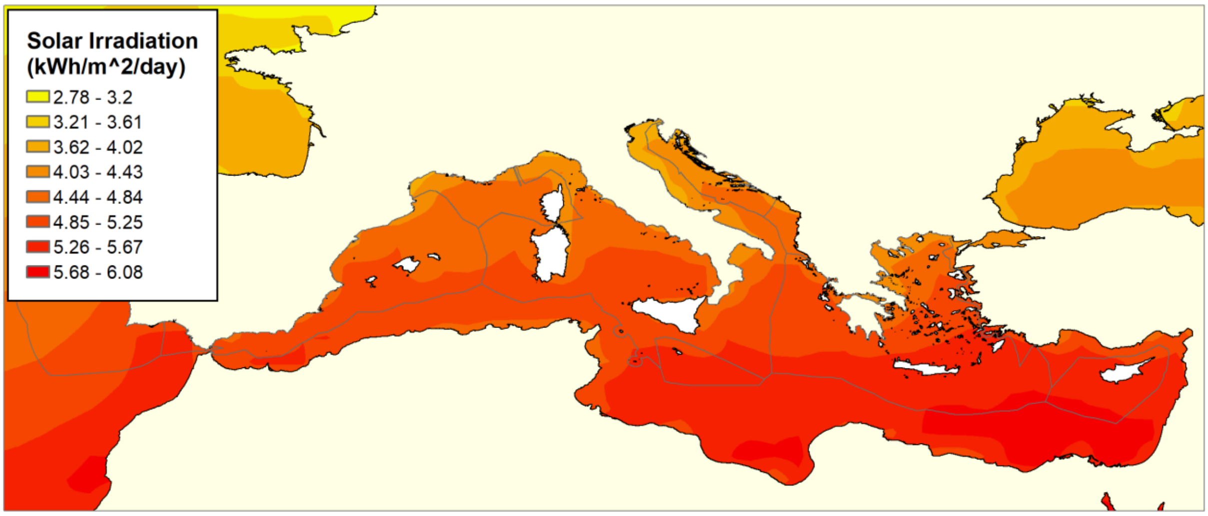

Figure 1-14: Solar irradiation levels in the Mediterranean region

(Source: Guidehouse)

For wind energy technology, wind speed data in m/s at 10 m above sea level is available (National Centers for Environmental Information Climatic Data, n.d.). From the available climatological average wind speed data time series, quarterly and annual average wind speeds at hub height are calculated at a 1/60-degree raster map. The climatological annual average wind speed data is shown in Figure 1-15.

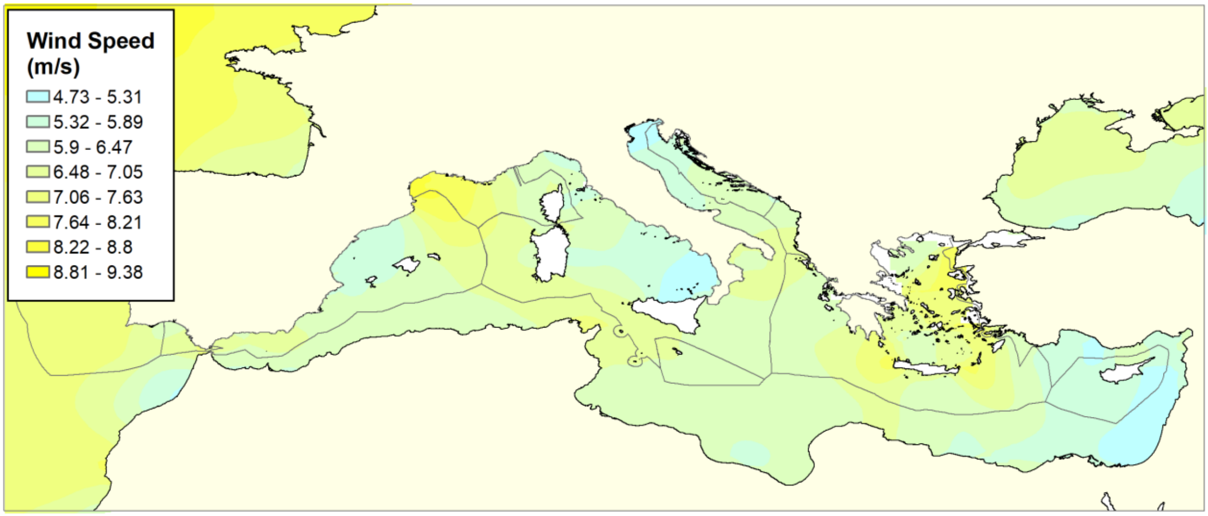

Figure 1-15: Annual average wind speed at 10 m above sea level

(Source: Guidehouse)

Wave energy resource data is available in kW/m. Annual average wave resource data is available at individual buoy locations from two publications (Arena F. et al., 2015; Pontes M.T et al., 1998). Using spatial interpolation techniques, an approximate wave resource map was created from the point buoy data. The level of available wave resources is presented in Figure 1-16.

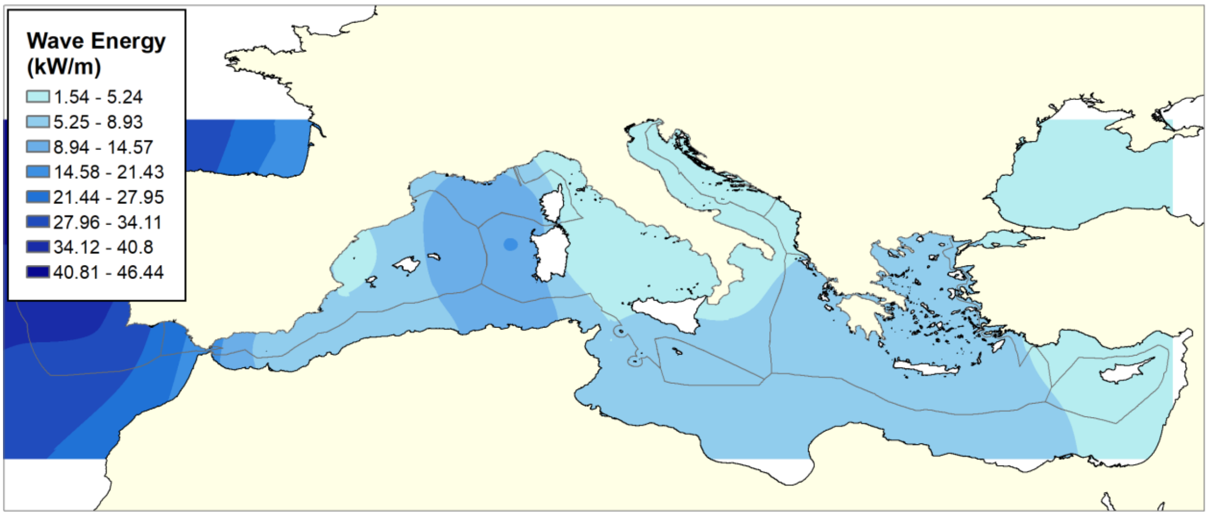

Figure 1-16: Wave energy resource level

(Source: Guidehouse)

In addition, locations are excluded where the resource value is below a certain critical value. This cut-off can be thought of as reflecting the economic competition for wind power or wave energy with other generation technologies and economic investments. Resource levels below the critical value for a technology are assumed to be too low to make an economically feasible investment possible for that technology.

In the case of wind energy, a location is excluded if wind speeds at hub height is below the global critical value. Wave energy is excluded from locations having a resource level below a critical average annual level.

Table 1-14 shows the critical resource levels for each offshore technology. The limit used for offshore wind was established by Guidehouse's in-house resource model. This limit has also been confirmed in practice. No commercial-scale wind farms are developed in established markets that have an average wind speed at hub height below 8 m/s. The critical value for wave technology is based on observation, as no projects have been developed with an average wave resource level below 5 kW/m.

Table 1-14: Resource limitations of offshore energy production technologies

Limitation	Bottom-fixed wind turbines	Floating bottom wind turbines	Wave energy
Minimum average resource level	> 8 m/s in at least one quarter	> 8 m/s in at least one quarter	> 5 kW/m

(Source: Guidehouse)

For each of the three technologies, this report also excludes areas where the resource level is below the critical level. This results in an available area after critical resource exclusion. Figure 1-17, Figure 1-18, and Figure 1-19 show the area available to bottom-fixed wind, floating wind, and wave technology after geographical constraints and the additional exclusion below critical resource level.

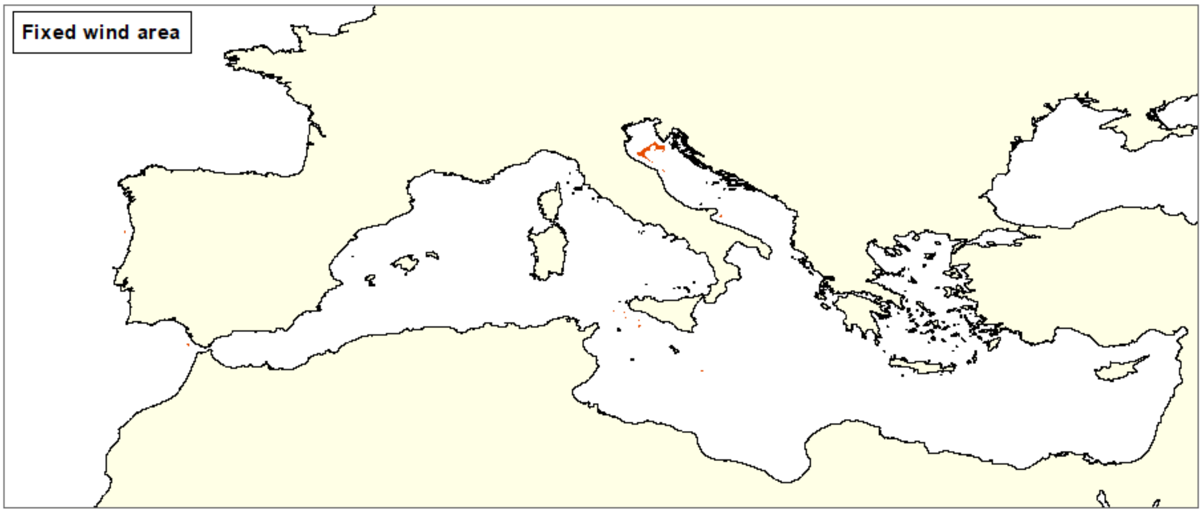

Figure 1-17: Area available for bottom-fixed wind turbines after resource-specific exclusion

(Source: Guidehouse)

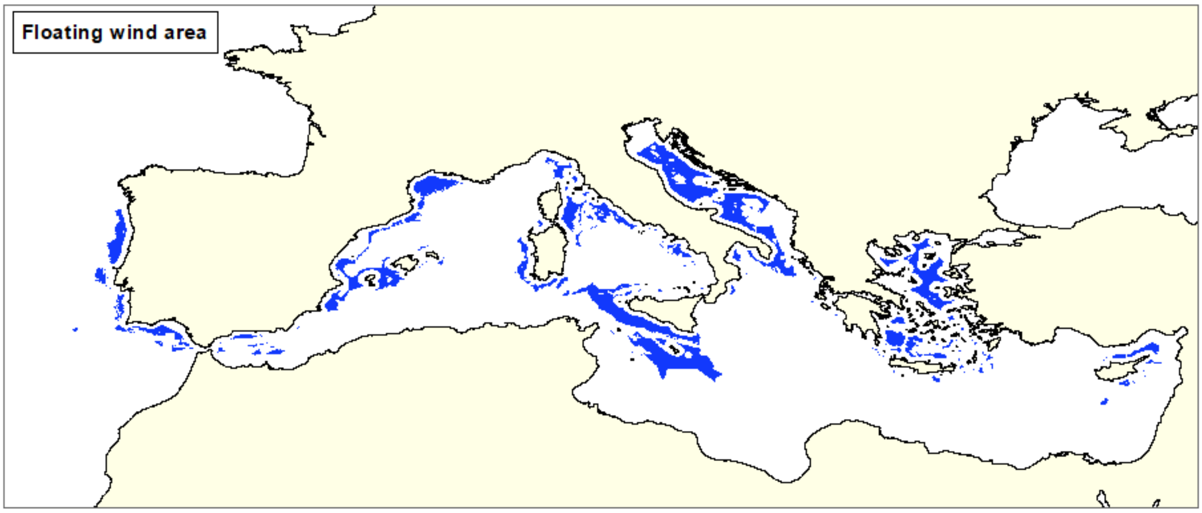

Figure 1-18: Area available for floating wind turbines after resource-specific exclusion

(Source: Guidehouse)

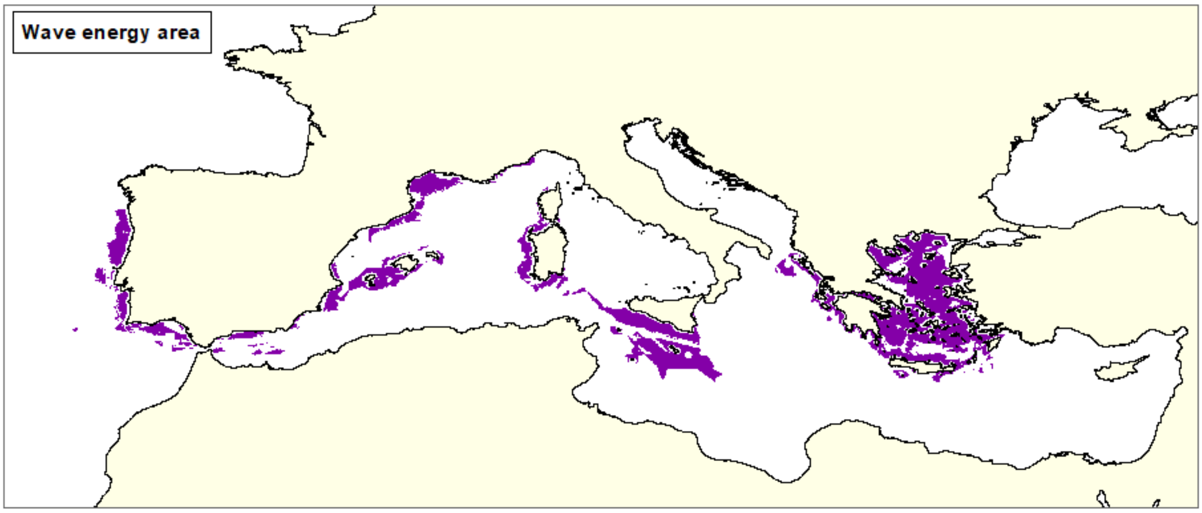

Figure 1-19: Area available for wave energy after resource-specific exclusion

(Source: Guidehouse)

1.4 Renewable technology potential

The following section presents the approach and results of this report's RES potential analysis.

1.4.1 Offshore resource potential

The hub height of the wind turbines dictates offshore wind resource potential. The tip height of offshore wind turbines has increased from 100 m in 2010 to more than 200 m in 2016. This trend is anticipated to continue, given that turbines are currently in production with a tip height of 260 m and a hub height of 150 m (International Energy Agency, 2019). Larger hub heights result in a higher average annual wind speed at hub height and allow for larger turbine blades and swept areas. All these factors combined lead to increased capacity factors and yields for offshore wind turbines. By 2030, a hub height of 150 m is expected to become the new standard, and that the trend should continue to result in a commercially viable hub height of 180 m by 2050.

As this study also considers onshore wind energy from islands in the Mediterranean Sea, a similar approach was conducted for onshore wind turbines. In recent years, the average hub height of onshore wind turbines in Germany increased from 93 m in 2008 to 133 m in 2018 (Fraunhofer, n.d.). Based on the expectation that this trend will continue, a hub height of 150 m is expected for 2030. However, in contrast to the increased growth expected in the development of offshore turbines, onshore turbines experience more constraints, given social acceptance, environmental concerns, and other height restrictions. For this reason, an average hub height of 150 m is expected for 2050 as well.

The resource potential is determined for 2030 and 2050 for the available area shown in Figure 1-21, Figure 1-22, and Figure 1-23. The area is represented as a geographic raster with cells of 1x1 km. The calculations are carried out per raster cell and summarized per country or production block (for production block definition, see Section 1.6).

1.4.1.1 Offshore wind

To determine the offshore wind resource potential, annual average wind speed is used. The average wind speed is sampled at the geographic location of each raster cell. The wind speed, given at 10 m above sea level, is extrapolated to hub height using the logarithmic wind speed profile with a roughness length of 0.0002 m at sea (Suisse Éole, 2020).

The wind speed is input to a standard Full Load Hour-wind speed relationship (Held, 2010):

$$FLH = 728\ v - 2{,}368 \qquad \text{[hours/year]}$$

This study assumes a wind farm installed power density of 7 MW/km2. Figure 1-20 from the European Maritime Spatial Planning Platform (European MSP Platform, 2018a) gives the offshore wind farm capacity densities of current projects. A clear trend is not visible, but 7 MW/km^2 is very much in the middle of the range.

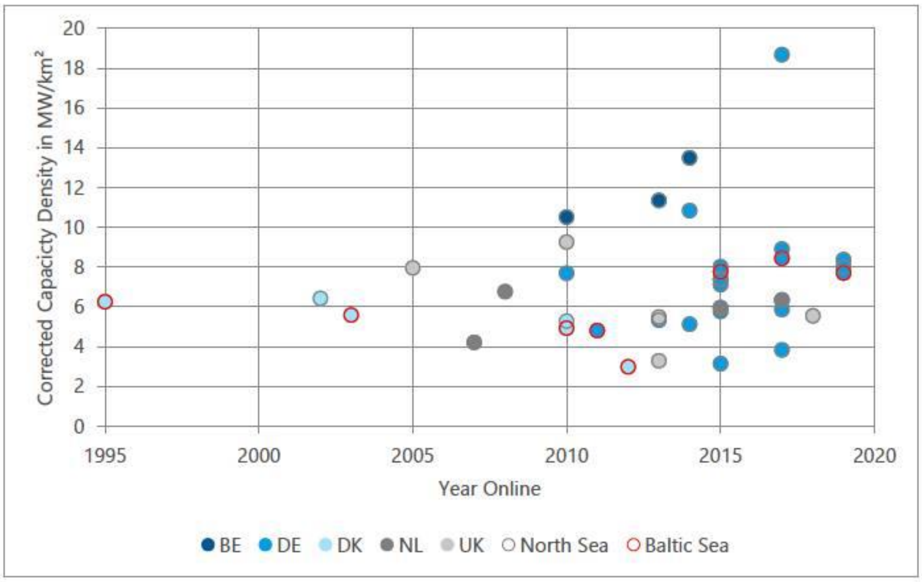

Figure 1-20: Capacity density of European offshore wind farms

(Source: Guidehouse)

From the full-load hours (FLH),[83] the assumed offshore wind power density of 7 MW/km^2, and the raster cell area (1 km^2 in our case), the offshore wind resource potential is calculated in MWh/year. This calculation also applies an operational efficiency of 90% and an array efficiency of 90%. The operational efficiency gives the share of time that the wind turbine is not offline for maintenance. The array efficiency measures the loss that multiple turbines will cause because of mutual interference. The efficiencies are combined by multiplication, resulting in an overall efficiency of 81%.

The efficiency values are treated the same as Guidehouse's in-house model for resource potential calculation. The values are on the low side to remain conservative when determining maximal technical resource potential. These values are also justified because offshore wind technologies are relatively new in the Mediterranean.

1.4.1.2 Wave

For wave resource potential determination, this study uses a method comparable to the method for offshore wind. For wave energy technology, the best estimate of the capacity factor is from the Ocean Energy Systems/International Energy Agency LCOE report (OES & IEA, 2015). This relationship can be approximated with the following mathematical relationship:

$$\text{Capacity Factor} = 0.0445 \times \text{phi}^{0.552}$$

Here *phi* is wave resource in kW/m at the raster cell location. The wave FLH are determined by multiplying the capacity factor with 8,760 hours. The wave resource potential in MWh/year is then

[83] FLH equal the number of hours resulting from dividing the energy output of the turbine over the year by its rated power. In practice, a wind turbine will run for a longer time (load hours) than given by the FLH, as it will often run at less than 100% rated capacity.

calculated from the full load hours, the assumed wave power density (12.5 MW/km^2),[84] the raster cell area (1 km^2), and a wave operational efficiency of 95% (OES & IEA, 2015).

This study could not find any indication of how wave energy technology will develop after 2030. Therefore, the technical parameters are assumed to be the same in 2030 and 2050. However, as explained by Figure 1-19, this study does assume further cost reductions for wave energy between 2030 and 2050, even if it is unknown which technological developments this will come from.

1.4.1.3 Tidal

In the Mediterranean, significant tidal resources are only available in two specific locations: the straits of Messina and Gibraltar. This study found a resource potential of 125 GWh/year for the Strait of Messina (Coiro et al., 2013). In the Strait of Gibraltar, this study found a tidal potential capacity of 25 GW (Physical oceanography group, University of Malaga). With an expected capacity factor of 10%, this study obtained a tidal resource potential of 22 TWh/year in that area.[85]

1.4.1.4 Results

For all offshore technologies, the resulting available area within the EEZs of different countries after resource specific exclusions is in shown in Table 1-15. This study does not provide an area value for tidal technology, as it is available at only two specific locations.

Table 1-15: Available area in km^2 for offshore technologies after resource-specific exclusions

EEZ ID	Country	Bottom-fixed wind available area 2030 (km^2)	Bottom-fixed wind available area 2050 (km^2)	Floating wind available area 2030 (km^2)	Floating wind available area 2050 (km^2)	Wave available area 2030 and 2050(km^2)
1	Croatia	1,158	1,468	18,104	18,414	0
2	Cyprus	0	0	6,702	7,824	0
3	France	0	0	10,474	10,474	11,455
4	Greece	0	0	37,702	37,702	138,682
5	Italy	1,451	1935	83,797	84,917	44,844
6	Malta	76	76	22,652	22,652	25,309
7	Portugal	79	79	18,383	18,383	27,177
8	Slovenia	0	0	0	0	0
9	Spain	48	48	31,204	31,204	44,440
	Total	2,812	3,606	229,018	231,570	291,907

(Source: Guidehouse)

The values given in Table 1-15 represent the technical potential available if all suitable areas would be used to install RES technologies. In practice, legal, societal, economic, and other barriers will limit the amount of potential area that can be used.

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[84] SWECO internal communication.
[85] SWECO internal communication.

For both offshore wind technologies, the resource potential in 2050 is higher than the potential in 2030. This fact is a consequence of the increased wind turbine hub height by 2050. Turbine hub height influences the resource potential in two different ways. Firstly, the increased hub height results in a higher average wind speed at hub height and an increased local resource potential.

Secondly, the area available to offshore wind increases with an increased hub height. The higher hub height means a higher wind speed at hub height. This fact results in more locations meeting the minimum resource limit of 8 m/s windspeed at hub height. Therefore, more area is available, and the total resource potential is higher.

Table 1-16: Annual technical resource potential for offshore technologies

EEZ ID	Country	Bottom-fixed wind potential 2030 (TWh/a)	Bottom-fixed wind potential 2050 (TWh/a)	Floating wind potential 2030 (TWh/a)	Floating wind potential 2050 (TWh/a)	Wave potential2030 and 2050 (TWh/a)	Tidal potential 2030 and 2050 (TWh/a)
1	Croatia	17.9	22.9	313.2	325.3	0.0	0.0
2	Cyprus	0.0	0.0	109.7	128.1	0.0	0.0
3	France	0.0	0.0	271.0	276.5	174.6	0.0
4	Greece	0.0	0.0	840.3	858.4	1810.3	0.0
5	Italy	24.2	31.9	1,610.2	1,662.9	623.6	0.1
6	Malta	1.4	1.4	430.5	440.4	341.0	0.0
7	Portugal	1.9	1.9	427.3	436.3	887.9	0.0
8	Slovenia	0.0	0.0	0.0	0.0	0.0	0.0
9	Spain	1.0	1.1	580.5	594.0	660.8	22.0
	Total	46.3	59.2	4,582.6	4,722.0	4,498.3	22.1

(Source: Guidehouse)

The increase in resource potential for floating wind is mainly due to the first reason: higher local resource potential because of higher wind speeds at hub height. A relatively small increase of about 4% occurs in resource potential for floating wind.

For bottom-fixed wind, the increase in resource potential is much larger and reaches 32%. This increase is caused by the substantial increase in area available to the bottom-fixed technology between 2030 and 2050. The bottom-fixed wind potential is mainly concentrated in the Adriatic Sea. In that location, the most important limiting factor for resource potential is the area available for generation, and the available area is in turn constrained by the minimum resource limit.

Table 1-17: Installed capacity potential for offshore technologies

EEZ ID	Country	Bottom-fixed wind installed capacity 2030 (GW)	Bottom-fixed wind installed capacity 2050 (GW)	Floating wind installed capacity 2030 (GW)	Floating wind installed capacity 2050 (GW)	Wave installed capacity 2030 and 2050 (GW)	Tidal installed capacity 2030 and 2050 (GW)
1	Croatia	8.1	10.3	126.7	128.9	0.0	0.0
2	Cyprus	0.0	0.0	46.9	54.8	0.0	0.0
3	France	0.0	0.0	73.3	73.3	143.2	0.0
4	Greece	0.0	0.0	263.9	263.9	1,733.5	0.0
5	Italy	10.2	13.5	586.6	594.4	560.6	0.2
6	Malta	0.5	0.5	158.6	158.6	316.4	0.0
7	Portugal	0.6	0.6	128.7	128.7	339.7	0.0
8	Slovenia	0.0	0.0	0.0	0.0	0.0	0.0
9	Spain	0.3	0.3	218.4	218.4	555.5	25.0
	Total	19.7	25.2	1,603.1	1,621.0	3,648.8	25.2

(Source: Guidehouse)

For floating wind, the important limiting factors are maximum depth and distance to shore. Therefore, for this technology, the relative increase in available area is very small compared to bottom-fixed wind.

Table 1-17 shows resource potential installed capacities. The values represent the capacities that can be maximally installed in areas available to the different technologies for renewable generation. The following figures show the geographic variation of the resource potential for bottom-fixed wind turbines, floating wind turbines, and wave energy installations for 2030 and 2050.

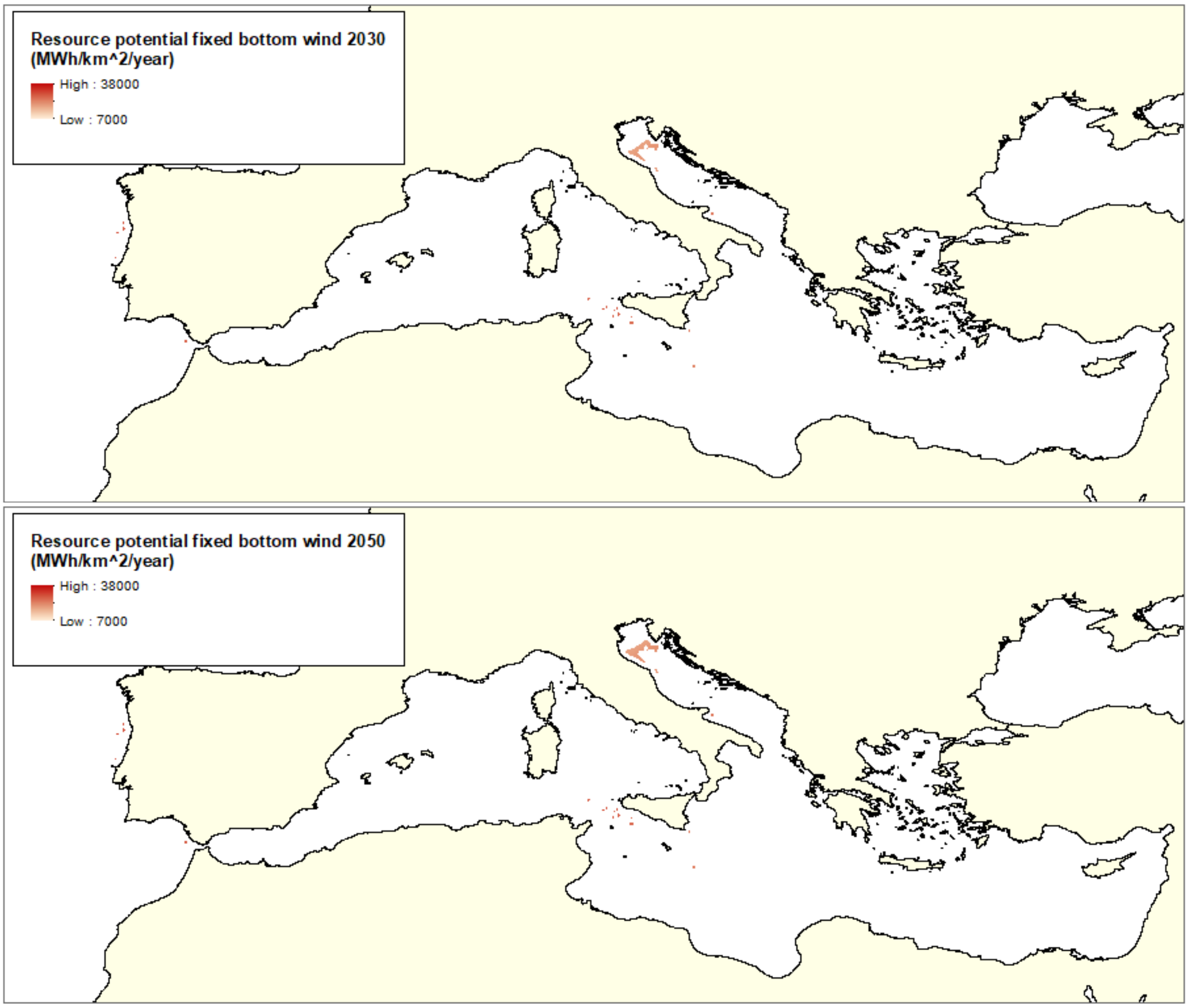

Figure 1-21: Resource potential for bottom-fixed wind turbines in 2030 and 2050

(Source: Guidehouse)

Figure 1-21 shows the resource potential of bottom-fixed wind. The map indicates the areas determined before by spatial exclusions. In the available areas, the colour code indicates the level of the available resources in MWh/km^2/year. Darker red colours mean higher resource levels. In the same way, Figure 1-22 shows the resource potential of floating wind technology.

Figure 1-23 shows the resource potential of wave energy installations. Here, the resource levels are indicated with blue colour scale, with darker blue corresponding to higher resource levels. Resource levels are the same for 2030 and 2050.

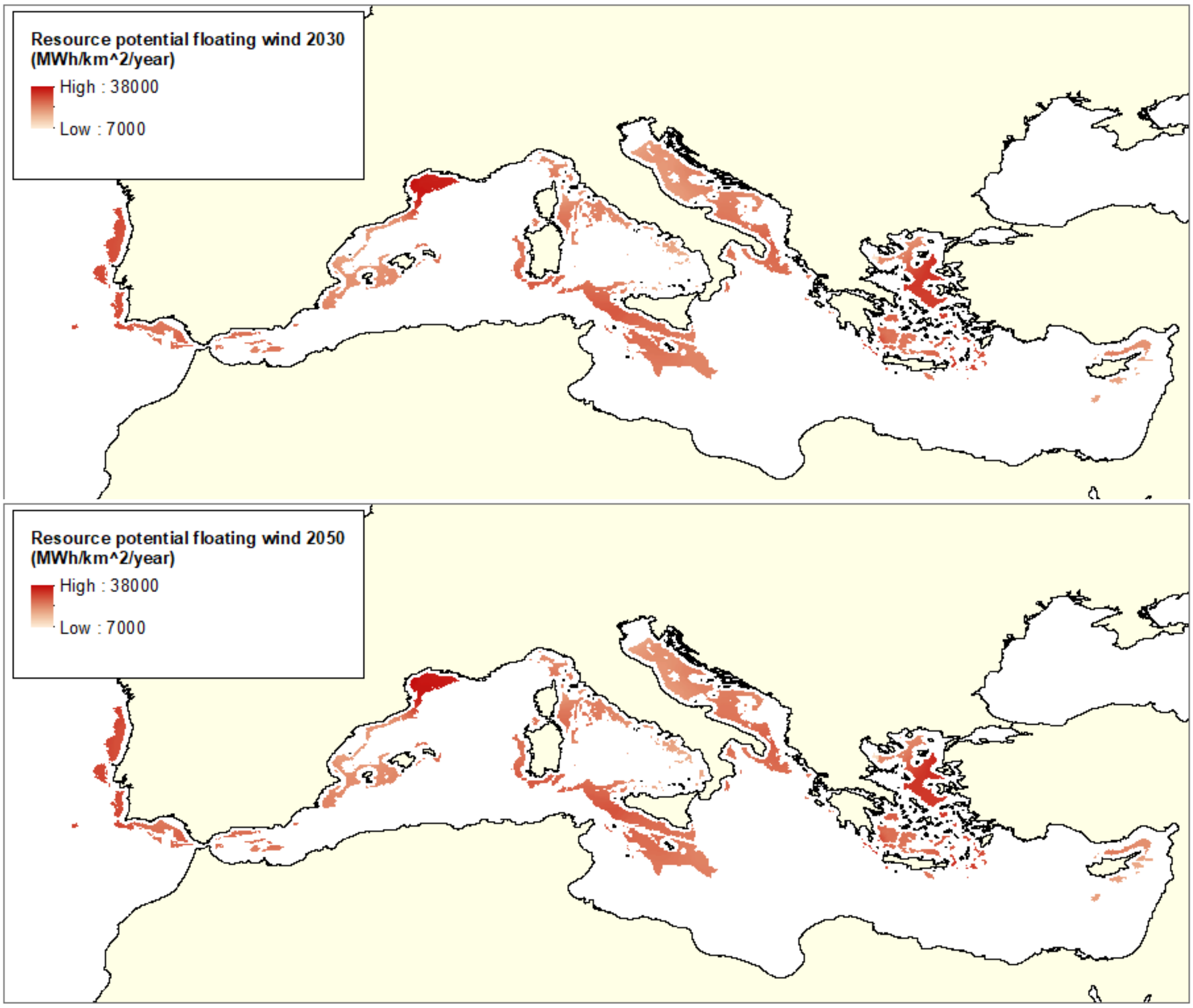

Figure 1-22: Resource potential for floating wind turbines in 2030 and 2050

(Source: Guidehouse)

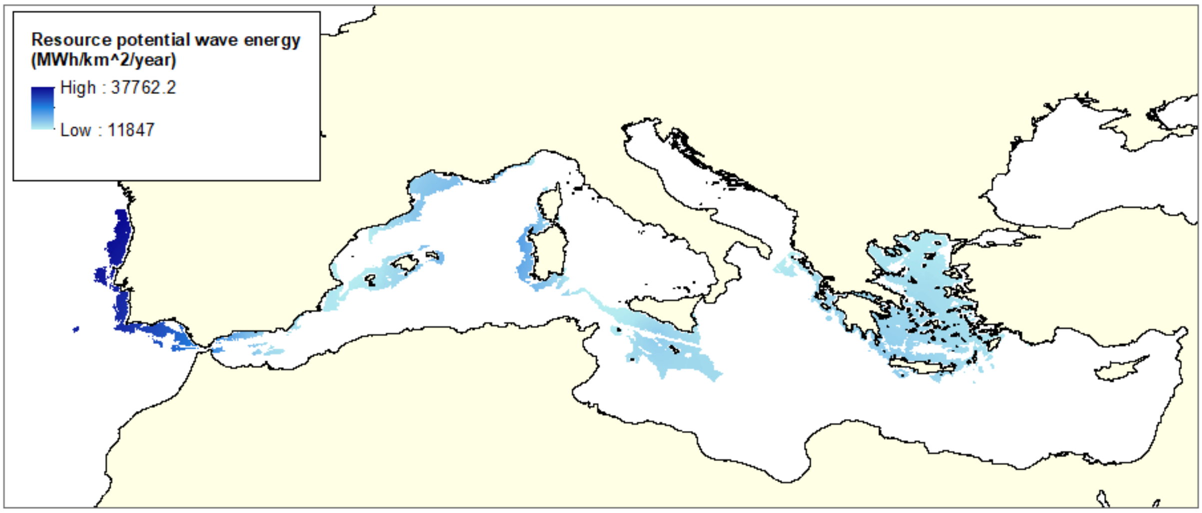

Figure 1-23: Resource potential for wave energy installations in 2030 and 2050

(Source: Guidehouse)

1.4.2 Resource potential on islands

This study considers the following technologies on islands: onshore wind, large-scale utility solar PV, and rooftop solar PV. It determines the resource potential for these onshore renewable technologies using an area-related method. This analysis does not look at individual islands but determines the average annual resource potential over all islands per country.

From the Guidehouse in-house resource potential model (Deng, et al., 2015), country-level values are known that express the percentage of the country's area available for RES generation for each technology. This study assumes that on islands alone, these percentages are the same as for the whole country. Onshore wind and utility-scale solar PV use a percentage of available surface area. For rooftop solar PV, the available rooftop area is translated into available area per capita by using average values of rooftop area per capita. The values used are shown in Table 1-18.

Using this study's geographical map, the coordinates of the location and area in square kilometres of all islands on the map within the EEZs of each country under study were determined. Figure 1-39 shows the islands involved. This study also uses a population density map (SEDAC, 2015) and combines it with the island areas to arrive at an estimate of the number of inhabitants of each island.

Table 1-18: Factors of area available for onshore technologies

Country	Suitable roof area per capita in 2030 (m2/capita)	Suitable roof area per capita in 2050 (m2/capita)	Area available for utility PV (%)	Area available for onshore wind (%)
Croatia	7.9	8.1	1.9%	2.3%
Cyprus	7.5	7.9	3.8%	12.0%
France	11.6	12.1	1.2%	3.9%
Greece	7.8	8.1	1.2%	1.3%
Italy	7.5	7.9	1.2%	2.4%
Malta	6.6	7.1	2.4%	9.9%
Portugal	7.7	7.9	0.8%	2.1%
Slovenia	14.1	14.7	0.5%	0.1%
Spain	7.2	7.6	1.0%	1.9%

(Source: Guidehouse)

Table 1-19: PV conversion factors

Technology	Year	Module efficiency	Performance ratio	Ground coverage	Overall conversion
Utility PV	2030	24.0%	80%	23.0%	4.4%
Utility PV	2050	29.5%	80%	26.5%	6.3%
Rooftop PV	2030	24.0%	80%	-	19.2%
Rooftop PV	2050	29.5%	80%	-	23.6%

(Source: Guidehouse)

For onshore wind, the same method was used as the method for offshore wind, described in Section 1.4.1. The average wind speed was sampled at the island location and calculated at hub height. The hub height is taken to be 150 m in all cases. The same formula for FLH and value of power density as for offshore wind are used to get the potential per square kilometre. Then, the island area and the percentage of area available from Table 1-18 gave the resource potential per island. For onshore wind, an operational efficiency of 98% and an array efficiency of 90% are assumed. The resource potential per country is determined by summing up the values from all islands within each country.

For solar photovoltaics, the study first determined the area available. For utility-scale solar PV, the available area was determined by multiplying the island area with the percentage of area available taken from Table 1-18. For rooftop solar PV, the available area was determined by multiplying the rooftop area per capita from Table 1-18 with the number of inhabitants.

Then, this study calculated the PV resource potential using:

- The module efficiency (IEA, 2012)
- The performance ratio[86]; this ratio captures the system's conversion efficiency from the module's output to usable electricity
- For large-scale utility PV, a ground coverage value[87]; this value is an estimate of the share of land capturing energy, i.e., the share actually covered with PV cells

Values are shown in Table 1-19. The values are taken from Guidehouse's in-house resource potential model and are on the conservative side. In general, this report tries to use numbers on the safe or low side when estimating maximal resource potential.

The conversion factors are multiplied together to get the overall solar conversion factor. Solar irradiation in kWh/m2/day sampled at the location of each island is then translated into solar resource potential in MWh/year by using this overall conversion factor and the previously determined available area. The resource potential per country is determined by summing up the values from all islands within each country.

The results of the resource calculations are shown in Table 1-20. Average resource values summed per country are given in TWh/year. For onshore wind, the resource potential is the same in 2030 and 2050 as this study assumes that the onshore wind turbine hub height will be the same in both years, as explained in Section 1.4.1. Table 1-21 presents the capacities of the different onshore technologies that can be maximally installed on islands.

Table 1-20: Annual resource potential for technologies on islands

Country	Onshore wind potential 2030 (TWh/a)	Onshore wind potential 2050 (TWh/a)	Rooftop PV potential 2030 (TWh/a)	Rooftop PV potential 2050 (TWh/a)	Utility PV potential 2030 (TWh/a)	Utility PV potential 2050 (TWh/a)
Croatia	1.5	1.5	0.3	0.4	4.3	6.0
Cyprus	18.9	18.9	3.4	4.4	30.3	42.9
France	6.8	6.8	1.4	1.8	7.8	11.1
Greece	7.0	7.0	4.3	5.5	23.0	32.5
Italy	23.5	23.5	22.4	28.9	43.7	61.9
Malta	0.7	0.7	1.1	1.4	0.7	0.9
Portugal[88]	0.0	0.0	0.1	0.1	0.1	0.1
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0
Spain	1.8	1.8	2.9	3.8	3.7	5.3
Total	60.3	60.3	36.0	46.4	113.6	160.8

(Source: Guidehouse)

[86] The term performance ratio, also called the quality factor (Q), refers to the relationship between actual yield and target yield. It indicates which portion of the generated current can actually be used.

[87] The ground coverage is derived from typical power densities of solar farms (25-50 MW/km^2) in comparison with the raw module power density of a typical solar cell of 125-150MW/km^2.

[88] For Portugal, the islands are located in the Atlantic Ocean and not in the Mediterranean Sea.

Table 1-21: Installed capacity potential for technologies on islands

Country	Onshore wind installed capacity 2030 (GW)	Onshore wind installed capacity 2050 (GW)	Rooftop PV installed capacity 2030 (GW)	Rooftop PV installed capacity 2050 (GW)	Utility PV installed capacity 2030 (GW)	Utility PV installed capacity 2050 (GW)
Croatia	0.6	0.6	0.2	0.3	3.1	4.4
Cyprus	7.9	7.9	2.1	2.7	18.4	26.0
France	2.4	2.4	0.9	1.1	4.9	6.9
Greece	2.1	2.1	2.6	3.3	13.7	19.4
Italy	8.3	8.3	13.1	16.9	26.1	36.9
Malta	0.2	0.2	0.6	0.8	0.4	0.6
Portugal[88]	0.0	0.0	0.0	0.1	0.0	0.1
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0
Spain	0.7	0.7	1.8	2.4	2.3	3.3
Total	22.1	22.1	21.4	27.6	68.9	97.5

(Source: Guidehouse)

1.5 Economic potential

Task 1.5 determines the LCOE for each generation technology across the Mediterranean region in the zones where they are applicable based on:

- Available area (derived in Task 1.3)
- Energy yield (derived in Task 1.4)
- Technology-specific CAPEX and OPEX projections for 2030 and 2050 scenarios based on public literature and Guidehouse in-house cost modelling expertise.

LCOE maps illustrate the areas with economic potential for offshore energy in the region. Also, costs curves that indicate the LCOE (€/MWh) versus generated power (TWh) for each of the Mediterranean areas are used to assess the economic potential for offshore energy in the Mediterranean.

1.5.1 LCOE methodology

The LCOE or the cost of generating electricity for a technology system over the system's lifetime is calculated using the following formula and associated parameters (NREL, n.d.):

$$\mathbf{LCOE} = \left(\frac{\mathbf{CAPEX} \times \mathbf{CRF} \; + \mathbf{fixed\ OPEX}}{\mathbf{8,760} \; \times \; \mathbf{capacity\ factor}}\right) \qquad \mathbf{Capital\ Recovery\ Factor\ (CRF)} = \frac{\mathbf{i(1+i)^n}}{\mathbf{(1+i)^n - 1}}$$

The following parameters are included in the cost analysis:

- CAPEX: relates to the investment cost expressed in €/MW installed
- Fixed OPEX: relates to the operation and maintenance cost expressed as fixed €/MW/year

- Capacity factor: represents the share of the time in a year that a power plant generates power
- i: represents the discount rate that depends on the technology's cost of capital (cost of debt and cost of equity) and the financial risk. The LCOE cost calculation uses different weighted average cost of capital (WACC) rates per technology.
- Lifetime: years of the technology's power plant

Grid connection costs, taxes, land costs, and decommissioning costs are excluded from the LCOE cost calculation. Although grid connection costs may be significant in certain regions with limited grid connectivity and this situation may vary between countries, these costs are not specific to the cost development of each technology. Onshore and offshore transmission asset connection costs (i.e., offshore substation and export cable) are not considered in this economic potential assessment, which focuses on production technologies and production blocks. Only connection costs between the different individual pieces of equipment within an offshore energy plant (e.g., the array cables that connect the turbines in an offshore wind farm to an offshore substation) are included in these CAPEX and fixed OPEX estimates. The grid connection is subject to further optimisation in Task 3.

In centralised grid delivery models, these costs are often borne by Transmission System Operators and not by project developers (Navigant, 2019) Taxes are specific to each country and not intrinsic to the cost development of each technology. Similarly, although land costs may have a particular importance in certain densely populated regions or countries such as Malta, these may be very specific to each country and have not been included as part of the CAPEX or OPEX input assumptions of each onshore technology. Finally, decommissioning costs are very uncertain at this point and do not have a large impact on the overall LCOE. Decommissioning costs are estimated to represent a small share of the total undiscounted project costs between 2-3%. (Topham E. and McMillan, 2017). In addition, the impact of decommissioning costs on the LCOE is estimated around 1% (Department of Business, Energy and Industrial Strategy, 2018). Table 1-22 gives an overview of the approach taken per technology on the cost inputs and calculation method.

Table 1-22: Cost modelling approach per renewable energy technology

Technology	CAPEX/OPEX approach	LCOE approach
Bottom-fixed offshore wind	CAPEX for 2030 and 2050 on a local level based on local water depth OPEX for 2030 and 2050 on a local level based on distance to shore	LCOE varies on a local level due to differences in costs (based on distance to shore and water depth) and wind yield (Task 1.4)
Floating offshore wind	Fixed CAPEX for 2030 and 2050. • Less dependency on water depth • Higher cost uncertainty than for bottom-fixed offshore wind, which is a more mature technology Average OPEX for 2030 and 2050 based on local distance to shore	LCOE varies due to local differences in wind energy yield and OPEX (Task 1.4)
Solar PV	Fixed CAPEX and OPEX for 2030 and 2050, irrespective of location as solar PV modules are a European market: • Utility solar PV • Rooftop solar	LCOE varies due to differences in solar energy yield (Task 1.4)
Onshore wind	Fixed CAPEX and OPEX for 2030 and 2050, irrespective of location as onshore wind turbines are a European market	LCOE varies due to differences in wind energy yield (Task 1.4)
Wave energy	Fixed CAPEX and OPEX for 2030 and 2050	LCOE varies due to differences in wave energy yield (Task 1.4)
Tidal energy	Fixed CAPEX and OPEX for 2030 and 2050	LCOE varies due to differences in tidal energy yield (Task 1.4)

(Source: Guidehouse)

Importantly, CAPEX levels for bottom-fixed offshore wind depend on water depth. Guidehouse's offshore wind cost model is used as a basis to differentiate CAPEX costs for sites with differing water depths. However, in this economic assessment, floating offshore wind CAPEX is assumed to be independent from water depths. In the light of the aim of the study and of Task 1, the cost analysis is used to identify the 10 most promising TMAs for further analysis in Tasks 2 and 3. The error introduced through this cost simplification should not affect the outcome of the selected sites strongly since there is a maximum water depth deemed feasible for floating offshore wind.

In terms of fixed OPEX cost levels, cost differentiation based on the project's distance to shore becomes relevant. Typically, both bottom-fixed and floating offshore wind projects include the use of Service Operation Vessels in their operation and maintenance strategies for wind farms located at distances to shore greater than 75 km. Therefore, this significant operational cost is included as an OPEX element in the LCOE calculation only for sites at a distance to shore greater than 75 km (The Crown Estate, 2013). Figure 1-24 and Figure 1-25 show the specific CAPEX and OPEX input values used for 2030 and 2050 to calculate LCOE levels per technology.

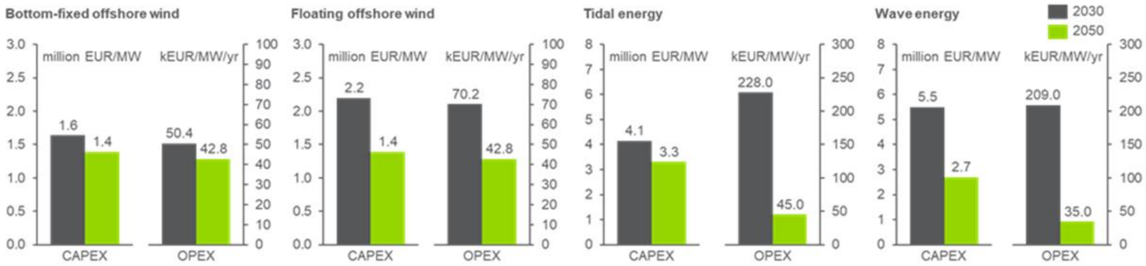

Figure 1-24: CAPEX and OPEX for 2030 and 2050 for offshore technologies

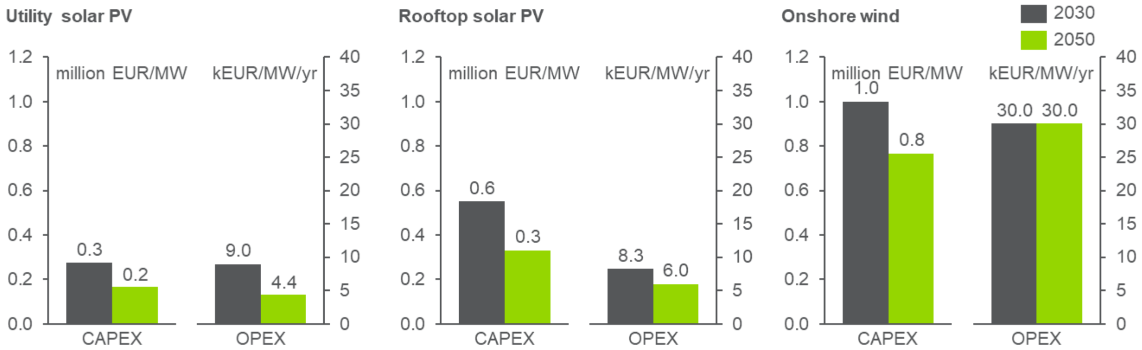

Figure 1-25: CAPEX and OPEX for 2030 and 2050 for onshore technologies

(Source: Guidehouse)

Figure 1-24 and Figure 1-25 suggest that utility solar PV followed by rooftop solar PV and onshore wind are the technologies with the lowest projected investment costs towards 2030 and 2050. Investment costs for floating offshore wind are anticipated to remain higher than those of bottom-fixed offshore wind. However, towards 2050, investment costs for floating offshore wind are expected to reach similar cost levels as bottom-fixed offshore technology.

Wave and tidal energy technologies should remain the most expensive technologies. In 2030, investment costs for wave and tidal are expected to remain approximately 5.5 times and 4 times as high as the investment costs for onshore wind, respectively. Towards 2050, a significant decline in investment costs is expected for wave energy technology. A detailed list of the investment and operational input cost figures used for 2030 and 2050 and its sources is included in Figure 1-26 Multiple sources have been considered for each cost input assumption, and the cost inputs chosen are in line with other well-known studies from the International Energy Agency, the International Renewable Energy Agency, and ASSETS.

Table 1-23: WACC and lifetime per generation technology for LCOE cost analysis

	Offshore energy				Onshore energy on islands		
	Bottom-fixed offshore wind	Floating offshore wind	Tidal energy	Wave energy	Utility Solar PV	Rooftop Solar PV	Onshore wind
WACC (%)	5.5%[91]	5.5%[91]	10.0%[89]	10.0%[89]	5.6%[90]	5.6%[90]	7.0%[90]
Lifetime (years)	30[91]	25[91]	20[89]	20[89]	25[90]	25[90]	25[90]

(Source: Guidehouse)

The WACC is heavily dependent on each technology's cost of debt financing, cost of equity financing, and the financial risk of the markets considering these technologies. Values for the technologies' lifetime are taken from current standard industry practices. Table 1-23 shows an overview of the estimated WACC assumed for the Mediterranean region and the lifetime used per technology.

1.5.2 LCOE results per technology

LCOE are calculated per country based on the methodology explained in Section 1.5.1; the available area and energy yields derived from Tasks 1.3 and 1.4, respectively; and the cost input assumptions taken in Section 1.5.1. Figure 1-26 and Figure 1-27 show the LCOE levels in €/MWh per technology and per country.

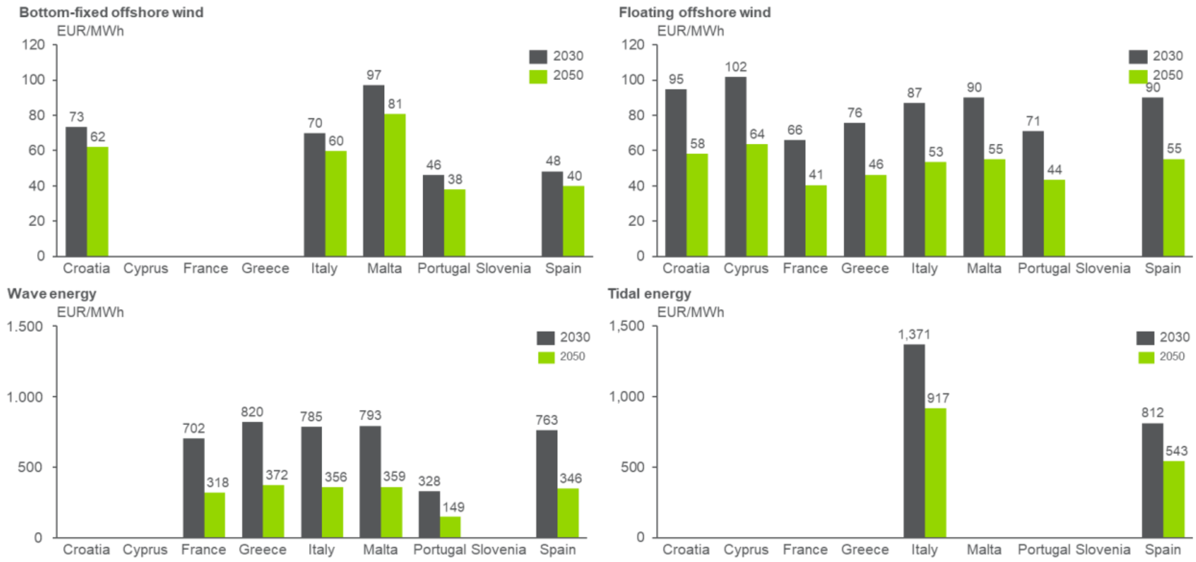

Figure 1-26: Average LCOE levels for offshore technologies per country for 2030 and 2050

(Source: Guidehouse)

Figure 1-26 shows the average LCOE results calculated based on the input parameters in Figure 1-24, Figure 1-25, and Table 1-23. Input assumptions are further detailed in Section 1.5. Average LCOE results show that bottom-fixed offshore wind is most cost competitive in Portuguese and

[89] (OES & IEA, 2015)

[90] (Bachner et al., 2019)

[91] (BVG Associates, 2017)

Spanish waters, with LCOE levels around 46-48 €/MWh in 2030 and 38-40 €/MWh in 2050. Notably, the bottom-fixed offshore wind potentials in these areas remain low at 1.9 TWh/year and 1.1 TWh/year, respectively according to Table 1-16. Italy's and Croatia's potentials are higher at 24-32 TWh/year and 18-23 TWh/year, respectively.

Waters off the coasts of France and Portugal are the preferred locations for floating offshore wind farms. LCOE levels in those areas range 66-71 €/MWh in 2030 and 41-44 €/MWh in 2050. However, floating offshore wind potentials are highest in Italy (1610-1663 TWh/year), Greece (840-858 TWh/year), and Spain (581-594 TWh/year).

For wave energy, Portuguese waters result in the best economic option again, with a significantly lower LCOE in 2030 and 2050 compared to the rest of the member states, namely 328 €/MWh (2030) and 149 €/MWh (2050). Portugal has the second highest wave energy potential (888 TWh/year) after Greece (1810 TWh/year).

Among the two selected sites for tidal energy, Spain hosts the site with a significantly lower LCOE and the highest tidal energy potential compared to Italy. Tidal energy projects in Spain could deliver a total of 22 TWh/year at an LCOE level of 812 €/MWh in 2030 and 543 €/MWh in 2050. Finally, LCOE levels are not determined for countries where the resource potential is zero, as derived in Task 1.4.

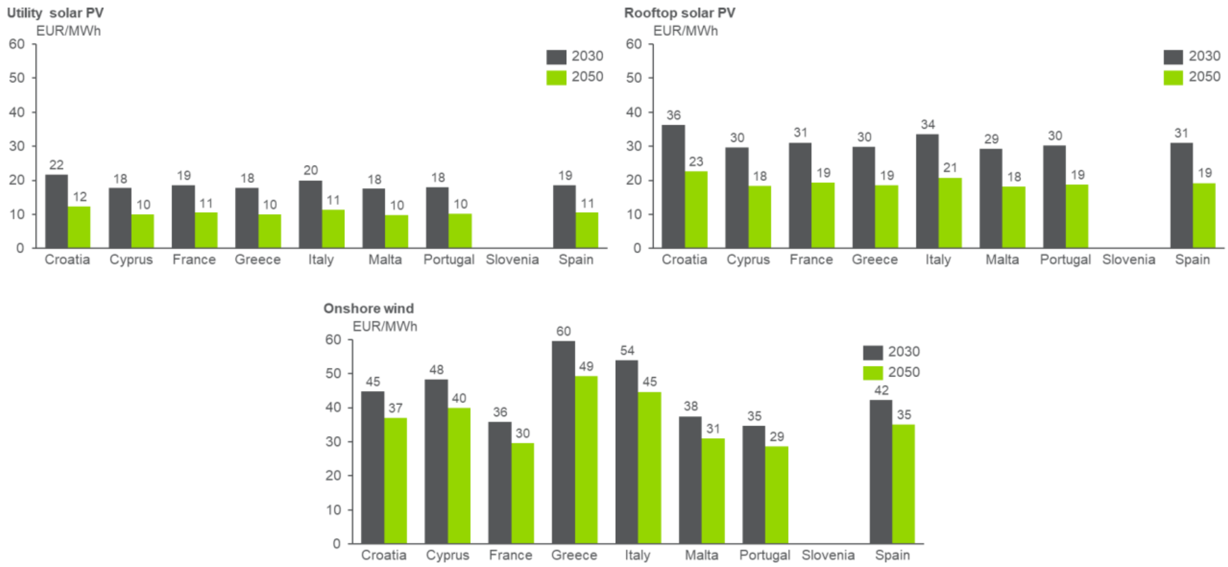

Figure 1-27: Average LCOE levels for onshore technologies on islands for 2030 and 2050

(Source: Guidehouse)

LCOE levels for onshore technologies are generally much lower than those for offshore technologies (Figure 1-27). The LCOE levels are a result of our input assumptions and do not include any costs for grid connection. Utility solar PV and rooftop solar PV show attractive economic potential in all member states except in Slovenia, where the resource potential was set to zero since there are no islands. LCOE levels for utility solar PV technology range 18-22 €/MWh in 2030 and 10-12 €/MWh in 2050. For rooftop solar PV, LCOE levels amount to 29-36 €/MWh in 2030 and 18-23 €/MWh in 2050. Onshore wind LCOE levels are higher than those of solar technologies but still below those of bottom-fixed offshore wind. Similar to solar energy, onshore wind energy is an available resource on all countries' islands except in Slovenia, with LCOE levels ranging between 35-60 €/MWh (2030) and 29-49 €/MWh (2050).

1.5.3 Geographical analysis of LCOE

The LCOE has a geographical dependency through several factors. The annual yield depends on the average resource potential of the technology, thereby strongly influencing the cost of electricity produced over the lifetime of a production installation. The LCOE for bottom-fixed wind turbines have a high dependency on the water depth. Deeper waters result in increased material use for the foundations of the wind turbines and increased installation costs. The depth dependency of bottom-fixed offshore wind turbines already led to an exclusion of all waters with a depth over 50 m, resulting in a very limited available area for deployment.

Figure 1-28 and Figure 1-29 present the geographical variation of the LCOE of bottom-fixed wind in 2030 and 2050.

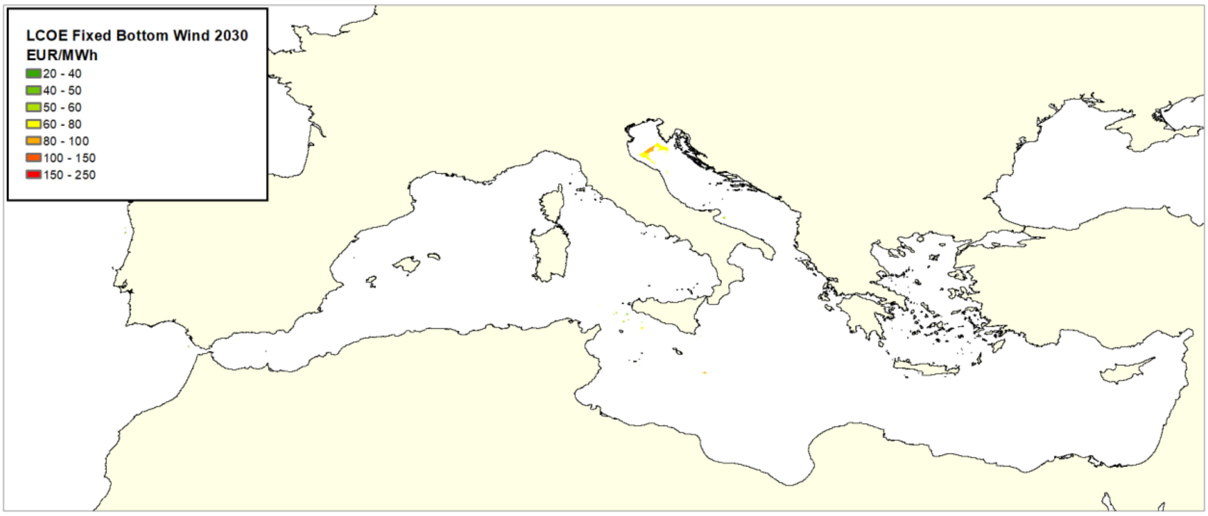

Figure 1-28: LCOE of bottom-fixed wind in 2030[92]

(Source: Guidehouse)

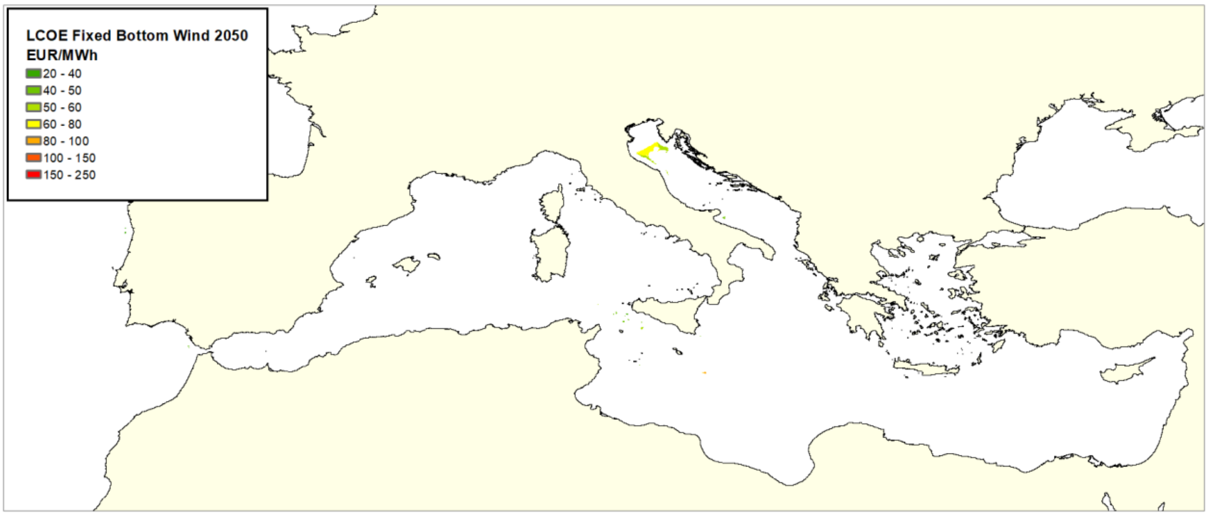

Figure 1-29: LCOE of bottom-fixed wind in 2050

(Source: Guidehouse)

Figure 1-30 presents the LCOE of floating wind in 2030, and Figure 1-31 presents the LCOE of floating wind in 2050.

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[92] Please note that the available area for fixed bottom wind turbines is relatively small, mostly located in the Adriatic Sea.

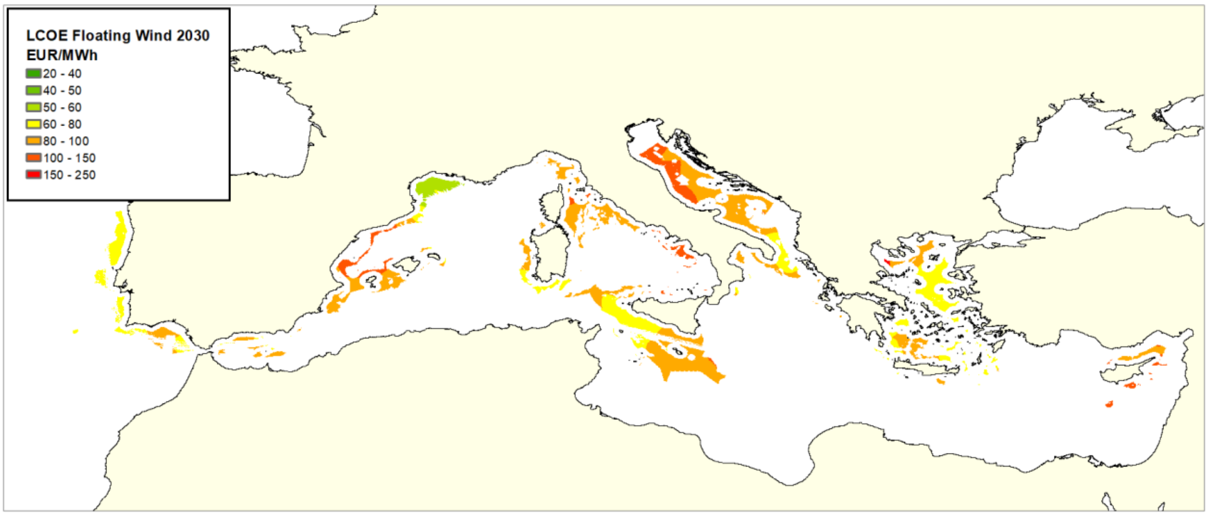

Figure 1-30: LCOE of floating wind in 2030

(Source: Guidehouse)

Floating wind turbines have less spatial constraints as they can be deployed up to a depth of 1,000 m. However, the technology is still in early phases of deployment and not nearly as mature as bottom-fixed wind turbines.

Figure 1-30 shows that most of the available area has an LCOE of 60 to 100 €/MWh in 2030 (LCOE values without grid connection costs to shore; see Section 1.5.1). Increased deployment in the Mediterranean Sea and in other regions of the world is expected to drive down costs and increase efficiency in the rollout of floating wind turbines. Figure 1-31 shows that spatial availability increases slightly due to higher hub heights; meanwhile, LCOE decreases significantly for floating wind turbines in 2050 due to reduced costs and increased efficiency.

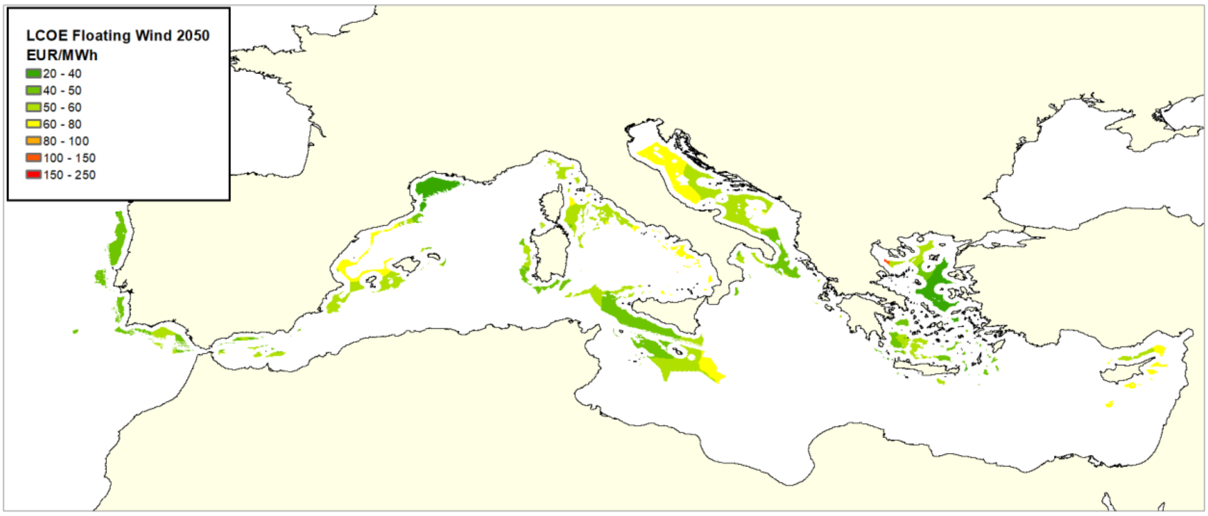

Figure 1-31: LCOE of floating wind in 2050

(Source: Guidehouse)

Figure 1-32 and Figure 1-33 show maps of the LCOE of wave technology in 2030 and 2050. In these figures, the geographic variation of LCOE levels of floating wave technology are shown. Estimated spatial availability and wave resource potential is the same in both years investigated. Low maturity of wave technology and lack of technological progress paths with clear and strong cost reduction potential cause high LCOE levels. For 2030, an LCOE of up to 900 €/MWh is expected. In 2050, the LCOE is expected to drop to a range of 100-400 €/MWh as the technology is likely to develop.

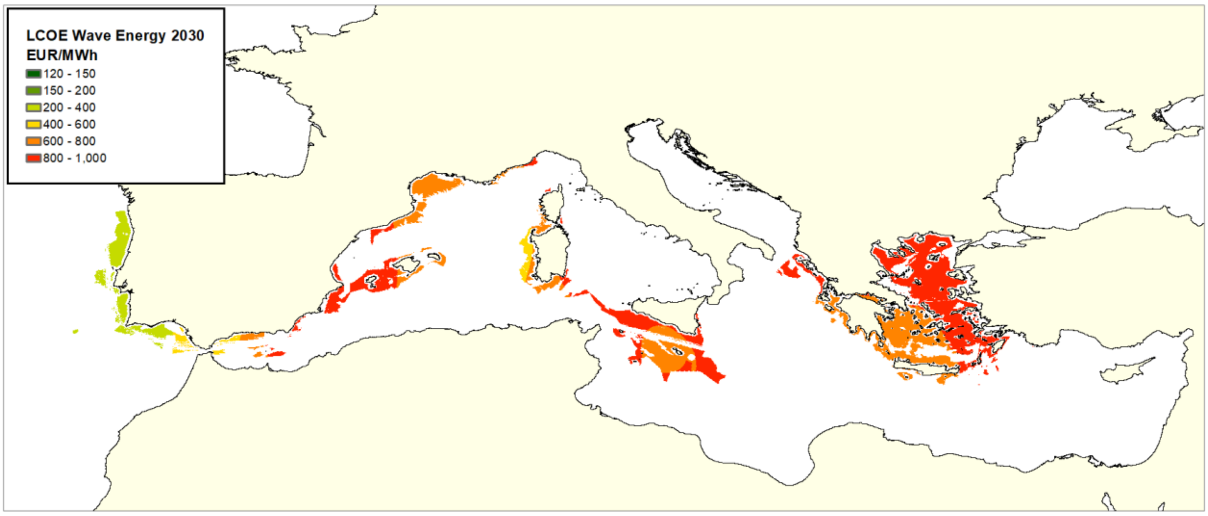

Figure 1-32: LCOE of wave technology in 2030

(Source: Guidehouse)

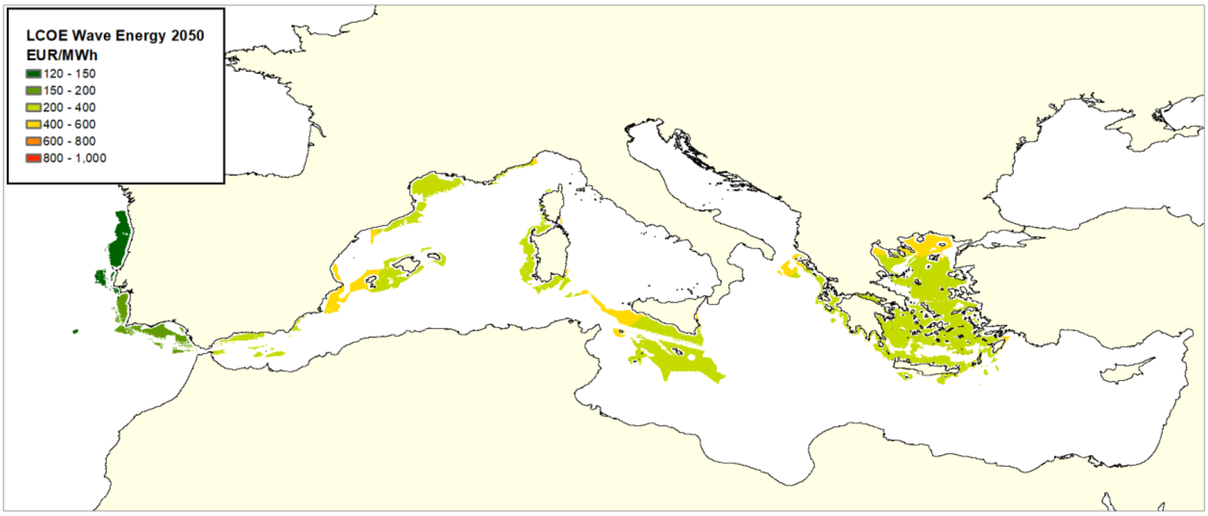

Figure 1-33: LCOE of wave technology in 2050

(Source: Guidehouse)

1.5.4 Cost curves

Cost curves show the LCOE against the available cumulative resource potential for each technology. By sorting the LCOE for all locations and summing the resource potential for each next expensive location, the amount of resource potential available below a certain level of LCOE can be shown. The cost curve plots in this section show the locations are colour coded according to EEZ.

Figure 1-34 shows the cost curves for bottom-fixed wind. Again, the potential for bottom-fixed wind turbines is limited, but the maturity of the technology results in a low LCOE. Most potential occurs in Italy and Croatia, which represents the resource potential of the area in the Adriatic Sea. We see again the total potential in 2050 is higher because the assumption of an increased hub height in 2050 and cost levels are lower for that year.

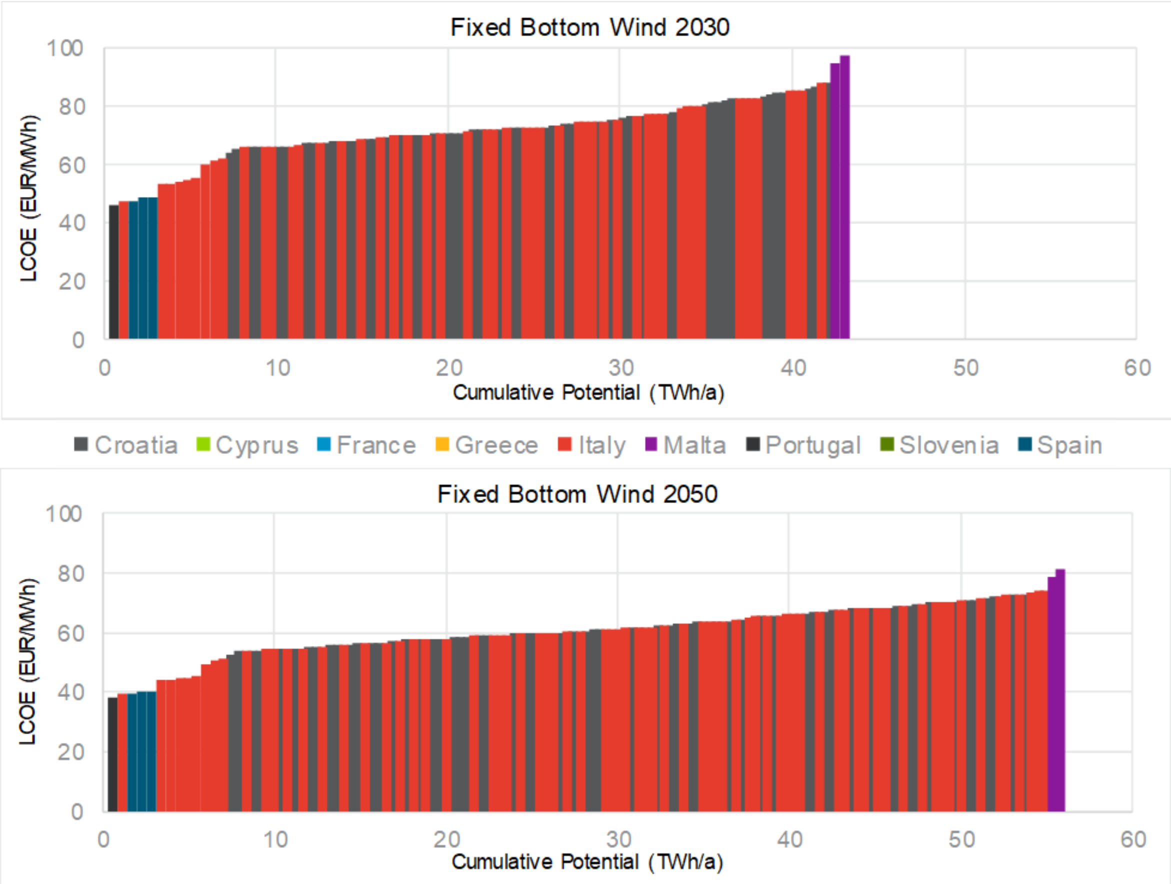

Figure 1-34: Cost curves for bottom-fixed wind in 2030 and 2050

(Source: Guidehouse)

Figure 1-35 shows the cost curves for floating wind technology in 2030 and 2050. The less mature technology shows higher LCOE levels than for bottom-fixed wind. For floating wind in 2050, the increased hub height results in a higher cumulative potential. In 2050, the technological advancement results in a lower LCOE for floating wind turbines.

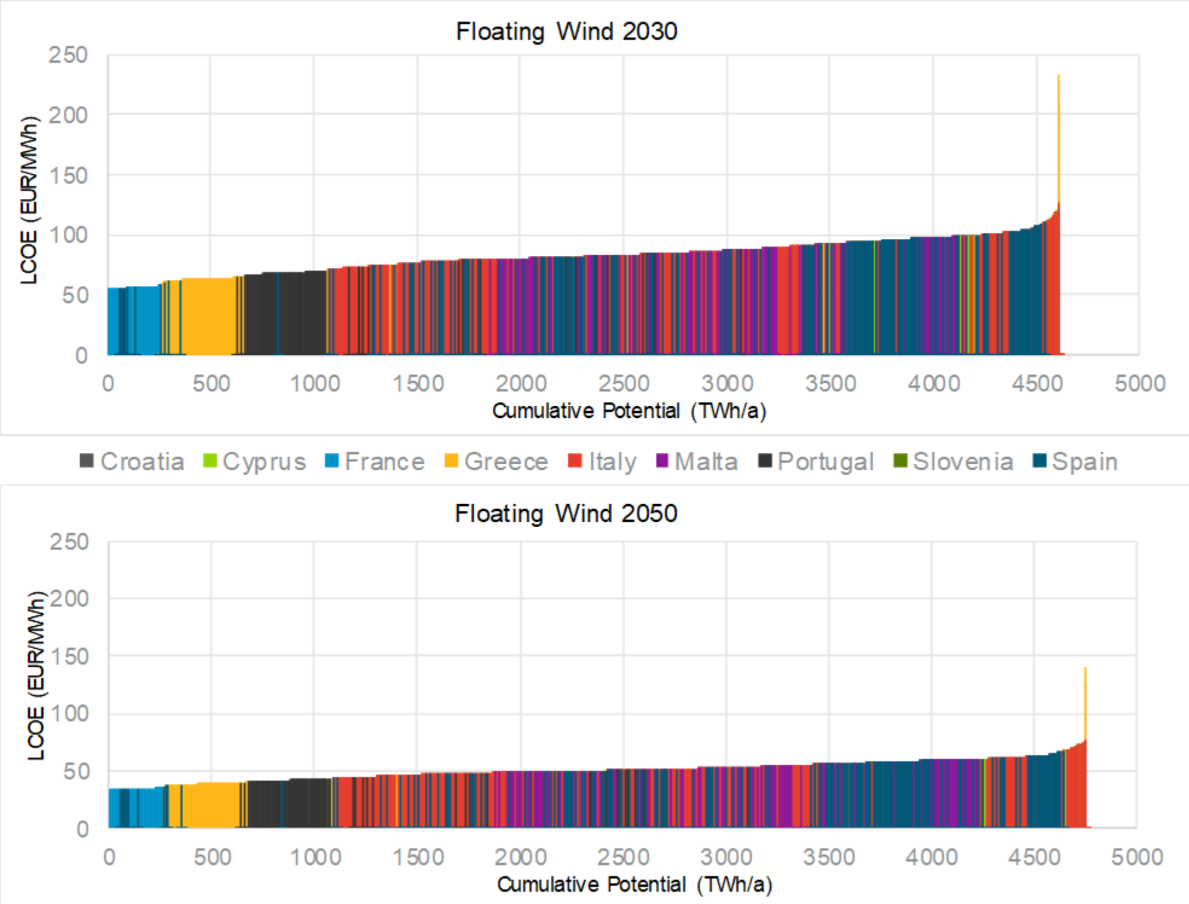

Figure 1-35: Cost curves for floating wind in 2030 and 2050

(Source: Guidehouse)

The cost curves for wave technology in 2030 and 2050 are shown in Figure 1-356. The substantial wave resource potential of the Atlantic coast of Portugal and (to a lesser extent) of Spain remains clearly visible. Higher waves in the Atlantic part of this area result in LCOE levels below 400 €/MWh in 2030. In the Mediterranean, less wave energy is available, resulting in clearly higher LCOE levels of 500–900 €/MWh. Costs are expected to decrease significantly between 2030 and 2050. The LCOE for wave energy in the Portuguese part remains below 200 €/MWh in 2050. All of these values are still significantly above those for wind energy and OV on islands as well as offshore wind and tidal.

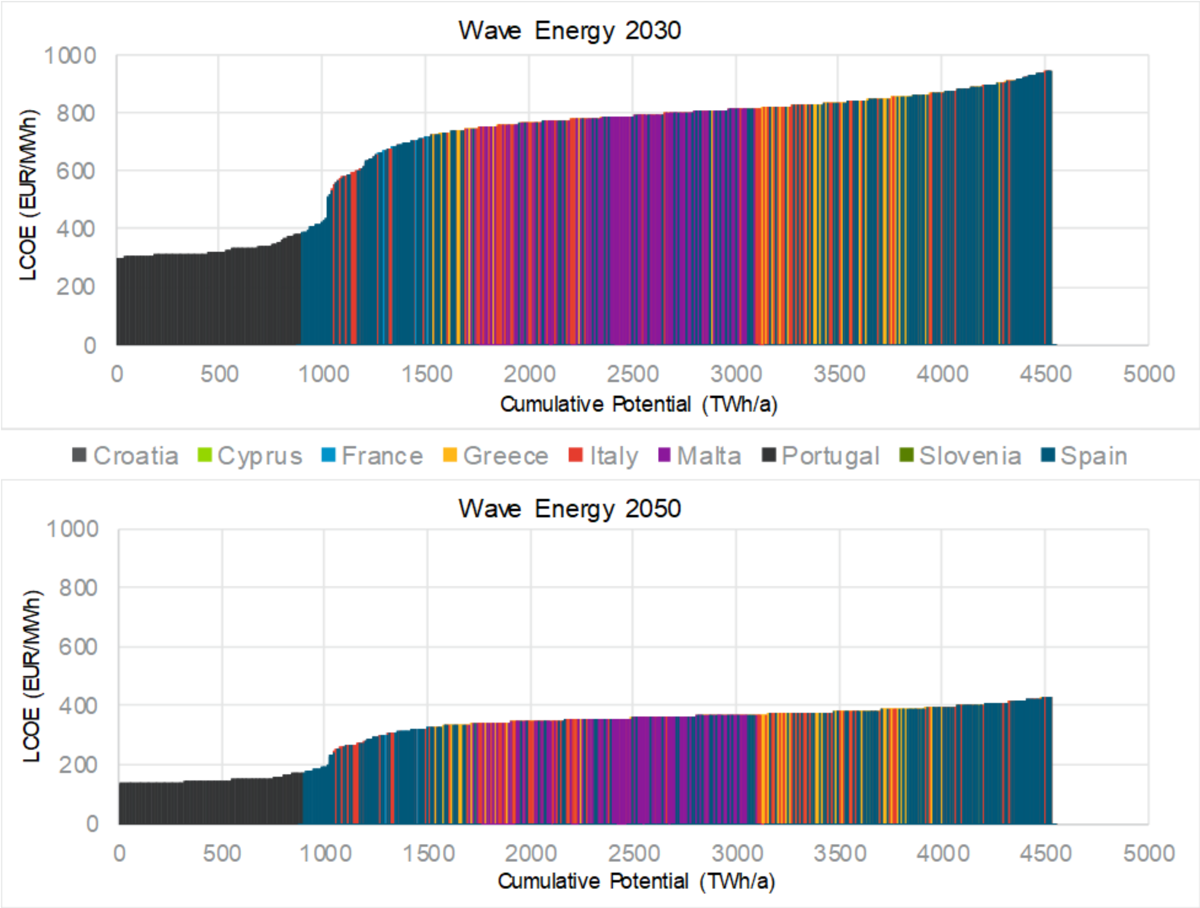

Figure 1-36: Cost curves for wave technology in 2030 and 2050

(Source: Guidehouse)

This study has also determined the combined cost curves with the following considerations:

- For each location in the offshore area under study, the study determined if at least one technology has a resource potential above zero.
- Then, the study determined which technology has the lowest LCOE in those locations.
- Each location was then assigned the resource potential of its cheapest technology.
- After sorting by LCOE and taking the cumulative sum of the assigned resource potentials, the combined cost curve was obtained.

The results for 2030 and 2050 are show in Figure 1-37. In these figures, the cost curves are colour coded with the cheapest technology of the location. The potential for bottom-fixed wind turbines is very low compared to floating wind turbines. Wave energy has the highest LCOE levels. Wave energy LCOE drops in 2050 but remains expensive when compared with the other technologies.

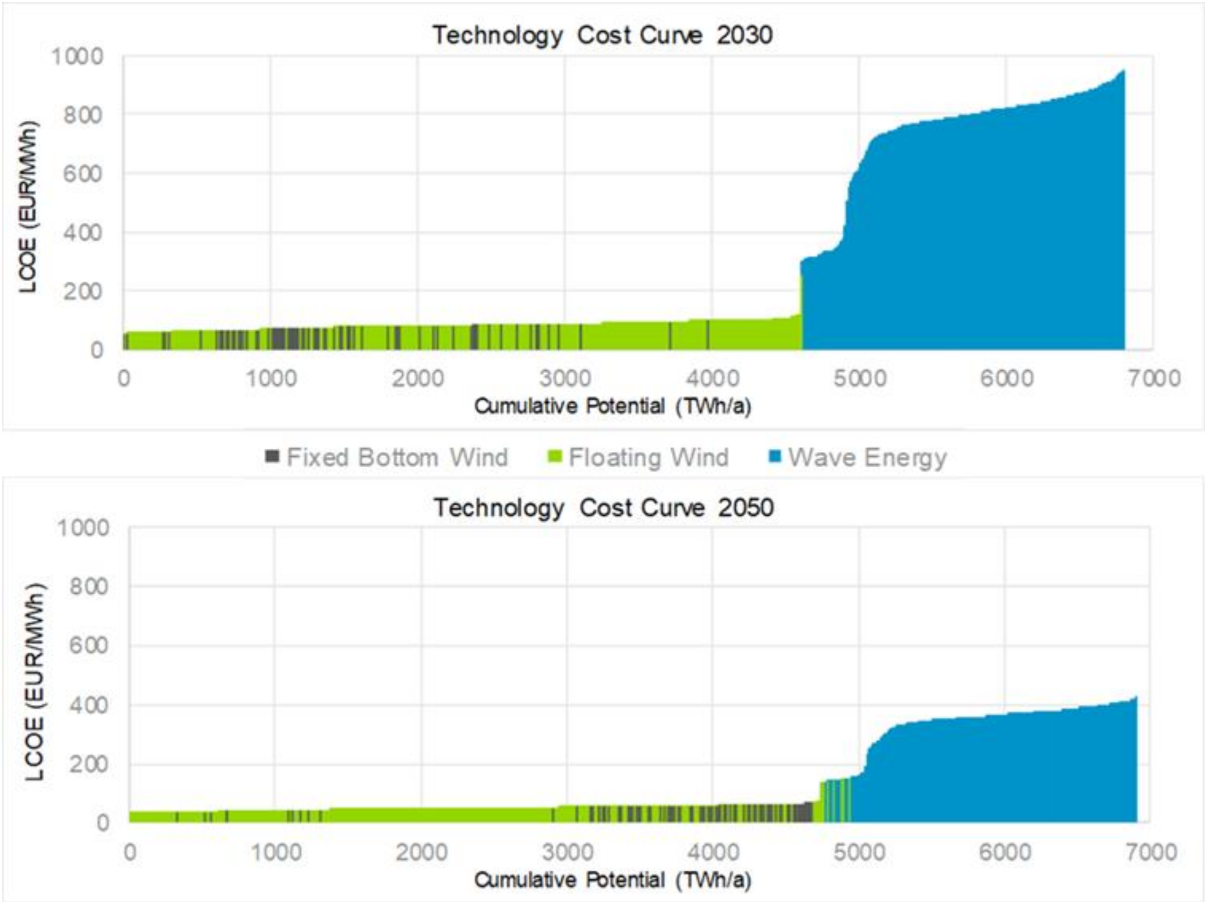

Figure 1-37: Combined cost curves for all offshore technologies in 2030 and 2050

(Source: Guidehouse)

1.6 Performance ranking

For the Mediterranean region under study, this section provides a more detailed look at selected areas that are most promising for offshore energy development. This study identifies the areas with the greatest cost-effective potential for various technologies or combinations thereof, using a manual ranking system.

1.6.1 TMAs and production zones

Within the areas available for power generation by wind and wave energy, TMAs are identified where the power production is high. These 10 TMAs were chosen based on the available areas for the four technologies. Area locations are carefully considered and chosen based on appropriate levels of resource potential and LCOE. Some areas are prioritised above other regions for more practical reasons. For example, the TMA in the northern part of the Adriatic Sea has not been selected for the LCOE (which is relatively high) due to the availability of bottom-fixed wind turbine development areas. As the technology readiness level of bottom-fixed wind turbines is higher than that of floating bottom wind turbines, this area should be prioritized in an offshore energy production rollout. Also, locations favourable for including the connection hub within a meshed grid are given higher priority.

The TMAs have a size of roughly 120x120 km but are not always square. The aspect ratio can vary to best fit regions of high resource potential. Within the TMAs, this study defines several production blocks. Production blocks have a size of roughly 140 km^2, which corresponds to a typical offshore wind farm size of 1 GW having a power density of 7 MW/ km^2. The production blocks do not necessarily fill the entire TMAs but are defined only at locations with sufficient resource potential. The locations of the production blocks remain the connection point for the grid options analysis in Task 2. For each production block, this study calculated total resource potential, maximum installed capacity, and average LCOE for all technologies. When considering resource costs for LCOE calculations in production blocks, all connection costs within the production blocks are considered. All other grid connection costs are part of the analysis in Tasks 2 and 3. Figure 1-38 presents the TMAs and defined production blocks.

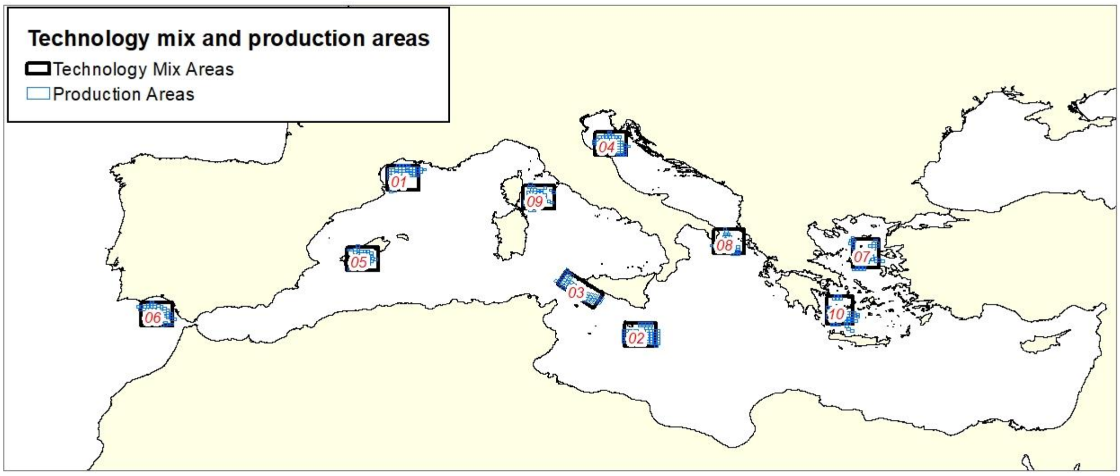

Figure 1-38: TMAs and production areas within the TMAs

(Source: Guidehouse)

Table 1-24, Table 1-25, and Table 1-26 present the results summarised over the production blocks defined in the TMAs. The results represent the total technical potential available if all production blocks are used completely. Table 1-24 shows the installed capacity if the production blocks are fully used.

Table 1-24: Installed capacity potential for each technology in production blocks defined for TMAs

TMA label	Description	Bottom-fixed wind installed capacity 2030 (GW)	Bottom-fixed wind installed capacity 2050 (GW)	Floating wind installed capacity 2030 (GW)	Floating wind installed capacity 2050 (GW)	Wave installed capacity 2030 (GW)	Wave installed capacity 2050 (GW)
01	Gulf of Lion	0.0	0.0	49.2	49.2	89.9	89.9
02	Malta	0.5	0.5	68.8	68.8	126.1	126.1
03	Sicily	1.6	1.6	67.0	67.0	83.4	83.4
04	Gulf of Venice	12.9	17.2	42.7	47.0	0.0	0.0
05	Baleares	0.0	0.0	37.4	37.4	74.2	74.2
06	Gulf of Cádiz	0.2	0.2	34.5	34.5	64.2	64.2
07	North Aegean Sea	0.0	0.0	51.9	51.9	96.0	96.0
08	Italy - Ionian Sea	0.0	0.0	35.1	35.1	30.0	30.0
09	Corsica - Sardinia	0.0	0.0	36.3	36.3	0.0	0.0
10	South Aegean Sea	0.0	0.0	49.5	49.5	94.0	94.0
	Total	15.2	19.4	472.5	476.8	657.8	657.8

(Source: Guidehouse)

Table 1-25: Total resource potential in production blocks defined for TMAs

TMA label	Description	Bottom-fixed wind potential 2030 (TWh/a)	Bottom-fixed wind potential 2050 (TWh/a)	Floating wind potential 2030 (TWh/a)	Floating wind potential 2050 (TWh/a)	Wave potential 2030 (TWh/a)	Wave potential 2050 (TWh/a)
01	Gulf of Lion	0.0	0.0	202.2	206.2	110.5	110.5
02	Malta	1.4	1.4	184.3	188.5	134.5	134.5
03	Sicily	4.9	5.0	209.2	213.8	79.1	79.1
04	Gulf of Venice	28.2	38.0	97.2	108.7	0.0	0.0
05	Baleares	0.0	0.0	90.6	92.7	76.2	76.2
06	Gulf of Cádiz	0.6	0.6	99.4	101.7	138.7	138.7
07	North Aegean Sea	0.0	0.0	184.2	188.0	96.3	96.3
08	Italy - Ionian Sea	0.0	0.0	103.9	106.2	28.2	28.2
09	Corsica - Sardinia	0.0	0.0	95.5	97.7	0.0	0.0
10	South Aegean Sea	0.0	0.0	143.8	147.0	106.1	106.1
	Total	35.1	45.0	1,410.3	1,450.5	769.5	769.5

(Source: Guidehouse)

Table 1-26: Average LCOE in production blocks defined for TMAs

TMA label	Description	Average LCOE bottom-fixed wind 2030 (€/MWh)	Average LCOE bottom-fixed wind 2050 (€/MWh)	Average LCOE floating wind 2030 (€/MWh)	Average LCOE floating wind 2050 (€/MWh)	Average LCOE wave 2030 (€/MWh)	Average LCOE wave 2050 (€/MWh)
01	Gulf of Lion			57.0	35.0	694.6	314.9
02	Malta	96.6	80.3	90.8	55.5	800.8	363.1
03	Sicily	55.2	45.7	75.1	46.1	906.1	410.8
04	Gulf of Venice	73.4	61.4	103.4	63.6		
05	Baleares			96.6	59.1	832.2	377.3
06	Gulf of Cádiz	48.2	39.8	81.7	50.0	398.0	180.5
07	North Aegean Sea			66.4	40.8	851.4	386.0
08	Italy – Ionian Sea			79.2	48.5	914.4	414.6
09	Corsica – Sardinia			89.8	55.0		
10	South Aegean Sea			80.7	49.4	756.5	343.0

(Source: Guidehouse)

The onshore resource potential on islands will also be considered in Tasks 2 and 3. Figure 1-39 indicates the involved islands. To determine what percentage of islands will be connected to the power grid under consideration, the distance to the nearest TMA is determined for all islands. This distance can be used to establish whether a connection to an island is economically feasible.

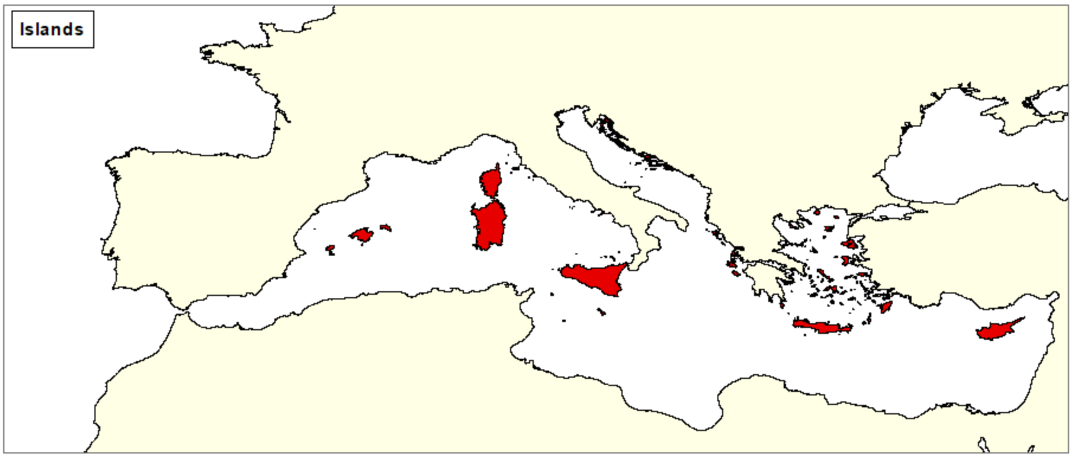

Figure 1-39: Islands in the Mediterranean Sea with major onshore wind and solar power capabilities

(Source: Guidehouse)

Table 1-27 shows the potential of onshore technologies on islands close to the TMAs. Nearby islands are defined as islands whose midpoint is within 100 km of the centre of the closest TMA.

This distance roughly represents the size of the TMAs. Additionally, some nearby large islands that have a part of their coast close to a TMA (such as Corsica, Sardinia, Sicily, and Crete) are included.

Table 1-27: Potential of onshore technologies on islands near TMAs

TMA label	Description	Onshore wind potential 2030 (TWh/a)	Onshore wind potential 2050 (TWh/a)	Rooftop PV potential 2030 (TWh/a)	Rooftop PV potential 2050 (TWh/a)	Utility PV potential 2030 (TWh/a)	Utility PV potential 2050 (TWh/a)
01	Gulf of Lion	0.0	0.0	0.0	0.0	0.0	0.0
02	Malta	0.7	0.7	1.1	1.4	0.7	0.9
03	Sicily	11.5	11.5	16.1	20.7	22.8	32.2
04	Gulf of Venice	0.3	0.3	0.0	0.0	0.8	1.1
05	Baleares	1.5	1.5	2.6	3.4	3.2	4.5
06	Gulf of Cádiz	0.0	0.0	0.0	0.1	0.0	0.1
07	North Aegean Sea	1.2	1.2	0.4	0.5	3.2	4.6
08	Italy – Ionian Sea	0.2	0.2	0.3	0.3	0.6	0.8
09	Corsica – Sardinia	18.4	18.4	7.1	9.1	28.0	39.7
10	South Aegean Sea	2.7	2.7	2.0	2.6	9.6	13.6
Total		36.6	36.6	29.6	38.2	68.9	97.5

(Source: Guidehouse)

Table 1-28 shows the proposed ranking of the TMAs. Ranking is primarily based on lowest LCOE of offshore wind but also considers:

- Available potential (offshore and onshore on nearby islands)
- Maturity of technology (e.g., bottom-fixed wind in the Adriatic)
- Closeness to expected grid expansion (e.g., from TYNDP 2018)
- Proximity to load centres

Remarkable ranking criteria are mentioned in the Remarks column in the table.

Table 1-28: TMA rankings

TMA label	Description	Ranking	Remarks
01	Gulf of Lion	1	Low LCOE Close to load centre
07	North Aegean Sea	2	Low LCOE
03	Sicily	3	Low LCOE Large potential of onshore technologies on nearby islands, Close to planned grid connection Sicily – Tunisia
04	Gulf of Venice	4	Substantial bottom-fixed offshore wind with relatively low LCOE in 2030 Close to load centre
08	Italy – Ionian Sea	5	
09	Corsica – Sardinia	6	Large potential of onshore technologies on nearby islands Close to planned grid connection
10	South Aegean Sea	7	Close to load centre
06	Gulf of Cádiz	8	Far from load centre
02	Malta	9	High LCOE Far from load centre
05	Baleares	10	High LCOE Far from load centre

(Source: Guidehouse)

Figure 1-40 shows the TMAs labelled with their ranking number.

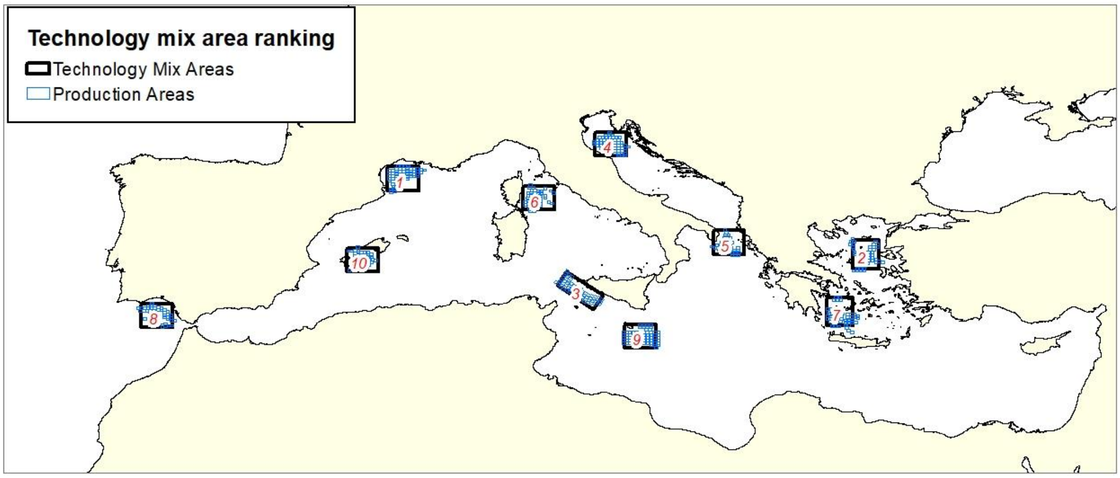

Figure 1-40: TMA map with rankings

(Source: Guidehouse)

1.6.2 Time series data

For a detailed analysis of the production scenarios in Sweco's power market model, normalised time series were generated for each of the TMAs for all technologies considered. Normalised time series characterise the shape of renewable generation in time. It also contains hourly capacity factors that, when multiplied by the installed capacity of a renewable technology, give the hourly power generation. The time series are defined per TMA and taken to be the same for each production block within the TMA.

For technologies on islands, this study assumes that they have a time series profile equal to that of the closest TMA.

For wind energy, this study uses the MERRA-2 global dataset[93] to obtain a time series of hourly capacity factor values (one year, 2014). Data from the Merra-2 database is available from Renewables.ninja.[94] For offshore wind, the wind speed data for 150-meter hub height was obtained at the location of the TMA's centre. Multiplying wind speed data by the logarithmic wind speed factor obtained values at 180-meter hub height for the offshore wind 2050 time series. For onshore wind on islands, wind speed data at 150 m was obtained for an onshore location near the TMA under consideration.

Also available from Renewables.ninja is wind power production data. The website uses the properties of a generic wind turbine to determine this power output. From the wind speed data, the production data is obtained by using the power curve of the wind turbine.

Power output from Renewables.ninja is only available for 150 m hub height. By using the same power curve as Renewables.ninja, this study calculated the offshore wind power production at a hub height of 180 m from the wind speed values at 180 m hub height. The power generation time series are normalised by dividing the wind power output by the nominal capacity of the generic wind turbine used in determining the power curve.

For time series of solar PV on islands, this study determined the normalised power production for each of the defined TMAs and calculated the time series for an onshore location close to each of the TMAs. For a certain island, the PV time series of the TMA closest to the island was used. PV time series are taken to be the same for large-scale utility PV and rooftop PV.

Solar PV time series were derived by using the standard solar energy tool PVsyst.[95] This study chose a generic solar PV module and alternating current (AC)/direct current (DC) inverter available within PVsyst. Then, PVsyst calculates the solar power output time series of this system at each of the chosen locations. The PV power production is calculated with the appropriate irradiation time series for each location. The irradiation time series are available within PVsyst and specified for a typical meteorological year. In the PV time series calculations, a time series for temperature correction is employed. However, the temperature time series is not exported. The solar energy time series are normalised by dividing the power output by the nominal capacity of the generic solar module used in the calculation.

Wave energy output shows much less variation than wind or solar power. For wave energy, this study used monthly averages. In each month, the time series has the same hourly value equal to the average of that month. Time series are taken to be the same for the whole Mediterranean region. Values are taken from monthly wave resources measured in Italy[96] and are normalised with the installed capacity of wave energy technology in the referenced project.

1.7 Task 1 conclusions

The deployment of offshore technologies for electricity generation in the Mediterranean Sea has been slow so far, and the existing installed offshore capacities consist of mainly floating offshore

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[93] (Rienecker et al., 2011)

[94] (Staffel et al., 2016); data obtained from www.renewables.ninja.

[95] https://www.pvsyst.com/

[96] (Vicinanza, 2011)

wind, wave, and tidal pilot and demonstration projects. Onshore technologies such as onshore wind and solar PV are widespread across the Mediterranean islands. Most of the countries in the region have elaborated and submitted their final NECPs with an outline of their climate strategy and targets per technology set for the coming decade. The highest targets are set for offshore wind, followed by onshore energy, while wave and tidal energy targets are modest. The pathways to reach 2030 targets and beyond differ substantially per country.

An assessment of the potentially suitable technologies for RES production in the Mediterranean area shows that floating offshore wind remains a very promising technology. This fact is due to large available areas with favourable wind speeds, suitable water depths, and relatively high capacity factors, resulting in a technical potential of approximately 4,600 TWh/a by 2030 and 4,700 TWh/a by 2050. This data corresponds to an installed capacity potential of approximately 1,600 GW in 2030 and 1,620 GW in 2050.

Also, onshore technologies on islands, such as onshore wind and rooftop and utility-scale solar PV, are promising technologies due to their maturity level, regulatory readiness, projected cost levels, and social acceptance (in the case of solar). The technical potential for onshore wind is 60 TWh/a or 22 GW in 2030 and 2050. For solar PV (rooftop and utility-scale combined), this study found a technical potential of 150 TWh/a (90 GW) in 2030 and 207 TWh/a (125 GW) in 2050.

Wave energy has a significant technical potential at 4,500 TWh/a or 3,650 GW by 2050,[97] comparable to floating offshore wind. However, the technology is less mature and more expensive than the aforementioned offshore and onshore technologies. Bottom-fixed offshore wind technical potential is rather limited due to water depth constraints in the Mediterranean Sea and is approximately 46 TWh/a (20 GW) in 2030 and 60 TWh/a (25 GW) in 2050. The role for tidal energy will be more limited due to its limited resource and high cost levels; its technical potential is limited to 22 TWh/a or 25 GW in 2050.

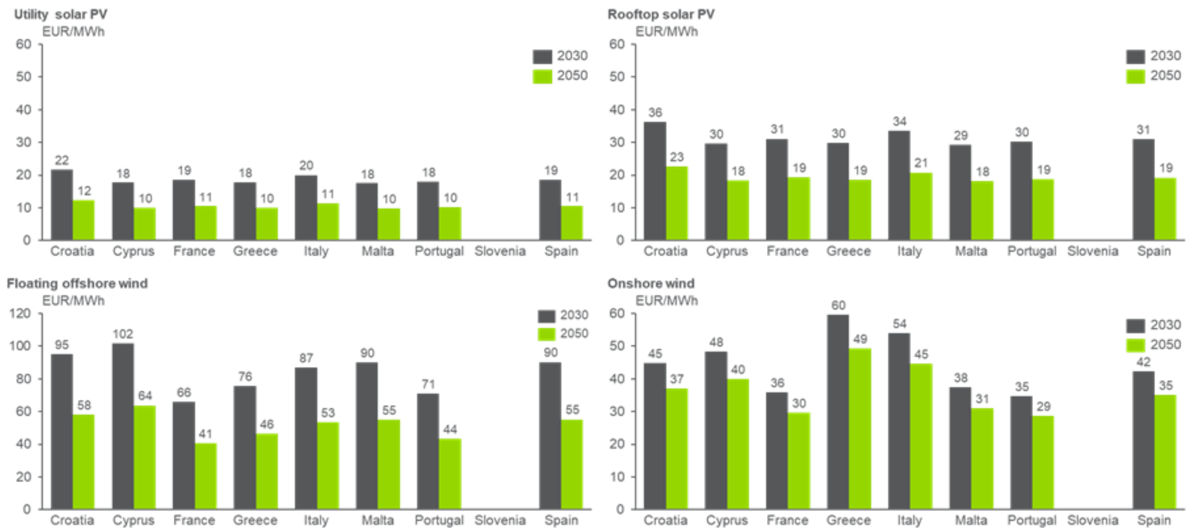

Figure 1-41: LCOE estimates of the most promising technologies

(Source: Guidehouse)

TMAs are identified where the resource potential is high within the areas available for power generation by wind and wave energy. These 10 TMAs were chosen after careful consideration based on the available areas for the three technologies with appropriate levels of resource potential and LCOE. One area is identified because of the technology readiness level of bottom-fixed wind. Areas that fit within a possible offshore meshed grid are prioritized. The final selection of TMAs covers a wide range of the Mediterranean Sea from the Spanish Gulf of Cádiz to the Greek Aegean Sea. For each of the TMAs, normalised time series are generated based on climatological

[97] For wave technology, the technical potential is assumed to be the same in 2030 and 2050. See Section 1.4.1.2.

data. These time series quantify the resource generation profile in time for all considered technologies.

Within the TMAs, this study defined several production blocks. Chosen production blocks have a size of roughly 140 km^2 and cover the available area for all technologies within the TMAs. This 140 km^2 size corresponds to a typical offshore wind farm size of 1 GW with a power density of 7 MW/km^2. For each production block, the resource potential is calculated along with the maximum installed capacity and the average LCOE for all technologies. A ranking for TMAs is proposed.

2.0 Production scenarios

Following the analysis of the technical – and economic potential, two offshore energy scenarios with the onshore capacity and generation scenario in each country for 2030 and 2050 were developed. Then, assessing the market context of the offshore generation share in terms of electricity price and RES share was provided.

2.1 Scenarios

Based on the economic offshore energy production potential as identified in Task 1, this study developed two realistic scenarios for each of the Mediterranean countries and for the years 2030 and 2050: the NECP scenario and the Ambitious scenario. These scenarios differ only with regards to production capacity installed offshore; all other parameters such as fuel prices, demand, and transmission capacity are kept constant. Also, LCOE for the different technologies are the same in both scenarios, despite different volumes. These scenarios are essentially production scenarios, only differing in installed offshore capacity. For each of the years 2030 and 2050, this study developed one production scenario with NECP offshore energy generation and one production scenario with ambitious offshore energy generation (see Figure). The NECP scenario fulfils the targets in the NECPs, and the ambitious scenario has an increased share of offshore power generation.

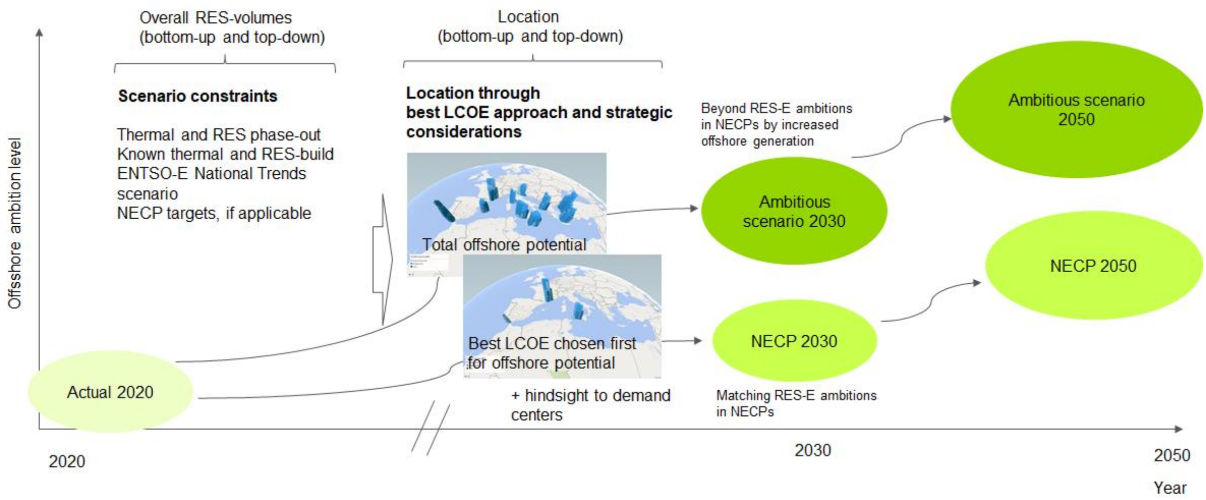

Figure 2-1: NECP production scenario versus ambitious production scenario

(Source: Sweco)

The production scenarios include all renewable and non-renewable technologies for EU-27, as the power market model covers the EU as a whole (in addition to Norway and Switzerland). In the model, Italy is divided into six bidding zones, and installed capacity and demand is defined for each zone. For the other Mediterranean member states, installed capacity is defined at a national level, meaning that intranational transmission systems are not explicitly modelled. Non-interconnected systems are included in the model as part of the national systems. The production scenarios were defined in two steps: by identifying the overall volumes and then assigning the offshore Renewable Electricity Sources (RES-E) capacities to specific production blocks in the TMAs.

Overall capacities are based on 2020 actuals and a thorough review of:

- Estimated phase out and potential renewal of existing production capacity
- Known plans for new capacity installations
- The integrated NECPs per country and their RES targets, especially existing plans for offshore RES generation (NECP scenario)

- Decarbonization targets: the TYNDP's National Trends scenario and the scenarios for 2030 and 2050 developed in the European Commission's long-term strategy for a climate-neutral economy.

As stated above, the NECP and ambitious scenarios only differ with regards to production capacity installed offshore, and the scenarios share the same underlying assumptions regarding electricity demand and deployment of onshore generation technologies. For both scenarios, overall volumes, capacities, and electricity demand are aligned with explicit targets or indicative of trajectories presented in the respective NECPs and other relevant long-term strategic documents. Therefore, the scenarios can describe pathways with national efforts for achieving a climate-neutral economy at the EU level by 2050. Even though cross-border transmission capacities have an important role in balancing the variability of intermittent production sources and cover smaller energy imbalances, the scenarios do not include large net producing countries supplying electricity to other member states through large international power flows. On the contrary, each Member State is assumed to cover its annual electricity demand nationally to a large extent.

Overall capacities are based on 2020 actuals and Sweco's continuous scenario work updates, which is described in Appendix B.1. For 2030, the capacities are aligned with the most updated NECPs available at the time of writing with regards to:

- **Targets concerning the share of RES in electricity consumption.** Almost all NECPs contain explicit targets concerning shares of renewable electricity generation in 2030 (for some countries, such as Croatia, the target indicates achieving the overall target for share of RES in energy consumption). The total installed RES capacity, onshore as well as offshore, is determined to achieve the presented targets.
- **Explicit targets or indicative trajectories of installed RES capacity in 2030.** Most of the NECPs contain technology-specific capacity targets or indicative trajectories for reaching the general targets. Assumptions concerning installed capacity are aligned with the targets or indicative trajectories in the respective NECPs as much as possible (primarily the with additional measures scenarios).
- **Targets concerning phase out of existing nuclear or fossil generation technologies.** Several of the NECPs contain targets concerning the phase out of nuclear or fossil power generation. For example, Portugal, Spain, France, Italy, and Greece all present targets of phasing out coal and lignite before 2030, and the NECPs for Spain and France contain targets of reducing nuclear power generation.

As of the execution of this study, not all countries have submitted their final NECP to the European Commission. When possible, capacities are aligned with targets and trajectories of the final NECPs; otherwise the draft NECPs have been used.

For 2050, Sweco's long-term scenarios are aligned with existing targets in the NECPs and national long-term strategies. Relevant objectives presented in the documents are summarized in Table 2-1.

Table 2-1: Relevant objectives for the electricity system in 2050 for this study's scenarios

Country	Target
Portugal	100% share of RES in electricity generation
Spain	100% share of RES in electricity generation
France	Virtually carbon-free energy production by 2050 (with residual pollutants being fossil fuels for air and sea transport and residual leaks)
Italy	Climate-neutral economy
Slovenia	Contribute to climate-neutral economy at an EU level
Croatia	Contribute to climate-neutral economy at an EU level
Greece	Climate-neutral economy
Cyprus	Contribute to climate-neutral economy at an EU level
Malta	Contribute to climate-neutral economy at an EU level

(Source: Sweco)

For 2050, the NECPs at most contain objectives concerning the share of RES in electricity generation, and the NECPs do not contain technology-specific trajectories or targets for installed capacity. Based on installed capacities in 2030, estimated phase out and potential renewal of existing production capacity, and the relevant objectives in Table 2-1, overall capacities are determined by the following principles:

- **RES capacity is installed to meet existing targets concerning share of RES in electricity generation and assumed electricity demand in 2050 (annually).** For member states without existing targets concerning RES shares in 2050, the expansion of RES is based on Sweco's long-term scenarios. The RES shares for these member states have been computed in order to compare power generation in 2050 with more general national and EU targets.
- **Limited capacity increases are assumed for bio- and hydropower, and the expansion of RES generation is mainly met by variable production sources from solar PV and on- and offshore wind.** Future expansions of hydropower are limited due to resource limitations and environmental restrictions. Biogenic material also makes up a limited resource, and the demand for bioenergy is expected to increase in other sectors as the transition to a carbon-free energy system progresses. In these scenarios, hydropower capacity within the Mediterranean member states remains basically constant between 2030 and 2050 while biopower capacity increases by 20%. This change can be compared with variable production capacity, which increases by 60% during the same period. The increase in biopower capacity mainly occurs for cogeneration plants, replacing current fossil cogeneration.
- **Pumped hydro and battery storage remain an unexplored potential. In the model, pumped hydro and battery storage are used mainly to balance production and demand variations within the day.** At longer timescales, other types of electricity storage will be necessary. The additional need for peak capacity is currently modelled by natural gas, and the electricity cost at these hours is determined by the marginal cost of natural gas generation. For countries with ambitions of zero or almost zero fossil generation, this model can represent other dispatchable sources such as increased bio generation or storage through hydrogen or power-to-X fuels.
- **Coal and oil generation capacity is almost entirely phased out from the electricity systems of the Mediterranean member states by 2050**. Oil generation capacity is

phased out from baseload and cogeneration and is only used for peak generation in a few member states. Baseload and cogeneration by natural gas are completely phased out in Portugal, Spain, and France and to a large extent in Italy. Between 2030 and 2050, new natural gas capacity is only introduced in Slovenia and Croatia to replace phased-out nuclear and oil generation.

- **Nuclear power capacity is based on current capacity, national targets, and estimated phase out at the end of existing plants' life cycles.** French nuclear capacity is reduced according to the national long-term target of reducing the nuclear share of power generation to 50%by 2035. In Spain, nuclear capacity is assumed to be phased out completely by 2050, based on the target scenario of the Spanish NECP. In Slovenia, nuclear power generation is assumed to be phased out at the end of the existing power plant's life cycle between 2040 and 2045.

Assumed production capacities for the scenarios are shown in Figure 2-2 and Table 2-2. All capacities are included per member state, regardless of location of offshore capacities (Mediterranean Sea or other). The capacity assumptions in the model show a decrease in fossil-based thermal capacity in all countries and a strong increase of solar and onshore wind power production. In addition, offshore wind power is taking a substantial share of the renewable capacity in Spain, France, Italy, and Greece.

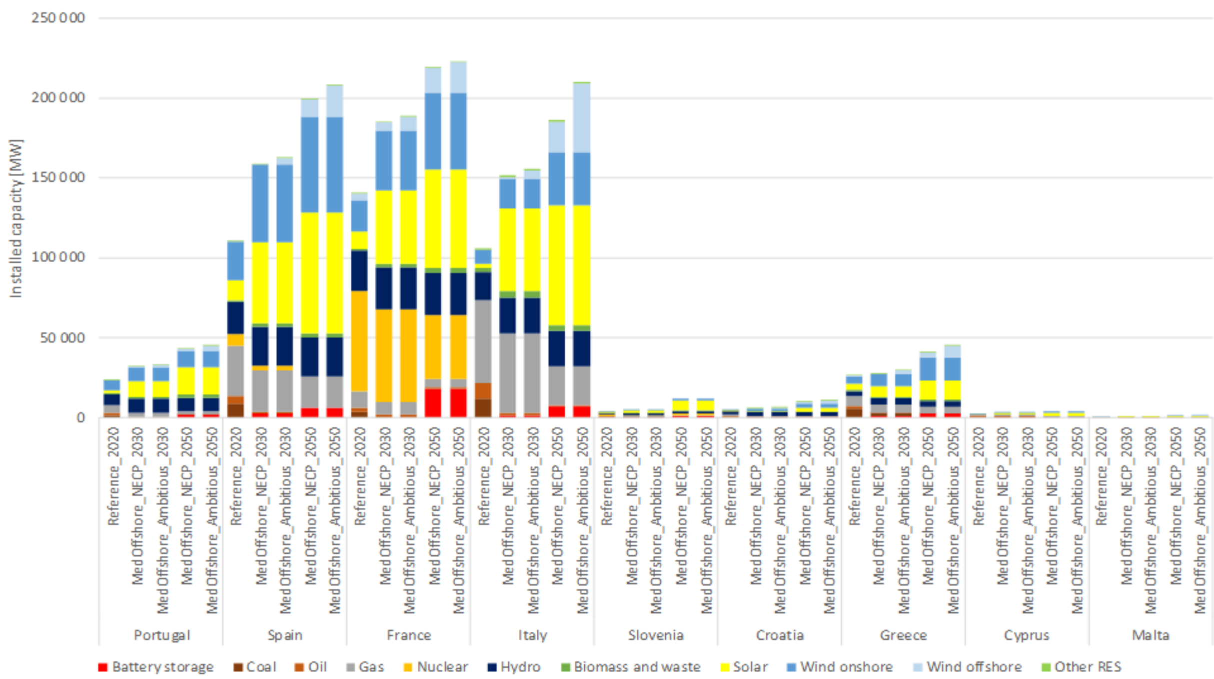

Figure 2-2: Capacity assumptions in the different production scenarios for the Mediterranean member states

(Source: Sweco)

Table 2-2: Capacity assumptions (MW)

	Year	Scenario	Portugal	Spain	France	Italy	Slovenia	Croatia	Greece	Cyprus	Malta
Battery storage	2030		0	2 500	0	1 450	0	0	1 000	150	0
	2050		2 000	6 000	18 000	7 200	1 200	700	2 500	200	100
Coal	2030		0	0	0	0	600	300	2000	0	0
	2050		0	0	0	0	0	0	0	0	0
Oil	2030		450	1 200	1 950	1 850	0	50	100	900	250
	2050		0	0	1 050	300	0	0	100	0	0
Gas	2030		2 800	31 500	8 000	49 700	450	600	5 150	900	300
	2050		2 000	20 100	5 150	24 700	450	250	3 900	900	400
Nuclear	2030		0	3 200	58 000	0	700	0	0	0	0
	2050		0	0	40 200	0	1,000	0	0	0	0
Hydro	2030		8 500	24 150	26 400	22 200	1 300	2 600	3 900	0	0
	2050		8 500	24 150	26 400	22 200	1 700	2 600	3 900	0	0
Biomass and waste	2030		1 400	2 350	2 000	4 000	100	200	500	50	0
	2050		2 000	2 750	2 950	3 750	50	150	900	50	0
Other RES	2030		150	100	250	950	0	50	100	0	0
	2050		150	100	250	950	0	50	100	0	0
Solar	2030		9 450	50 750	45 900	52 000	1 650	600	6 850	850	250
	2050		17 200	75 500	61 650	74 700	6 400	2 400	11 900	2 200	700

	Year	Scenario	Portugal	Spain	France	Italy	Slovenia	Croatia	Greece	Cyprus	Malta
Wind onshore	2030		9 000	48 600	37 150	18 400	150	1 300	7 650	200	0
	2050		10 000	60 000	48 050	33 450	1 000	2 650	14 600	800	200
Wind offshore	2030	NECP	300	0	5 400	1 000	0	0	0	0	0
		Ambitious	1 500	4 000	8 900	5 350	0	450	2 200	0	0
	2050	NECP	1 300	11 000	15 400	19 150	0	950	3 250	0	0
		Ambitious	3 000	19 650	19 200	42 950	0	1 850	7 400	0	500

(Source: Sweco)

2.1.1 Offshore capacities in the scenarios

As described in Task 1, the deployment of offshore technologies in the Mediterranean region is currently very limited, and the amount of targeted or projected offshore capacity in 2030 presented in the NECPs is relatively small. Based on explicit targets in the NECPs, installed offshore capacity in the Mediterranean should amount to around 2,000 MW in 2030 (depending on how much of the French target production is located to the Mediterranean). This amount can be compared with the 22,000 MW currently installed in the northern seas (roughly half of which is located in the UK) or the total offshore capacity of around 90,000 MW assumed in the EU's baseline scenario for 2030, presented in the European Commission's vision for a climate-neutral EU by 2050 (European Commission, 2018). Mediterranean offshore generation is also assumed to be limited in the long-term scenarios for the European power system developed in the TYNDP scenario report for 2020, where offshore wind capacity in 2040 ranges between 2,000-4,000 MW (assuming 20% of French offshore capacity is in the Mediterranean).

Some key factors behind the low expectations of Mediterranean offshore generation are the high-water depth (thus the limited potential for bottom-fixed offshore wind), the comparatively low technology readiness level, and the high LCOE of floating wind and marine technologies. Based on the findings of Task 1, the LCOE of wave and tidal remains considerably above a competitive level through 2050, while the LCOE of floating offshore wind decreases towards current LCOE levels of bottom-fixed turbines in 2030 and towards 2050. Both bottom-fixed and floating offshore wind remain viable technology options for increasing renewable power generation in the Mediterranean member states.

However, the future deployment of offshore power generation in general depends on its competitiveness with alternative electricity sources, including other renewable electricity sources. For the Mediterranean, the situation depends on its attractiveness compared to onshore wind and solar power generation. Task 1 concluded that the LCOE of onshore wind and solar should continue to drop and remain below the LCOE of offshore wind. This situation is most evident for utility-scale solar PV, for which the estimated LCOE in 2030 and 2050 is roughly one-quarter of the LCOE of floating offshore wind. The role of offshore wind in decarbonization of the Mediterranean power system is influenced to a large extent by other factors limiting the potential of onshore wind and solar or enhancing the attractiveness of offshore wind compared to the onshore alternatives, or both. These important factors include:

- Availability of land and competing land or seabed uses
- Public acceptance of large deployments of wind and solar capacity
- Captured price of electricity (As the share of variable power generation grows larger, the benefit of producing at different hours than other production sources increase.)
- Market barriers for distributed power generation

Although some of these aspects may be captured in predictive modelling of future power systems, an adequate representation of national conditions is difficult to present in its entirety. The objective of Task 2 is to develop two realistic power production scenarios for 2030 and 2050 for use in the cost-benefit analysis and evaluation of grid options and bottlenecks in Task 3: one production scenario with offshore energy generation compliant with NECPs and one production scenario with higher ambitions. The amount of offshore generation in the two scenarios is not the result of an energy investment model and should not be interpreted as the optimal deployment of offshore generation based on specific sets of polices or LCOE estimations. Rather, offshore capacity in each Member State is set based on technical potential, national targets, and judgments about timing and likelihood for realization of ongoing projects up to 2030. The costs and benefits of the proposed offshore generation are analysed more closely in Task 3.

2.1.1.1 NECP scenario

For 2030, the offshore capacity in the NECP scenario is based on the explicit targets of the most recent NECPs presented in Table 1-3. For countries without explicit targets concerning offshore generation in the Mediterranean, the installed Mediterranean capacity is based on existing offshore projects listed in Table 1-8. Of the countries without any explicit targets concerning offshore generation, only Greece has ongoing projects, with a total capacity of around 3,400 MW of offshore wind projects in the planned or permitting development stages and a 0.75 MW wave prototype project under development. However, the progress for offshore wind projects has been slow, and 4C's offshore database of global wind farm projects lists all projects as dormant (4C Offshore, 2020). In the NECP scenario, installed Greek offshore wind capacity in 2030 is therefore assumed to be zero. For 2050, the offshore capacity is based on a general assessment of each Member State from relevant national objectives, EU targets, and electricity demand in 2050. Given that each Member State is assumed to cover its annual electricity demand nationally to a large extent, offshore capacity is then estimated from assumptions concerning demand and the future development of other production technologies. For example, a large amount of offshore capacity is assumed to be installed in Italy due to ambitious targets, a relatively high electricity demand, and a limited potential for nuclear and onshore wind deployment.

Installed offshore capacity and the offshore share of power generation are presented for each Member State in Table 2-3. In the NECP scenario, Mediterranean offshore wind capacity grows from 2,400 MW in 2030 to 32,700 MW in 2050 while marine power technologies stay limited to prototype projects and initial capacity targets throughout the period. Mediterranean offshore wind is mainly located in Italy and Spain, but significant amounts are also found in France and Greece. The offshore share of power generation in 2050 ranges between 0% and 15%.

Table 2-3: Installed offshore capacity and offshore share of power generation in the NECP scenario

Country	Offshore wind capacity (MW)		Wave capacity (MW)		Tidal capacity (MW)		Offshore share of power generation	
	2030	2050	2030	2050	2030	2050	2030	2050
Portugal	300 (0 Med.)	1,300 (0 Med.)	70 (0 Med.)	70 (0 Med.)	0	0	2%	6%
Spain	0	11,000 (6,000 Med.)	50 (0 Med.)	50 (0 Med.)	0	0	0%	12%
France	5 400 (1,400 Med.)	15,400 (3,400 Med.)	0	0	240 (0 Med.)	240 (0 Med.)	4%	11%
Italy	1 000	19 100	0	0	0	0	1%	17%
Slovenia	0	0	0	0	0	0	0%	0%
Croatia	0	950	0	0	0	0	0%	11%
Greece	0	3,250	0	0	0	0	0%	15%
Cyprus	0	0	0	0	0	0	0%	0%
Malta	0	0	0	0	0	0	0%	0%
Total	6,700 (2,400 Med.)	51,000 (32,700 Med.)	130 (0 Med.)	130 (0 Med.)	240 (0 Med.)	240 (0 Med.)	2%	12%

(Source: Sweco)

2.1.1.2 Ambitious scenario

Installed capacity and offshore share of power generation in the ambitious scenario are presented in Table 2-4. The ambitious scenario assumes immediate measures and investments in offshore wind throughout the Mediterranean, resulting in offshore wind capacity increasing to 13,300 MW in

2030. Given the long permitting and installation times for offshore wind projects, little capacity is expected to be installed before 2027. Even by assuming a rather efficient development time of 7 years including permitting and a rapid, immediate increase of offshore wind development projects, the assumed increase in offshore wind capacity in 2030 requires an average installation rate of around 4.5 GW/a. between 2027-2030. This scenario can be compared with the installation rate in the northern seas, which during the last 5 years has been around 3 GW p.a. on average. The 2030 offshore wind capacity in the ambitious scenario can therefore be regarded as very ambitious; however, the proposed capacity can be realized. The rapid increase of offshore wind projects is assumed to continue, and in 2050, the amount of installed offshore wind capacity is expected to be twice as large as the installed capacity in the NECP scenario, with a total capacity of 76 GW. This situation can be compared with Wind Europe's vision for 2050, which allocates 70 GW in the Mediterranean.

As for wave and tidal, no additional development is assumed compared with the NECP scenario. The reason for the limited buildout of marine power is the high LCOE compared with offshore wind and the large potential for offshore wind estimated in Task 1. Due to the very high potential for offshore wind in the Mediterranean, the need for commissioning more expensive marine power projects is assessed to be small.

Table 2-4: Installed offshore capacity and offshore share of power generation in the ambitious scenario

Country	Offshore wind capacity (MW)		Wave capacity (MW)		Tidal capacity (MW)		Offshore share of power generation	
	2030	2050	2030	2050	2030	2050	2030	2050
Portugal [98]	1 500 (0 Med.)	3 000 (1,500 Med.)	70 (0 Med.)	70 (0 Med.)	0	0	9%	13%
Spain	4 000 (2,000 Med.)	19 650 (14,600 Med.)	50 (0 Med.)	50 (0 Med.)	0	0	5%	20%
France	8 850 (3,350 Med.)	19,200 (7,200 Med.)	0	0	240 (0 Med.)	240 (0 Med.)	6%	14%
Italy	5 300	42 900	0	0	0	0	5%	33%
Slovenia	0	0	0	0	0	0	0%	0%
Croatia	450	1,850	0	0	0	0	7%	20%
Greece	2,200	7,400	0	0	0	0	13%	29%
Cyprus	0	0	0	0	0	0	0%	0%
Malta	0	500	0	0	0	0	0%	45%
Total	22,300 (13,300 Med.)	94,500 (75,950 Med.)	130 (0 Med.)	130 (0 Med.)	240 (0 Med.)	240 (0 Med.)	6%	21%

(Source: Sweco)

[98] Portuguese islands are not included since they are located in the Atlantic.

Based on the above information, the concrete mix and location for offshore capacity to be added—wave, tidal, bottom-fixed, or floating wind power—has been based on two main factors: ranking the TMAs and a best LCOE approach for each of the production blocks within the TMAs, up to the total annual generation volume required for the NECP or ambitious scenario and strategic considerations for production location.

The best LCOE approach simply uses the production blocks with the lowest LCOE over those with higher LCOE on a regional Mediterranean level and within a country. However, a strict best LCOE approach would not necessarily lead to scenarios that are optimal from a wider perspective.

Therefore, the initial strategic considerations for location of the production blocks also included basic considerations of where demand centres in the respective countries are located, meaning that this study implicitly avoided the need to build out the transmission grid just to accommodate the offshore volumes. As an example, for Italy, this study used the Gulf of Venice for bottom-fixed and floating offshore wind due to its location close to the highly industrialized north of Italy instead of the lower LCOE locations around Sicily. In addition, a regional spread to two or more offshore locations for a country minimizes the risk for the same weather patterns impacting the variable power production.

In this study, the capacity of complete production blocks was always added. Typically, as the size of each production block is around 140 km^2, each production block has roughly the capacity for an offshore wind park of 1 GW. For power market simulations, this study has not yet allocated RES-E capacity specifically to islands since these capacities are included in the capacities for the entire bidding zone.

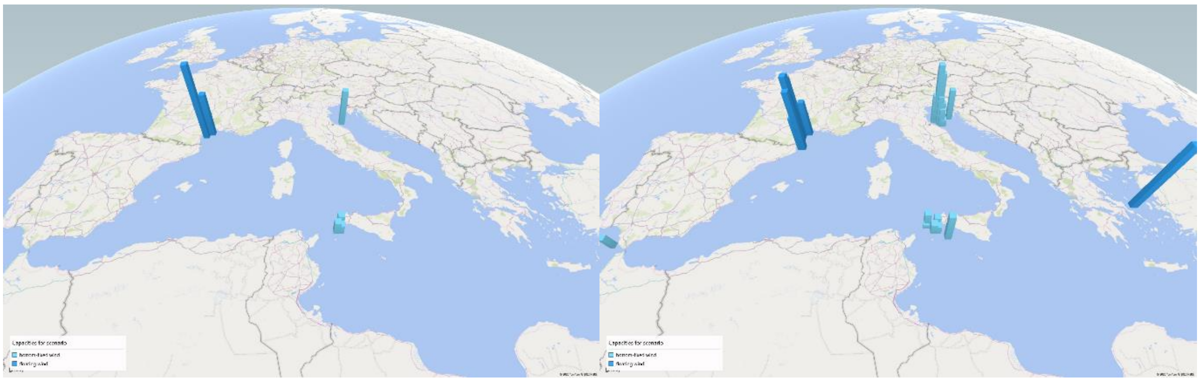

Figure 2-3: Regional distribution of offshore generation capacity in the NECP (left) vs. ambitious scenario 2030 (right)

(Source: Sweco)

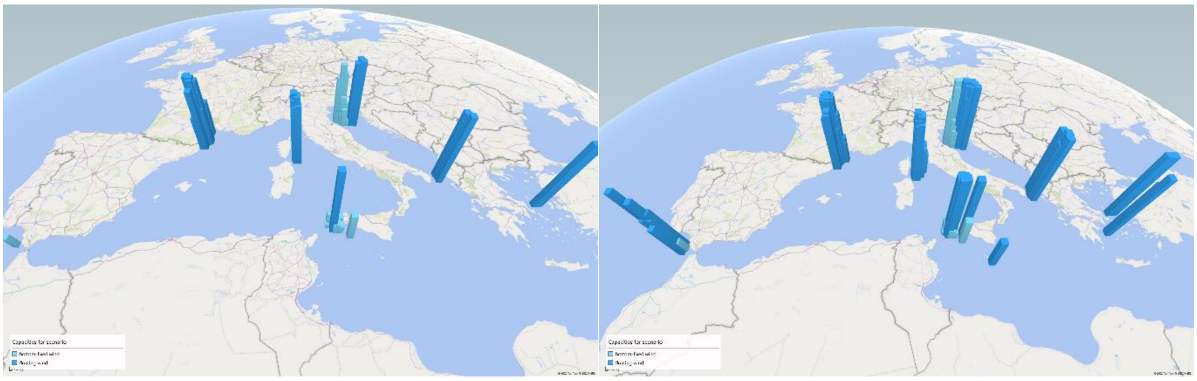

Figure 2-4: Regional distribution of offshore generation capacity in the NECP (left) vs. ambitious scenario 2050 (right)

(Source: Sweco)

2.1.2 Other main assumptions

Fuel and carbon prices are key assumptions for determining the merit order of power generation and, consequently, the price level of electricity prices. For the study, fuel prices are based on the fuel price assumptions used in the national trend's scenario of the TYNDP scenario report 2020. The scenarios in the TYNDP report only stretch as far as 2040, so for 2050, the fuel prices are based on the 2040 values. Although a simplification, an eventual price development between 2040 and 2050 is regarded to be small compared with the big uncertainty in the projections of future fuel prices. For CO_2, prices have been accommodated by the EC and are based on modelling assessments within the development of EU's long-term scenarios for 2050. Table 2-5 gives an overview of the fuel price assumptions and a comparison with assumptions used in other ENTSO-E, EU, and International Energy Agency scenarios. In most scenarios, the carbon price increases dramatically towards 2040 and 2050, increasing the impact of the carbon price on electricity prices. On the other hand, the impact of the prices of carbon and fossil fuels is expected to decrease as the share of renewables in power generation increases.

Table 2-5: Fuel price assumptions used in the study compared with other ENTSO-E, EU, and IEA scenarios[99]

Fuel	Medgrid offshore (€/MWh)		TYNDP 2020 (€/MWh)		EU LTS scenarios (€/MWh)		IEA Stated policies (€/MWh)		IEA Sustain. Development (€/MWh)	
	2030	2050	2030	2040	2030	2050	2030	2040	2030	2040
Hard Coal	15.5	24.9	15.5	24.9	13.7	15.5	9.7	9.9	7.4	7.6
Natural Gas	24.9	26.3	24.9	26.3	37.2	46.5	24.3	27.0	22.8	22.8
Light Oil	73.8	79.9	73.8	79.9	80.6	95.6	57.2	66.7	40.8	38.9
Heavy Oil	52.6	61.9	52.6	61.9	50.4	60.0	35.6	41.7	25.0	23.7
Nuclear	1.7	1.7	1.7	1.7	-	-	-	-		
Lignite	4.0	4.0	4.0	4.0	-	-	-	-		
CO_2 (€/ton)	28	250	27-53	75-100	28	250-350	33	43	75	125

(Source: Sweco)

Cross-border transmission capacities for 2030 are based on current capacities and planned projects in TYNDP 2020. Additional transfer capacities through 2050 have been added based on the ST 2040 scenario in TYNDP 2020 and through Sweco's identification of required capacities in the iterative modelling process. The assumed interconnection levels of the Mediterranean member states are shown in Table 2-6. Although increasing from 2017, the interconnection levels of Portugal, Spain, Italy, and Greece are below the EU 2030 target in 2030 and 2050.

[99] Prices have been transformed to comparable units and fuel types by Sweco.

Table 2-6: Assumed interconnection levels in the NECP scenario compared with the EU 2030 target[100]

	2017 (Actual)[101]	2030	2050	EU 2030 target
Portugal	9%	13%/11%	13%/10%	15%
Spain	6%	8%/9%	9%/9%	15%
France	9%	17%/20%	20%/22%	15%
Italy	8%	12%/9%	13%/10%	15%
Slovenia	84%	151%/128%	97%/83%	15%
Croatia	52%	103%/116%	70%/78%	15%
Greece	11%	12%/7%	17%/14%	15%
Cyprus	0%	69%/	103%	15%
Malta	24%	24%	15%	15%

(Source: Sweco)

Another key parameter for the power market modelling is the future development of electricity demand. European electricity demand is expected to increase significantly towards 2050 due to electrification in the transport, heating, and industry sectors. However, the extent to which electrification will affect electricity demand varies greatly between different scenarios and depends on expectations of energy efficiency measures. In the analysis, electricity demand assumptions are based on the national trends' scenario of the TYNDP scenario report 2020. The national trends scenario aims to reflect the commitments of each Member State in meeting the targets set by the EC and includes the national objectives of the draft NECPs. The electricity demand in 2050 is based on an extrapolation of ENTSO-E's TYNDP national trend scenario for 2040 and Sweco's long-term demand scenarios, with the exception of Cyprus, whose demand has been adjusted to comply with the long-term, 2050 projections in the NECP. The electricity demand in 2030 and 2050 is shown in Figure 2-5 as relative to the demand in 2015. For the Mediterranean member states, the total electricity demand is assumed to increase by 4% and 18% in 2030 and 2050, respectively. This scenario can be compared with the European Commission's long-term scenarios produced in the in-depth analysis supporting the Commission's vision for a climate-neutral EU by 2050 (European Commission, 2018), where EU electricity demand increases by 16% to 2030 in the baseline scenario and between 36-75% to 2050 depending on the scenario.

[100] The interconnection level is calculated as the net transfer capacity (import/export) divided by the total installed power generation capacity.

[101] (European Commission, 2017)

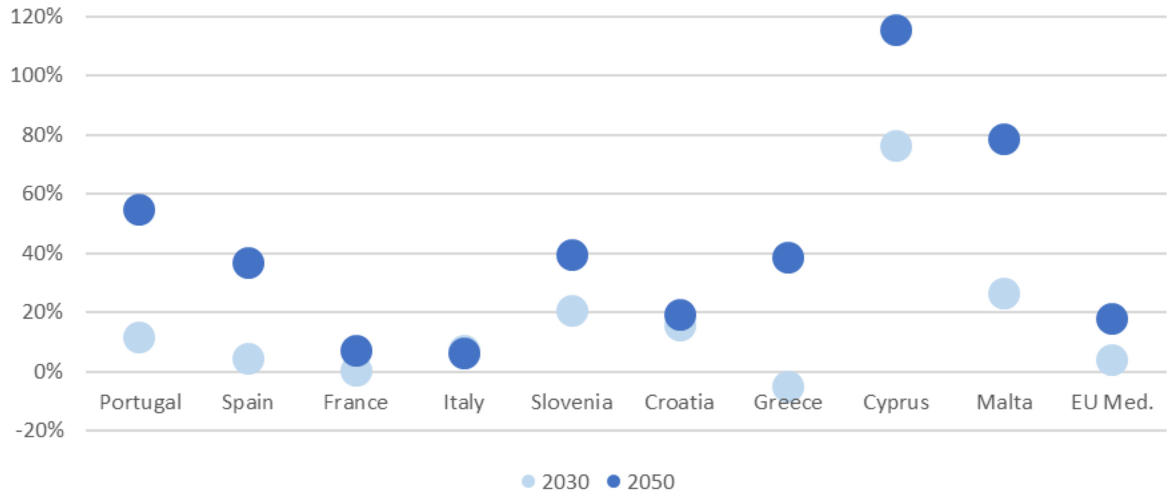

Figure 2-5: Electricity demand increase relative to 2015

(Source: Sweco)

The load profile we currently use for 2030 and 2050 is not adjusted for the changes in consumption within the different sectors.

2.2 Key results from the power market modelling

In this section, we present the key results of the power market modelling. In the analysis, we use our power market model Apollo, described in detail in Appendix B, to analyse the defined production scenarios in an energy-only market. Again, Apollo is not an investment model, and for each scenario, installed capacities of production, transmission, and flexibility technologies are defined by Sweco as described above. Based on installed capacities, electricity demand, and fuel prices, Apollo optimizes generator dispatch by an hourly time resolution and provides information on generation, transmission, emissions, and power prices.

2.2.1 Power generation share of renewable electricity produced on- and offshore

Development of generation in the different scenarios is shown in Figure 2-6. Figures for each Member State can be found in Appendix 0.

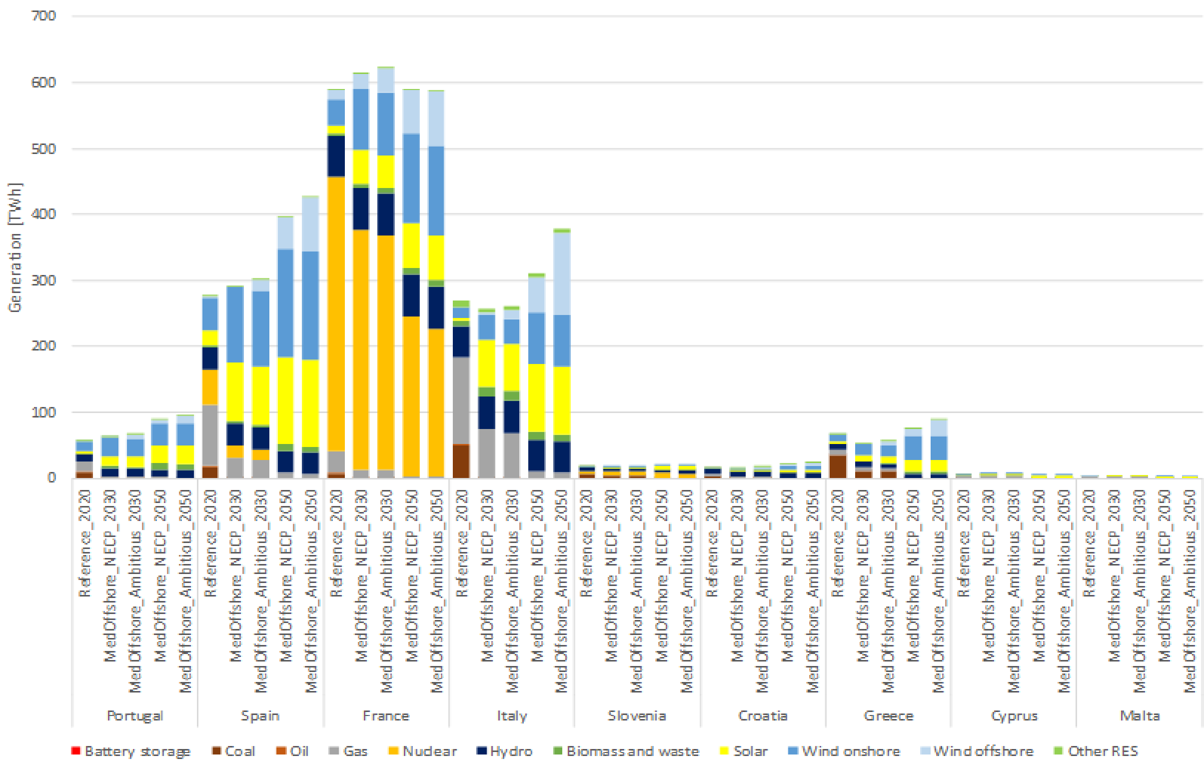

Figure 2-6: Generation in the four production scenarios compared with the 2020 reference scenario

(Source: Sweco)

To test the viability of the production scenarios, the generation results have been tested against the national targets in terms of share of produced electricity, on- and offshore. In all four scenarios, the resulting national RES shares (the green dots in Figure 2-7) reach at least the national target for 2030 (grey bar). In most countries, the ambitious scenarios add a few percentage points between 2% and 9% in RES-share for 2030. This contributes further to a higher RES share in Europe and to decarbonization.

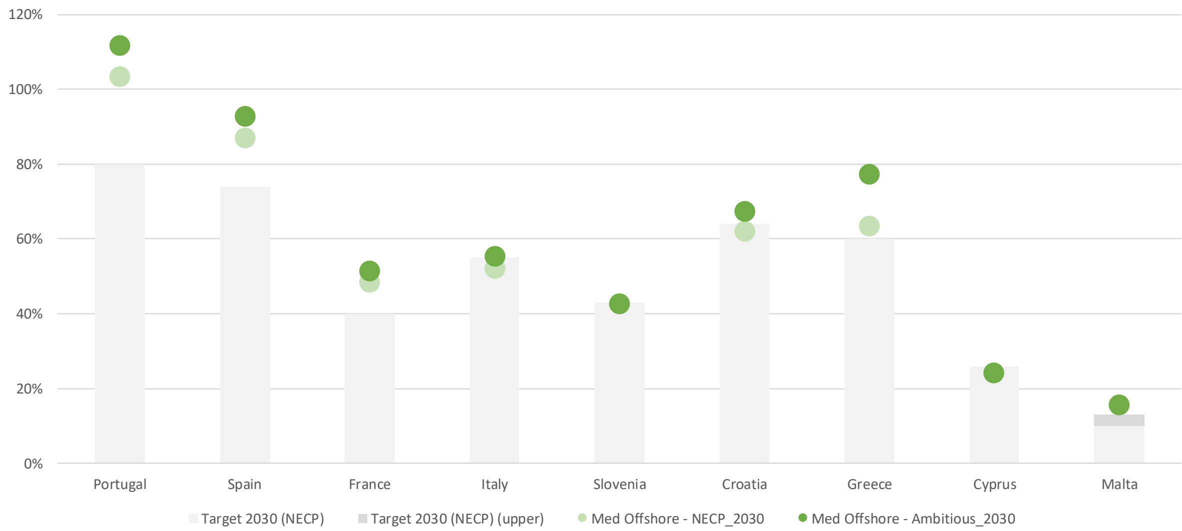

Figure 2-7: RES share for the Mediterranean countries in the two offshore generation scenarios in 2030

(Source: Sweco)

2.2.2 Assessing the market context of the production scenarios

To analyse the long-term market context, such as electricity price as an important precondition for investment in these offshore RES-E assets, this study models the European power market with Sweco's European Power Market Model Apollo, reflecting SRMC in an energy-only market. Hourly production time series for relevant production blocks from Task 1 are used as input for the modelling.

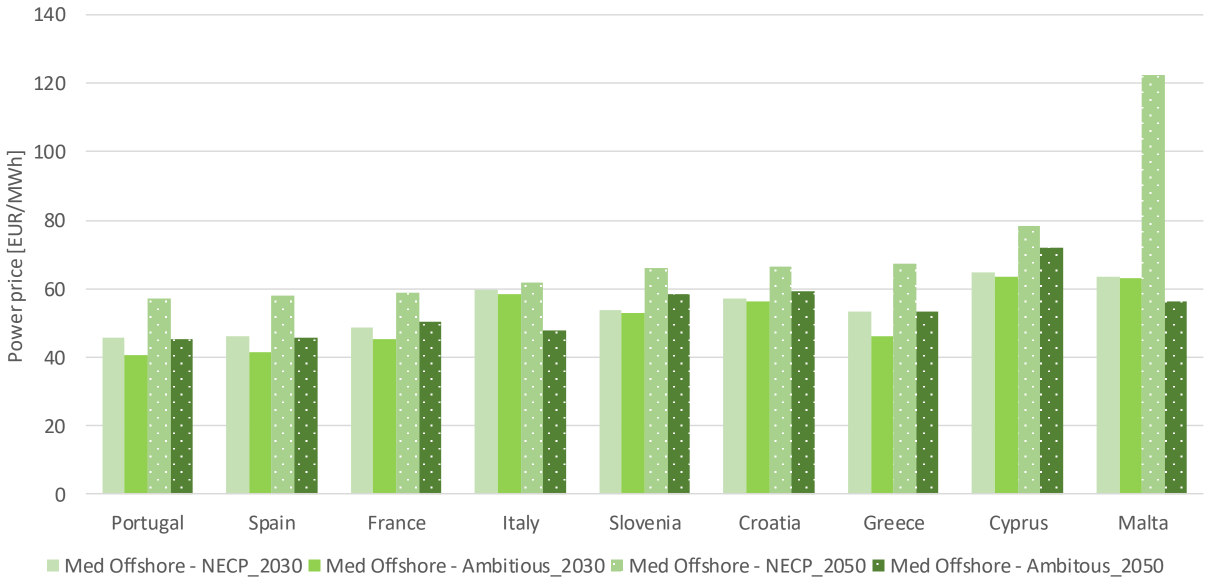

Figure 2-8: Power prices

(Source: Sweco)

Power prices defined as short-run, marginal cost-based power prices in our power market model are rather comparable throughout all countries in 2030, and power price levels still hinge very much on fuel price and the CO_2 price. With a decreasing share of fossil-based thermal capacity and increasing share of variable renewables with low or close-to-zero marginal costs, power prices in 2050 still hinge on the CO_2 price, which is assumed as 250 €/t in our scenarios. Regardless of scenario year, power prices fall significantly with increased offshore RES-E ambitions.

To assess the market context, this study also looked at prices for each technology and compared these to the LCOE of the chosen production blocks. Since grid connection costs, taxes, and decommissioning costs are excluded from the LCOE cost calculation, the comparison is underestimating actual LCOE by a few €/MWh and will only give a rough result. Nevertheless, interesting observations can be made.

In general, captured prices for offshore wind are slightly lower than the average power price in respective bidding zones in both 2030 scenarios. For Spain (about 5 €/MWh) and Greece (about 11 €/MWh), captured prices for offshore wind are considerably lower than the power price in the ambitious scenario due to the high share of RES installed and similar production patterns from other regions pushing down power prices at times.

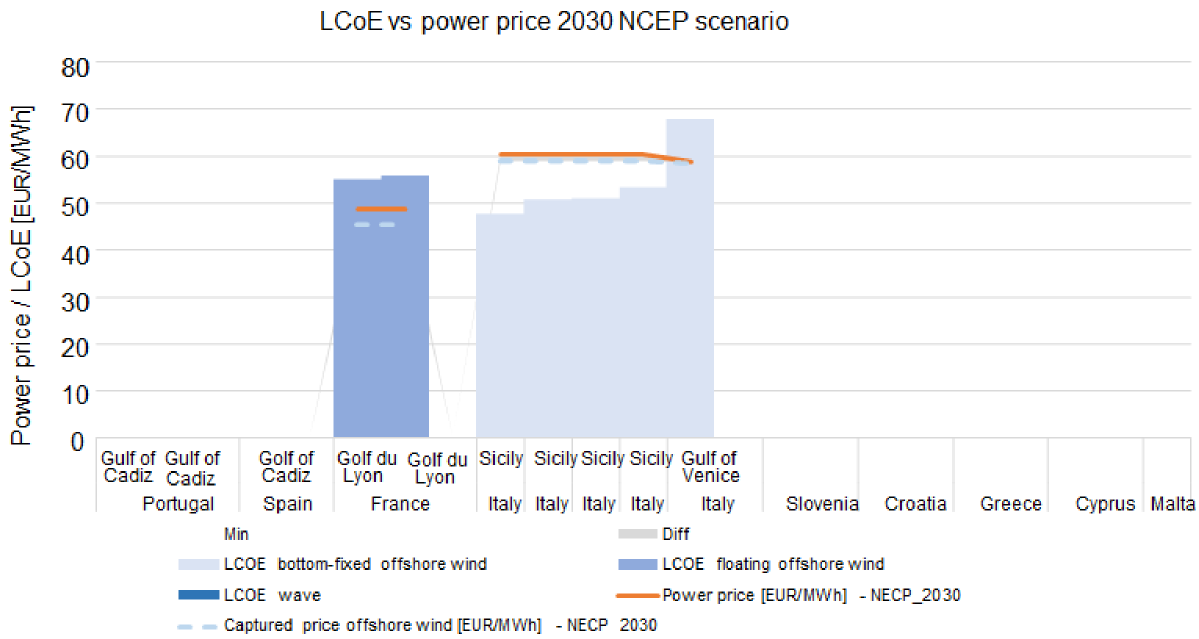

Figure 2-9: LCOE[102] vs. power prices and captured prices in the 2030 NECP scenario

(Source: Sweco)

Nevertheless, in most countries and TMAs, general power prices and captured prices are high enough to cover a substantial part of the LCOE of the chosen production blocks with either bottom-fixed or floating offshore wind power (see Figure 2-9 and Figure 2-10).

For Sicily, the results indicate that at least a large part of the assumed production (567 MW) could be installed on its own merits without the need for RES support. However, there would be a RES support need for floating wind in the Gulf of Lion both in France and Spain and the North Aegean Sea in addition to bottom-fixed wind in the Gulf of Venice.

[102] LCOE values are without the dedicated grid connection, as calculated in Task 1.

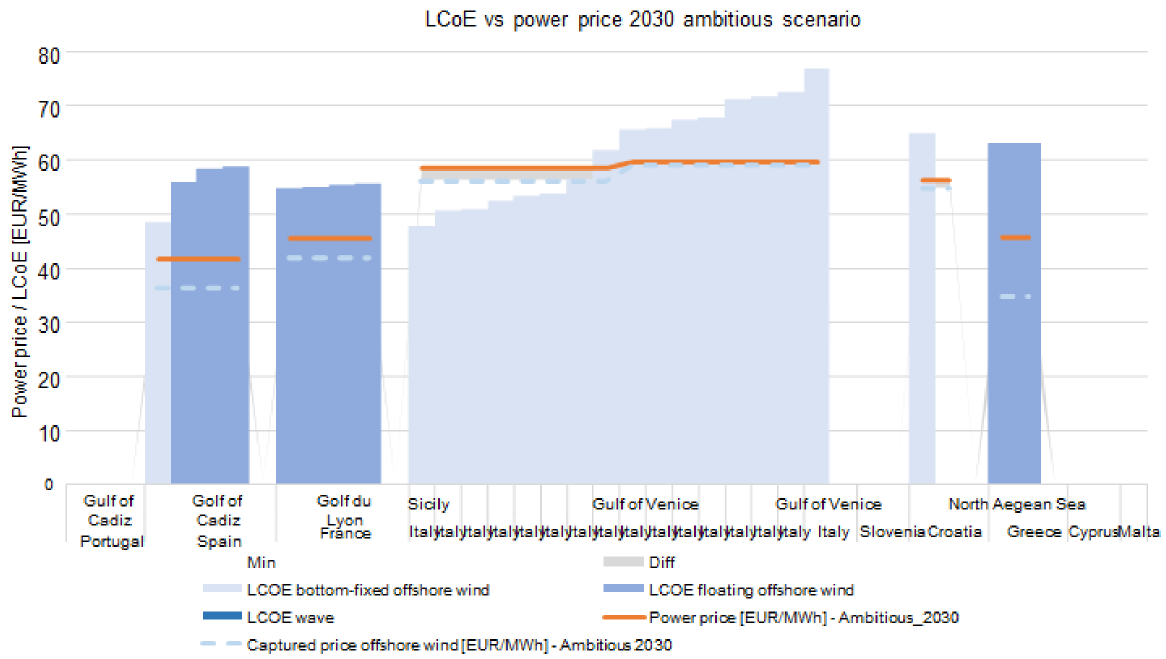

Figure 2-10: LCOE vs. power prices and captured prices in the 2030 ambitious scenario

(Source: Sweco)

2.2.3 CO_2 emissions

The analysis shows that CO_2 emissions fall significantly in most Mediterranean countries between 2020 and 2030, most significantly in Portugal, Spain, Italy, and Greece (see Figure 2-11).

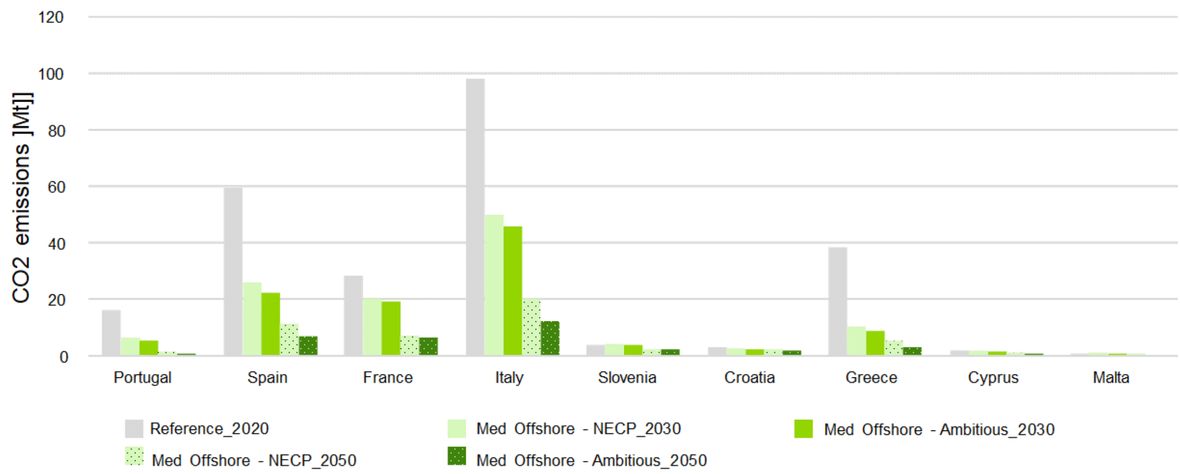

Figure 2-11: CO_2 emissions from power production in 2020, 2030, and 2050 in the different production scenarios

(Source: Sweco)

Furthermore, the biggest additional gains can be made in almost all Mediterranean countries by introducing more offshore generation, especially within the 2050 horizon (see Figure 2-12).

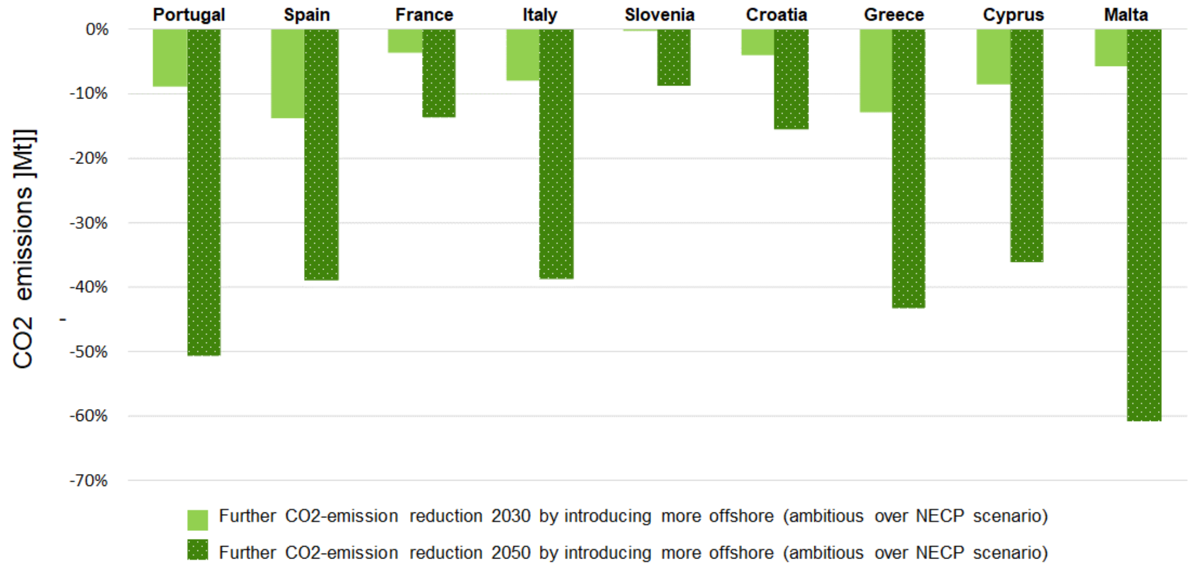

Figure 2-12: Further CO_2 emissions savings for the NECP and ambitious scenarios

(Source: Sweco)

2.3 Task 2 conclusions

Comparing all four scenarios designed to reach or exceed the respective national target for 2030, the ambitious scenarios add a few percentage points between 2% and 22% in RES share for 2030. This contributes further to a higher RES share in Europe and to decarbonization.

Power prices are rather comparable throughout all countries in 2030, and power price levels depend still very much on fuel price and the CO_2 price. With a decreasing share of fossil-based thermal capacity and increasing share of variable renewables with low or marginal costs close to zero, power prices in 2050 still hinge on the CO_2 price but to a lesser degree, depending on how much fossil-based capacity remains in the European power system. This study observes a strong price volatility towards and an increasing number of hours with zero prices. Regardless of scenario year, power prices fall significantly with increased offshore RES-E ambitions.

In general, captured prices for offshore wind are slightly lower than the average power price in the respective bidding zones in both 2030 scenarios. For Spain and Greece, captured prices for offshore wind are considerably lower than in the ambitious scenario due to the high share of RES installed and similar production pattern from other regions pushing down power prices at times.

Nevertheless, in most countries and TMAs, general power prices and captured prices are high enough to cover a substantial part of the LCOE of the chosen production blocks with either bottom-fixed or floating offshore wind power. For Sicily, results indicate that at least a large part of the assumed production could be installed on its own merits without the need for RES support. However, there would be a RES support need for the floating wind in the Gulf of Lion (both in France and Spain) and the North Aegean Sea in addition to bottom-fixed wind in the Gulf of Venice. The analysis also shows that CO_2 emissions fall significantly in most Mediterranean countries between 2020 and 2030, most significantly in Portugal, Spain, Italy, and Greece, and that substantial additional gains can be made in almost all Mediterranean countries by introducing more offshore generation, especially with the 2050 horizon.

3.0 Grid options

Building on the work in previous tasks, this section lays out options for grid connection in the 10 TMAs. In Task 1, the TMAs with associated production blocks were defined such that:

- Each TMA contains about 40-70 production blocks.
- Each production block, with a specified geographic location, has a given potential for renewable energy production defined through a maximum installed power and a production time series. The LCOE for each type of renewable energy technology has also been determined.

In Task 2 we set up two scenarios, which describe projected outcomes in 2030 and 2050, with conservative and ambitious expansions levels. The scenarios define:

- The total installed offshore renewable energy per country
- Which production blocks are activated
- Which technology is chosen for each activated production block

Thus, Task 3 suggests ways to connect the realised production blocks to the transmission grid onshore, and, if deemed suitable, to each other.

3.1 Method

The grid connection was made in three steps. First, a base alternative was calculated. The base alternative is a radial connection of each activated production block, meaning a straight line to the nearest onshore 380 kV-400 kV transmission grid station in the same country as the production block. Locations of grid stations have been retrieved from the ENTSO-E grid map and further adjusted through other map studies where possible. The connection was designed (HVAC or HVDC) and dimensioned based on the installed power of the production block and the distance from the production block to the transmission grid station. The radial connection does not have full redundancy, meaning that failure of a component might lead to the loss of an entire production block. For certain cases with parallel cables, however, failure of a cable might mean that the remaining cables can still transmit part of the production from the production block. Failure of one component will not lead to the loss of production from more than one production block.

As a second step, a partial optimization was made where production blocks were grouped together to share one or more common links to shore, creating a hub connection. This situation means that the connection can be built for higher powers and that the price per MW connected decreases. The downside is that production blocks become dependent on each other. Failure of a single cable might mean loss of production from several production blocks rather than just one.

In a third step, the specific conditions at each TMA were assessed, and an optional grid connection was considered, if deemed advantageous. Such a connection can include grouping of several production blocks, connecting a production block to more than one onshore station, or connecting production blocks so that two countries become interconnected. The benefits of the optional grid connection have been described qualitatively, and the costs have been listed. If the optional grid connection includes meshing (i.e., connection of a production block or a group of production blocks to more than one onshore station), there will be a higher redundancy than in the radial connection and hub connection. Loss of one component in this case does not lead to loss of full production from a production block or group of production blocks. Figure 3-1 describes schematically the three different steps.

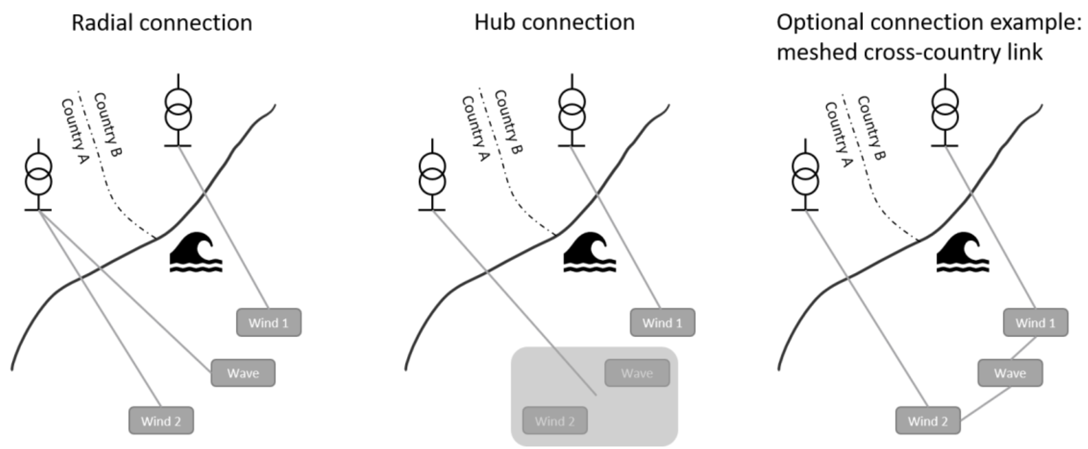

Figure 3-1: Grid connection steps

(Source: Sweco)

3.1.1 Assumptions for the radial connection

The following assumptions were made in the construction of the radial connection:

- Each production block has been connected to the nearest onshore 380-400 kV transmission grid station in the same country as the production block.
- Only cables have been considered—no overhead lines.
- Cable routes have been calculated as the bird flies. For the subsea part of the cable, a linear sea bottom slope has been assumed.
- No consideration has been given to the bottom topology, apart from the depth at the production block.
- Technology (HVAC or HVDC) has been chosen based on the cable length and total cost (CAPEX, OPEX, and losses) over 25 years. For AC, 220 kV has been assumed. The unit cost figures and loss figures used are listed in Appendix C.
- Each connection has been dimensioned so that it can transmit the full power of the production block.
- The maximum single connection has been assumed to be 2 GW for technical reasons.

3.1.2 Assumptions for the hub connection

The following assumptions were made in the construction of the hub connection:

- Each production block has been connected to the nearest onshore 380-400 kV transmission grid station in the same country as the production block.
- Only cables have been considered—no overhead lines.
- All production blocks connecting to the same station have been grouped together, and the connecting distance was assumed to be equal to the average distance from the included production blocks to the station.
- The associated costs and losses for the connection have been calculated using the total installed power of the grouped production blocks and the average distance.
- Technology (HVAC or HVDC) has been chosen based on the total cost (CAPEX, OPEX, and cost of losses) over 25 years. For AC, 220 kV has been assumed. The unit cost figures and loss figures used have been listed in Appendix C.

If the total power of the grouped production blocks exceeds 2 GW, the connection has been calculated as a multiple of the costs for a 2 GW connection.

The above procedure means that no detailed design of how and where the production blocks would be interconnected in reality was made. Instead, it is assumed that interconnection is possible and that the cost for the total connection relates only to the total installed power and the average distance. Thus, this is not an attempt to lay out a detailed connection option. Rather, it is an indication at a general level of what cost benefits might come from market forces, further developments of grid codes, and a more coordinated realization of projects in comparison with the radial connection.

3.1.3 Considerations for optional grid connection design

The following considerations were made when determining whether there are advantageous optional grid connections:

- Are there obvious benefits of connecting a production block or a group of production blocks to more than one station in the same country? If so, is this extra connection shorter or of the same magnitude as a connection between the stations onshore?
- Are there ways to connect production blocks belonging to different countries together, thereby forming a link between the countries? If so, is the extra connection short in relation to the option of directly connecting the two countries?
- Are there planned or ongoing interconnection projects in the vicinity of the TMA so that there might be coordination benefits if an optional grid connection was used?
- Are there obvious ways to connect the production blocks to stations not belonging to the 380 kV-400 kV transmission grid that might mean significantly lower costs?

Based on the above analysis, a maximum of one optional grid connection was calculated for each TMA. If there were other strong candidates, they are mentioned but not evaluated numerically.

3.2 Grid Connection Results

In this section, the calculated grid connections for each TMA is described for each scenario. Connection costs are also presented.

3.2.1 TMA: Gulf of Lion

Table 3-1 describes a summary of the outcome for the different scenarios for this TMA, with production blocks connecting to the south of France and northeast of Spain.

Table 3-1: Activated production blocks for Gulf of Lion

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
France	2	4	4	8	1.4	3.3	3.3	7.2
Spain	0	3	8	16	0.0	1.8	5.8	10.8
Total	2	7	12	24	1.4	5.1	9.2	18.0

(Source: Sweco)

3.2.1.1 Radial connection

The radial connection for the four scenarios is illustrated in Figure 3-2, and the associated costs are listed in Table 3-2. The individual connections are 35 km-111 km, connecting production blocks with an installed power of 320 MW-990 MW. Blue squares are production block centres while red circles are transmission grid stations.

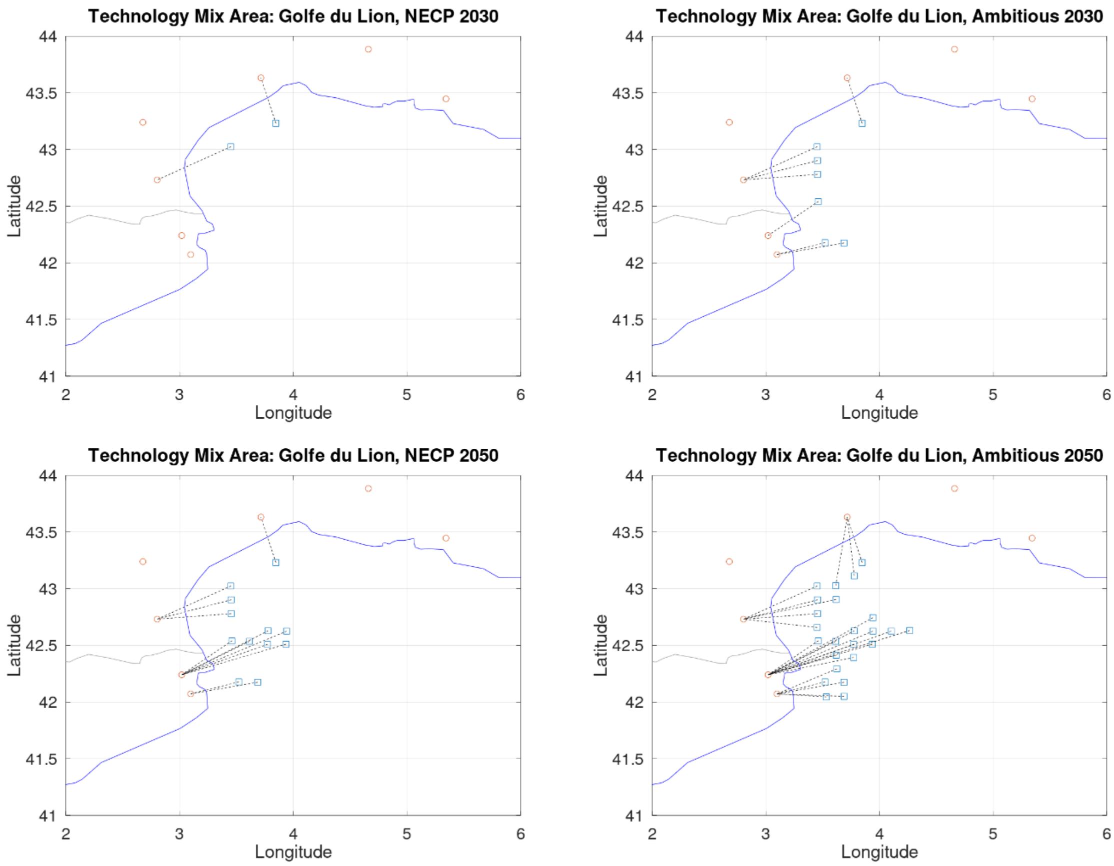

Figure 3-2: Radial connection for Gulf of Lion

(Source: Sweco)

Table 3-2: Costs and losses for radial connection, Gulf of Lion

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
France	320	700	700	1,527	4	9	9	21	206	503	515	1,125
Spain	0	409	1,446	2,945	0	5	20	42	0	261	915	1,686
Total	320	1,109	2,146	4,473	4	15	29	62	206	764	1,430	2,811

(Source: Sweco)

3.2.1.2 Hub connection

The hub connection for the four scenarios is illustrated in Figure 3-3, and the associated costs are listed in Table 3-3. The separate connections are 43 km-77 km, connecting production block groups with a total installed power of 410 MW-7,350 MW. Blue squares are production block centres while red circles are transmission grid stations.

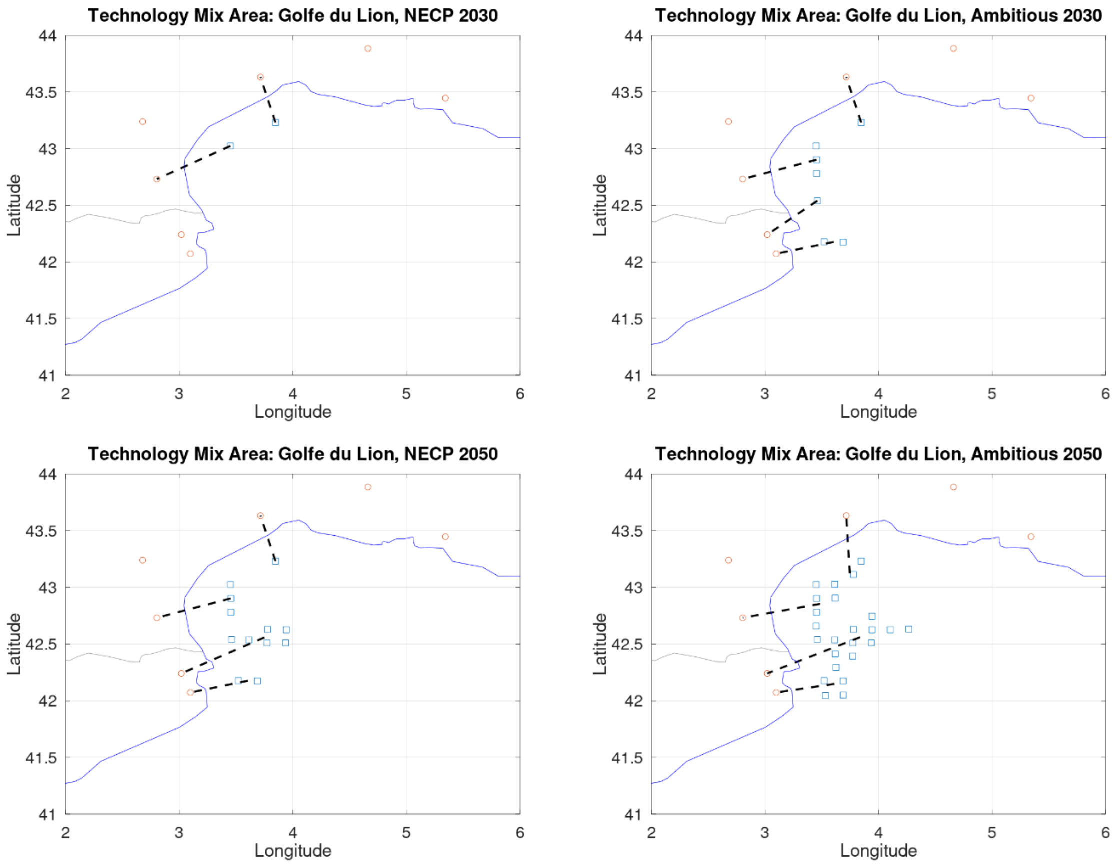

Figure 3-3: Hub connection for Gulf of Lion

(Source: Sweco)

Table 3-3: Costs and losses for hub connection, Gulf of Lion

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
France	320	392	392	555	4	5	5	8	206	386	395	636
Spain	0	331	533	580	0	5	8	8	0	267	535	636
Total	320	722	924	1,135	4	10	13	16	206	653	930	1,272

(Source: Sweco)

3.2.1.3 Optional grid connection

In this TMA, production blocks that connect to France and Spain are quite close to each other. Therefore, the chosen optional grid connection interconnects production blocks to create a link between France and Spain, increasing the transfer capacity across the Pyrenees. This is feasible for the ambitious scenario in 2030, the NECP scenario in 2050, and the ambitious scenario in 2050. The extra interconnection was made with the hub connection as a starting point and has been illustrated in Figure 3-4. The added link is displayed in red.

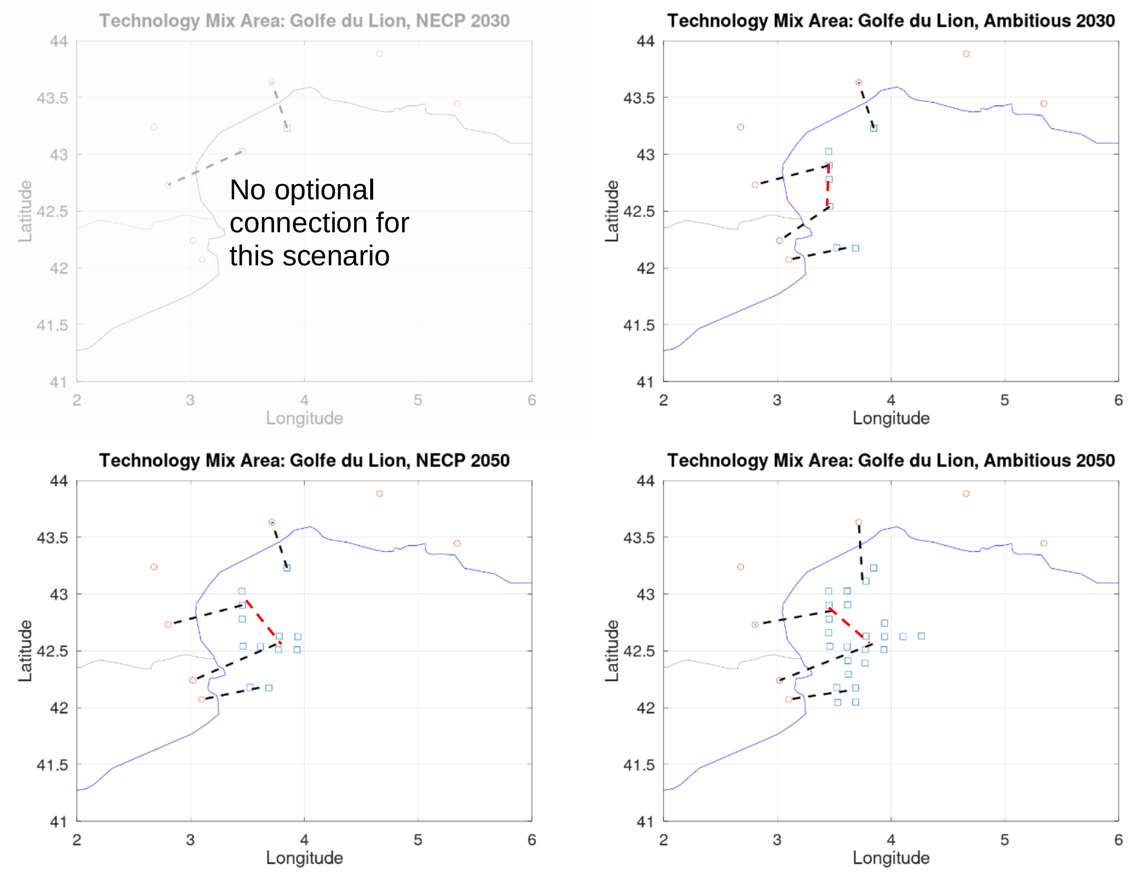

Figure 3-4: Optional grid connection for the Gulf of Lion

(Source: Sweco)

The dimensioning of the added link is not self-evident. Furthermore, the added link introduces possibilities to change the dimensioning of the links to shore since there is now more than one path from each production block to shore. The suitable dimensions depend on strategic choices:

- What is the value of extra redundancy for the grid connection versus the extra costs of a link with a higher capacity?
- What is the value of having the possibility to sell the produced electricity to more than one country versus the extra cost of a link with higher capacity?
- What are the projected possibilities for selling spare capacity in the created cross-country link versus the extra cost of a link with higher capacity?

The necessary investigations to answer the above questions are beyond the scope of this study. As a rough estimate, the extra link is dimensioned here so that its capacity is equal to the greater of the two links to shore. Furthermore, the weaker of the two links to shore is also upgraded so that its capacity is equal to the greater one. Thereby, the whole set of links has the same capacity. The motivation for this upgrade is that the connection of France and Spain across the Pyrenees is a known weak section of the grid. This topic is discussed further in Section 3.4. The suggested design implies some possible operational choices:

- The set of links can be used as a cross-country interconnector, and its spare capacity can be sold.
- The full power of either of the two groups of production blocks can be fed to either country, in case of outage of the other group of production blocks.

The details of the optional connection are summarized in Table 3-4. Losses are not included since they depend on how the meshed grid is operated.

Table 3-4: Costs for optional grid connection in the Gulf of Lion

Scenario	CAPEX (M€)				OPEX (M€/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
France	320	504	728	1,362	4	7	10	19
Spain	0	558	924	1,670	0	8	13	24
Cross country	0	204	362	575	0	4	7	11
Total	**320**	**1,266**	**2014**	**3,606**	**4**	**18**	**30**	**54**
Link capacity (GW)	0	2.8	4.5	7.4				

(Source: Sweco)

3.2.2 TMA: Malta

Table 3-5 describes a summary of the outcome for the different scenarios for this TMA with production blocks connecting to Italy.

Table 3-5: Activated production blocks for Malta

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Malta	0	0	0	1	0	0	0	0.5

(Source: Sweco)

3.2.2.1 Radial connection

Production blocks are only activated in the 2050 ambitious scenario. The radial connection is illustrated in

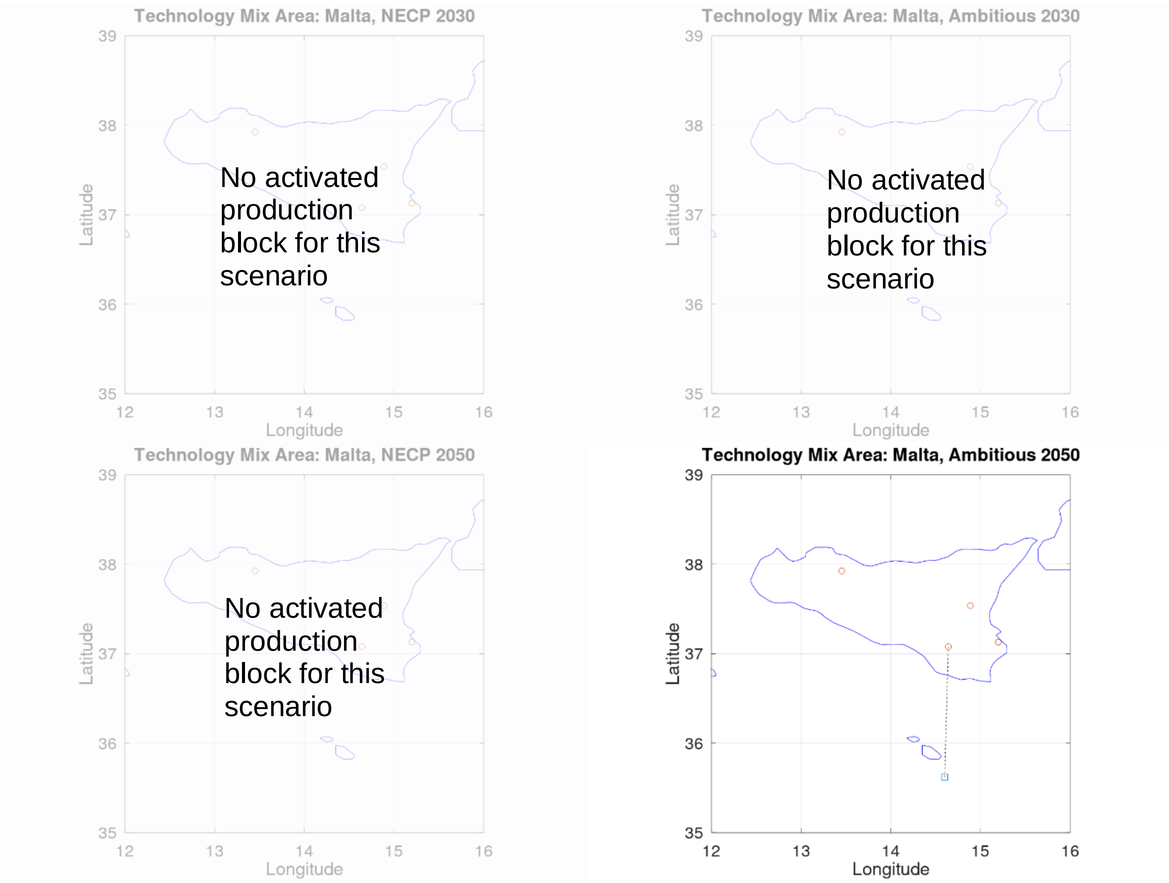

Figure 3-5, and the associated costs are listed in Table 3-6. Because there is no 380 kV-400 kV station on Malta, the connection is made to Italy instead. The size of the production block is 490 MW, and the connection length is about 160 km. Blue squares are production block centres, and red circles are transmission grid stations.

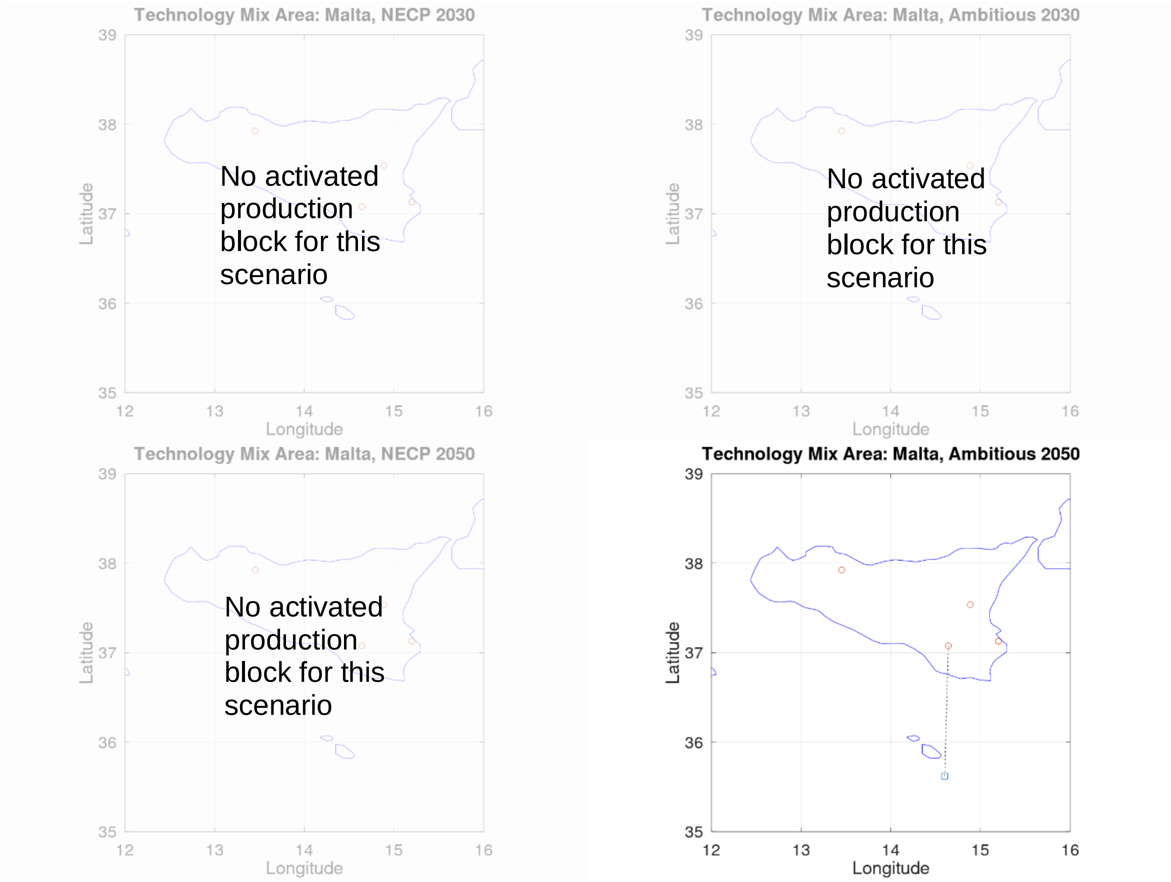

Figure 3-5: Radial connection for Malta

(Source: Sweco)

Table 3-6: Costs and losses for radial connection, Malta

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Malta	0	0	0	278	0	0	0	4	0	0	0	51

(Source: Sweco)

3.2.2.2 Hub connection

Because only one production block is activated in this TMA, there is no possibility of group production blocks for higher efficiency, so no hub connection is defined.

3.2.2.3 Optional grid connection

No 380 kV-400 kV transmission grid station exist on Malta. However, Malta has a 220 kV link to Sicily. Therefore, the optional grid connection studied here will be to connect to Malta at 220 kV instead of to Italy at 380 kV-400 kV. On a general level, the consequences of this choice are:

- The connection length decreases from 160 km to 35 km. The costs are thereby drastically decreased.
- The possibility to export full power from the production block becomes dependent on:
  - The capacity of the link between Malta and Sicily

– The need for power on Malta

The capacity of the current link between Malta and Sicily is 200 MW. Thus, it is unlikely that the full power of the production block (490 MW) can be exported, as it would require full power flow through the link and an excess load of 290 MW on Malta. A detailed study of the possibility to export the power is beyond the scope of this report, but it is likely that curtailment would be necessary. The details of the optional grid connection are illustrated in Figure 3-6 and in Table 3-7.

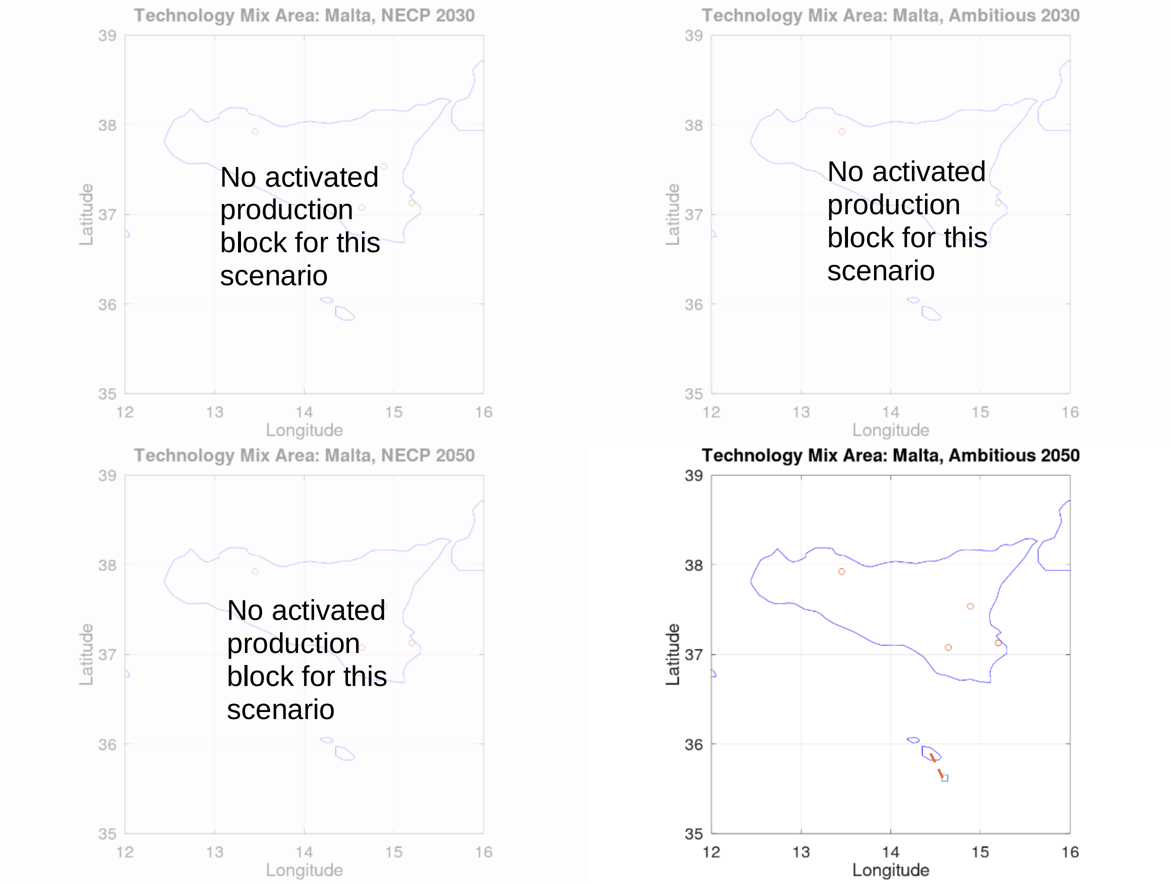

Figure 3-6: Optional grid connection for Malta

(Source: Sweco)

Table 3-7: Costs for optional grid connection, Malta

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Malta	0	0	0	99	0	0	0	1	0	0	0	44

(Source: Sweco)

3.2.3 TMA: Sicily

Table 3-8 describes a summary of the outcome for the different scenarios for this TMA with production blocks connecting to Sicily.

Table 3-8: Activated production blocks, Sicily

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	4	8	9	15	0.6	1.4	2.4	8.7

(Source: Sweco)

3.2.3.1 Radial connection

The radial connection for the four scenarios is illustrated in Figure 3-7, and the associated costs are listed in

Table 3-9. The individual connections are 90 km-163 km, connecting production blocks with installed power of 70 MW-1,060 MW. Blue squares are production block centres, and red circles are transmission grid stations.

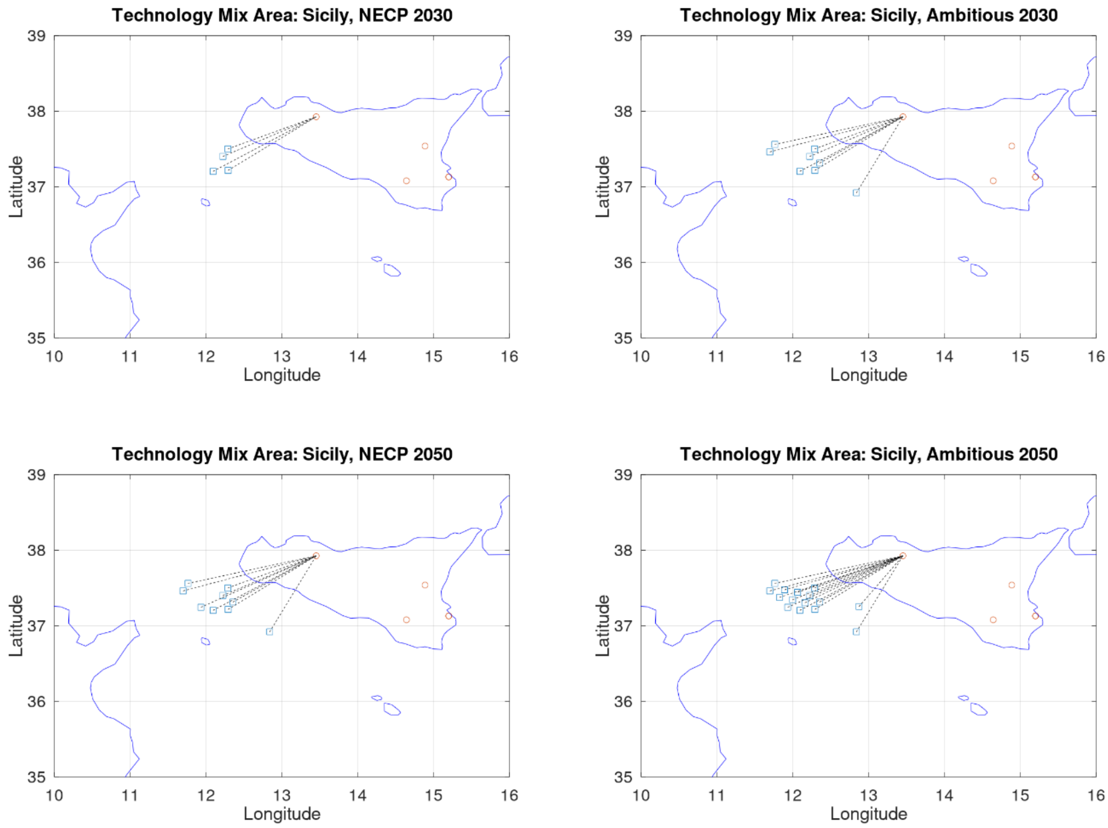

Figure 3-7: Radial connection for Sicily

(Source: Sweco)

Table 3-9: Costs and losses for radial connection, Sicily

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	711	1,529	1,920	3,961	8	18	23	47	59	148	295	1,115

(Source: Sweco)

3.2.3.2 Hub connection

The hub connection for the four scenarios is illustrated in Figure 3-8, and the associated costs are listed in

Table 3-10. The separate connections are 127 km-136 km, connecting production block groups with a total installed power of 570 MW-8,690 MW. Blue squares are production block centres, and red circles are transmission grid stations.

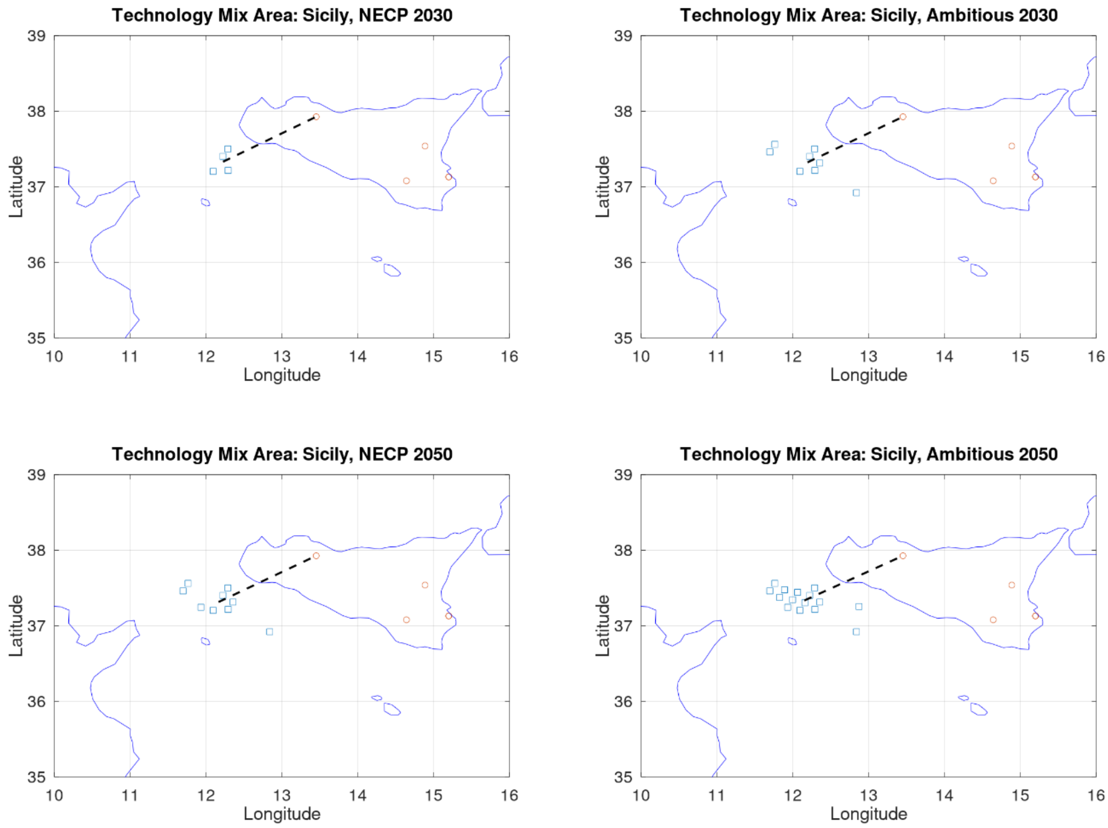

Figure 3-8: Hub connection for Sicily

(Source: Sweco)

Table 3-10: Costs and losses for hub connection, Sicily

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	211	423	789	2,173	2	6	8	26	60	172	143	1,099

(Source: Sweco)

3.2.3.3 Optional grid connection

For this TMA, no clear favourable optional grid connection was identified. However, in the ENTSO-E 10-year network development plan, there is an HVDC interconnection project linking Sicily with Tunisia. The status is in permitting, and the commissioning date is currently set to 2027 (see Figure 3-9). Procedural and political issues apart, it is possible to envisage technical solutions where the connection of the production blocks is realised in parallel with the HVDC link or where the two projects are integrated as a single multipole HVDC link. In either case, the two links would have an impact on each other, though the economic outcome of such an impact is beyond the scope of this study to describe. Section 3.4 contains some additional comments on this issue.

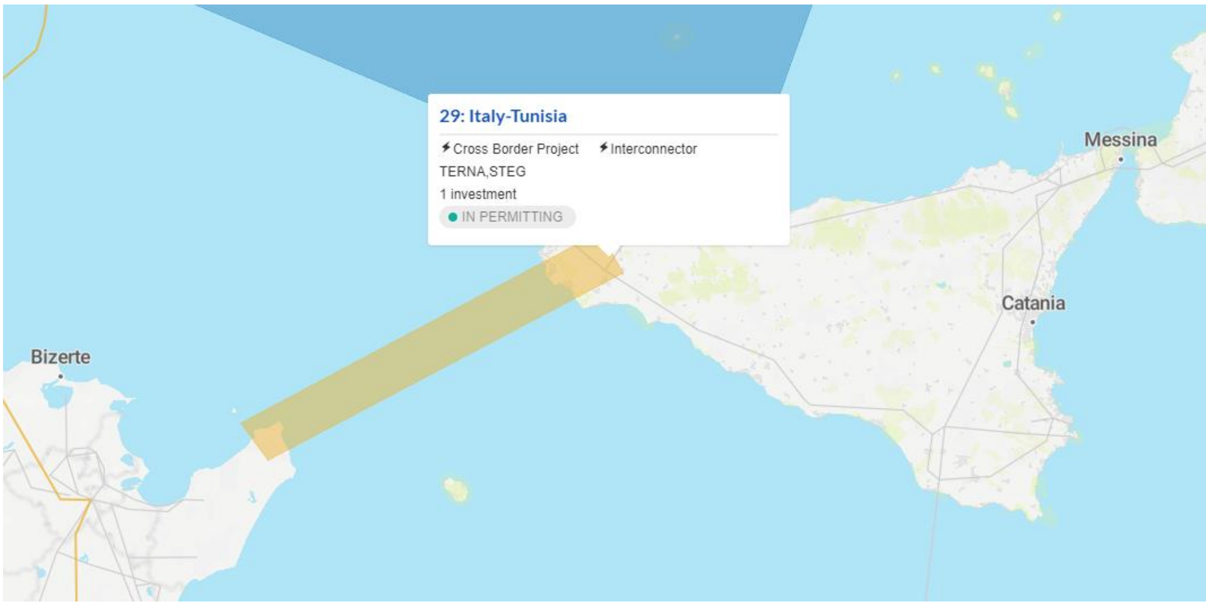

Figure 3-9: Planned interconnection Italy-Tunisia[103]

(Source: (ENTSO-E, 2019b))

3.2.4 TMA: Gulf of Venice

[103] From ENTSO-E 10-year network development map.

Table 3-11 summarises the outcome for the different scenarios for this TMA with production blocks connecting to Italy and Croatia.

Table 3-11: Activated production blocks for Gulf of Venice

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	1	8	12	22	0.4	4	8	16.4
Croatia	0	1	2	3	0	0.4	1	1.9
Total	1	9	14	25	0.4	4.4	9	18.3

(Source: Sweco)

3.2.4.1 Radial connection

The radial connection for the four scenarios is illustrated in Figure 3-10, and the associated costs are listed in

Table 3-12. The individual connections are 31 km-112 km, connecting production blocks with an installed power of 110 MW-970 MW. Blue squares are production block centres, and red circles are transmission grid stations.

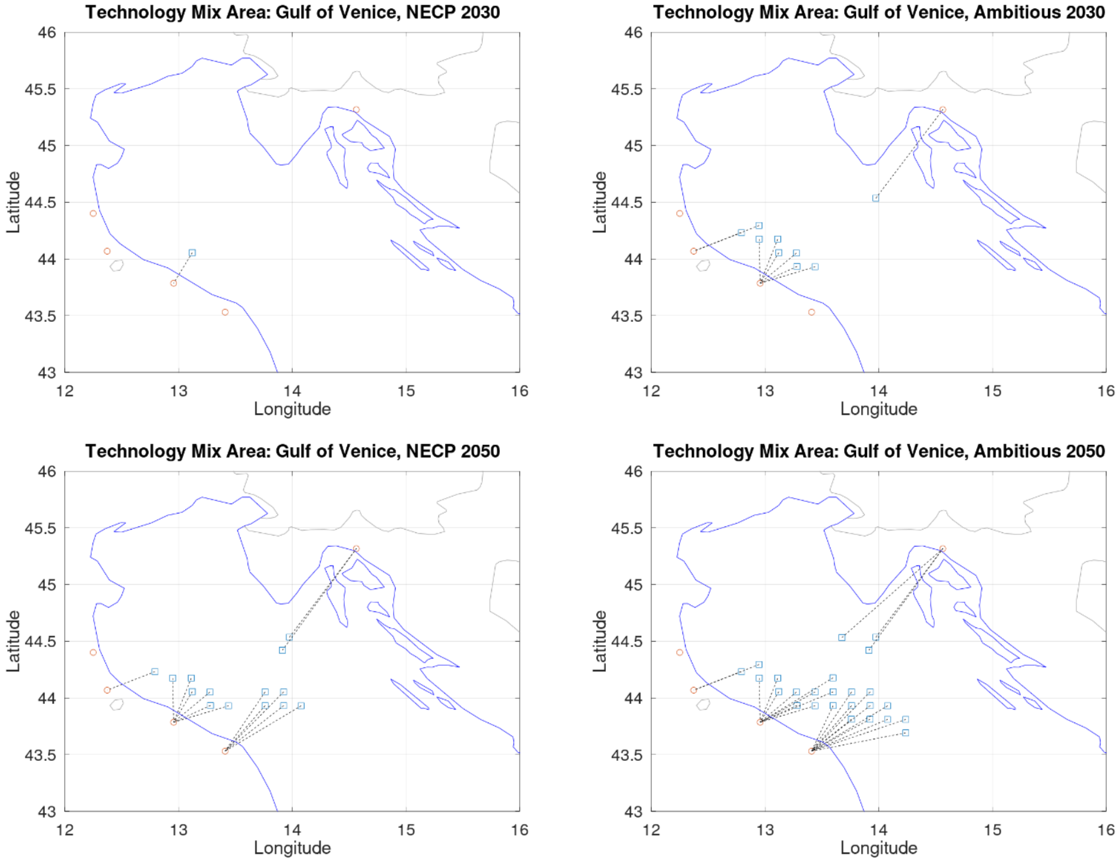

Figure 3-10: Radial connection for Gulf of Venice

(Source: Sweco)

Table 3-12: Costs and losses for radial connection, Gulf of Venice

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	102	1,031	1,977	3,912	1	14	29	57	24	221	474	978
Croatia	0	202	426	776	0	3	7	13	0	202	426	776
Total	102	1,233	2,403	4,687	1	17	36	70	24	423	900	1,754

(Source: Sweco)

3.2.4.2 Hub connection

The hub connection for the four scenarios is illustrated in Figure 3-11, and the associated costs are listed in

Table 3-13. The separate connections are 33 km-107 km, connecting production block groups with a total installed power of 430 MW-10,010 MW. Blue squares are production block centres, and red circles are transmission grid stations.

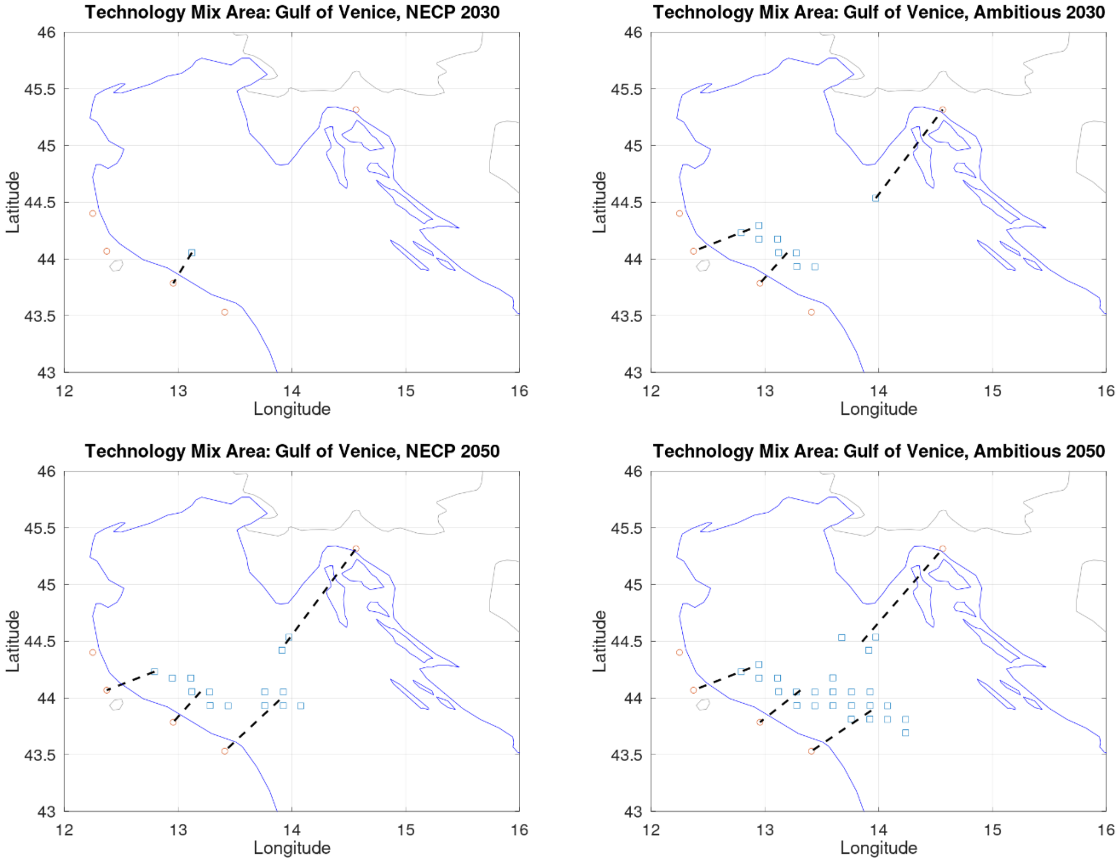

Figure 3-11: Hub connection for Gulf of Venice

(Source: Sweco)

Table 3-13: Costs and losses for hub connection, Gulf of Venice

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	102	532	1,183	2,369	1	8	18	36	24	228	487	1,004
Croatia	0	202	334	472	0	202	334	472	0	202	334	472
Total	212	423	789	2,173	2	6	8	26	60	172	143	1,099

(Source: Sweco)

3.2.4.3 Optional grid connection

In this TMA, the distance between production blocks belonging to Italy and Croatia is of the same order of magnitude as or shorter than the distance from Croatian production blocks to the Croatian shore. Therefore, the chosen optional grid connection is to add an extra offshore link between production blocks belonging to Italy and Croatia, creating a link that can be used for cross-country power flow. This is feasible for the ambitious scenario in 2030, the NECP scenario in 2050, and the ambitious scenario in 2050. The extra interconnection was made with the hub connection as a starting point and has been illustrated in

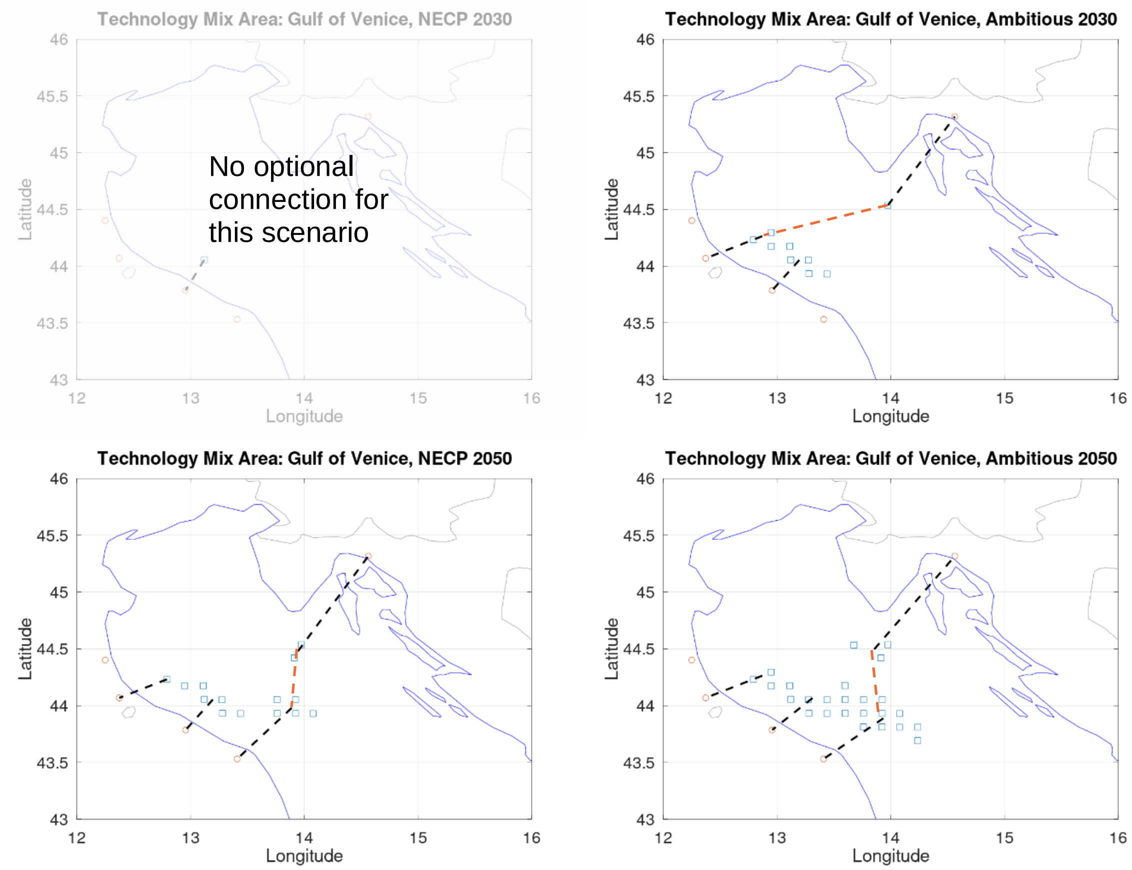

Figure 3-12. The added link is displayed in red.

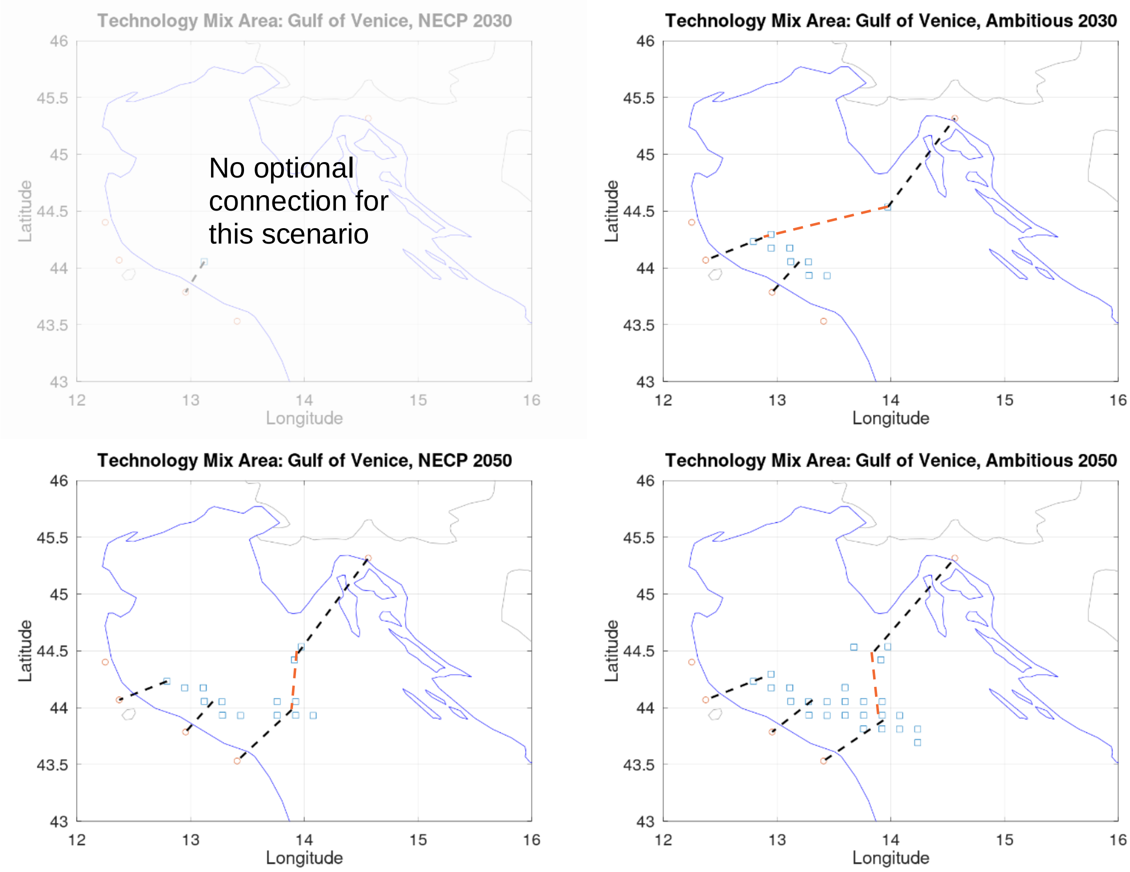

Figure 3-12: Optional grid connection for Gulf of Venice

(Source: Sweco)

The dimensioning of the added link is not self-evident. Furthermore, the added link introduces possibilities of changing the dimensioning of the links to shore since more than one path now exists from each production block to shore. The suitable dimensions depend on strategic choices:

- What is the value of extra redundancy for the grid connection versus the extra costs of a link with a higher capacity?
- What is the value of having the possibility to sell the produced electricity to more than one country versus the extra cost of a link with higher capacity?
- What are the projected possibilities for selling spare capacity in the created cross-country link versus the extra cost of a link with higher capacity?

The necessary investigations to answer the above questions are beyond the scope of this study. As a rough estimate, the extra link is here dimensioned so that its capacity is equal to the weaker of the two links to shore (meaning the Croatian link). This implies several possible operational choices:

- The set of links can be used as a cross-country interconnector, and its spare capacity can be sold.
- The full power of the Croatian group of production blocks can be fed to either country in case of an outage of the Italian group of production blocks.
- Part of the power of the Italian group of production blocks can be fed to either country in case of an outage of the Croatian group of production blocks.

Figure 3-13 summarises the details of the optional connection. Losses are not included because they depend on how the meshed grid is operated.

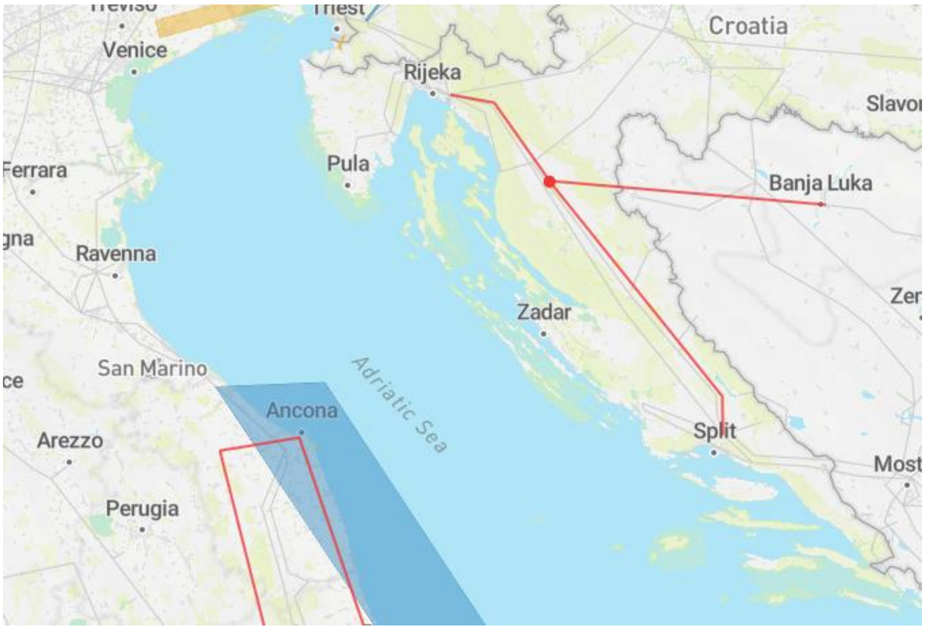

Figure 3-13: Planned projects in the vicinity of Gulf of Venice[104]

Notably, there are three projects in the ENTSO-E 10-year network development plan that are situated in the same region as this TMA: the Adriatic HVDC link, the Central Northern Italy Connector, and the CSE1 New (see Figure 3-13). The two former projects exist to strengthen the Italian transmission grid, and the latter project exists to strengthen the Croatian transmission grid and enable cross-country flows to and from Bosnia and Hercegovina. Neither of these projects have a direct impact on the layout of the optional grid connection, but if all of them are realised, the respective transmission grids will be better equipped to accept injections of power from the production blocks.

3.2.5 TMA: Gulf of Cádiz

Table 3-14 summarises the outcome for the different scenarios for this TMA with production blocks connecting to the south of Spain and Portugal.

Table 3-14: Activated production blocks for Gulf of Cádiz

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Spain	0	1	1	7	0	0.2	0.2	3.8
Portugal	0	0	0	2	0	0	0	1.5
Total	0	1	1	9	0	0.2	0.2	5.3

(Source: Sweco)

3.2.5.1 Radial connection

The radial connection for the four scenarios is illustrated in Figure 3-14, and the associated costs are listed in Table 3-15. The individual connections are 54 km-90 km, connecting

[104] From ENTSO-E 10-year network development map.

production blocks with installed power of 190 MW-990 MW. Blue squares are production block centres, and red circles are transmission grid stations.

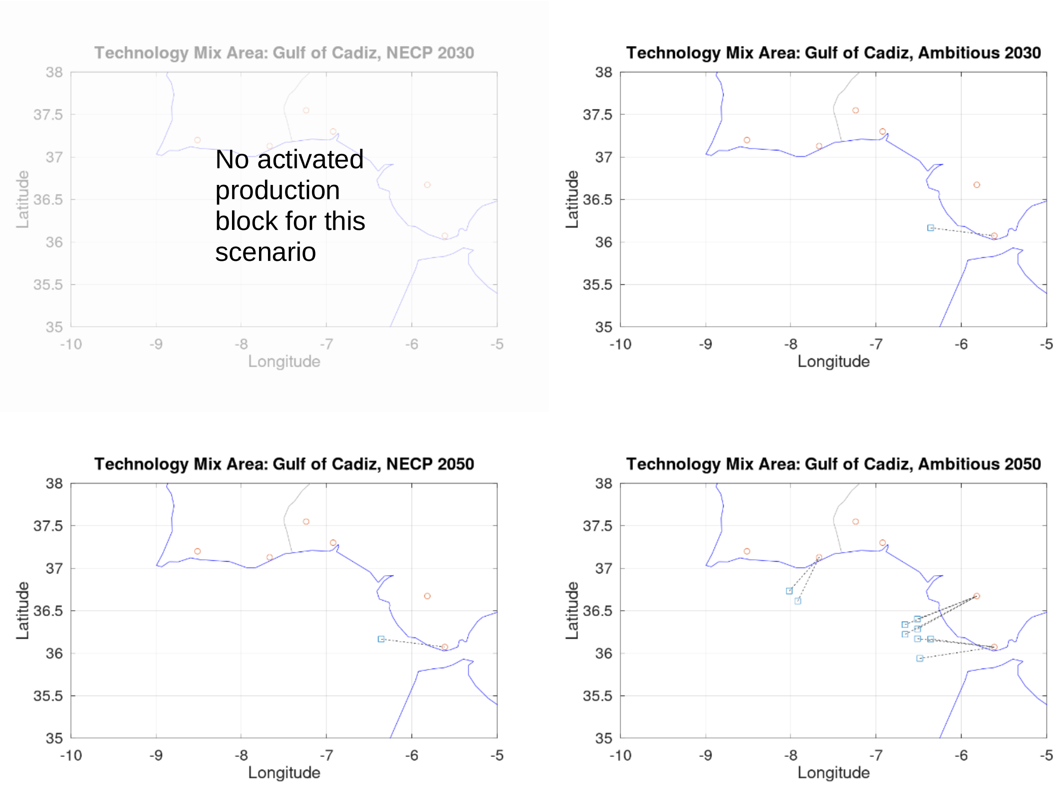

Figure 3-14: Radial connection for Gulf of Cádiz

(Source: Sweco)

Table 3-15: Costs and losses for radial connection, Gulf of Cádiz

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Spain	0	142	142	1,249	0	2	2	17	0	17	18	386
Portugal	0	0	0	345	0	0	0	5	0	0	0	345
Total	0	142	142	1,594	0	2	2	22	0	17	18	731

(Source: Sweco)

3.2.5.2 Hub connection

The hub connection for the four scenarios is illustrated in

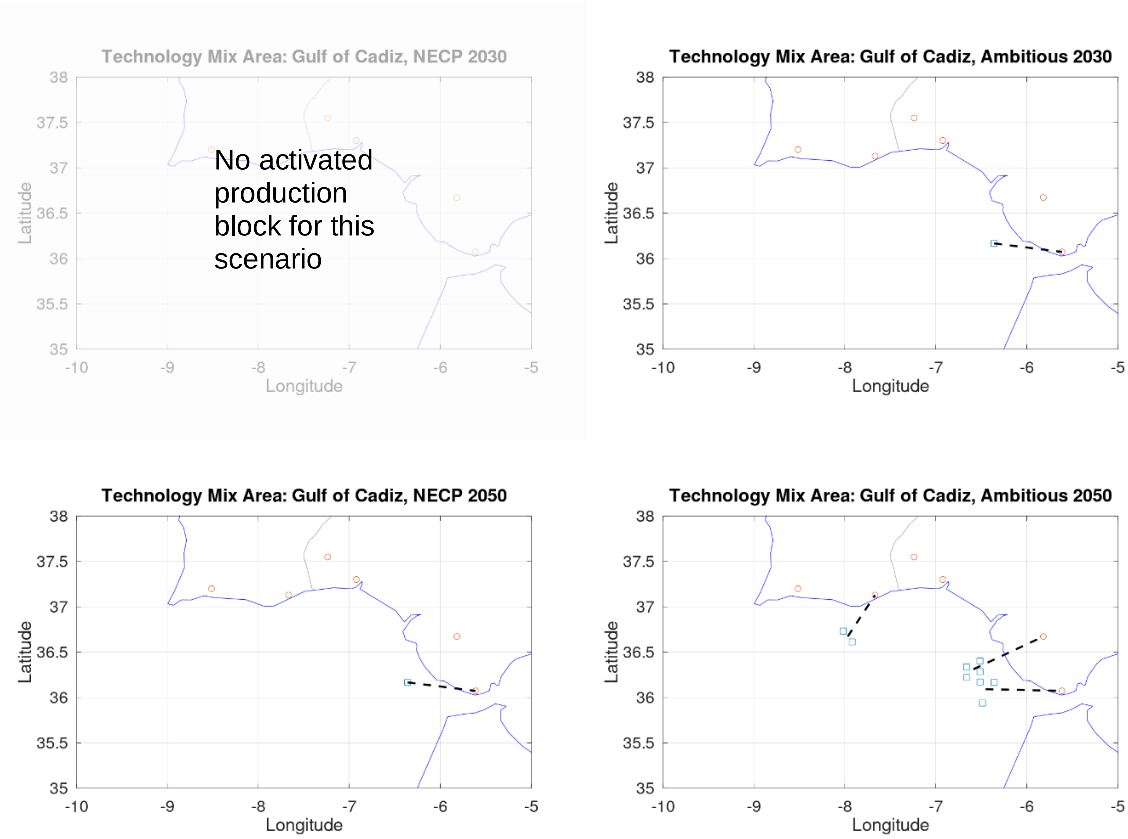

Figure 3-15. Only for the 2050 ambitious scenario does the hub connection differ from the radial connection. The separate connections for the 2050 ambitious scenario are 58 km-80 km, connecting production block groups with a total installed power of 1,180 MW-2,650 MW. Blue squares are production block centres, and red circles are transmission grid stations.

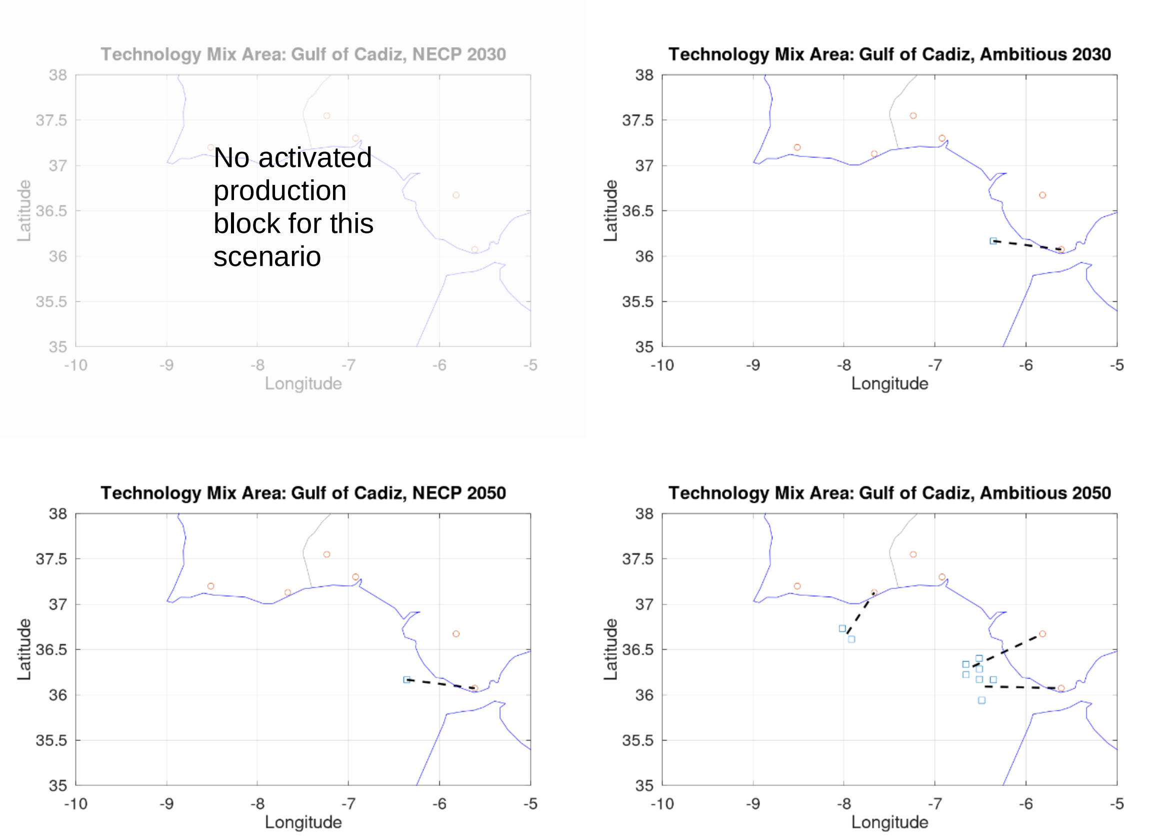

Figure 3-15: Hub connection for Gulf of Cádiz

(Source: Sweco)

3.2.5.3 Optional grid connection

For this TMA, no clear favourable optional grid connection was identified. The southern group of production blocks belonging to Spain could be connected to Morocco, creating an additional link between the countries. However, such a link would be significantly longer and more complex to operate compared with adding another cable along the same route as the existing ones. Thus, no optional grid connection has been defined.

However, Portugal and Morocco have agreed on plans for a link connecting the two countries. Procedural and political issues apart, it is possible to envisage technical solutions where the connection of the production blocks is realised in parallel with the envisaged link or the two projects are integrated as a single multipole HVDC link. In either case, the two links would have an impact on each other, though the economical outcome of such an impact is beyond the scope of this study to describe.

3.2.6 TMA: North Aegean Sea

Table 3-16 summarizes the outcome for the different scenarios for this TMA with production blocks connecting to central Greece.

Table 3-16: Activated production blocks for North Aegean Sea

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Greece	0	2	3	4	0	2.2	3.3	4.3

(Source: Sweco)

3.2.6.1 Radial connection

The radial connection for the four scenarios is illustrated in

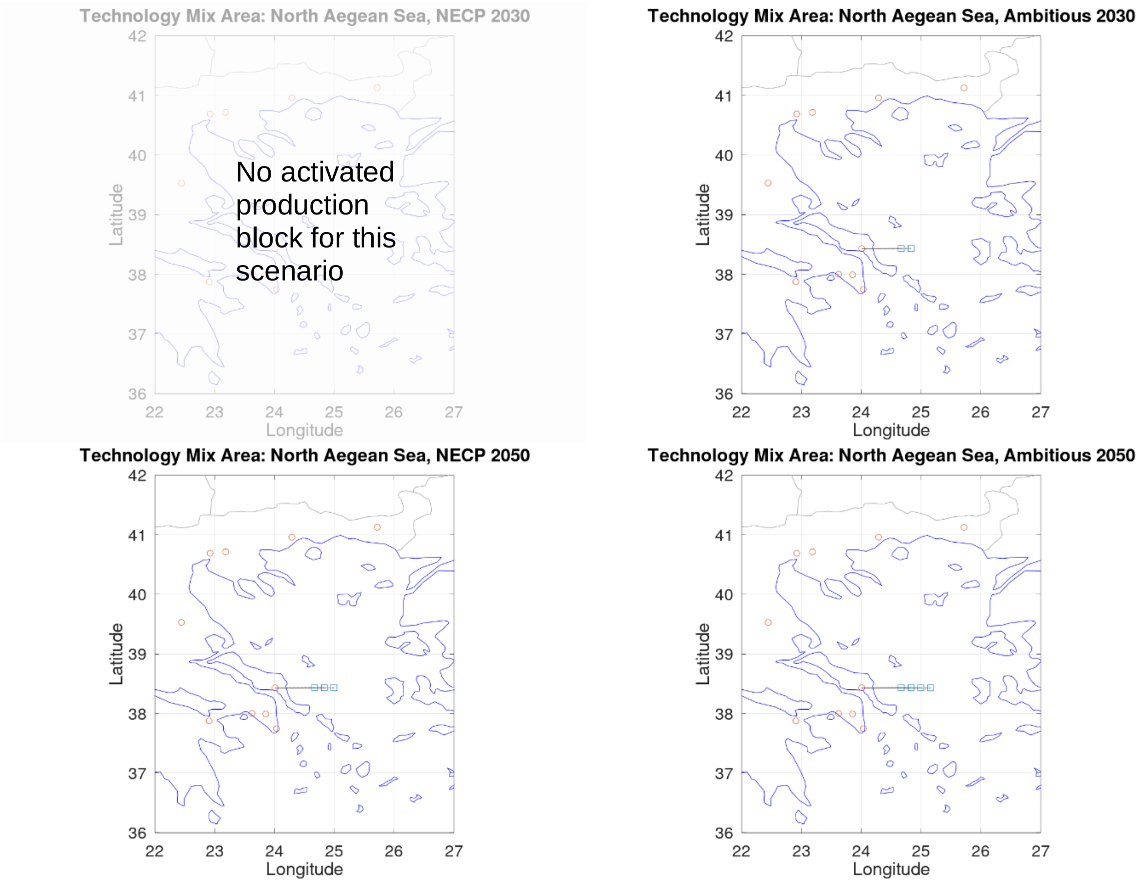

Figure 3-16, and the associated costs are listed in Table 3-17. The individual connections are 58 km-100 km, connecting production blocks with installed power of 1,085 MW. Blue squares are production block centres, and red circles are transmission grid stations.

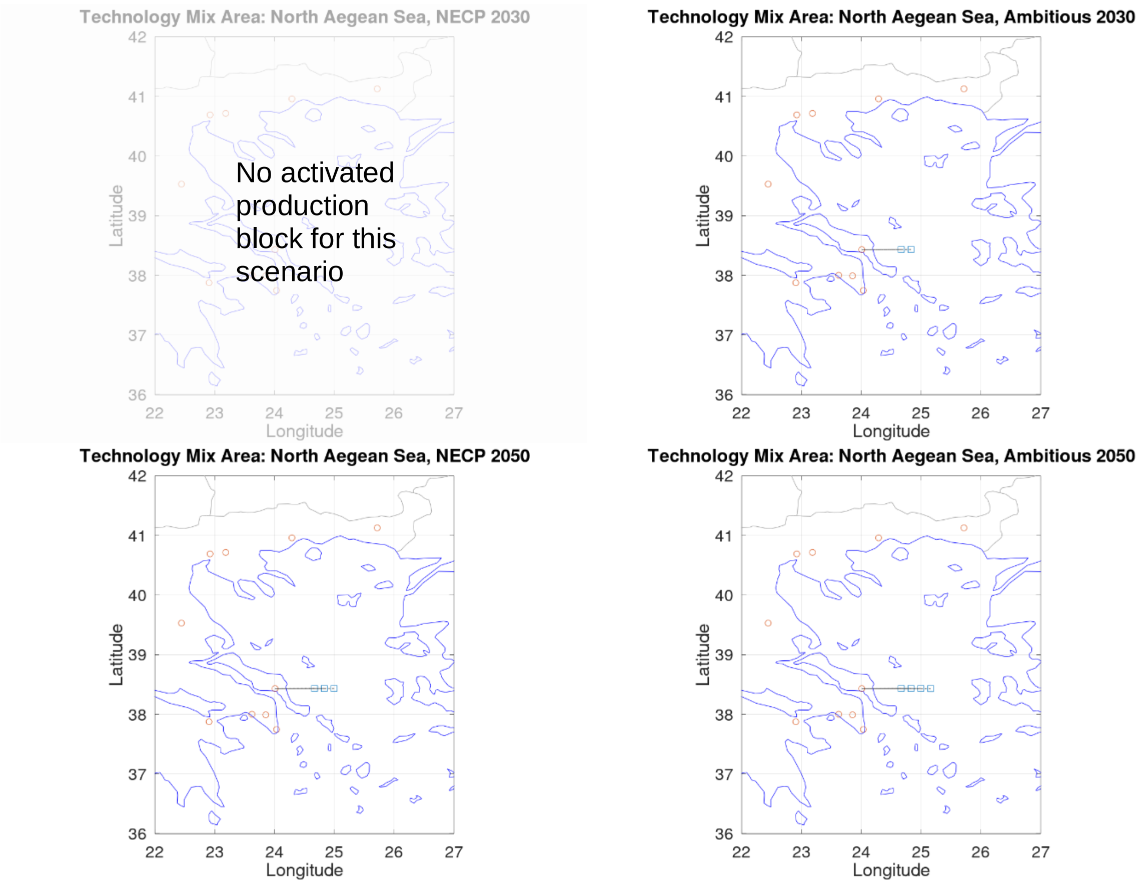

Figure 3-16: Radial connection for North Aegean Sea

(Source: Sweco)

Table 3-17: Costs and losses for radial connection, North Aegean Sea

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Greece	0	448	725	1,039	0	7	11	16	0	217	340	457

(Source: Sweco)

3.2.6.2 Hub connection

The hub connection for the four scenarios is illustrated in Figure 3-17, and the associated costs are listed in Table 3-18. The separate connections are 65 km-79 km, connecting production block groups with a total installed power of 2,170 MW-4,340 MW. Blue squares are production block centres, and red circles are transmission grid stations.

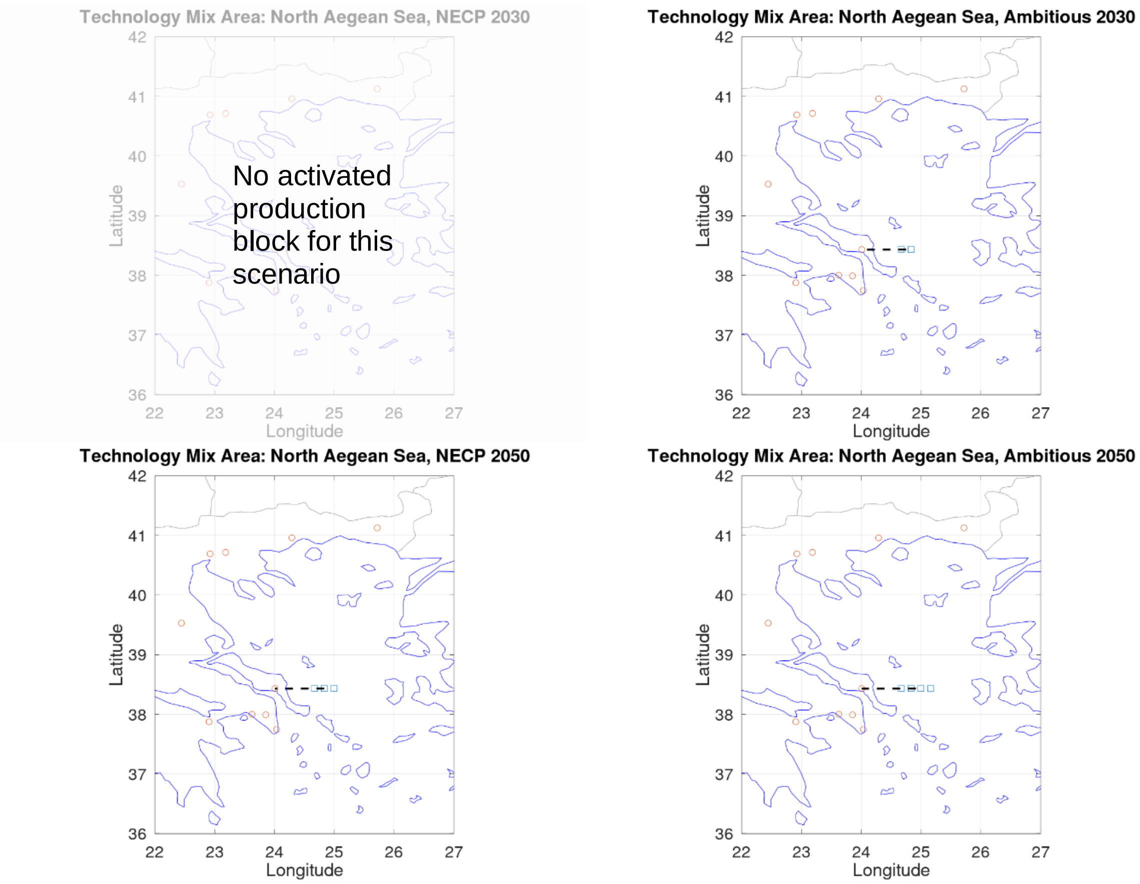

Figure 3-17: Hub connection for North Aegean Sea

(Source: Sweco)

Table 3-18: Costs and losses for hub connection, North Aegean Sea

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Greece	0	333	541	777	0	5	8	12	0	219	344	465

(Source: Sweco)

3.2.6.3 Optional grid connection

For this TMA, no clear favourable optional grid connection was identified. However, the Greek TSO foresees an extended submarine grid for the interconnection of major islands in the Aegean Sea, providing the capability for the connection of RES projects, in the 10-Year Network Development Plan for 2021-2030 (ADMIE, 2020). Procedural and political issues apart, it is possible to envisage technical solutions where such a grid is realized in parallel with the connection of the production blocks in the area. The economic benefits of such an integration are beyond the scope of this study to describe.

3.2.7 TMA: Ionian Sea

Table 3-19 summarizes the outcome for the different scenarios for this TMA with production blocks connecting to the south of Italy.

Table 3-19: Activated production blocks for the Ionian Sea

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	0	0	3	10	0	0	3.1	9.3

(Source: Sweco)

3.2.7.1 Radial connection

The radial connection for the four scenarios is illustrated in Figure 3-18, and the associated costs are listed in

Table 3-20. The individual connections are 57 km-89 km, connecting production blocks with installed power of 710 MW-1,040 MW. Blue squares are production block centres, and red circles are transmission grid stations.

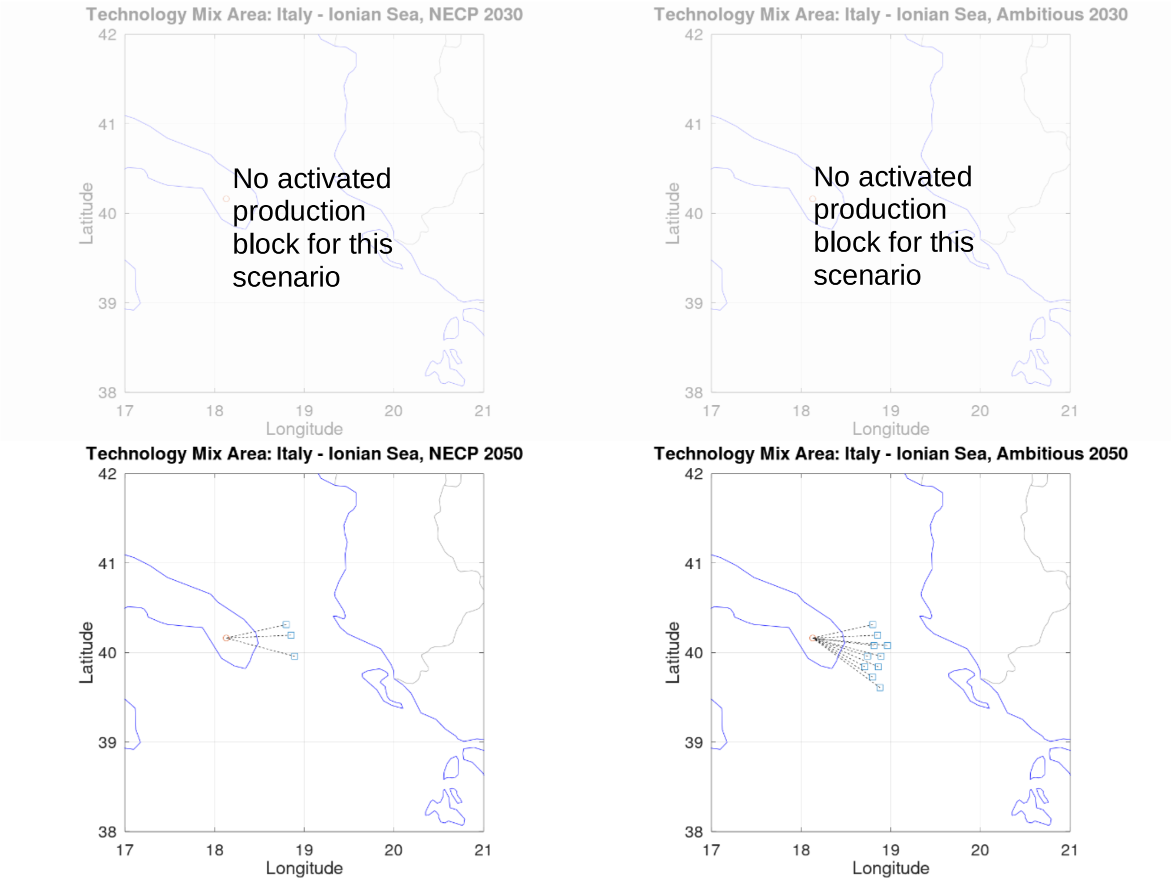

Figure 3-18: Radial connection for the Ionian Sea

(Source: Sweco)

Table 3-20: Costs and losses for radial connection for the Ionian Sea

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	0	0	614	2,094	0	0	8	27	0	0	261	769

(Source: Sweco)

3.2.7.2 Hub connection

The hub connection for the four scenarios is illustrated in Figure 3-19, and the associated costs are listed in Table 3-21. The separate connections are 63 km-67 km, connecting production block groups with a total installed power of 3060 MW-9,250 MW. Blue squares are production block centres, and red circles are transmission grid stations.

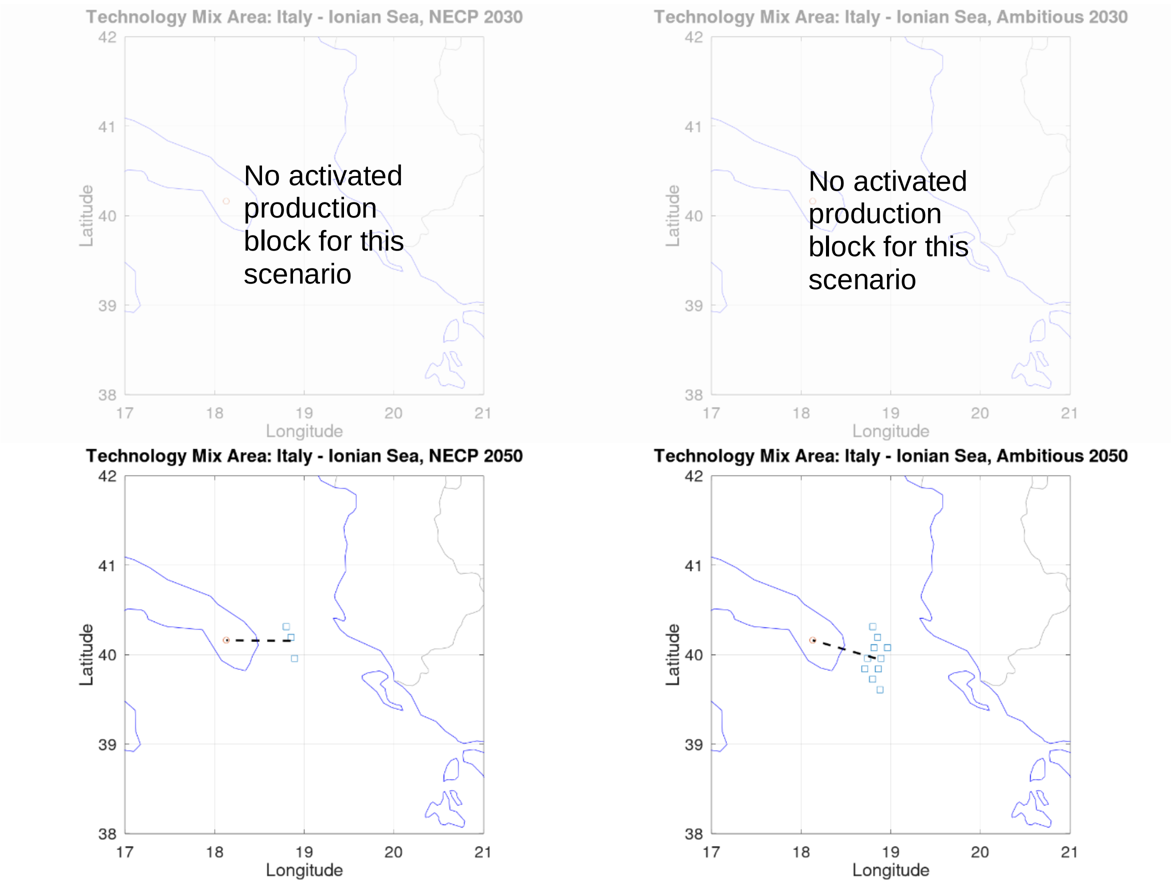

Figure 3-19: Hub connection for the Ionian Sea

(Source: Sweco)

Table 3-21: Costs and losses for hub connection, Ionian Sea

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	0	0	442	1,398	0	0	6	18	0	0	259	791

(Source: Sweco)

3.2.7.3 Optional grid connection

For this TMA, there is no obvious optional grid connection. Stations in Greece and Albania might have been considered for connection; however, in both cases, the distances are quite large, and in Greece's case, there is already an HVDC connection. Thus, for this TMA, no optional grid connection has been defined.

3.2.8 TMA: Corsica-Sardinia

Table 3-22 summarises the outcome for the different scenarios for this TMA with production blocks connecting to Italy.

Table 3-22: Activated production blocks for Corsica-Sardinia

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	0	0	6	12	0	0	5.6	8.6

(Source: Sweco)

3.2.8.1 Radial connection

The radial connection for the four scenarios is illustrated in Figure 3-20: , and the associated costs are listed in Table 3-23. The individual connections are 99 km-189 km, connecting production blocks with installed power of 300 MW-1,010 MW. Blue squares are production block centres, and red circles are transmission grid stations.

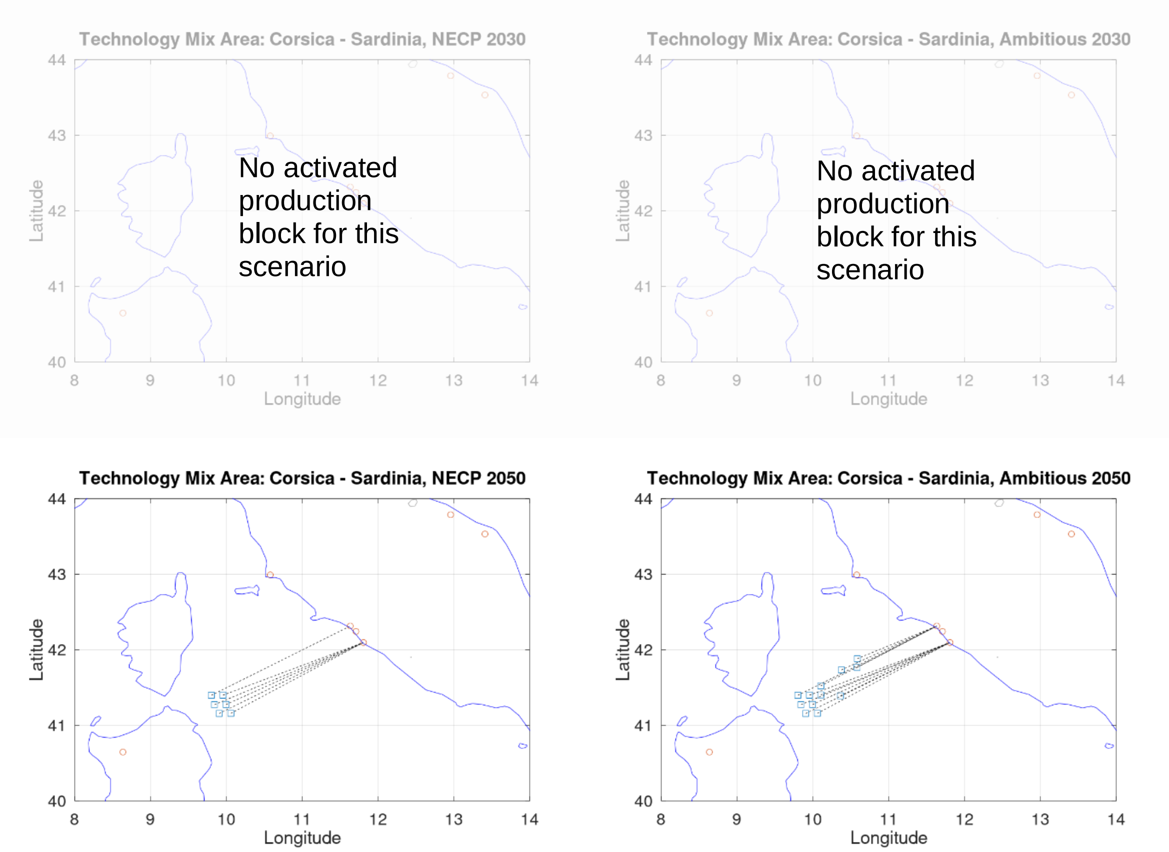

Figure 3-20: Radial connection for Corsica-Sardinia

(Source: Sweco)

Table 3-23: Costs and losses for radial connection for Corsica-Sardinia

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	0	0	3,160	4,831	0	0	57	86	0	0	448	665

(Source: Sweco)

3.2.8.2 Hub connection

The hub connection for the four scenarios is illustrated in

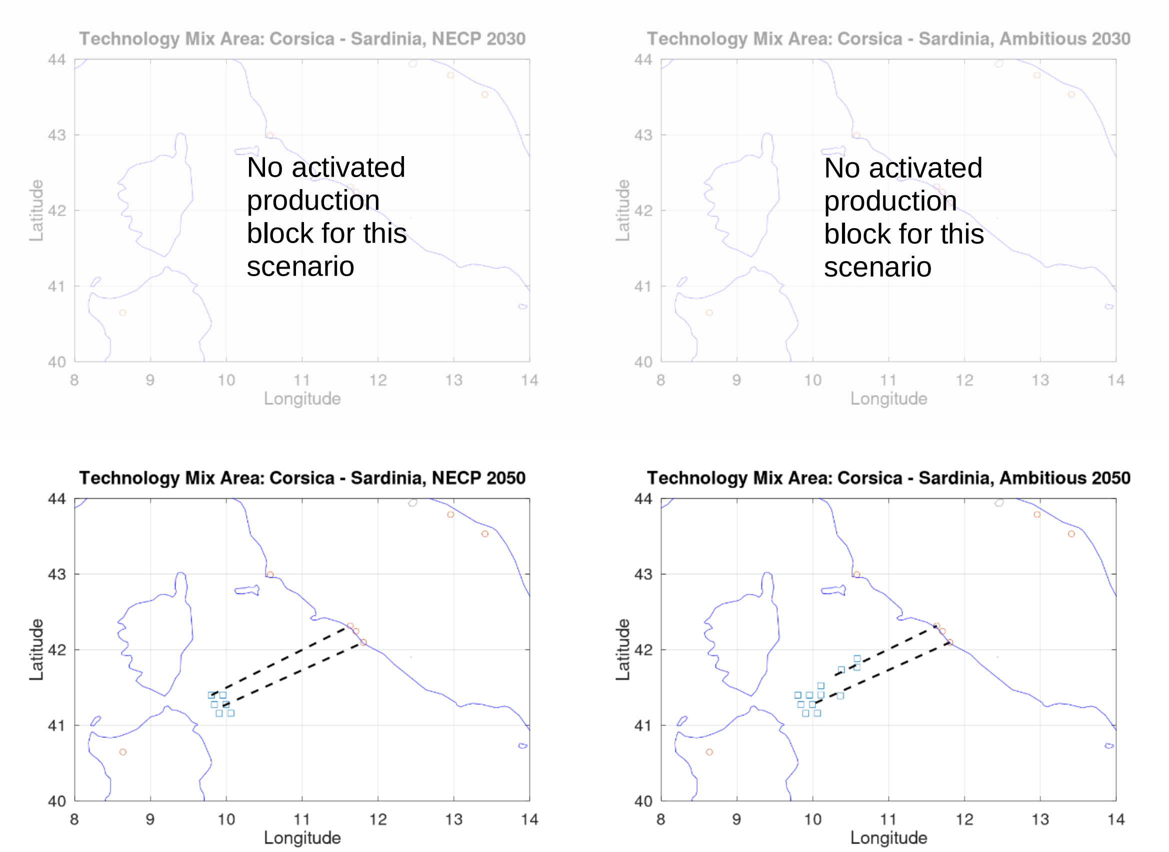

Figure 3-21, and the associated costs are listed in Table 3-24. The separate connections are 133 km-183 km, connecting production block groups with a total installed power of 1,010 MW-5,516 MW. Blue squares are production block centres, and red circles are transmission grid stations.

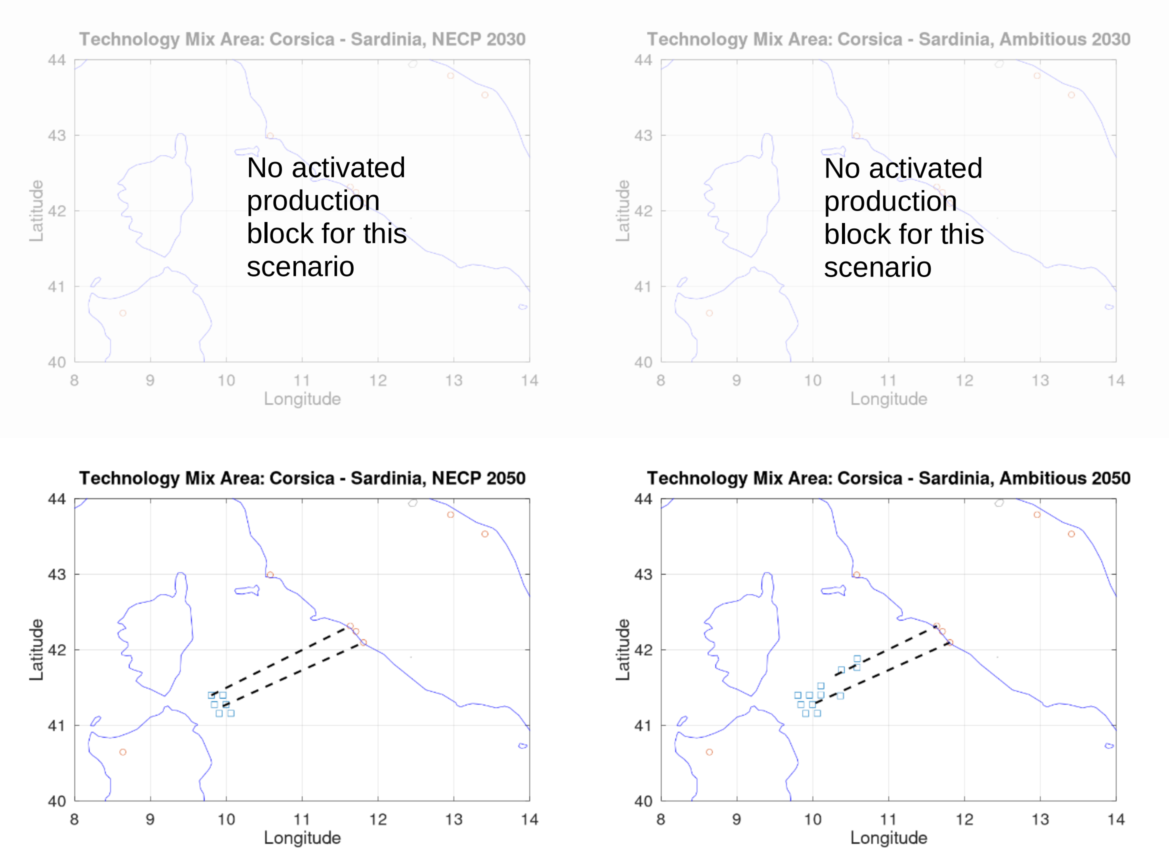

Figure 3-21: Hub connection for Corsica-Sardinia

(Source: Sweco)

Table 3-24: Costs and losses for hub connection, Corsica-Sardinia

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Italy	0	0	2,360	2,992	0	0	36	45	0	0	265	459

(Source: Sweco)

3.2.8.3 Optional grid connection

No obvious favourable optional grid connection was identified for this TMA. Though it would be possible to connect the production blocks to Sardinia or Corsica, the main load centres are on the mainland, rendering limited value to an additional and quite complex link from the islands to the mainland via the groups of production blocks. Thus, for this TMA, no optional grid connection has been defined.

Notably, in the ENTSO-E 10-year network development plan, an HVDC interconnection between northern Italy and Tunisia exists (see Figure 3-22). Procedural and political issues apart, it is possible to envisage technical solutions where the HVDC link is realised in parallel with the connection of the production blocks or integrated as a single multipole HVDC link. In any case, the projects would have an impact on each other, though the economic outcome of such an impact is beyond the scope of this study to describe. Section 3.4 contains some additional comments on this situation.

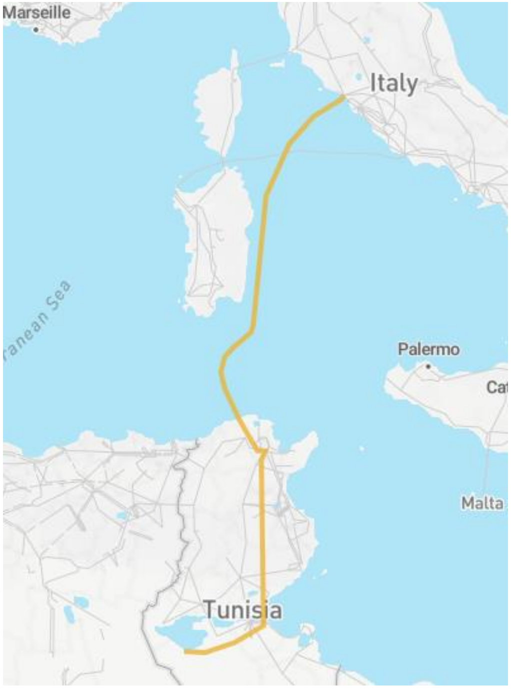

Figure 3-22: Planned projects in the vicinity of Corsica-Sardinia[105]

(Source: Sweco)

3.2.9 TMA: South Aegean Sea

Table 3-25 summarises the outcome for the different scenarios for this TMA with production blocks connecting to central Greece. Five of the eight activated production blocks are islands. These contribute with about 0.5 GW of the total installed power.

[105] From ENTSO-E 10-year network development map.

Table 3-25: Activated production blocks for South Aegean Sea

Scenario	Number of activated production blocks				Total installed power (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Greece	0	0	0	8	0	0	0	3.5

(Source: Sweco)

3.2.9.1 Radial connection

Production blocks are only activated in 2050 ambitious scenario. The radial connection is illustrated in

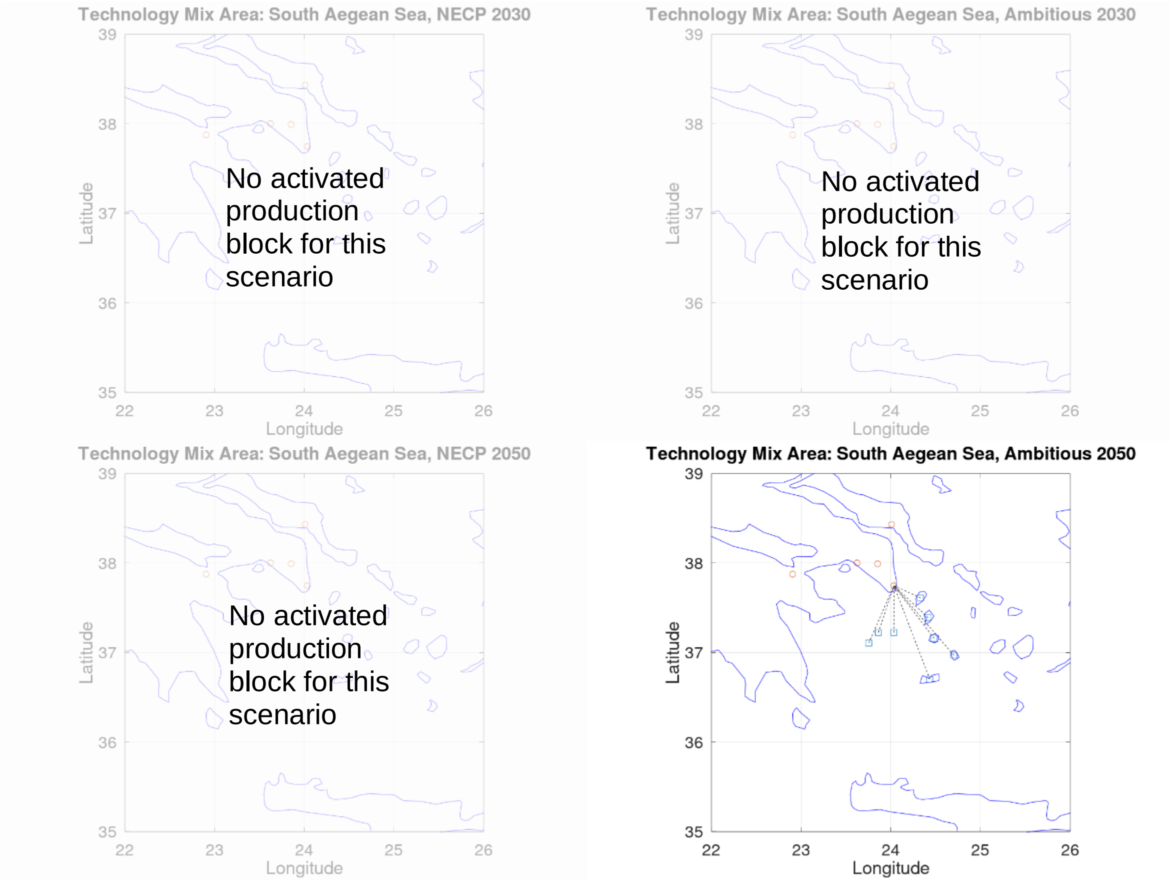

Figure 3-23, and the associated costs are listed in Table 3-26. For the sea-based production blocks, the individual connections are 58 km-75 km long, connecting production blocks with installed power of 940 MW-1,100 MW. For the islands, the individual connections are 30 km-121 km long, connecting production blocks with an installed power of 65 MW-140 MW. Blue squares are production block centres, and red circles are transmission grid stations.

Since island production blocks are rather small, the radial connection will give a relatively high cost per installed GW. Lumping them together, which is done in the next step, will result in better equipment utilization. The costs for the hub connection will significantly decrease.

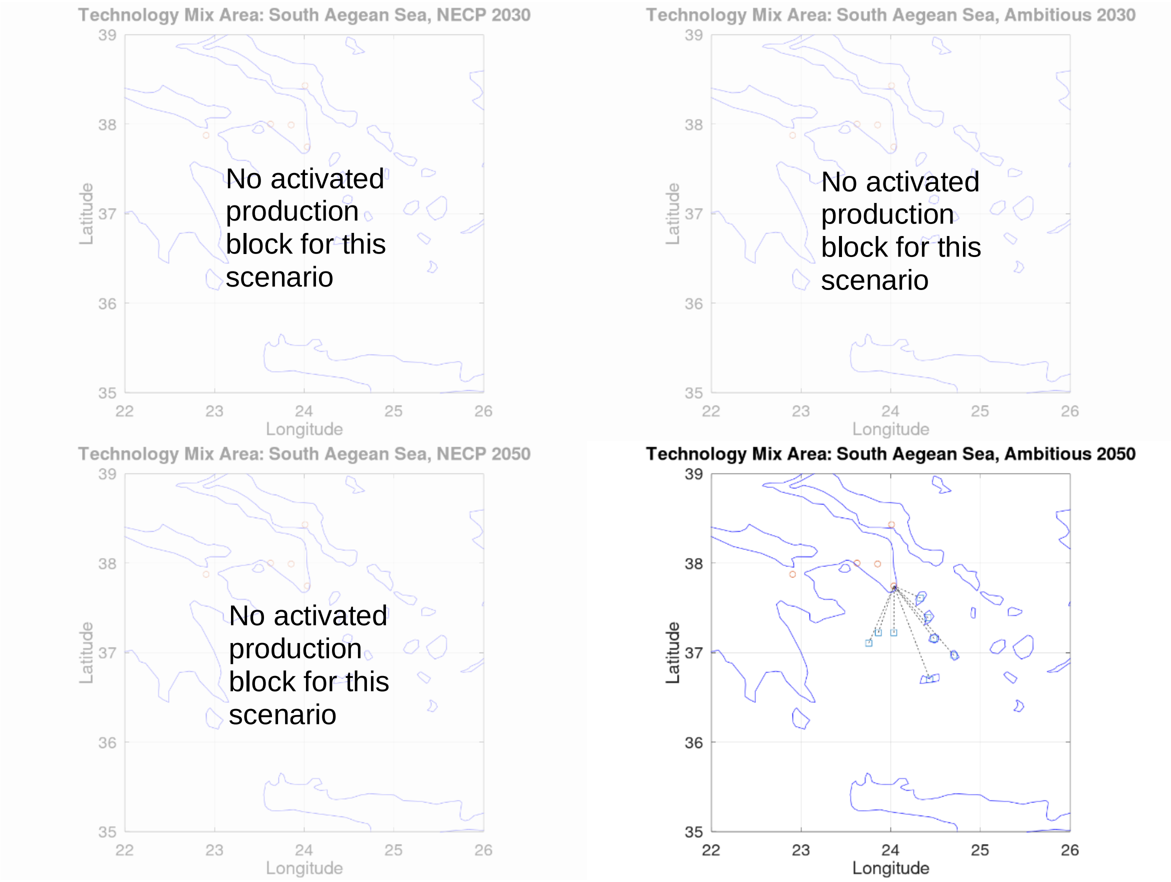

Figure 3-23: Radial connection for South Aegean Sea

(Source: Sweco)

Table 3-26: Costs and losses for radial connection, South Aegean Sea

Scenario	CAPEX [M€]				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Greece	0	0	0	1,378	0	0	0	21	0	0	0	319

(Source: Sweco)

3.2.9.2 Hub connection

The hub connection for the four scenarios is illustrated in Figure 3-24, and the associated costs are listed in Table 3-27. For this particular case, the hub connection was split into two parts, one connecting the sea-based production blocks and one connecting the islands. The separate connections are 65 km-77 km, connecting production block groups with a total installed power of 470 MW-3,070 MW. Blue squares are production block centres, and red circles are transmission grid stations.

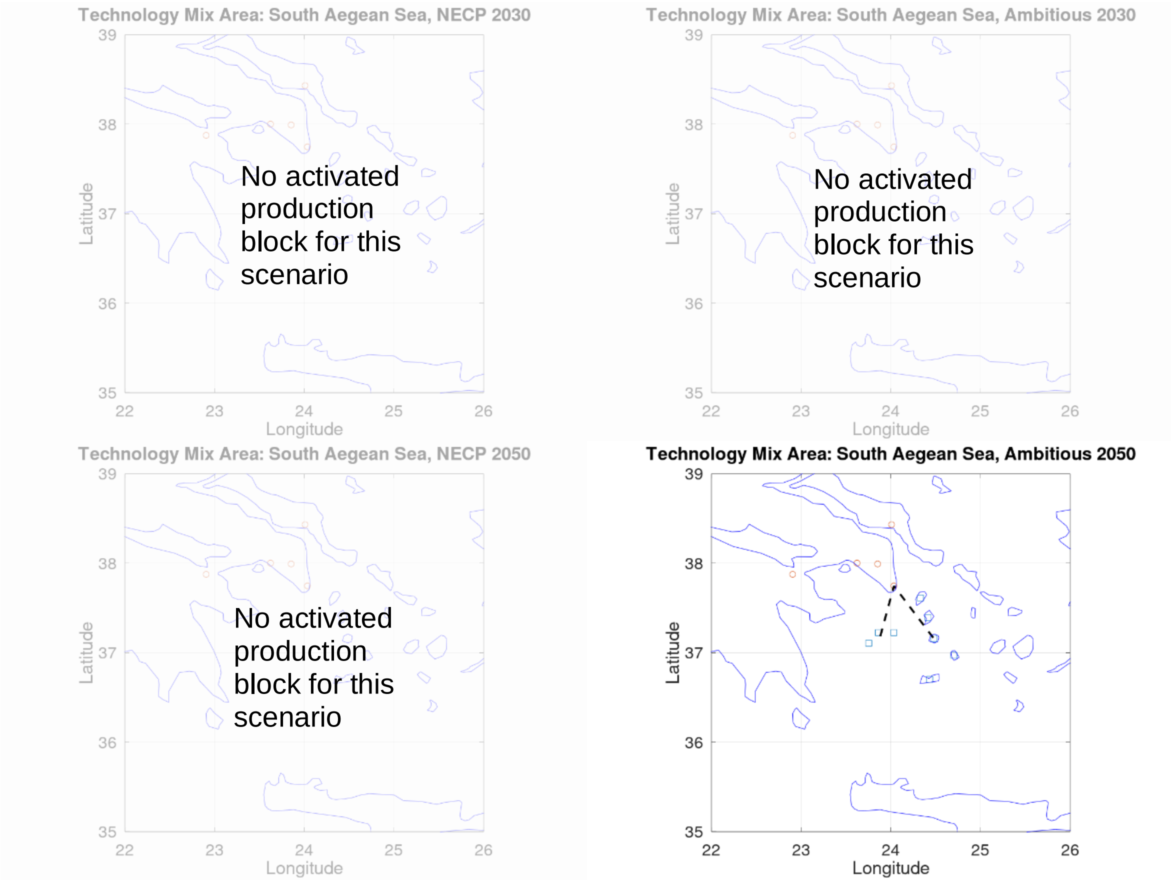

Figure 3-24: Hub connection for South Aegean Sea

(Source: Sweco)

Table 3-27: Costs and losses for hub connection, South Aegean Sea

Scenario	CAPEX (M€)				OPEX (M€/year)				Losses (GWh/year)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Greece	0	0	0	654	0	0	0	10	0	0	0	325

(Source: Sweco)

3.2.9.3 Optional grid connection

For this TMA, no clear favourable optional grid connection was identified. However, there are HVDC interconnection projects planned in this region. The Ariadne interconnector[106] and the Southern Aegean interconnector[107] should both connect Crete with mainland Greece, with connection points in the Athens region (see Figure 3-25). Furthermore, as mentioned in Section 3.2.6.3, the Greek TSO foresees an extended submarine grid for the interconnection of major islands in the Aegean Sea.[108] Procedural and political issues apart, it is possible to envisage technical solutions where the HVDC links or the submarine grid are realised in parallel with the connection of the production blocks or being integrated as single multipole HVDC links. In any

[106] http://www.ariadne-interconnection.gr/en/home-en/
[107] https://tyndp.entsoe.eu/tyndp2018/projects/projects/293
[108] https://www.admie.gr/sites/default/files/users/dssas/dpa-2021-2030-hartis.pdf

case, the projects would have an impact on each other, although the economic outcome of such an impact is beyond the scope of this study to describe. Section 3.4 contains some additional comments on this scenario.

Figure 3-25: Planned projects in the vicinity of South Aegean Sea from the Ariadne Interconnection website (left) and the ENTSO-E 10-year network development map (right)

(Source: Sweco)

3.2.10 TMA: The Baleares

For this TMA, no production blocks are activated in any of the scenarios.

3.3 Consequences for the transmission grids

In this section, the consequences for the transmission grids in the receiving countries are outlined on a general level for the 2030 scenarios only. The content of this section is largely based on interviews with people with insight into the transmission grid around the Mediterranean Sea (a list of interviewees can be found in 0). The descriptions follow the coastline of the Mediterranean Sea from west to east. Table 3-28 outlines the injections in each of the scenarios for the different parts of the connecting countries. Only the power flow corresponding to the radial and hub connections is displayed since the power flow in the optional connections is not fully defined.

Table 3-28: Summary of power injections per country

Scenario	Injected power per scenario (GW)			
	NECP 2030	Ambitious 2030	NECP 2050	Ambitious 2050
Portugal, south	0	0	0	1.5
Spain, total	0	2.0	6.0	14.6
Spain, southwest	*0*	*0.2*	*0.2*	*3.8*
Spain, northeast	*0*	*1.8*	*5.8*	*10.8*
France, south	1.4	3.3	3.3	7.2
Italy, total	1.0	5.4	19.1	43.5
Italy, northwest	*0*	*0*	*5.6*	*8.6*
Italy, Sicily	*0.6*	*1.4*	*2.4*	*8.7*
Italy, Sicily, from Malta	*0*	*0*	*0*	*0.5*
Italy, southeast	*0*	*0*	*3.1*	*9.3*
Italy, northeast	*0.4*	*4.0*	*8.0*	*16.4*
Croatia, west	0	0.4	1	1.9
Greece, total	0	2.1	3.3	7.8
Greece, south	*0*	*0*	*0*	*3.5*
Greece, southeast	*0*	*2.1*	*3.3*	*4.3*

(Source: Sweco)

In general, the transmission grid around the Mediterranean Sea is not very strong or well meshed. Therefore, any major injection of power (in the order of GW) will likely need reinforcements.

In the NECP 2030 scenario, injection of power is made at three locations: in the south of France (Gulf of Lion), in the south of Italy (Sicily), and in the northeast of Italy (Gulf of Venice). An injection of 1.4 GW from the Gulf of Lion is within the forecast for 2030 for that region of the French transmission grid. Therefore, this injection might be handled without any major additional reinforcements. Turning to Italy instead, the injection into Sicily is lower: 0.6 GW. The grid is weak in this region with a known bottleneck between Sicily and mainland Italy. An injection of power here would further increase the general power flow in Italy from the south to the north. Thus, significant grid reinforcements would likely be necessary in Italy due to this injection. The least demanding point of injection for the NECP 2030 scenario is in the north of Italy. An injection here of 0.4 GW might alleviate the congestions stemming from the Italian south-north power flow mentioned earlier. For this part, only minor grid reinforcements might have to be made.

In the ambitious 2030 scenario, the injections mentioned in the previous paragraph are increased. In addition, power is injected into the southwest of Spain (Gulf of Cádiz), the northeast of Spain (Gulf of Lion), the northwest of Croatia (Gulf of Venice) and southeast of Greece (North Aegean Sea). For the south of Spain, the injection is only 0.2 GW, meaning that although the grid in general is not very strong in this region, it might suffice with only minor reinforcements or no reinforcements at all. In the northeast of Spain, the injection is 1.8 GW, meaning that major reinforcements are likely unavoidable. The injection into France in the Gulf of Lion is increased from 1.4 GW in the NECP 2030 scenario to 3.3 GW. For such an injection, major grid reinforcement will likely be necessary. The need for reinforcements increases for the Italian grid since the injection into Sicily increases from 0.6 GW for the NECP 2030 scenario to 1.4 GW. For the Gulf of Venice, the injection into Italy is increased drastically, from 0.4 GW in the NECP 2030 scenario to 4.0 GW. Thus, the necessary grid reinforcements also go from minor to major. From the Gulf of Venice, injection of power into Croatia, with 0.4 GW in this scenario, might be handled with only minor grid reinforcements. Finally, the ambitious 2030 scenario includes an injection of 2.1 GW into the southeast of Greece from the North Aegean Sea—the second largest injection in this scenario. However, this injection is made into the Athens region, which is the main load centre in Greece with roughly 1/3-1/2 of the peak load. Thus, the injected power might result in a less congested grid since it limits the need for power flow from the northwest of Greece. Therefore, for Greece, minor grid reinforcements might suffice.

In summary, the NECP 2030 scenario necessitates major grid reinforcements in the Italian grid, at least in the south. The ambitious 2030 scenario necessitates major grid reinforcements in the north of Spain, the south of France, and in the south and north of Italy. For Greece and Croatia, only minor grid reinforcements may be needed.

Although it is out of this report's scope to assess the consequences of the 2050 scenarios region by region, all involved countries except for Portugal should experience major needs for reinforcements in the conservative scenario, whereas in the ambitious scenario, all countries will be affected in a major way.

3.4 Connection of different TMAs and relations to other planned projects

The option of connecting one or more of the TMAs to each other will be explored in this section. There are two plausible options for interconnection:

- **Direct connection.** For this option to be feasible, there needs to be an obvious benefit of the connection, relative to the option of connecting the transmission grids without going through the TMAs.
- **Connection in coordination with other planned infrastructure projects.** The ENTSO-E TYNDP project sheets will be used as input for this option.

Looking at the 10 TMAs and how they are spread out across the Mediterranean Sea (see Figure 3-26), the distances between any two TMAs are very large. Thus, the option of a direct connection of two TMAs is not considered economically feasible for two reasons. First, the cost of such a connection would be the same as or larger than the cost of connecting the national grids to each other without going through a TMA; second, a cross-country link involving a production site along its way has a capacity that is not as predictable as a dedicated transmission link.

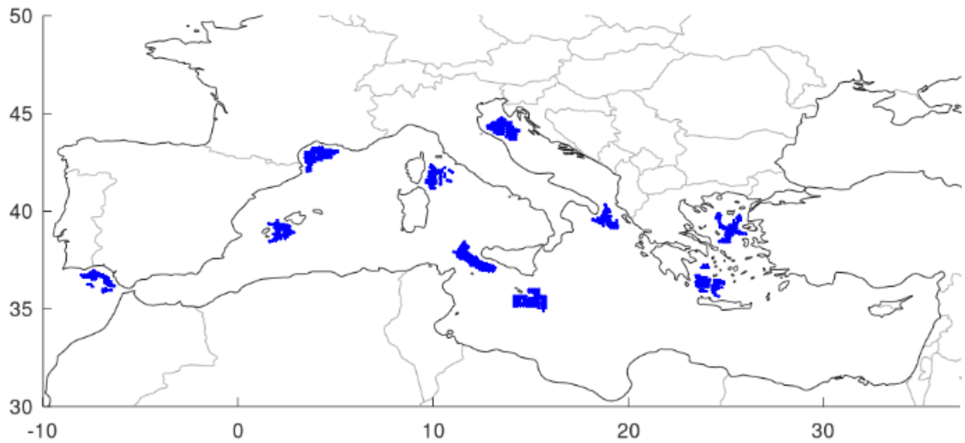

Figure 3-26: Overview of the 10 TMAs

(Source: Sweco)

Some possibilities exist for the option of integrating the TMAs with planned or envisaged future infrastructure projects. In Figure 3-27 displays the ENTSO-E 10-Year Network Development Plan (TYNDP), illustrating projects around the Mediterranean Sea in different stages of consideration. Some of these projects have been described briefly in the earlier sections on optional grid connections.

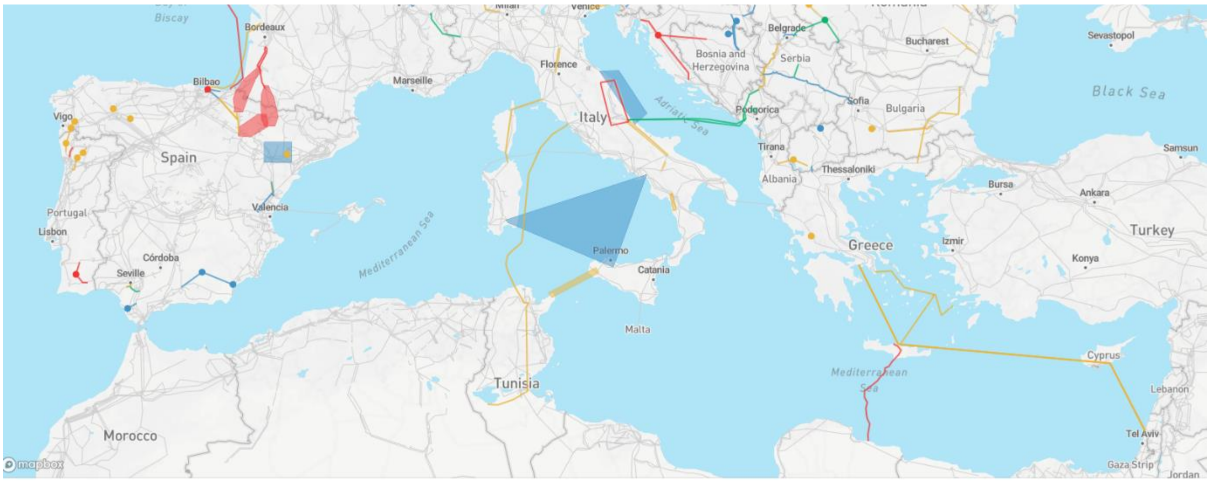

Figure 3-27: Planned transmission projects in or around the Mediterranean Sea[109]

(Source: Sweco)

Studying Figure 3-26 and Figure 3-27, two of the TMAs are located close to projects that involve interconnection of Italy and Tunisia, namely TMA Sicily and TMA Corsica-Sardinia. Thus, this is one option for connecting TMAs to each other. The distances are very large, however, and such an interconnection relies heavily on coordination of the four projects. In summary, coordinating each of the TMAs with either of the HVDC interconnections seems more manageable than considering a full interconnection.

The link connecting the Corsica-Sardinia TMA to shore (described in Section 3.2.8) has a 2050 maximum capacity of 6-9 GW depending on the scenario compared with the planned capacity of the ENTSO-E TYNDP TuNur (Tunisia-Central Italy) link that is 2 GW. Integrating the two links (assuming additional HVDC converters in the TMA) would decrease the total cost for the two projects. Since the common cable path for the two projects is quite long (in the order of 100-200 km), significant cost benefits could likely be achieved. However, integrating the two links would add a factor of uncertainty in the cross-country transfer capacity since the capacity would be dependent on the production from the TMA. In general, this situation is not desirable for TSOs due to difficulties in planning. On the other hand, it could be argued that for a future case, additional grid codes and market forces might provide a framework in which two entities share a common link with certain limitations, low uncertainties, and a clear benefit to both parties.

A similar argument could be made for the integration of the TMA of Sicily (described in Section 3.2.3) with the ENTSO-E TYNDP Sicily-Tunisia interconnector. The planned capacity of the latter is 0.6 GW, and the maximum capacity of the link connecting the TMA to shore is 0.6 GW-8.7 GW, depending on the scenario. The shared cable path would be in the order of 50 km or more, again providing a possibility for cost benefits.

Finally, the possibilities of integration of the South Aegean Sea TMA (described in Section 3.2.9) with the Ariadne interconnector could also be studied in the same way. The planned capacity of the Ariadne interconnector is 1 GW, and the 2050 maximum capacity of the link connecting the TMA to shore is 3.5 GW. The shared cable path would be in the order of 50 km or more, providing a possibility for cost benefits here as well.

For Gulf of Lion, the optional grid connection (see Section 3.2.1.3) involved a link between production blocks belonging to France and production blocks belonging to Spain, creating a

[109] From the ENTSO-E 10-year network development map.

cross-country link. Such a link would increase the transfer capacity between the countries, which might affect the planned grid reinforcements in the western part of the Pyrenees (marked in red in Figure 3-27). The planned reinforcements would result in an estimated increase of transfer capacity of 1.5+1.5 GW.[110] The proposed offshore link in the TMA with a maximum capacity of 2.8 GW, 4.5 GW, and 7.4 GW for the 2030 ambitious scenario, the 2050 NECP scenario, and the 2050 ambitious scenario, respectively, could work as either a complement or substitution for the planned reinforcements. Looking at a future situation with high amounts of PV generation being transported from northern Africa through Europe, both the reinforcements across the Pyrenees and an offshore link may be needed.

3.5 Cost-benefit analysis for the production scenarios and grid options

On an overall level, the quantifiable differences between the different production scenarios and grid options consist of:

- CAPEX and OPEX
  - CAPEX and OPEX for offshore power generation
  - CAPEX and OPEX for different grid configurations offshore including cost of hubs and costs of RES curtailment
  - CAPEX and OPEX for necessary grid reinforcements onshore
- Socioeconomic parameters such as:
  - Socioeconomic welfare impact (producer surplus, consumer surplus, congestion rent)
  - Savings in CO_2 emissions
- Other factors such as:
  - Security of supply
  - RES integration

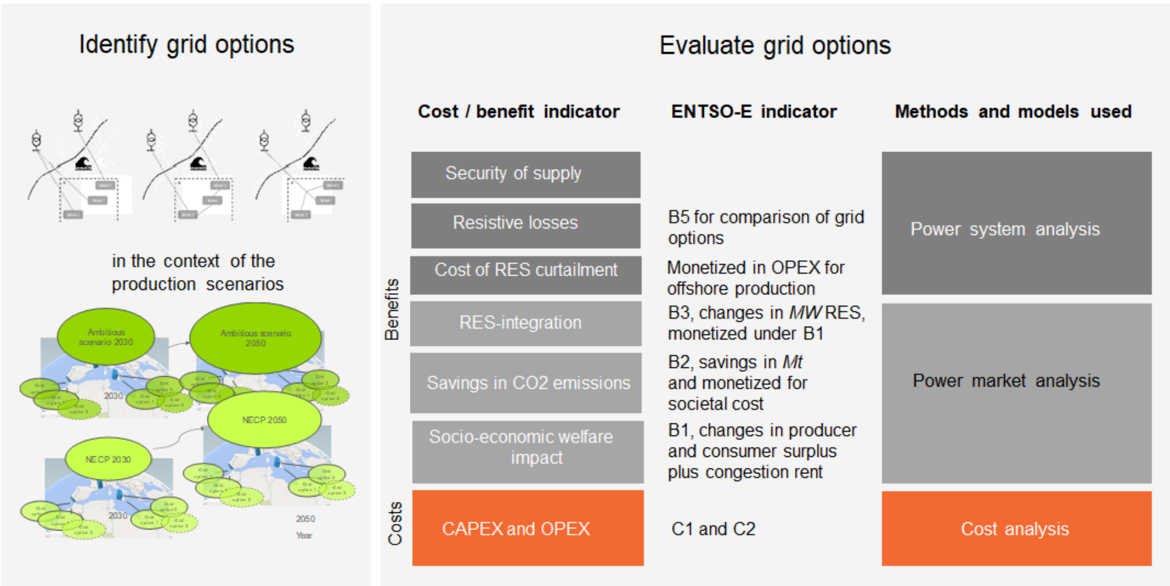

Figure 3-28: Analysis of different production scenarios and grid options

(Source: Sweco)

In general, this study's methodology is aligned with the latest draft of ENTSO-E's cost and benefit methodology from autumn 2019 as shown in Figure 3-28, focusing on the cost and benefit elements without considering residual impacts.

[110] ENTSO-E TYNDP 2018 Project sheets 270 and 276.

The analysis of CAPEX and OPEX for the different grid options, resistive losses, cost of RES curtailment, and the evaluation of security of supply are explained in Section 3.1. The socioeconomic parameters of producer surplus, consumer surplus, congestion rent, and CO_2 emissions from power generation are the result of extensive power market modelling of the different production scenarios and grid options.

The CAPEX and OPEX values for offshore power generation used in the scenarios are the results from Task 1 and their deployment in the production scenarios. Then, the CAPEX and OPEX costs were added for the different grid configurations offshore. Both CAPEX for power generation and external grid connection are annualised with their respective life-length and WACC (see Table 1-23).

This study aimed at including rough CAPEX and OPEX cost estimates for necessary onshore grid reinforcements due to the offshore generation for 2030, based on TSO expert interviews rather than grid modelling. However, this study does not have quantification yet and therefore must leave out these costs from the analysis. For 2050, estimates for onshore grid reinforcements will not be possible since they would require a much more detailed understanding of the detailed grid in 2050 in the reference scenario than can be made in this study.

Costs and benefits are summarised to show the effects on the system as a whole and for the Mediterranean region as a whole rather than for each Member State, since positive effects in one MS could cause negative impacts on one or more member states. The effects per Member State are available, however.

3.5.1 Cost-benefit analysis for 2030 scenarios

The following production scenarios and grid options were analysed for 2030:

- 2030_NECP_RC (the 2030 NECP scenario with radial connection from each production block to shore)
- 2030_NECP_HC (the 2030 NECP scenario with a hub connection to shore)
- 2030_Ambitious_RC (the 2030 ambitious scenario with radial connection)
- 2030_Ambitious_HC (the 2030 ambitious scenario with a hub connection to shore)
- 2030_Ambitious-OC-TMA1 (the 2030 ambitious scenario with an interconnector between France and Spain through TMA1)
- 2030_Ambitious-OC-TMA5 (the 2030 ambitious scenario with an interconnector between Italy and Croatia through TMA5)

Socioeconomic effects and CO_2 emissions are simulated with Sweco's power market model Apollo, described in Appendix B.1. All market modelling analysis is based on a single model year, either 2030 or 2050, simulated with a single weather year, 2014. While this study does compare scenarios for the same model year (e.g., the 2030 NECP and 2030 ambitious scenario), comparisons are best made for smaller changes in generation, as the same transmission capacities are assumed in both scenarios. Furthermore, for the evaluation of the interconnector options, this study only compares the respective scenario without the interconnector to the scenario with the interconnector.

3.5.1.1 CAPEX and RES integration

Figure 3-29 shows a comparison of the different levels of RES integration in the 2030 production scenarios and their grid options compared to the CAPEX levels required for these investments. The CAPEX levels are total levels expressed in 2019 real terms, not annualized values. Therefore, these levels should be interpreted as investments that must made in offshore power generation and grid connection up to 2030 to reach the RES integration of about 2.4 GW offshore wind capacity in the Mediterranean in the NECP scenario (see Table 2-3) and 13.3 GW of offshore capacity in the ambitious scenario as summarized in Table 2-4.

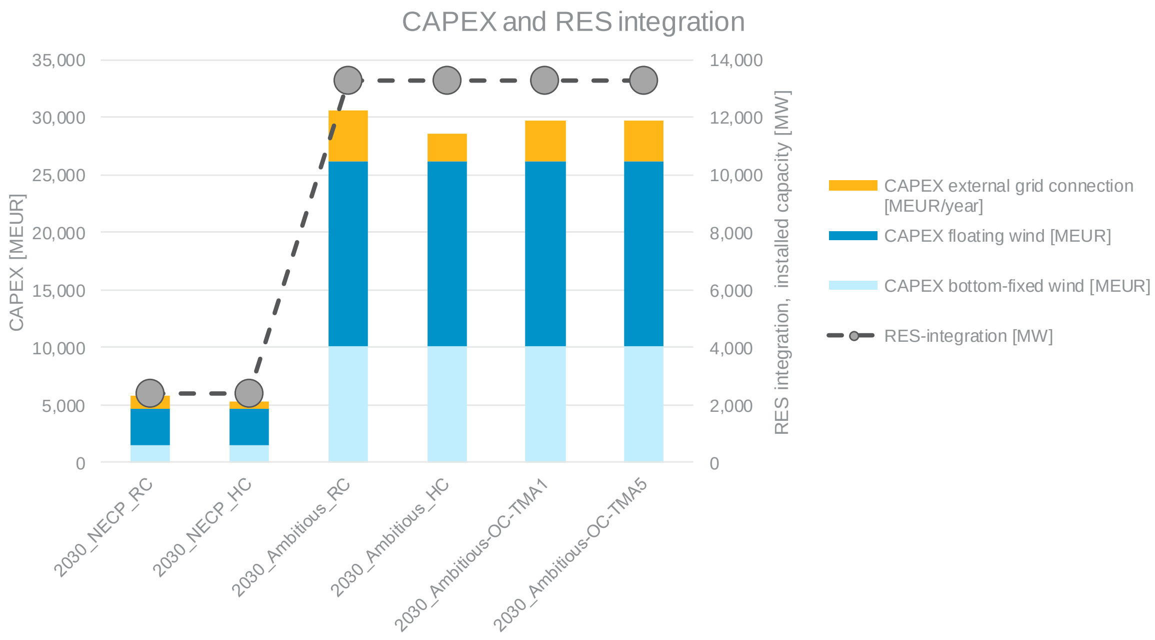

Figure 3-29: CAPEX and RES integration for the various 2030 production scenarios and grid options

(Source: Sweco)

The analysis shows that the hub connection provides a lower CAPEX than the radial connection, regardless of production scenario. The total CAPEX of integrating about 2.4 GW of offshore generation, including grid connection by 2030 in the NECP scenario, is around 6 billion €. The total CAPEX of integrating 13 GW in the ambitious scenario is about 28-31 billion €, depending on grid connection and whether an interconnector is integrated or not. Despite utilizing some of the best sites for bottom-fixed offshore, this study is also using a significant amount of floating offshore sites in 2030. Floating offshore wind stands for about two-thirds of the investments in offshore power generation in our ambitious 2030 scenario.

3.5.1.2 Socioeconomic welfare results

Based on the power market modelling results with a single weather year (2014) with a representative wind pattern, the ambitious scenario shows a significantly higher consumer surplus and lower producer surplus due to generally lower prices. This situation occurs due to new RES-E volumes being brought into the market and more congestion for the existing grid resulting in higher congestion rent.

The two interconnector options connecting two countries show a diverse picture. The interconnector from Spain to France yields higher socioeconomic welfare results mainly based on a higher producer surplus in Spain and Portugal and increased congestion rent for France, resulting in a positive result for the Mediterranean region. However, the decrease in congestion in Croatia for the TMA5 interconnector is not offset by a higher consumer surplus.

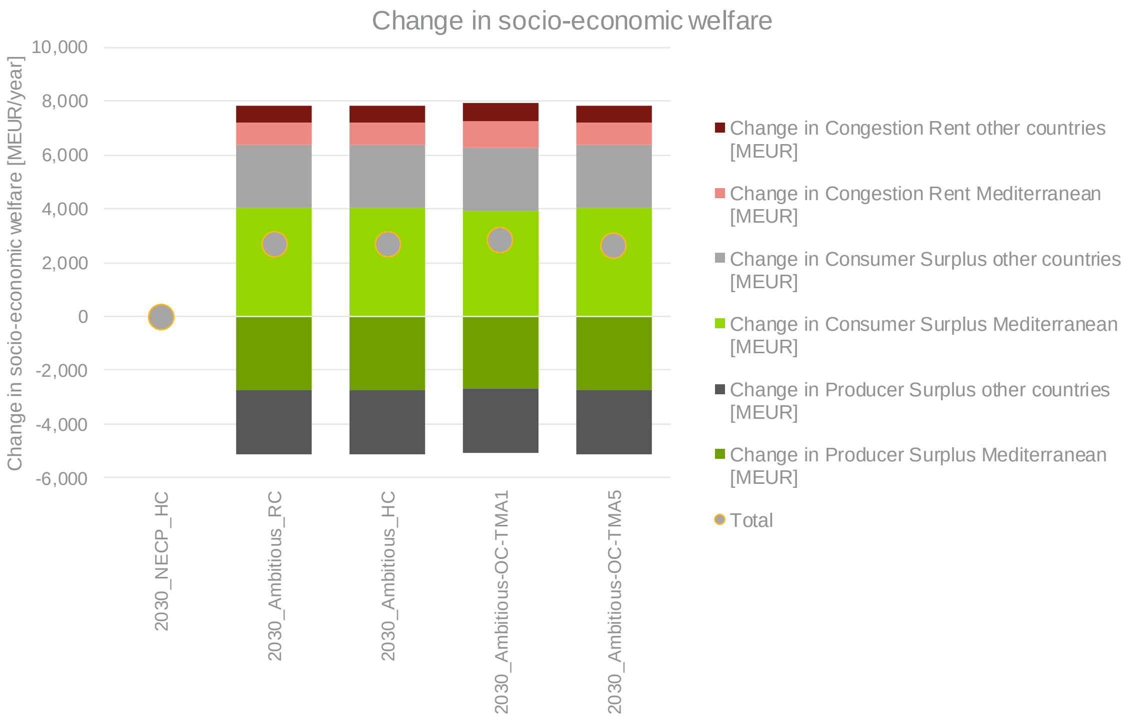

Figure 3-30: Change in socioeconomic welfare for 2030 production scenarios and grid options compared to the 2030 NECP scenario with radial connection

(Source: Sweco)

The interconnector option for TMA1 leads to increased export from Spain to France and from Portugal to Spain, raising power prices in Portugal by 0.3 €/MWh and in Spain by 0.5 €/MWh while slightly decreasing the power price in France as a bigger and more connected system with 0.1 €/MWh. In turn, this situation leads to a higher producer surplus in Spain and Portugal but a lower producer surplus in France while consumer surplus increases in France and decreases in Spain and Portugal as a consequence of higher prices. Congestion rent for the existing interconnectors from Spain is dropping slightly, as these are used less, but congestion rent is increasing for France (see Figure 3-30). From an overall Mediterranean perspective, the socioeconomic results are also positive with 126 M€/year.

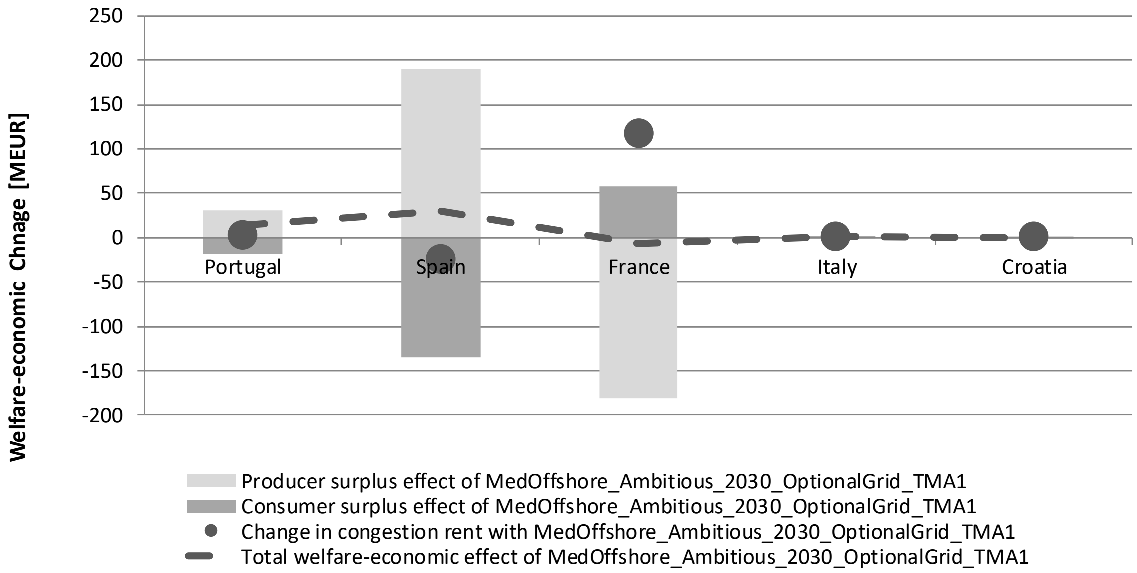

Figure 3-31: Socioeconomic results for the 2030 ambitious TMA1 interconnector option compared with a non-interconnector base case (2030 ambitious)

(Source: Sweco)

The interconnector option for TMA5 leads to lower power prices in Croatia (-1 €/MWh) while the power price in Italy remains largely unchanged. This situation leads to a lower producer surplus in Croatia and a somewhat lower producer surplus in Italy while consumer surplus increases in Croatia and Italy. Congestion rent for the existing interconnectors from and to Croatia are dropping significantly. From an overall Mediterranean perspective, the socioeconomic results are also slightly negative at -8 M€/year. However, results of this magnitude might very well change if simulated with different weather years.

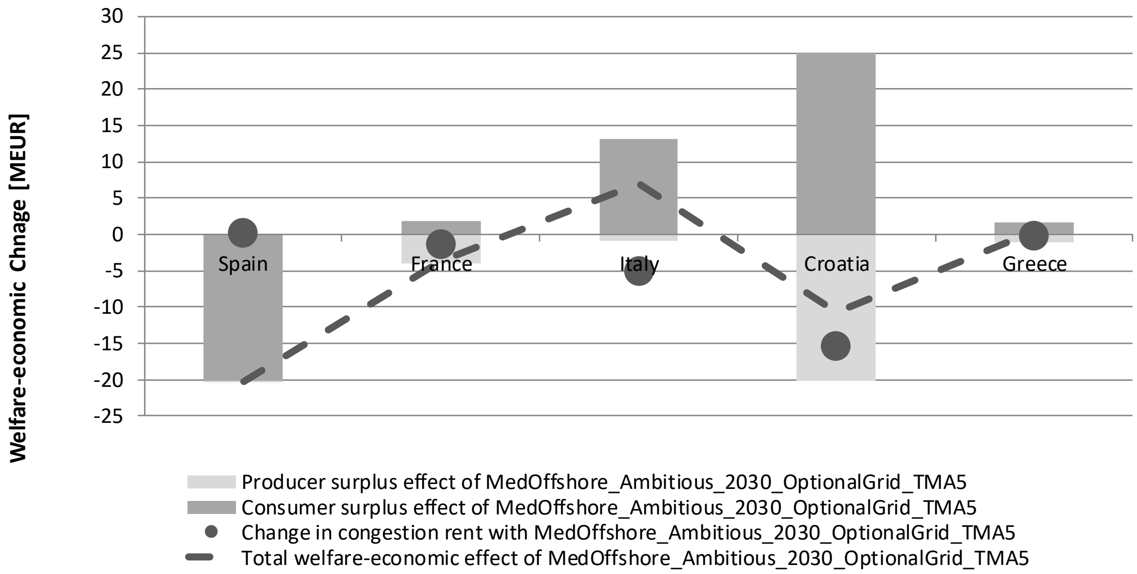

Figure 3-32: Socioeconomic results for the 2030 ambitious TMA5 interconnector option compared with a non-interconnector base case (2030 ambitious)

(Source: Sweco)

3.5.1.3 Savings in CO_2 emissions

Figure 3-33 shows the CO_2 emission savings of the production scenarios and their grid options compared with the NECP 2030 scenario with a radial connection. The ambitious scenario produces savings of around 15 Mt of CO_2 annually by replacing fossil-fuelled generation. While the radial or hub grid configuration does not affect the market outcome, the integration of markets using an additional interconnector in TMA1 and TMA5 does. Both interconnections could contribute to annual CO_2 emissions savings of about 0.2 Mt.

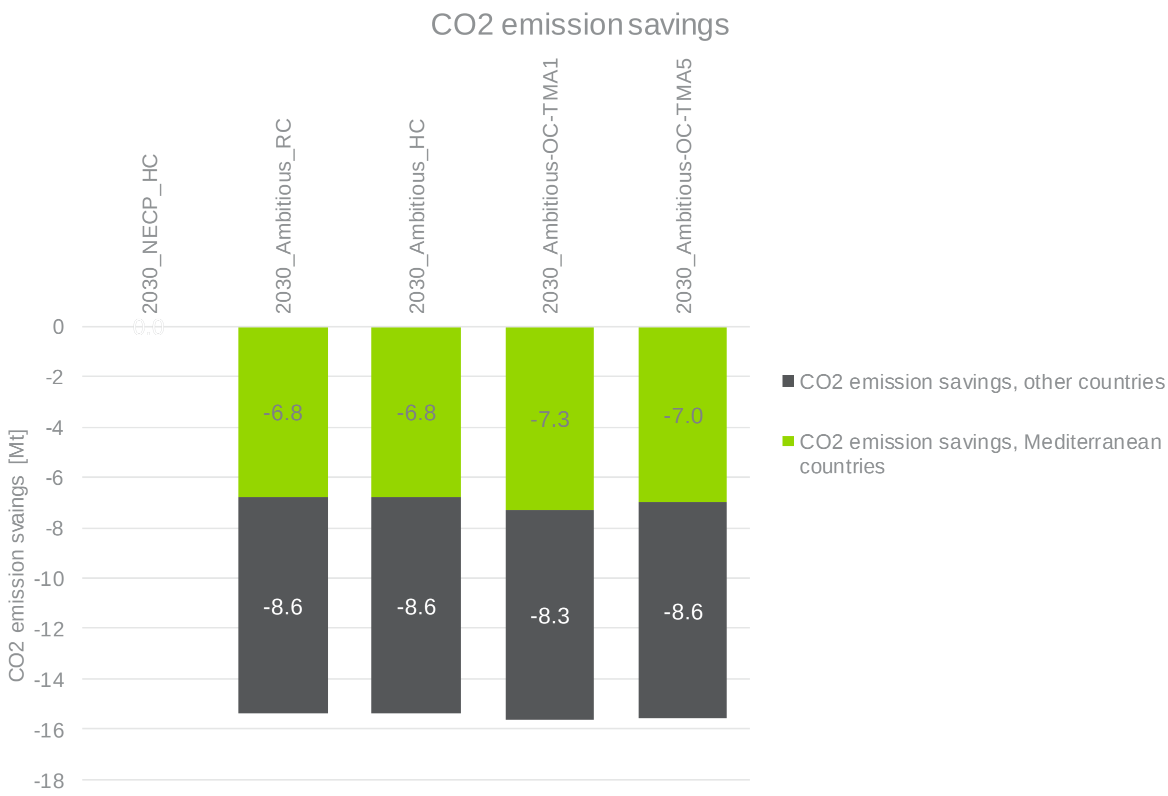

Figure 3-33: CO_2 emissions savings of the production scenarios and their grid options compared with the NECP 2030 scenario with a radial connection

(Source: Sweco)

The CO_2 savings for the Mediterranean countries alone are slightly higher for the TMA1 connection than for the TMA5 connection.

3.5.1.4 Summary

Table 3-29 summarizes the costs and benefits for including the additional benefit of avoided CO_2 emissions in relation to the 2030 NECP scenario with a radial connection. A positive figure in the table means lower cost (e.g., a lower grid connection cost) and higher benefits while a negative figure means higher cost or less benefits than the 2030 NECP scenario with a radial connection. The societal cost of CO_2 emissions is much higher than reflected in the current CO_2 price. However, to have a bottom line, the cost is varied between the current CO_2 price (see Table 3-29 Figure 3-34) and 150 €/t[111] (see Figure 3-35).

[111] Value set to 150 EUR/t for comparison. The choice of value does not aim to quantify the abatement cost but rather aims to illustrate the scenario if the abatement cost were at that level and included in the analysis.

Table 3-29: Summary of costs and benefits[112] for production scenarios and grid options in 2030 in relation to the 2030 NECP scenario with radial connection, societal cost for CO_2=EU-ETS price

	2030_NECP_HC	2030_Ambitious_RC	2030_Ambitious	2030_Ambitious-OC-TMA1	2030_Ambitious-OC-TMA5
Annual cost offshore power generation (M€/year)	0	-2,238	-2,238	-2,238	-2,238
Annual cost external grid connection (M€/year)	34	-239	-96	-181	-175
Welfare economics Mediterranean countries (M€/year)	0	2,112	2,112	2,238	2,104
Welfare economics other countries (M€/year)	0	584	584	626	566
Total monetized effects	**34**	**218**	**362**	**445**	**257**
CO_2 emissions avoided, Europe (Mt)	0	-15.4 Mt	-15.4 Mt	-15.6 Mt	-15.6 Mt
RES integration (MW)	0	10,871	10,871	10,871	10,871

(Source: Sweco)

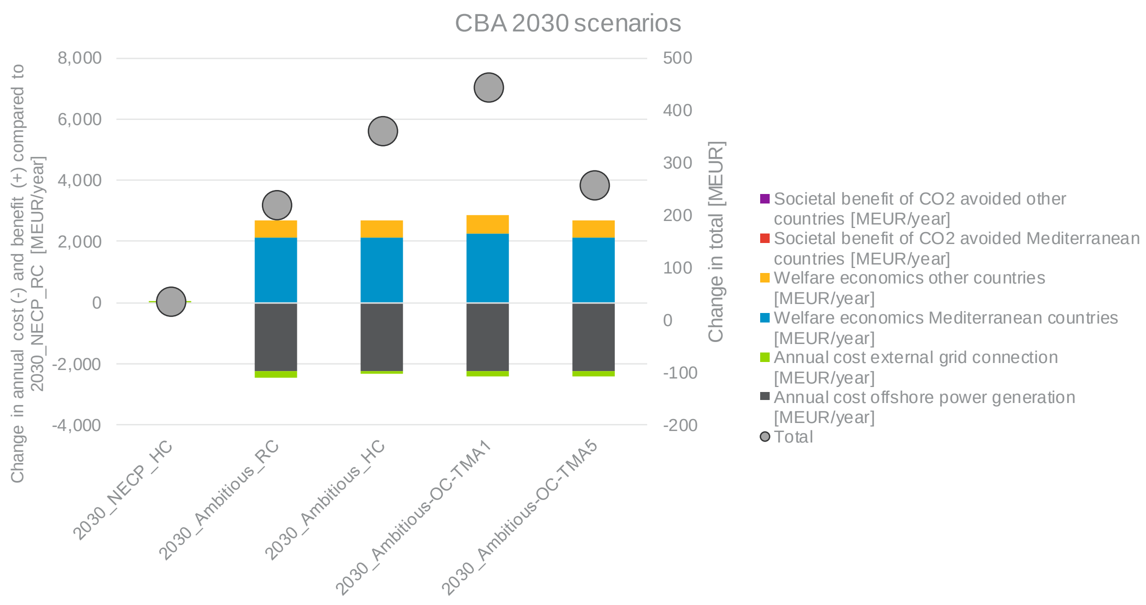

Figure 3-34: Costs and benefits of the different 2030 production scenarios and grid options with societal cost of CO_2 equal to EU-ETS price (28 €/t)

(Source: Sweco)

[112] There are parameters that could significantly affect the cost-benefit analysis results, other than the cost of onshore grid reinforcement and CO_2 price, including: weather years examined, scenarios examined, WACC for different components (where decisive policies can have a beneficial impact), the impact of grid failures (this may have a significant impact on offshore connections; see for example the historical low availability of the existing Italy-Greece interconnector). This study analysed one single normal weather year, normal grid availability, and one WACC level.

With the analysed parameters for 2030, all ambitious scenarios with 13 GW RES integration yield higher benefits than the NECP scenarios with 2 GW of installed offshore capacity by lowering power prices and increasing consumer surplus, with and without a higher price than EU-ETS as societal cost for CO_2. However, this analysis disregards the cost for onshore grid reinforcement, which could not be monetized.

In addition, of the analysed grid options, the hub connections always show better results than the radial connections in 2030. Of the interconnector options, the results indicate that an interconnector between Spain and France via the TMA 1 (Gulf of Lion) could be promising. This TMA should be further analysed for onshore grid connection costs and indicators of security of supply, as it provides benefits such as positive socioeconomic results and contributes to an emissions reduction of 0.2 Mt of CO_2 per year.

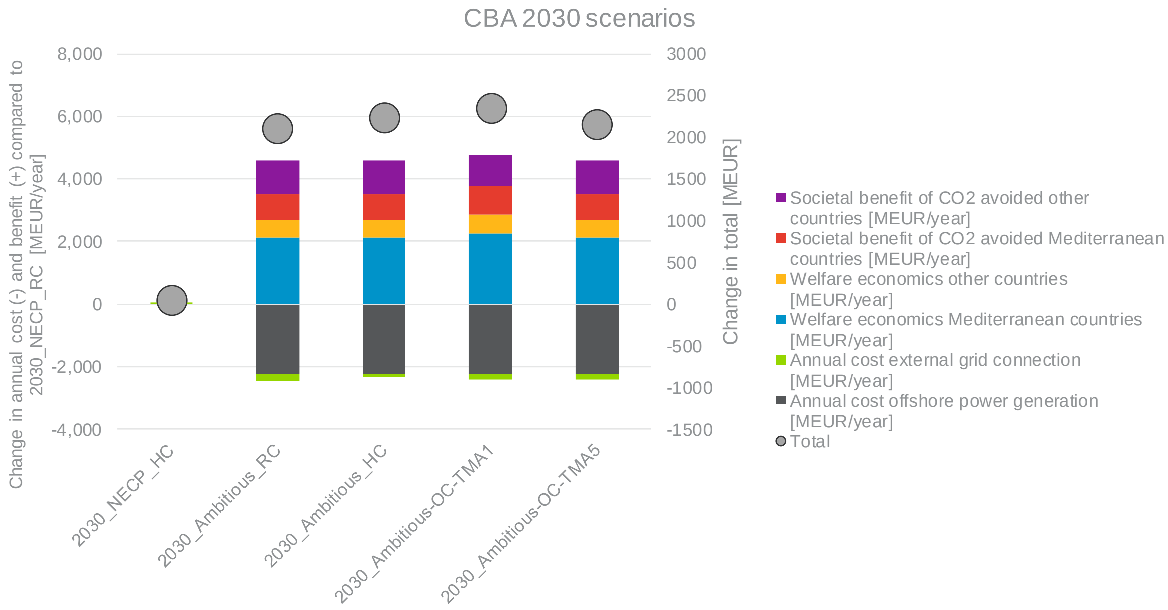

Figure 3-35: Costs and benefits of the different 2030 production scenarios and grid options with an assumed societal cost of CO_2 of 150 €/t

(Source: Sweco)

3.5.2 Cost-benefit analysis for 2050 scenarios

This study analysed the following production scenarios and grid options:

- 2050_NECP_RC (the 2050 NECP scenario with radial connection from each production block to shore)
- 2050_NECP_HC (the 2050 NECP scenario with a hub connection to shore)
- 2050_NECP-OC-TMA1 (the 2050 NECP scenario with an interconnector between France and Spain and TMA1)
- 2050_NECP-OC-TMA5 (the 2050 NECP scenario with an interconnector between Italy and Croatia and TMA5)
- 2050_Ambitious_RC (the 2030 ambitious scenario with radial connection)
- 2050_Ambitious_HC (the 2030 ambitious scenario with a hub connection to shore)
- 2050_Ambitious-OC-TMA1 (the 2050 ambitious scenario with an interconnector between France and Spain and TMA1)
- 2050_Ambitious-OC-TMA5 (the 2050 ambitious scenario with an interconnector between Italy and Croatia and TMA5)

3.5.2.1 CAPEX and OPEX and RES-integration

Figure 3-36 compares the different levels of RES integration in the year 2050 production scenarios and their grid options compared with the CAPEX levels required for these investments. The CAPEX levels are total levels expressed in 2019 real terms, not annualized values; therefore, these should be interpreted as investments that have to be made in offshore power generation and grid connection up to 2050 to reach the RES integration of about 82 GW of offshore capacity in the Mediterranean, of which 76 GW are located in the Mediterranean TMAs defined in this study and the remaining capacity- outside of it. As in the 2030 scenarios, the hub connection always provides a lower CAPEX than the radial connection.

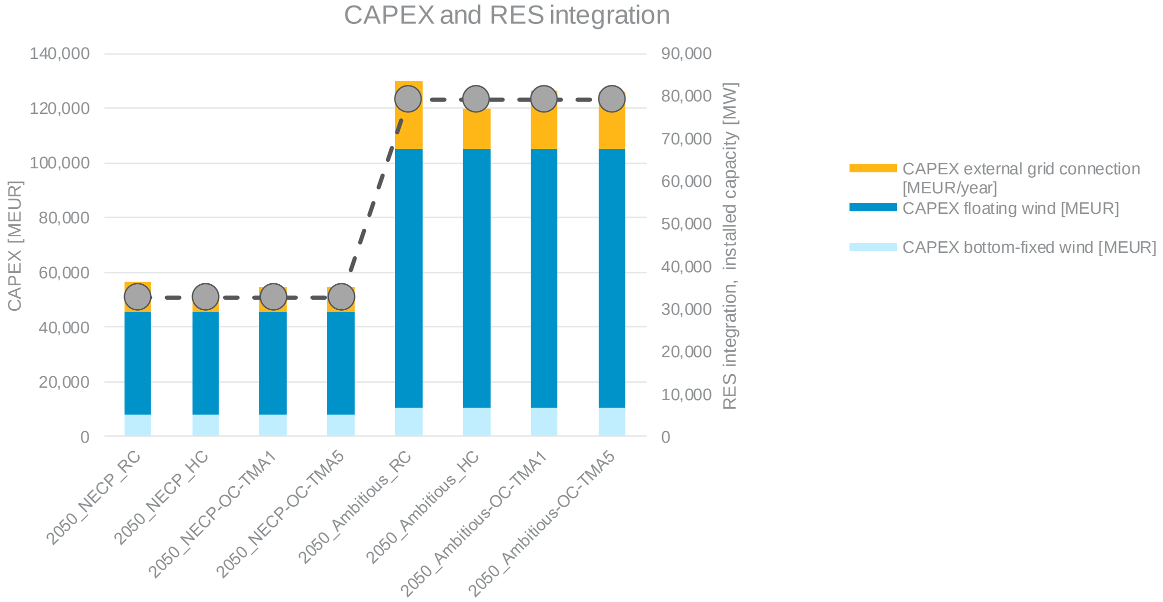

Figure 3-36: CAPEX and RES integration for the various 2050 production scenarios and grid options

(Source: Sweco)

3.5.2.2 Socioeconomic welfare results

Similar to 2030, the 2050 ambitious scenario shows a significantly higher consumer surplus and lower producer surplus due to generally lower prices. In this scenario, new RES-E volumes are being brought into the market along with more congestion for the existing grid resulting in higher congestion rent.

The two interconnector options connecting two countries show a diverse picture. The interconnector from Spain to France yields higher socioeconomic welfare results mainly based on a higher producer surplus in Spain and Portugal and increased congestion rent for France, resulting in a positive result for the Mediterranean region. However, the decrease in producer surplus is just offset by an increase in congestion rent for Croatia for the TMA5 interconnector.

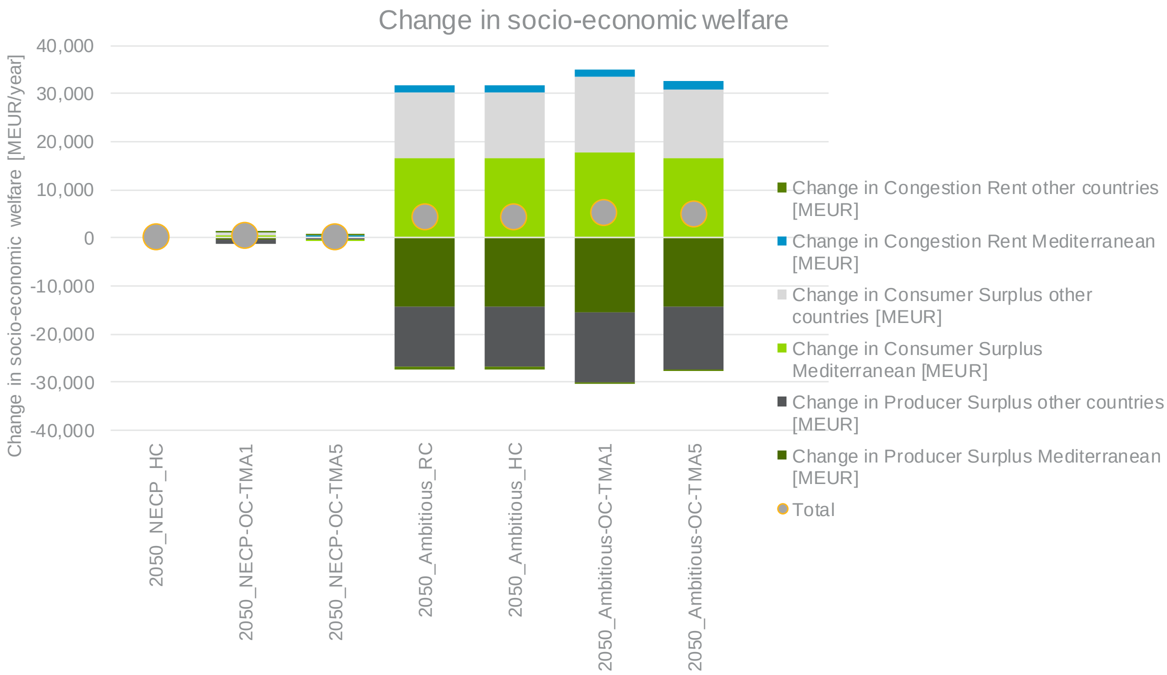

Figure 3-37: Change in socioeconomic welfare for 2050 production scenarios and grid options compared with the 2050 NECP scenario with radial connection, CO_2 price 250 €/t

(Source: Sweco)

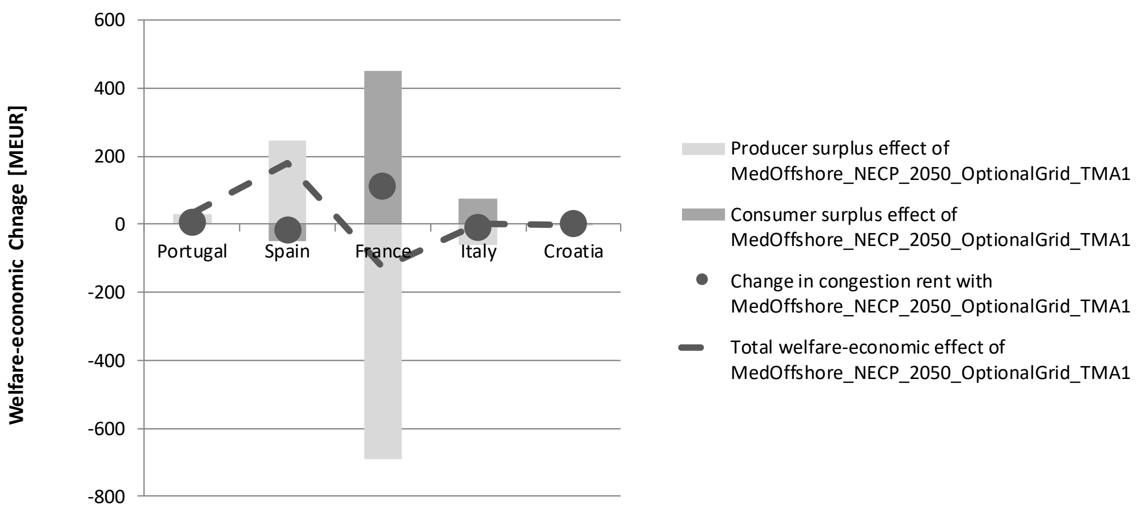

Figure 3-38: Socioeconomic effects of an interconnector for TMA1 between Spain and France, compared with base case (no interconnector), 2050 NECP scenario

(Source: Sweco)

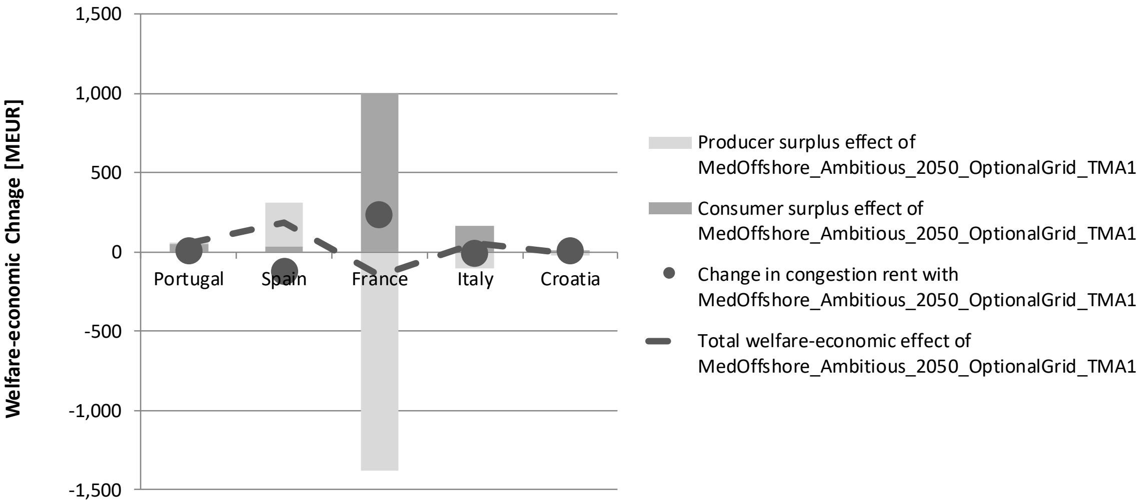

Figure 3-39: Socioeconomic effects of an interconnector for TMA1 between Spain and France, compared with base case (no interconnector), 2050 ambitious scenario

(Source: Sweco)

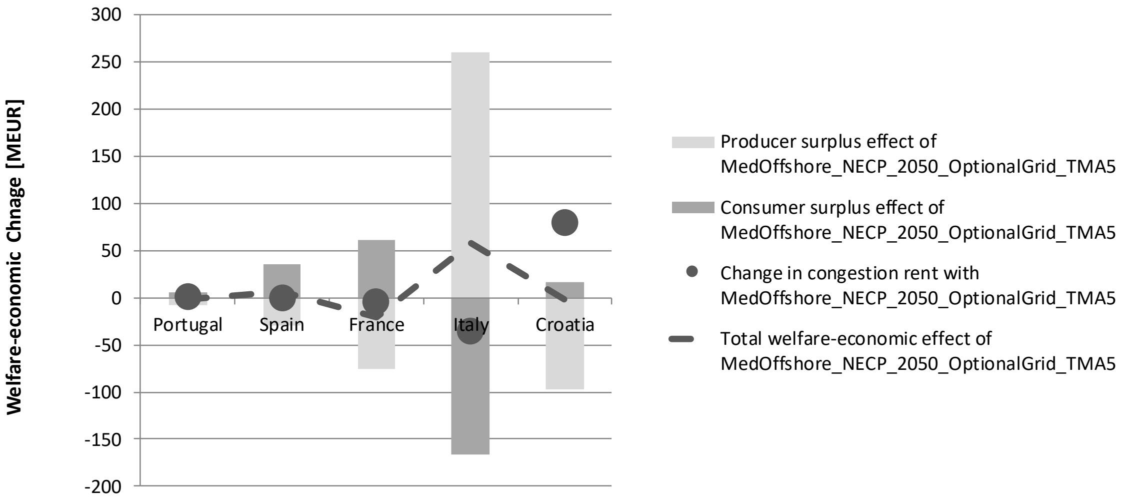

Figure 3-40: Socioeconomic effects of an interconnector for TMA5 between Croatia and Italy, compared with base case (no interconnector), 2050 NECP scenario

(Source: Sweco)

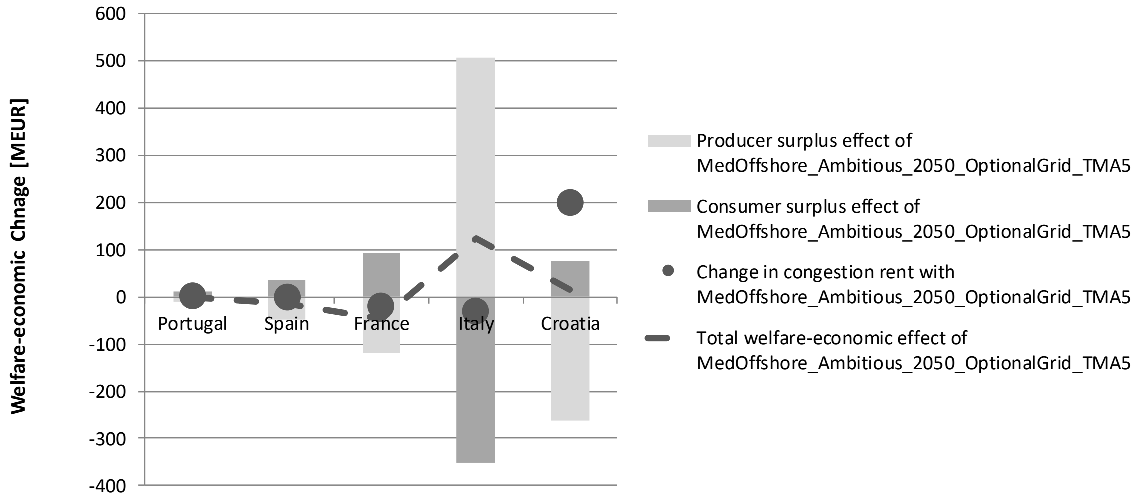

Figure 3-41: Socioeconomic effects of an interconnector for TMA5 between Croatia and Italy, compared with base case (no interconnector), 2050 ambitious scenario

(Source: Sweco)

3.5.2.3 Savings in CO2 emissions

Figure 3-42 shows the CO_2 emissions savings of the production scenarios and their grid options compared with the NECP 2050 scenario with a radial connection. The ambitious scenario produces savings around 6 Mt-7 Mt of CO_2 annually by replacing fossil-fuelled generation in Europe. Also, about two-thirds of these savings can be made in other countries outside of the Mediterranean. While the radial or hub grid configuration does not affect the market outcome, the integration of markets using an additional interconnector in TMA1 and TMA5 does. Both interconnections could contribute to annual CO_2 emissions savings of about 0.3 Mt-0.5 Mt.

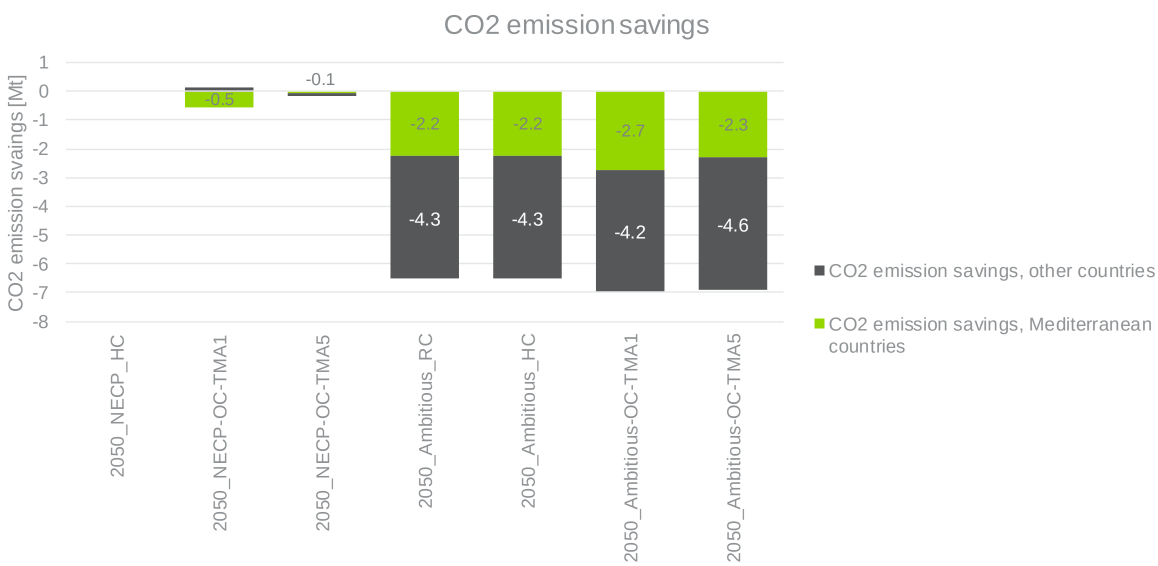

Figure 3-42: CO_2 emissions savings of the production scenarios and their grid options compared with the NECP 2050 scenario with a radial connection

(Source: Sweco)

3.6 Task 3 conclusions

For all production scenarios, the hub connection requires lower CAPEX than the radial connection alternatives. The reason for this fact is that the hub connection utilizes a common interconnection for several production blocks, thereby limiting the construction and material costs. On the downside, this also means a limited decrease in security of supply, as the outage of a cable could mean the loss of more than one production block. Another difference between the radial connection and the hub connection is that the former can be realised without coordination of the different production blocks, whereas the latter assumes that the whole group of production blocks is realised as a common project. A common project is more difficult to achieve with a step-by-step approach and generally requires a bigger commitment in terms of investments and policies. Thus, a full comparison between the options needs to take into consideration not only the summary costs but also the strategic choices involved.

As for the alternative of connecting several TMAs to each other, this study concludes that the distances between TMAs are too large for this to be feasible in relation to the distances between TMAs and the transmission grid. However, in a few cases, possible coordination benefits exist for ongoing or planned projects in the region and the realisation of TMAs. More specifically, this concerns the following TMAs: Sicily, Corsica-Sardinia, and the North and South Aegean Sea. For Sicily, potential exists for the integration with the ENTSO-E TYNDP Sicily-Tunisia interconnector, which shares an approximate cable path with the link from the TMA spanning some 50 km or more. For Corsica-Sardinia, potential exists for the integration with the ENTSO-E TYNDP TuNur (Tunisia-Central Italy) link, which shares an approximate cable path with the link from the TMA, spanning some 100 km or more. For the North Aegean Sea, potential exists for coordination with a foreseen submarine grid connecting major islands, laid out in the national TYNDP. For the South Aegean Sea, potential exists for the integration with the Ariadne interconnector, which shares an approximate cable path with the link from the TMA spanning some 50 km or more. There is also potential for integration with a foreseen submarine grid connecting major islands, laid out in the national 10-Year Network Development Plan and the ENTSO-E TYNDP Southern Aegean interconnector.

All scenarios require considerable investments in offshore power generation and the connection to the onshore grid, often including considerable reinforcement of the onshore grid. At the same time, especially in 2030, limited RES support will be needed for the offshore wind generation investments to be realised. The total CAPEX of integrating about 2.4 GW of offshore generation including grid connection by 2030 in the NECP scenario is around 6 billion €. The total CAPEX of integrating 13 GW in the ambitious scenario is about 28-31 billion €, depending on grid connection and whether an interconnector is integrated or not. Despite utilizing some of the best sites for bottom-fixed offshore, this study is also using a significant amount of floating offshore sites in 2030. Floating offshore wind stands for about two-thirds of the investments in offshore power generation in the ambitious 2030 scenario. To reach the RES integration of about 82 GW of offshore capacity in the Mediterranean in the ambitious 2050 scenario (of which 76 GW is in the Mediterranean TMAs defined in this study), about 120-130 billion € of accumulated investments are necessary until 2050.

The cross-country interconnection from Italy to Croatia in the Gulf on Venice was found to not be economically beneficial, whereas the Gulf of Lion interconnector from France to Spain was found to be economically beneficial. However, the French permanent representative has expressed strong doubts as to the plausibility of the interconnector due to seabed conditions and public acceptance, among other things.

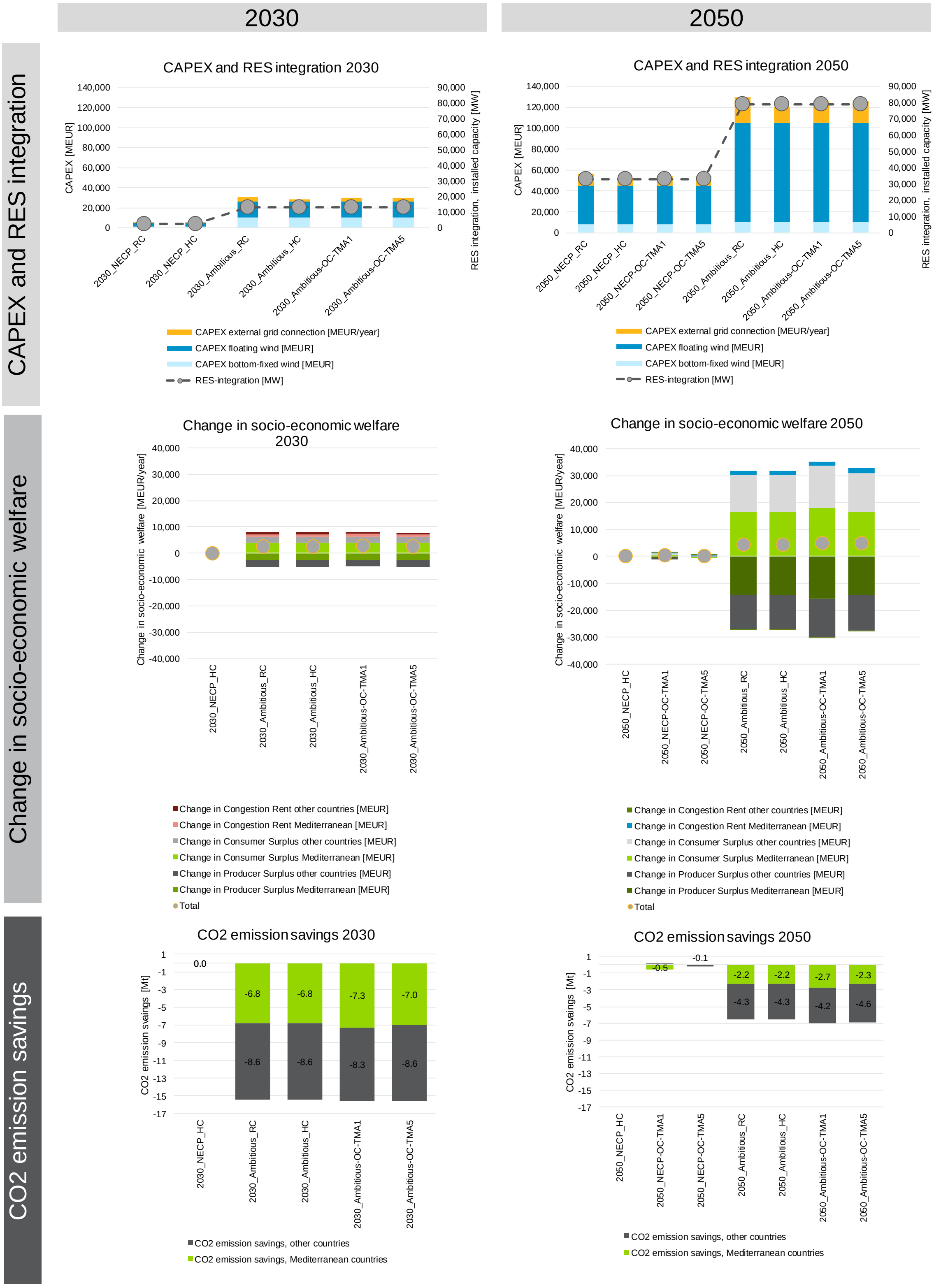

Figure 3-43: Summary of CAPEX, RES integration, change in socioeconomic welfare and CO_2 savings in the various 2030 and 2050 scenarios

(Source: Sweco)

With the analysed parameters for 2030, all ambitious scenarios with 13 GW RES integration yield higher socioeconomic benefits than the NECP scenarios with 2 GW of installed offshore capacity by lowering power prices and increasing consumer surplus, with and without a higher price than EU-ETS as societal cost for CO_2. However, this analysis disregards the cost for onshore grid reinforcement or additional support scheme costs, which could not be monetized.

Of the interconnector options, the 2030 and 2050 results indicate that an interconnector between Spain and France via TMA 1 (Gulf of Lion) could be promising. This option should be further analysed for onshore grid connection costs and indicators of security of supply, as it provides positive socioeconomic results and contributes to an emission reduction of 0.2 Mt of CO_2 per year.

4.0 BARRIERS AND IMPLEMENTATION CHALLENGES

This section presents identified barriers and implementation challenges for offshore renewables and an offshore grid in the Mediterranean. Developing a regional offshore electricity grid and offshore renewable energy in the Mediterranean faces barriers on different levels. Identification of these barriers is key for designing targeted solutions and mitigation measures. In Section 5.0, recommendations for solutions and mitigation measures are presented for the categories of barriers most crucial to facilitating the next steps for development in the Mediterranean.

4.1 Identification of barriers and implementation challenges

This report reviewed the most up to date studies to identify a long list of the most impactful barriers and implementation challenges for offshore grid and offshore renewable energy developments.[113] Prior studies identified challenges and barriers for the development of an offshore grid in the North Sea and Baltic Sea among other areas. A share of identified challenges thus pertains to offshore grid development in European sea basins in general. Appendix D further details and provides regional context for each identified barrier and implementation challenge. The identified barriers and implementation challenges are grouped per category (see Table 4-1):

- **Offshore grid and renewable generation technologies:** Offshore grid development needs specific mature technologies, such HVDC protection equipment for meshing and long-distance connections. In the Mediterranean, certain renewable generation technologies such as floating wind, wave, and tidal are required given the specific regional conditions. Within the region, multiple technologies are already being developed and tested as best practices for scaling up further.
- **Offshore grid design and planning:** Design and planning criteria are key to kick-starting the development of an offshore grid in the Mediterranean region. Design and planning range from availability of adequate marine spatial planning data, defining common grid planning criteria and modelling tools, to regional cooperation and communication on various levels.
- **Offshore and onshore grid:** Grid connections for offshore renewable energy generators should be defined in terms of grid delivery model, connection regimes, procedures, and priorities. An offshore grid delivery model defines the responsibilities between stakeholders (developer, TSO, etc.) for the development of offshore grid transmission assets for renewable generation units (see Appendix D). Currently most countries in the Mediterranean have no defined model for the connection of offshore renewables to the onshore grid, which hampers scaling up. For example, France is one of the Mediterranean countries with a defined grid delivery model in place for offshore wind, placing the responsibility of offshore grid development on the French TSO Réseau de Transport d'Électricité rather than the developer.
- **Market design specific to the offshore area:** A meshed or regional offshore grid might consist of hybrid projects and other large-scale offshore infrastructure. An appropriate market design might be required for the offshore area to reflect the new bottlenecks and behaviour of the interconnected system.
- **Offshore RES generation:** Operational requirements of offshore renewable energy plants should be coordinated between countries. In addition, alignment of support scheme design and support allocation mechanisms is important for ensuring optimal offshore energy development in the region and facilitating offshore hybrid projects.
- **Offshore grid operation:** Grid operation in terms of dispatch regulation, cross-border capacity allocation and congestion management (CACM), and operation should be coordinated on a regional level to ensure secure operation of an offshore grid.
- **Administrative/governance process:** The development of an offshore grid and offshore RES generation units requires administrative, governance, regulatory, and legal

[113] (PROMOTioN, 2019c); (PROMOTioN, 2017a); (3E and Project Partners, 2015); (PwC, 2016); (Interreg, 2017); (Integrid, 2019); (MAESTRALE, 2016); (Intelligent Energy Europe, 2016); (3E and Project Partners, 2015); (Soukissian et al., 2017); (Javier Serrano-González and Roberto Lacal-Arántegui, European Commission, Joint Research Centre, Institute for Energy and Transport, March 2015); (Roland Berger, 2019)

frameworks to be in place to ensure roles, processes, and responsibilities are clearly defined for stakeholders.

- **Cost allocation and financing:** Offshore grid and offshore renewable development at a regional level is highly capital intensive and will require views on cost developments of technologies, financing options, and availability of capital. An important barrier is the lack of a framework for cost-benefit sharing for joint projects at a regional level.
- **Social and environmental constraints:** Offshore grid and renewable developments will need to overcome social and environmental barriers related to public acceptance in touristic areas, the development of skilled personnel, and understanding the cumulative environmental impact of large-scale offshore grid infrastructure.

4.2 Ranking and scoping of barriers and implementation challenges

The identified barriers and implementation challenges are geographically scoped and ranked based on their applicability and impact to the Mediterranean situation, respectively. The geographical scope of each barrier can include:

- **EU-wide barriers and implementation challenges** that also play a role in the development of offshore grids and offshore renewable energy across other European sea basins, such as the Northern Seas and the Baltic Sea, and will most likely be solved within those basins first.
- **Region-specific barriers and implementation challenges** applying to one or more member states or localities in the Mediterranean, requiring specific attention to facilitate regional offshore developments.

A rank is subsequently assigned to each barrier according to its level of impact for offshore developments in the Mediterranean region: low, moderate, or strong. Offshore grid and renewable developments in the Mediterranean region currently lag behind other European sea basins, such as the Northern and Irish Seas and the Baltic Sea. Some of the barriers should be solved during developments in those sea basins and should not have a strong impact when developments move to a further stage in the Mediterranean. Further details on each barrier and implementation challenge and their geographical scope and impact are provided in Appendix D. Table 4-1 summarizes the results of the analysis. The list of barriers and implementation challenges, their scope and impact have been reviewed by the Advisory Board and a selected list of interviewees from key stakeholder associations in the offshore area[114] (see 0).

Table 4-1. Identified barriers and implementation challenges per category with geographical scope and ranking[115]

	Barrier	Geographical scope	Rank
Offshore grid and renewable generation technologies			**Strong**
1	Availability of mature offshore renewable energy and grid technologies suitable for the development of an offshore grid in the Mediterranean	Region-specific / EU-wide	**Strong**
2	Coordinated offshore grid technologies and interoperability of assets	EU-wide	**Strong**
3	Availability of supply chain for components, labour force, and infrastructure to develop offshore renewables and grid infrastructure	EU-wide / Region-specific	**Strong**
Offshore grid design and planning			**Moderate**
1	Data availability for planning	Region-specific	**Moderate**
2	Regional communication and cooperation on various levels	Region-specific	**Moderate**
3	Competing offshore activities limit exploitation of full offshore renewables potential	Region-specific	**Strong**
4	Natural constraints	Region-specific	**Moderate**
5	Regional offshore grid development strategy	Region-specific	**Moderate**

[114] Wind Europe; ENTSO-E; Med TSO; Ocean Energy; Med Reg.

[115] See 1.1.1.1Appendix D for further details.

	Barrier	Geographical scope	Rank
6	Offshore grid planning criteria	EU-wide	Moderate
7	Joint standard models and datasets for long-term grid planning	EU-wide	Moderate
Offshore and onshore grid			Moderate
1	(Aligned) grid transmission asset responsibility for offshore energy generators (offshore grid delivery model)	Region-specific	Strong
2	Aligned rules (regimes and procedures) for onshore grid infrastructure (connection, expansion, and reinforcement)	Region-specific	Moderate
Market design specific to the offshore area			Moderate
1	Bidding zone arrangement for the offshore area	Region-specific (/EU-wide)	Strong
Offshore RES generation			Strong
1	Aligned balancing responsibility of offshore renewable generators	EU-wide	Strong
2	Aligned requirements and standards for RES grid services	EU-wide / Region-specific	Moderate
3	(Aligned) renewable energy support schemes and support allocation mechanism	Region-specific	Strong
Offshore grid operation			Moderate
1	Aligned priority dispatch regulation for offshore renewable energy	Region-specific	Moderate
2	Alignment of cross-border CACM in offshore grid operation	EU-wide	Moderate
3	Regional offshore grid maintenance strategy	Region-specific	Moderate
Administrative/governance process			Strong
1	Development of national and joint regional marine spatial plan and integrated coastal zone management	Region-specific	Moderate
2	Alignment of licensing, permitting, and consenting procedures for development of offshore renewable energy	Region-specific	Moderate
3	Legislative issues on a national level to clarify mandates for offshore grid development by the national TSO	Region-specific	Strong
4	Regulatory framework for islands on a national and regional level regarding renewables and fossil fuel support	Region-specific	Strong
5	Jurisdictional definition regarding grid development within EEZ	Region-specific	Strong
Cost allocation			Moderate
1	Aligned grid charges/grid connection costs for renewable generation units	Region-specific	Moderate
2	Cross-border cost allocation method (CBCA) for offshore grid infrastructure (cost-benefit sharing)	EU-wide	Strong
3	Cost information of new technologies	EU-wide	Moderate
Financing			Moderate
1	Availability and cost of capital for offshore grid and renewable energy generation assets	Region-specific	Moderate
2	Common (and sharing of) financing mechanisms/ financing rules for joint offshore renewable projects	EU-wide	Strong
3	Tailored and sufficient investment incentives for offshore grid and renewables	Region-specific	Moderate
Social constraints			Strong
1	Public acceptance of offshore renewable energy developments	Region-specific	Strong
2	Availability of skilled personnel and targeted training and education programs	Region-specific	Moderate
Environmental constraints			Moderate

	Barrier	Geographical scope	Rank
1	Environmental protection areas limiting exploitation of full RES potential	Region-specific	**Moderate**
2	RES development restrictions due to impact on animal migration routes	Region-specific	**Moderate**
3	Understanding cumulative environmental impact of large-scale offshore grid infrastructure	Region-specific	**Strong**

(Source: Guidehouse)

4.3 Task 4 conclusions

Task 4 identified a list of barriers and implementation challenges for offshore grid and offshore renewable development in the Mediterranean along several categories. Each barrier was presented with its geographical scope and level of impact on regional developments (further detail in Appendix D). The categories of barriers with the highest priority at a regional level are identified as:

- Offshore grid and renewable generation technologies: grid connection and technology maturity
- Offshore RES generation related to support schemes
- Administrative/governance processes
- Social and environmental constraints

The results feed into Section 5.0, where recommendations for solutions and mitigation measures are presented for the categories of barriers most crucial to facilitating next steps for development in the Mediterranean.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This section presents initial recommendations for further work on policy and regulatory developments and provides initial proposals for pilot projects.

5.1 Key findings

One key finding of this study is that the economically sound renewable energy potential seems higher than the potential represented by NCEPs for 2030, and this potential can further increase by 2050. In all four scenarios, the resulting national RES shares (the green dots in Figure 2-7) reach at least the national target for 2030 (grey bar). In most countries, the ambitious scenarios add a few percentage points—between 2% and 9%—in RES share for 2030.

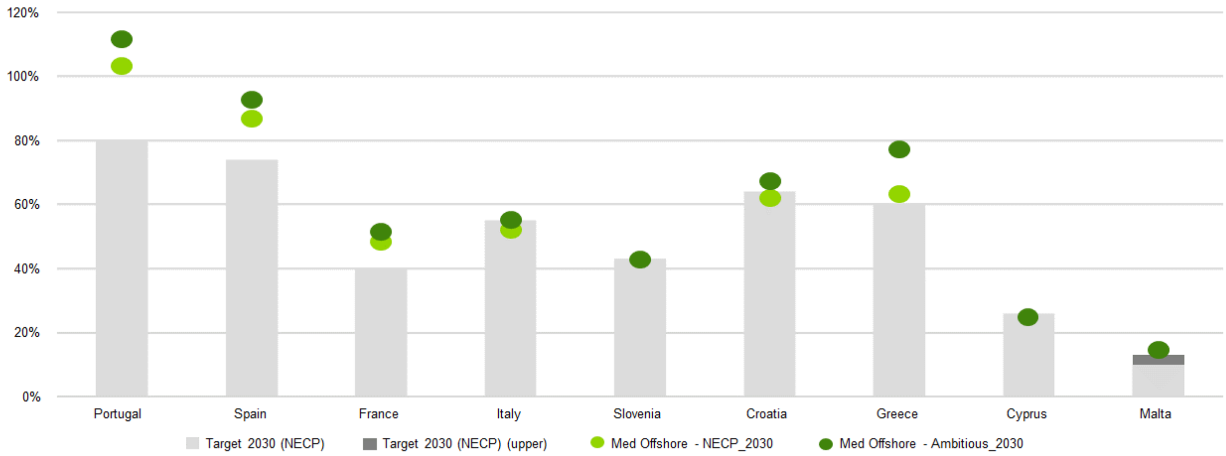

Figure 5-1: RES share for the Mediterranean countries in the two offshore generation scenarios in 2030

(Source: Sweco)

This potential includes mainly floating wind technology, as this technology fits best the geographic specificities of the Mediterranean region and its cost is expected to decrease in the future. The analysis shows that additional offshore wind capacity, and floating wind in particular, can be added to the Mediterranean energy systems in a cost-effective manner: 13 GW by 2030 and 80 GW by 2050 in the ambitious scenario. This addition would increase the share of RES generation from 2% to 6% in the NCEP scenario in 2030 and from 12% to 21% in the ambitious scenario in 2050. Other contributing technologies are mainly bottom-fixed wind and onshore technologies such as solar PV and onshore wind. Although this study forecasts growth of wave and tidal energy, it is not expected to develop in the Mediterranean region with the assumptions adopted for the analysis for the following reasons: limited economic potential in the Mediterranean region, relatively low maturity, small capacity of technologies under development, and high costs. However, ocean energies may develop under specific conditions, such as further support of R&D efforts.

For the Mediterranean region under study, this study identified selected areas (TMAs) that are most promising for offshore energy development. The 10 areas with the greatest cost-effective potential for various technologies or combinations thereof are the Gulf of Lion, Malta, Sicily, Gulf of Venice, Gulf of Cadiz, North Aegean Sea, Ionian Sea, Corsica-Sardinia, South Aegean Sea, and the Baleares. The analysis and scenarios focused on these identified TMAs. Based on the economic offshore energy production potential in each of the areas, this study developed two realistic scenarios (the NECP scenario and the ambitious scenario) in two-time perspectives: 2030 and 2050.

In the process, interesting developments were observed in specific locations (e.g., Greece and Malta), and further analysis on the sub regional level may show interesting offshore opportunities in countries not represented in this analysis. Increasing the share of renewable energy should have positive CO_2 reduction effects. It should decrease power prices from more renewable investments, which will be particularly important to inhabited islands where (fossil-based) energy has been commonly subsidized to assure comparable energy prices with the mainland.

The other key conclusion is that the Mediterranean region does not require one meshed grid solution covering the entire region. On the contrary, this study recommends considering several sub regional hubs linking offshore installations with interconnectors. For all production scenarios, the hub connection yields lower CAPEX than the strictly radial connection alternatives. The reason is that the hub connection utilizes a common interconnection for several production blocks, thereby limiting the construction and material costs. On the downside, it requires coordination between production blocks and sometimes neighbouring states and their policies. Additionally, some coordination benefits of ongoing or planned interconnection projects are possible in the following TMAs: Sicily, Corsica-Sardinia, and the North and South Aegean Seas. The following section proposes several interesting concepts that should be further analysed and that leverage the established Med TSO and ENTSO-E processes. A full comparison of the options needs to take into consideration not only the summary costs but also the strategic choices involved.

5.2 Policy recommendations for member states

This section focuses on supportive policy and regulatory measures that would facilitate deployment of offshore energies in the Mediterranean region, overcoming the barriers identified in Section 4.0. The categories of barriers with the highest priority at a regional level were identified as:

- Offshore renewable energy potential analysis and grid developments
- Offshore RES generation related to support schemes
- Social constraints and opportunities

Policy recommendations to remove these barriers on a regional level are presented in the following section.

5.2.1 Offshore renewable potential analysis and grid developments

As stated in the findings of Task 1 and 2, substantial offshore renewable energy potential exists, exceeding the current member states' ambitions expressed in their NECPs (see Section 1.1). To further understand this potential and possible offshore grid developments, this study proposes the following measures on the member state level:

- Prepare detailed analysis of potential for economically viable variable renewables (vRES) offshore and on islands.
- Analyse the potential constraints and potential multiuse of space in maritime spatial plans, including possibilities to use the protected areas, limitations from bird migration routes, existing oil and gas industry (O&G), and military sites.
- Support the development of environmental impact studies, including monitoring birds and mammals, and procedures for pre-investment and post-investment for bird migration routes in particular.
- Develop best practices for minimizing impacts on wildlife from energy generation infrastructure.
- Consider increasing the level of RES ambition of the NECPs with an updated analysis of the economic potential in the NECP review process.
- Revisit the grid development plans, including potential grid development of offshore energy and additional interconnectors concepts, corresponding with the plans for RES exploitation.
- Further develop offshore grid design and planning. This analysis is needed to facilitate vRES (both on- and offshore) development and integration into the power grids on all voltage levels. EU member states can further increase cooperation within bilateral/multilateral working groups and Med TSO for grid planning for the most attractive production blocks.
- Facilitate offshore and onshore grid connection models. Most Mediterranean countries do not have offshore grid connection models (grid delivery model) for offshore RES in place yet. Therefore, there is an urgent need to facilitate this process on the regional level and with active EU support. This study recommends the following:
  - Quantify the onshore grid effects of the two proposed scenarios.

  - Discuss the proposed models for the connection of offshore RES with neighbouring countries (both in the EU and outside of the EU, depending on the possible interconnector), in particular for the development of joint hybrid offshore RES projects.
  - Coordinate within the subregions (e.g., Spain-Portugal-Morocco, Spain-France, Italy-Tunisia, or Greece-Cyprus-Israel).

5.2.2 Offshore RES generation support

As mentioned in Section 4.0, most Mediterranean EU countries do not yet have support schemes for offshore RES in place. Analysis of the costs of offshore renewable energies is one of the priority recommendations for the entire region. Variable RES utilization will have a positive cost effect on overall cost of energy in the region and specifically in islands, which will have a crucial impact on the level (or availability) of any support schemes.

Developing rules for this element of RES plant operation (both on- and offshore) should also be considered. Therefore, this study proposes the following activities:

- Initiate detailed cost analysis for exploiting the additional RES offshore potential and the necessary support schemes.
- Align balancing and grid services markets and propose cross-border coordination where RES producers could offer services.
- Address the cost and carbon intensity of energy on islands—a priority for prompt decarbonization and the elimination of energy poverty; Italy and Greece indicate higher levels of support for islands, but Italy also links dedicated support to system analysis on islands. Another solution would be to redirect energy subsidies /tax allowances for islands from fossil energy to renewable energy (Navigant & E3 Modelling, 2017).
- Propose and discuss ways of aligning support schemes/balancing and grid services within the specific subregions.

5.2.3 Social constraints and opportunities

The Mediterranean region contains unique nature (including major bird migration routes from Africa to Europe) and an abundance of various economic activities (such as fishing, shipping, and tourism), but it is mainly the core touristic region in Europe. Therefore, social and environmental constraints belong to key barriers to be addressed on the member state and EU level. Section 5.5 provides some ideas for further research necessary to better understand these constraints.

Also, a number of measures can be taken at the EU and member state level to overcome unnecessary hurdles in these fields:

- Funding promotion and education programs to promote sustainable tourism and sustainable touristic regions
- RES skills build up and expanding the RES job skill base in the region across the entire value chain
- Support for the development of dedicated training and education programs, or programs for knowledge sharing across EU member states.
- Support regional associations of TSOs, islands, industry, and communities with cooperation and knowledge sharing in the region

5.3 The role of the EC

Regional cooperation in energy, grid, and spatial planning is key for cost optimization of the deployment of offshore RES technologies in the region. The EC plays a crucial role in facilitating sub regional and regional coordination of efforts also in the Mediterranean region. Therefore, this study proposes that the EC prioritize the following:

- **RES potential and development**
  - Support the development of a consistent methodology for analysis of potentials for offshore energy and onshore energy on islands.

  - Provide further structured guidance on the regional/cross-border coordination of maritime spatial planning and energy planning in the region, including a framework for competing offshore activities and multiuse of the offshore area to optimally exploit offshore RES potential, in the shallower coastal waters in particular.
  - Facilitate discussion on support scheme designs and balancing and grid services solutions in the subregions and across the region (including non-EU countries) for offshore RES and for joint offshore projects in particular.
- **Grid developments**
  - Support the development and coordination of offshore, onshore, and cross-border grid development and operational standards via Med TSO and ENTSO-E for a dedicated regional RES growth strategy (including offshore energies, islands, and interconnectors with non-EU member states).
  - Facilitate the development of the models via Med TSO/ENTSO-E and support bilateral and multilateral discussions.
  - Develop the minimal requirements for grid/onshore delivery models in the calls for Projects of Common Interest (for infrastructure and cross-border RES projects).
  - Develop key rules for cross-border capacity allocation and a regional grid maintenance strategy. The EU could play a leading role in this respect with active participation of the Mediterranean region countries, Med TSO, Med Reg, ENSTO-E, and ACER.
  - Facilitate development of aligned rules for onshore grid infrastructure development serving offshore energy sources.
- **Market design**
  - Continue the coordination of market coupling efforts.
  - Lead the discussion on regional bidding zone arrangements with active participation of the Med countries, Med TSO, Med Reg, ENTSO-E, and ACER.
  - Assist in the development of a cross-border cost allocation (CBCA) framework for cost sharing supporting the ongoing efforts of Med TSO.
  - Facilitate coordination of CBCA principles via leading a dialogue with member states or even developing the methodology.
- **Financing**
  - Facilitate overcoming the risk related to the cost of capital in south and south eastern Europe via an EU Renewable Energy Cost Reduction Facility or other facilitating programs supported by European Investment Bank or European Bank for Reconstruction and Development.
- **RDI**
  - Support RDI for less mature technologies such as wave, tidal, and floating offshore wind.
  - Facilitate RDI for the optimization of grid planning on a regional level.
  - Encourage RDI on the impact of various bidding zone configurations in the offshore area.

5.4 TMAs and recommendations on pilot projects

This analysis has identified the potential RES technologies for deployment offshore and on islands. For each of the identified and ranked 10 TMAs, this analysis has identified technology production blocks. The most interesting ones are:

- Gulf of Lion with high floating offshore wind and wave potential combined with the interconnection between Spain and France
- Gulf of Venice with a very interesting opportunity in bottom-fixed offshore wind, which could be connected to the shore with a hub connection and Italy-Croatia interconnection
- North Aegean Sea with substantial floating offshore wind and wave potential, with the possibility of linking these offshore resources with the extended submarine grid for interconnection of major islands in the Aegean Sea

- TMA southwest of Sicily offers floating and bottom-fixed offshore wind opportunities, large wave potential, and large potential for onshore technologies in Sicily and nearby islands; it is possible to imagine technical solutions where the connection of the production blocks is realized in parallel with the HVDC link in Italy-Tunisia, or the two projects being integrated as a single multipole HVDC link.
- TMA Corsica-Sardinia, similarly to Sicily, offers large offshore floating wind energy potential and potential for onshore technologies on the nearby islands. These offshore resources could be connected to Italy, but it is possible to consider connecting it to an HVDC interconnection between northern Italy and Tunisia in parallel with the connection of the production blocks or integrated it as a single multipole HVDC link.

Task 3 analysed possible grid concepts for all of these technology production blocks. All require further analysis to clearly understand their potentials and cost-effectiveness, including with additional novel technologies (e.g., floating PV, P2G).

For smaller scale, onshore and close-to-shore projects (not identified within the 10 TMAs but potentially adding value to local RES generation), introduction of MUPs could help overcome strong opposition from local stakeholders.

5.5 Recommendations for further work and analysis

This study is one of the first complex studies covering the entire EU Mediterranean region in relation to offshore energy deployment and offshore grid potential. Therefore, it generates a number of further research questions for each of the elements analysed. Below are some recommendations for further analysis.

5.5.1 Geographical scope and timeline

The study focused on the EEZs of the EU member states and did not analyse the offshore RES potential for non-EU countries, though it considered EU/non-EU transmission grid interconnections. Further optimisation of the potential for offshore RES energy and grid development in the region is possible if non-EU Mediterranean countries (e.g., the Balkans, Turkey, and North Africa) are included in the analysis. The region has established facilitators for this process, such as Med TSO, Med Reg, or (partly) the Energy Community.

This analysis confirms that most of the RES offshore potential could be unlocked around 2030 and afterward. Therefore, this study recommends starting long-term planning today and considering 2035 and 2040 as additional important time horizons for further analysis.

5.5.2 Technology choices and RES potential

This study analysed the potential of offshore technologies (bottom-fixed and floating offshore wind, wave, and tidal) and onshore technologies on islands (PV, onshore wind). The conclusions reached about each technology and RES potential include the following:

- Floating offshore wind offers the largest technical potential in the region due to wind speed and water depth. Additional analysis is recommended to understand the detailed potential of this energy source, its potential impact on the environment, and potential interference with other economic activities in the sea.
- Bottom-fixed offshore wind is the most mature offshore energy technology, offering relatively low LCOE. Some bottom-fixed offshore wind potential exists around the Greek and Croatian islands and in the Gulf of Venice. These may require further analysis, as this technology could become the first one to contribute to a substantial growth of offshore energy in the region.
- Wave and tidal have relatively low economic potential in the Mediterranean region compared with offshore wind. They are relatively immature technologies and require further support for technological development. On the other hand, they do not cause the visual impact of wind power, and they could be further developed and considered for smaller applications closer to islands and mainland shores.
- Onshore vRES potential in islands—in islands within the identified TMAs and with relatively mature onshore wind and PV in particular (given the vast solar potential in the region)—should be further explored for both inhabited and non-inhabited islands. This

exploration refers especially to PV in the built environment and small-scale commercial installations in the inhabited Mediterranean islands. The benefit of installing vRES in numerous uninhabited islands is that social acceptance is not an issue and a substantial cost reduction gain occurs related to installing mature and cheaper onshore technologies.

- This study provides a relatively conservative approach to the special constraints' analysis, including main shipping routes, fishing, environmental protection, and military use. More detailed analysis on the local level, including the potential multiuse of space, is needed to refine the potential analysis and the definition of the development zones.
- This study does not include the novel technologies, such as floating PV, CSP, P2X solutions (green hydrogen generation), and (green) gas transmission. Finally, this study did not analyse flexibility potential and demand of other storage options. Adding these technologies and infrastructural planning (power grids versus gas grids) and extending the analysis for the entire Med region (as recommended above) may further contribute to faster decarbonisation of the region.

5.5.3 Grid development needs

In general, the transmission grid around the Mediterranean Sea is not very strong or well meshed. Although increasing since 2017, the interconnection levels of Portugal, Spain, Italy, and Greece are below the EU 2030 target for 2030 and 2050. This analysis has found that the ambitious scenario shows significantly higher consumer surplus and lower producer surplus due to generally lower prices, as expected. This result occurs due to new RES-E volumes being brought into the market and more congestion for the existing grid resulting in higher congestion rents. In addition to the analysed grid options, the hub connections always show better results than the radial connections in 2030. All involved countries except for Portugal are anticipated to experience major needs for reinforcements in the conservative scenario, whereas all countries should be affected in a major way in the ambitious scenario. Further analysis taking into consideration RES potential and EU 2030 target realisation for interconnectivity is needed to understand the trade-offs between the lower cost of energy, the decrease of CO_2 emissions, and the cost of new infrastructure. This analysis should be developed for the whole region and for the specific new investment plans.

For onshore wind projects, grid interconnectivity may become an important issue since wind sites tend to be located further away from the grid and detailed, localisation-specific analyses need to be undertaken. Since the current analysis did not include any P2G options, extending the overall system optimisation analysis and exploring gas grid applicability for green hydrogen generation and transmission is recommended to optimise the use of available RES potential. This analysis is important to ensuring cost-efficient grid development to integrate the large amount of offshore RES to demand centres.

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Appendix A. Potential for offshore power generation background

This appendix presents the cost parameter inputs for a levelized cost of electricity (LCOE) assessment. Multiple sources from various well-known references such as the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), and ASSET have been examined for each cost input to ensure that reliable cost assumptions are taken for the LCOE calculation. Table A-1 and Table A-2 show the CAPEX assumptions chosen for the LCOE assessment.

Table A-1: CAPEX of technologies for LCOE assessment (million €/MW)

CAPEX	Offshore energy				Onshore energy on islands		
	Bottom-fixed offshore wind	Floating offshore wind	Tidal energy	Wave energy	Utility solar PV	Rooftop solar PV	Onshore wind
2030	1.6	2.2	4.1	5.5	0.3	0.6	1.0
2050	1.4	1.4	3.3	2.7	0.2	0.3	0.8

(Source: Guidehouse)

Sources for CAPEX parameters are:

- Bottom-fixed offshore wind CAPEX in 2030 and 2050: Energinet.dk, 2018. https://ens.dk/sites/ens.dk/files/Analyser/havvindsnotat_translation_eng_final.pdf.
- Floating offshore wind CAPEX in 2030: Portugal's Final Integrated National Energy and Climate Plan 2021-2030 (PNEC 2030), 2019. http://www.dgeg.gov.pt/.
- Floating offshore wind CAPEX in 2050: Given the lack of data, this study assumes floating offshore wind converges to bottom-fixed offshore wind cost levels in 2050.
- Wave & tidal CAPEX in 2030 and 2050: OES & IEA, 2015. International Levelized Cost of Energy for Ocean energy Technologies, page 6. https://testahemsidaz2.files.wordpress.com/2017/02/cost-of-energy-for-ocean-energy-technologies-may-2015.pdf.
- Utility solar PV CAPEX in 2030 and 2050: Vartiainen et al., 2019. Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelized cost of electricity. https://onlinelibrary.wiley.com/doi/epdf/10.1002/pip.3189.
- Rooftop solar PV CAPEX in 2030 and 2050: Based on National Renewable Energy Laboratory's (NREL) technology database (NREL, 2019b) and (NREL, 2019a), this study estimates rooftop CAPEX levels to be approximately double the amount of utility solar PV CAPEX levels in 2030 and 2050.
- Onshore wind CAPEX in 2030 and 2050: IRENA, 2019. Future of Wind. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf.

Excluding transmission costs, European bottom-fixed offshore wind capital costs are expected to drop to under 2,000 $/kW towards 2030 and to about 1,500 $/kW in 2040 (IEA, 2019). These costs are in line with the assumptions taken in the LCOE assessment (Energinet.dk, 2018) and represent the lower bound of installation costs in IRENA's Future of Wind report, which range from 1,700-3,200 $/kW in 2030 and 1,400-2800 €/kW in 2050 (Irena, 2019b). For floating offshore wind, this study assumed that by 2050 this technology will converge to cost levels similar to those of bottom-fixed offshore technology. Given the lack of data for 2050 projections, bottom-fixed offshore wind CAPEX levels are assumed to be the best estimate available.

For onshore wind, the CAPEX levels assumed according to Table A-1 also fall in the range given in IRENA's Future of Wind report, 800-1,350 $/kW in 2030 and 650-1,000 $/kW in 2050 (Irena, 2019b) and in the ASSET study, 988 €/kW in 2030 and 782 €/kW in 2050 (ASSET, 2018).

Guidehouse's CAPEX assumptions for solar technologies in 2030 and 2050 (Vartiainen, 2019) are also in the order of magnitude of IRENA's Future of Solar PV report: 340-834 $/kW in 2030 and of 165-481 $/kW in 2050 (Irena, 2019a). CAPEX levels in the ASSET study show higher solar PV overnight investment costs: 627 €/kW in 2030 and 407 €/kW in 2050 for utility-scale solar PV with a very high potential and 930 €/kW in 2030 and 610 €/kW in 2050 for small-scale rooftop systems (ASSET, 2018). However, the ASSET study dates from 2018, and given the rapid cost reductions that solar PV technology is experiencing, it seems realistic to think that 2019 sources incorporate more updated cost reductions that have a higher impact on overall capital cost projections.

For wave and tidal CAPEX values, this study's best estimate is based on an international study from Ocean Energy Systems and IEA (OES & IEA, 2015), a comprehensive technology study based on different international projects (e.g., SI Ocean, DTOcean, EquiMar, the Danish LCOE Calculation Tool, Carbon Trust, and US Department of Energy).

Table A-2: OPEX of technologies for LCOE assessment (k€/MW/year)

OPEX	Offshore energy				Onshore energy on islands		
	Bottom-fixed offshore wind	Floating offshore wind	Tidal energy	Wave energy	Utility solar PV	Rooftop solar PV	Onshore wind
2030	50	70	228	209	9	8	30
2050	43	43	45	35	4	6	30

(Source: Guidehouse)

Sources for OPEX parameters are:

- Bottom-fixed offshore wind OPEX in 2030 and 2050: Energinet.dk, 2018. Note on technology costs for offshore wind farms and the background for updating CAPEX and OPEX exists in the technology catalogue datasheets. CAPEX and OPEX cost values are assumed for a water depth of up to 38 m and a distance to shore of 22 km. LCOE values given include grid connection cost. https://ens.dk/sites/ens.dk/files/Analyser/havvindsnotat_translation_eng_final.pdf.
- Floating offshore wind OPEX in 2030 and onshore wind OPEX in 2030 and 2050: Portugal's Final Integrated National Energy and Climate Plan 2021-2030 (PNEC 2030), 2019. http://www.dgeg.gov.pt/.
- Floating offshore wind OPEX in 2050: Given the lack of data, this study assumes floating offshore wind converges to bottom-fixed offshore wind cost levels in 2050.
- Wave & tidal OPEX in 2030 and 2050: OES & IEA, 2015. International Levelized Cost of Energy for Ocean energy Technologies, page 6. https://testahemsidaz2.files.wordpress.com/2017/02/cost-of-energy-for-ocean-energy-technologies-may-2015.pdf.
- Utility solar PV OPEX in 2030 and 2050: Vartiainen et al., 2019. Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV LCOE included. Cost figures are given for utility-scale solar PV in European countries. LCOE ranges represent the cost level with a nominal WACC of 7% for three different locations in France, Italy, and Spain as described in Figure 9 of the report. https://onlinelibrary.wiley.com/doi/epdf/10.1002/pip.3189.
- Rooftop solar PV OPEX in 2030 and 2050: Based on the NREL technology database (NREL, 2019b), this study assumes rooftop OPEX levels in 2030 as an average of 6.5 k€/MW/year and 10 k€/MW/year and as an average of 4 k€/MW/year and 8 k€/MW/year in 2050.

Similarly, fixed operations and maintenance (O&M) costs assumed are in line with other O&M costs gathered from well-known studies. IEA reports O&M cost levels for bottom-fixed offshore wind of around 60 $/kW in 2030 and 50 $/kW in 2040 (IEA, 2019). The ASSET study projects rather aggressive fixed O&M cost levels for very remote offshore wind, 43 €/kW in 2030 and 39 €/kW in 2050 (ASSET, 2018). For floating offshore wind, given the lack of public data on 2050 cost projections, this study assumes similar fixed O&M levels for bottom-fixed offshore wind in 2050.

According to the ASSET study, utility-scale solar PV fixed O&M costs amount to 13.5 €/kW in 2030 and 10.8 €/kW in 2050. Small-scale rooftop solar PV O&M costs amount to 17 €/kW in 2030 and 13 €/kW in 2050 (ASSET, 2018). In a similar way as the CAPEX values, the 2019 assumptions taken might be incorporating more updated and advanced cost reduction projections compared to the 2018 ASSET study. For onshore wind, 2019 assumptions taken for fixed O&M remain on the higher side compared to ASSET fixed O&M costs, which amount to around 21 €/kW in 2030 and 20 €/kW in 2050.

Similarly for CAPEX levels, for wave and tidal OPEX values, this study bases our best estimate on a report by the OES and IEA (OES & IEA, 2015), which is based on a series of different international sources and projects.

Appendix B. Production scenarios background

B.1 Apollo

Sweco's power market model Apollo is used to simulate power supply and demand across the entire interconnected European market in an hourly resolution. The Apollo's standard dataset contains data for 31 countries and 43 bidding zones in the European market. As for the Mediterranean member states, Italy is divided into six bidding zones (north, centre-north, centre-south, south, Sicily, and Sardinia) while the other member states are modelled as one bidding zone. Generator dispatch and wholesale electricity prices are modelled based on a range of defined market input parameters and assumptions. Input parameters are demand, thermal capacity, RES-E capacity, available transmission capacity, hydrology, fuel price profiles and solar and wind profiles. Apollo captures the technical characteristics of 381 generating technology classes and efficiencies.

Apollo's intuitive interfaces allow simulations where it easily varies inputs to create, refine, and analyse different scenarios. Graphic visualization is key to interpreting results. The results of an Apollo model run are presented in a series of automatically generated Excel reports for a number of different themes. All reports contain interactive charts and graphs for an easy interpretation of the simulation results. Reports that generated by Apollo include:

- **Dashboard Analyzer:** this is Apollo's main report for short- and medium-term planning. It visualizes a wide range of outputs: weekly prices, weekly price structures, hydro generation, reservoir levels, and generation by week, generation in week, trade by week, and trade in week.

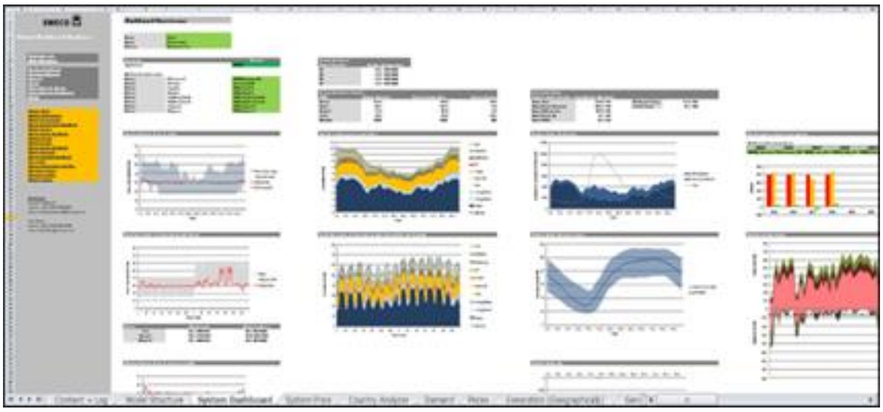

Figure B-1: Apollo's Dashboard Analyzer report

(Source: SWECO)

- **Scenario Analyzer:** An overview report that summarizes the operation of the system from an annual and weekly aggregate perspective, showing generation, price, and trade patterns.
- **Price Analyzer:** A detailed report that provides hourly price structures in different price zones and price differences across scenarios.
- **Economic Analyzer:** An overview report that looks at profitability of different generation technologies and welfare effects of various policies as defined in the input scenarios. The report includes a scenario overview, various output data tables, CO_2 emissions, and a hydro analyser.

Apollo is used for both short-term and long-term planning regularly to assess the longer-term effects of development in the Swedish and European electricity markets. Apollo's inclusion of most European countries and bidding zones is especially important in longer-term planning as Europe moves towards a single market. Typical uses for Apollo include scenario analysis, price volatility analysis following the integration of large shares of electricity generation from RES, interconnector profitability analysis, interconnector welfare analysis, and investment profitability, including income stream per technology. Apollo's hourly resolution provides additional insight into the value of flexibility, particularly in electricity systems with high penetrations of variable technologies.

For short-term-planning, Apollo is typically used to focus on one region and look at price forecasting, sensitivity studies including plant or interconnector outages, wet and dry year sensitivities, cold winters, and financial risk calculations. Users can choose the week of the year to start model simulations and are able to use near-term forecasts of most inputs to get a closer view of what lies in store.

Apollo optimizes the annual system cost for a defined scenario. Apollo is not an energy investment model, and the above input parameters are defined by the user for each modelled scenario and year. As a basis for simulations of future power systems, input parameters are defined for a reference scenario maintained through Sweco's continuous scenario work updates. The reference scenario is based 2020 actuals and Sweco assumptions of the development of new capacity installations and demand evolution. Production capacity is based on an aggregation of existing production facilities, known plans for new capacity, and estimated phase out and potential renewal of existing capacity. Additional new capacity is based on current trends, national targets, and Sweco assessments of the development of specific RES technologies. Transmission capacities are based on current capacities and planned projects in TYNDP 2018. Additional transfer capacities until 2050 have been added based on the TYNDP Identification of System Needs (IoSN) for 2040 in TYNDP 2018 and through Sweco's identification of required capacities in the iterative modelling process.

B.2 Transmission capacity assumptions

Table B-1: Assumed net transmission capacity between bidding zones in 2030 and 2050 (export)

Sum of Transmission Capacity [MW]	Column Labels			
Row Labels	MedOffshore_NECP_2030	MedOffshore_Ambitious_2030	MedOffshore_NECP_2050	MedOffshore_Ambitious_2050
Portugal	**3500**	**3500**	**4200**	**4200**
Spain	3500	3500	4200	4200
Spain	**13500**	**13500**	**18200**	**18200**
Exogenous	1200	1200	1200	1200
France	8100	8100	11800	11800
Portugal	4200	4200	5200	5200
France	**32450**	**32450**	**39950**	**39950**
Belgium	5750	5750	6350	6350
Germany	4800	4800	7300	7300
Ireland	700	700	1200	1200
Spain	8300	8300	11600	11600
Switzerland	5100	5100	5100	5100
UK	7800	7800	8400	8400
IT-NO	**10305**	**10305**	**15205**	**15205**
Austria	835	835	3735	3735
IT-CN	4150	4150	4150	4150
Slovenia	1710	1710	2710	2710
Switzerland	3610	3610	4610	4610
IT-CN	**5300**	**5300**	**7300**	**7300**
IT-CS	2750	2750	2750	2750
IT-NO	2150	2150	4150	4150
IT-SA	400	400	400	400
IT-CS	**20100**	**20100**	**20100**	**20100**
Exogenous	3200	3200	3200	3200
IT-CN	4200	4200	4200	4200
IT-SA	700	700	700	700
IT-SI	1000	1000	1000	1000
IT-SU	11000	11000	11000	11000
IT-SU	**8100**	**8100**	**8800**	**8800**
Greece	500	500	1200	1200
IT-CS	6500	6500	6500	6500
IT-SI	1100	1100	1100	1100
IT-SA	**1300**	**1300**	**1300**	**1300**
IT-CN	400	400	400	400
IT-CS	900	900	900	900
IT-SI	**3000**	**3000**	**3000**	**3000**
Exogenous	600	600	600	600
IT-CS	1000	1000	1000	1000
IT-SU	1200	1200	1200	1200
Malta	200	200	200	200
Slovenia	**6345**	**6345**	**8845**	**8845**
Austria	1200	1200	2200	2200
Croatia	2000	2000	2500	2500
Hungary	1200	1200	1200	1200
IT-NO	1945	1945	2945	2945
Croatia	**6562**	**6562**	**7062**	**7062**
Exogenous	2562	2562	2562	2562
Hungary	2000	2000	2000	2000
Slovenia	2000	2000	2500	2500
Greece	**1832**	**1832**	**5532**	**5532**
Bulgaria	782	782	2482	2482
Cyprus	0	0	2000	2000
Exogenous	550	550	550	550
IT-SU	500	500	500	500
Cyprus	**2000**	**2000**	**4000**	**4000**
Exogenous	1000	1000	2000	2000
Greece	1000	1000	2000	2000
Malta	**200**	**200**	**200**	**200**
IT-SI	200	200	200	200

(Source: SWECO)

Table B-2: Assumed net transmission capacity between bidding zones in 2030 and 2050 (import)

Sum of Transmission Capacity [MW]	Column Labels			
Row Labels	MedOffshore_NECP_2030	MedOffshore_Ambitious_2030	MedOffshore_NECP_2050	MedOffshore_Ambitious_2050
Portugal	**4200**	**4200**	**5200**	**5200**
Spain	4200	4200	5200	5200
Spain	**13000**	**13000**	**17000**	**17000**
Portugal	3500	3500	4200	4200
Exogenous	1200	1200	1200	1200
France	8300	8300	11600	11600
France	**28750**	**28750**	**37750**	**37750**
Belgium	4150	4150	4750	4750
Spain	8100	8100	11800	11800
Germany	4800	4800	7600	7600
Ireland	700	700	1200	1200
Switzerland	3200	3200	3200	3200
UK	7800	7800	9200	9200
IT-NO	**11040**	**11040**	**18040**	**18040**
Austria	1005	1005	4005	4005
IT-CN	2150	2150	4150	4150
Slovenia	1945	1945	2945	2945
Switzerland	5940	5940	6940	6940
IT-CN	**8750**	**8750**	**8750**	**8750**
IT-NO	4150	4150	4150	4150
IT-CS	4200	4200	4200	4200
IT-SA	400	400	400	400
IT-CS	**14350**	**14350**	**14350**	**14350**
Exogenous	3200	3200	3200	3200
IT-CN	2750	2750	2750	2750
IT-SU	6500	6500	6500	6500
IT-SA	900	900	900	900
IT-SI	1000	1000	1000	1000
IT-SU	**12700**	**12700**	**12700**	**12700**
IT-CS	11000	11000	11000	11000
IT-SI	1200	1200	1200	1200
Greece	500	500	500	500
IT-SA	**1100**	**1100**	**1100**	**1100**
IT-CN	400	400	400	400
IT-CS	700	700	700	700
IT-SI	**2900**	**2900**	**2900**	**2900**
Exogenous	600	600	600	600
IT-CS	1000	1000	1000	1000
IT-SU	1100	1100	1100	1100
Malta	200	200	200	200
Slovenia	**7475**	**7475**	**10275**	**10275**
Austria	1200	1200	2500	2500
Hungary	2565	2565	2565	2565
IT-NO	1710	1710	2710	2710
Croatia	2000	2000	2500	2500
Croatia	**5844**	**5844**	**6344**	**6344**
Exogenous	2644	2644	2644	2644
Hungary	1200	1200	1200	1200
Slovenia	2000	2000	2500	2500
Greece	**3098**	**3098**	**6698**	**6698**
Bulgaria	1198	1198	3098	3098
Exogenous	400	400	400	400
IT-SU	500	500	1200	1200
Cyprus	1000	1000	2000	2000
Cyprus	**1000**	**1000**	**4000**	**4000**
Exogenous	1000	1000	2000	2000
Greece	0	0	2000	2000
Malta	**200**	**200**	**200**	**200**
IT-SI	200	200	200	200

(Source: SWECO)

B.3 Power generation by fuel

Table B-3: Power generation by fuel category in 2030 and 2050 for the NECP and ambitious production scenarios

Sum of Generation [TWh]	Column Labels									
Row Labels	Portugal	Spain	France	Italy	Slovenia	Croatia	Greece	Cyprus	Malta	Grand Total
Battery storage										
MedOffshore_NECP_2030		-0,2		-0,1	0,0	0,0	-0,1	0,0	0,0	-0,4
MedOffshore_Ambitious_2030		-0,2		-0,1	0,0	0,0	-0,1	0,0	0,0	-0,4
MedOffshore_NECP_2050	-0,1	-0,4	-0,7	-0,4	-0,1	0,0	-0,2	0,0	0,0	-2,0
MedOffshore_Ambitious_2050	-0,1	-0,4	-0,7	-0,3	-0,1	0,0	-0,2	0,0	0,0	-1,9
Coal										
MedOffshore_NECP_2030					4,4	0,0	10,7			15,0
MedOffshore_Ambitious_2030					4,3	0,0	9,8			14,1
Oil										
MedOffshore_NECP_2030	0,7	0,5	0,9	0,7	0,0	0,0	0,0	0,0	0,0	2,8
MedOffshore_Ambitious_2030	0,7	0,5	0,9	0,7	0,0	0,0	0,0	0,0	0,0	2,8
MedOffshore_NECP_2050	0,0		0,0	0,0		0,0	0,0			0,0
MedOffshore_Ambitious_2050	0,0		0,0	0,0		0,0	0,0			0,0
Gas										
MedOffshore_NECP_2030	2,4	29,8	11,4	74,4	0,5	2,4	6,5	4,3	1,3	133,1
MedOffshore_Ambitious_2030	1,8	26,1	11,0	67,5	0,5	2,3	5,0	4,0	1,2	119,4
MedOffshore_NECP_2050	1,4	8,7	1,6	9,6	0,5	0,1	0,2	0,1	0,9	23,1
MedOffshore_Ambitious_2050	0,8	5,5	1,3	8,7	0,5	0,1	0,1	0,1	0,3	17,3
Nuclear										
MedOffshore_NECP_2030		18,4	364,3		5,4					388,1
MedOffshore_Ambitious_2030		16,9	357,2		5,4					379,5
MedOffshore_NECP_2050			242,6		6,8					249,3
MedOffshore_Ambitious_2050			224,3		6,5					230,8
Hydro										
MedOffshore_NECP_2030	11,6	33,2	64,2	48,4	4,6	8,4	6,6			177,0
MedOffshore_Ambitious_2030	11,6	33,2	64,2	48,5	4,6	8,4	6,6			177,1
MedOffshore_NECP_2050	11,6	33,2	63,8	48,1	4,6	8,4	6,6			176,3
MedOffshore_Ambitious_2050	11,6	33,2	63,7	46,3	4,6	8,4	6,6			174,4
Biomass and waste										
MedOffshore_NECP_2030	3,5	4,0	6,9	14,4	0,4	0,6	1,3	0,2	0,1	31,3
MedOffshore_Ambitious_2030	3,4	3,6	6,5	14,2	0,4	0,5	1,3	0,2	0,1	30,2
MedOffshore_NECP_2050	8,9	9,5	11,9	12,4	0,3	0,6	2,9	0,2	0,0	46,7
MedOffshore_Ambitious_2050	8,6	8,6	11,6	12,0	0,3	0,6	2,9	0,2	0,0	44,8
Solar										
MedOffshore_NECP_2030	15,9	88,4	50,2	72,3	1,8	0,8	9,9	1,2	0,4	241,1
MedOffshore_Ambitious_2030	15,9	88,4	50,2	72,3	1,8	0,8	9,9	1,2	0,4	241,1
MedOffshore_NECP_2050	28,6	131,5	67,5	102,8	7,0	3,2	17,0	3,1	1,2	362,0
MedOffshore_Ambitious_2050	28,6	131,5	67,5	102,8	7,0	3,2	17,0	3,1	1,2	362,0
Wind onshore										
MedOffshore_NECP_2030	27,1	116,1	93,8	37,1	0,2	2,7	16,2	0,4		293,7
MedOffshore_Ambitious_2030	27,1	116,1	93,8	37,1	0,2	2,7	16,2	0,4		293,7
MedOffshore_NECP_2050	32,3	164,7	134,9	78,0	1,7	6,0	36,4	1,7	0,5	456,3
MedOffshore_Ambitious_2050	32,3	164,7	134,9	78,0	1,7	6,0	36,4	1,7	0,5	456,3
Wind offshore										
MedOffshore_NECP_2030	1,2	0,0	22,3	3,0		0,0	0,0			26,5
MedOffshore_Ambitious_2030	6,1	16,1	37,2	14,3		1,1	7,5			82,2
MedOffshore_NECP_2050	5,7	47,3	65,6	53,4		2,3	11,6		0,0	185,8
MedOffshore_Ambitious_2050	11,9	83,6	83,4	123,8		4,5	26,1		1,6	334,9
Other RES										
MedOffshore_NECP_2030	0,7	0,2	0,6	7,1		0,1	0,4			9,1
MedOffshore_Ambitious_2030	0,7	0,2	0,6	7,1		0,1	0,4			9,1
MedOffshore_NECP_2050	0,8	0,2	0,6	7,1		0,2	0,4			9,2
MedOffshore_Ambitious_2050	0,8	0,2	0,6	7,1		0,2	0,4			9,2

(Source: SWECO)

Appendix C. Grid options background

As a basis for CAPEX and OPEX for the different grid connection alternatives, connections were modelled at an aggregated level using the following components:

- HVDC:
  - Offshore platform
  - Offshore converter station, 320 or 500 kV
  - Sea cable, 320 or 500 kV
  - Land cable, 320 or 500 kV
  - Onshore converter station, 320 or 500 kV
- HVAC:
  - Offshore platform
  - Offshore 220 kV switchgear
  - Offshore transformer to 220 kV
  - Sea cable, 220 kV
  - Land cable, 220 kV
  - Onshore 220 kV switchgear
  - Onshore 220/400 kV transformer

CAPEX figures for the above components were mainly retrieved from *Study of the Benefits of a Meshed Offshore Grid in Northern Seas Region – Final Report* (Cole, Martinot, Rapoport, Papaefthymiou, & Gori, 2014), assumed to be relevant for 2019, and summarized in Table C-1. Reactive compensation was assumed as an additional per-length cost for the HVAC alternative and assumed to include filtering needs.

OPEX was calculated as a percentage of CAPEX, with assumed values for different categories of components listed in Table C-1. Additional assumptions and cost figures include the following:

- Resistive losses for each connection were calculated based on the production time series for each technology and TMA.
- The choice of technology for each connection (HVAC or HVDC) was made based on the total cost over 25 years with an assumed cost for losses of 50 €/MWh.
- The capacities for the different dimensions of cables were calculated based on dimensioning criteria of 1.0 A/mm2 for aluminium conductors and 1.2 A/mm2 for copper conductors.

Table C-1: Cost catalogue for Task 3

HVDC CAPEX, from (Cole, Martinot, Rapoport, Papaefthymiou, & Gori, 2014)			
Component	**Cost**		**Remark**
DC platform	111.3	M€/unit	1
HVDC station VSC 500 MW 300 kV	83.5	M€/unit	1
HVDC station VSC 850 MW 320 kV	101.5	M€/unit	1
HVDC station VSC 1250 MW 500 kV	135.5	M€/unit	1
HVDC station VSC 2000 MW 500 kV	170	M€/unit	1
2x1x300mm² cu ±320 kV DC Offshore	600	€/m	
2x1x1000mm² cu ±320 kV DC Offshore	1000	€/m	2
2x1x2500mm² cu ±320 kV Offshore	1324	€/m	
2x1x1500mm² cu ±500 kV Offshore	1120	€/m	
2x1x2500mm² cu ±500 kV Offshore	1468	€/m	
2x1x500mm² alu ±320 kV Onshore	546	€/m	
2x1x2400mm² alu ±320 kV Onshore	750	€/m	
2x1x1500mm2 alu ±500 kV Onshore	858	€/m	
2x1x2500mm2 alu ±500 kV Onshore	1000	€/m	
Offshore cable installation cost	400	€/m	
Onshore cable installation cost	150	€/m	3
HVAC CAPEX, from (Cole, Martinot, Rapoport, Papaefthymiou, & Gori, 2014)			
Component	**Cost**		**Remark**
AC Platform	45.5	M€/unit	1
Transformation	10,000	€/MVA	
220 kV switchgear	2.68	M€/unit	
1x3x400mm² cu 220kV Offshore	540	€/m	
1x3x1600mm² alu 220 kV Offshore	875	€/m	
2x3x1600mm² alu 220 kV Offshore	1,750	€/m	

	3x3x1600mm² alu 220 kV Offshore	2,625	€/m	
	3x1x1200mm² alu 220 kV Onshore	525	€/m	
	3x1x1400mm² alu 220 kV Onshore	550	€/m	
	3x1x2000mm² alu 220 kV Onshore	625	€/m	
	6x1x1200mm² alu 220 kV Onshore	1,050	€/m	
	6x1x1400mm² alu 220 kV Onshore	1,100	€/m	
	6x1x2000mm² alu 220 kV Onshore	1,250	€/m	
	9x1x1400mm² alu 220 kV Onshore	1,650	€/m	
	9x1x2000mm² alu 220 kV Onshore	1,875	€/m	
	Offshore cable installation cost	400	€/m	
	Onshore cable installation cost	150	€/m	3
	Reactive compensation	63,250	€/MVA	4
	OPEX, assumed values			
	Type of component	**% of CAPEX**		
	AC stations, bays, and transformers	1.50		
	Land cables 220 -400 kV	0.15		
	Reactive compensation	1.50		
	HVDC stations	1.00		
	Marine HVDC and AC cables	2.00		
	Platforms	1.00		
	Remarks			
1	Mid-value of range given in (Cole, Martinot, Rapoport, Papaefthymiou, & Gori, 2014)			
2	Assumed value, not in (Cole, Martinot, Rapoport, Papaefthymiou, & Gori, 2014). Added to limit the step increase of cost when moving to a bigger cable dimension than 300 mm2.			
3	Assumed value, not in (Cole, Martinot, Rapoport, Papaefthymiou, & Gori, 2014)			
4	AC 220 kV cable is assumed to need 1 MVAr/km per phase			

(Source: SWECO)

Appendix D. Longlist of barriers

Table D-1 presents an overview of the identified barriers.

Table D-1: Barriers and implementation challenges for offshore grid and offshore renewable development with detailed description and ranking

	Barrier	Description and rationale barrier	Rank
Offshore grid and renewable generation technologies			
1	**Mature offshore renewable energy and grid technologies suitable for the development of an offshore grid in the Mediterranean**	**What:** The geographical and climatological conditions (water depth, bottom morphology, minimal distances from shore, availability of current speeds, lack of tides, etc.) of the Mediterranean require specific renewable energy technologies, such as floating wind turbines due to limited areas with shallow water depth.[116,117] **Why:** There is a need for mature technologies, adapted to the environmental characteristics of the Mediterranean. Sufficient maturity levels of technologies suitable for offshore energy development in the Mediterranean are required to exploit available RES potential, such as floating offshore wind or HVDC grid components. Currently, technologies such as floating offshore wind are not yet fully mature.[117]	**Strong**
2	**Coordinated offshore grid technologies and interoperability of assets**	**What:** For an offshore grid system to function in accordance with operational standards coordination of grid technologies in the region is important. This includes interoperability of protection systems in HVDC systems.[118] **Why:** Uncoordinated technologies could result in unsafe operation. For example, protection systems from different vendors should be able to connect and communicate with each other (Interoperability).[118] This is a key barrier of meshed offshore grids currently investigated under the PROMOTioN project for the Northern Seas.**Error! Bookmark not defined.**	**Strong**
3	**Availability of supply chain for components, labour force, and infrastructure to develop offshore renewables and grid infrastructure**	**What:** Developing and constructing an offshore grid and large-scale offshore renewables requires a large supply chain of raw materials, manufacturing of technical components, skilled personnel, and specialised infrastructure, such as specialised ships and ground transportation.[117] **Why:** Currently, there is limited experience with and manufacturing of offshore renewable and grid components in the Mediterranean Sea region. Supply chains and capacity must build up to ensure a timely development of offshore renewables and grid infrastructure.[119]	**Strong**

[116] (Soukissian et al., 2017)
[117] (WindEurope, 2019b)
[118] (PROMOTioN, 2017a)
[119] (Interreg, 2017)

	Barrier	Description and rationale barrier	Rank
Offshore grid design and planning			
1	**Data availability for planning**	**What:** Centralised and open access data is required for spatial planning and project development planning in the Mediterranean region. There is a need for regional data on sites such as military training sites, archaeological sites, and tourism areas, and for data on energy production, energy use, and energy efficiency on islands. **Why:** Not all required data is currently (publicly) available, and available data is often spread out between stakeholders and countries in the region—in particular, data regarding spatial constraints, archaeological and heritage sites, and island communities.[120]	**Moderate**
2	**Regional communication and cooperation on various levels**	**What:** To ensure successful development of a Mediterranean offshore grid that optimises the use of high potential offshore sites, a joint initiative from member states in the region with ongoing cooperation and communication efforts is important, on Transmission System Operator, regulatory,[121] and governmental levels and between terrestrial and maritime planning authorities on a national level and across countries. **Why:** Regional cooperation on TSO and governmental levels is required to develop an offshore grid. Currently cooperation in the region regarding offshore grid development is improving through various initiatives and associations. For example, Med-TSO published a report on key performance indicators for the regional electricity system in May 2020.[122]	**Moderate**
3	**Competing offshore activities limit exploitation of full offshore renewables potential**	**What:** High potential offshore sites for renewable energy generation often fall in areas where other offshore human activities occur such as industrial shipping, fishing, military training areas, oil rigs, cruise ship passage, tourism, and other marine activities.[123] **Why:** Competing uses of high potential offshore renewable sites limit the optimal exploitation of renewable energy. In the Mediterranean, this is particularly relevant in shallower water, which is limited due to the steep fall in bathymetry.[124] Shallow areas show high potential for bottom-fixed offshore wind and high levels of other offshore (touristic) human activities. Currently, there is no clear definition of multiple uses of high potential RES sites in the region.	**Strong**

[120] Databases that already exist are https://www.emodnet-humanactivities.eu/view-data.php and http://www.msp-supreme.eu/files/c-1-3-2-and-c-1-3-3-data-and-tools.pdf.

[121] European TSO cooperation already occurs through ENTSO-E and regional TSO cooperation through Med-TSO: https://www.med-tso.com/mission.aspx?f=&title=About+Med-TSO; cooperation on a regional Mediterranean level also takes place through MedReg, for example: http://www.medreg-regulators.org/Aboutus/Members.aspx

[122] Med-TSO, 2020. Deliverable 5.2 "Key Performance Indicators of the regional electricity system". https://www.med-tso.com/publications/Deliverable_5.2_Key_performance_indicators_of_the_regional_electricity_system.pdf

[123] (European MSP Platform, 2018b)

[124] (Soukissian et al., 2017)

	Barrier	Description and rationale barrier	Rank
4	**Natural constraints**	**What:** The geographical and climatological conditions of the Mediterranean Sea area provide natural constraints to the development of offshore renewables such as water depth, resource availability, and the presence of archaeological and cultural heritage sites.[125] Natural constraints are seen as hard constraints that restrict offshore development areas. **Why:** Water depth can be a barrier to some technologies, such as bottom-fixed offshore wind and offshore cable development. In the Mediterranean Sea area, shallow water is limited[126] and includes archaeological sites that are currently not well mapped in public and centralised databases (see **Data availability for planning**).	**Moderate**
5	**Regional offshore grid development strategy**	**What:** To maximally exploit renewable potential in the Mediterranean Sea region and develop joint projects, it is necessary to align development goals and plans for offshore renewable development and on- and offshore grids on a regional level through a joint offshore grid development strategy. On a European level, there is cooperation on transmission grid development in the 10-year network development plans from ENTSO-E.[127] On a regional level, increased focus is occurring on the development in the Mediterranean by Med-TSO.[128] **Why:** Offshore grid development benefits from regional collaboration to understand the siting, timing, planned clusters, and targets for offshore marine energy development; otherwise joint grid developments might not be optimised in step with renewable developments to bring renewable energy generation to the load centres in the region.	**Moderate**
6	**Offshore grid planning criteria**	**What:** The development of an offshore grid requires new planning criteria on a regional level to ensure the system will function safely and investments are optimised, in contrast with point-to-point interconnectors and radial connections of offshore renewable generators to shore.[129] This requirement is a common challenge for all offshore grid developments in European sea basins (e.g., Northern Seas). **Why:** For example, reliability standards for meshed offshore grids are an important planning criterion that do not yet exist. The current criterion of N-1 for transmission networks might not be appropriate anymore, amongst others being investigated in the Horizon 2020 PROMOTioN project.[130] On a regional level, there are ongoing efforts by Med-TSO.	**Moderate**

[125] (Soukissian et al., 2017)
[126] (Soukissian et al., 2017)
[127] (ENTSO-E, 2018d)
[128] Mediterranean Project I and Mediterranean Project II. https://www.med-tso.com/mediterranean2.aspx?f=
[129] (PROMOTioN, 2017a)
[130] (PROMOTioN, 2017a)

	Barrier	Description and rationale barrier	Rank
7	**Joint standard models and datasets for long-term grid planning**	**What:** To undertake joint grid planning and design, TSOs across the region need to adopt the same modelling tools for grid planning, network operation, and market simulations to have results that are broadly accepted and to achieve a joint strategy. In addition, joint assumptions (energy development scenarios, adopted weather data, etc.) and datasets need to be developed for these models to compare results and outcomes. **Why:** Currently, limited publicly available joint standard models and assumptions exist on a regional level. Ongoing efforts by the EU level increase availability of these (e.g. TYNDP scenarios, EU common grid model[131] and MedTSO initiatives).	**Moderate**
Offshore and onshore grid			
1	**(Aligned) grid transmission asset responsibility for offshore energy generators (offshore grid delivery model)**	**What:** Offshore renewables require a clear grid delivery model that defines the roles and responsibilities for the development, construction, ownership, O&M, and financing of transmission assets of offshore renewable generation units. These responsibilities often fall to the TSO, transmission asset owner (TAO), commercial developer, or another commercial party (e.g., OFTO in the UK). Generally, two main models exist: plan-led or developer-led, and a range of hybrid models combine aspects of both.[132] **Why:** Without a defined grid delivery model for transmission asset responsibilities, developers do not have clarity on costs and procedures for transmission asset development. This situation reduces developer confidence in developing offshore renewable energy. Currently, some Mediterranean countries do not have a specified grid delivery model yet.[132,133] For example, France is one of the Mediterranean countries with a defined grid delivery model for offshore wind, placing the responsibility of offshore grid development with the French TSO RTE rather than the developer. For joint projects, alignment of grid delivery models in the region could be an added benefit although not required.[134]	**Strong**

[131] (ENTSO-E, 2018a)

[132] (Navigant, 2019; WindEurope, 2019d)

[133] (RES Legal, 2020)

[134] Note that shared projects between two countries with different grid delivery models is not uncommon as, for example, TenneT and Vattenfall are investigating the feasibility of an interconnector between a TenneT offshore substation in the Netherlands and a Vattenfall offshore substation in the UK: TenneT, 2018. TenneT and Vattenfall to study potential Dutch and UK offshore wind farm connections. https://www.tennet.eu/news/detail/tennet-and-vattenfall-to-study-potential-dutch-and-uk-offshore-wind-farm-connections/

	Barrier	Description and rationale barrier	Rank
2	**Aligned rules (regimes and procedures) for onshore grid infrastructure (connection, expansion, and reinforcement)**	**What:** Onshore connection rules for offshore renewable energy specify the responsibilities to ensure appropriate hosting capacity of the onshore grid, and measures/compensations (if any) in case of delayed grid infrastructure.[135,136] To ensure timely operation of renewables, often anticipatory investments have to be made in the onshore grid to ensure offshore renewable energy can be evacuated to onshore load centres. **Why:** National differences in rules could hinder the timely development of grid infrastructure through delayed anticipatory investments and the operation of the renewable energy generators. In particular, for large-scale offshore developments, it is important that these rules match onshore grid connection plans, with potential long development lead times, to avoid temporarily stranded assets.	**Moderate**
Market design specific to offshore area			
1	**Bidding zone arrangement for the offshore area**	**What:** Bidding zones within Europe largely follow national borders. Bidding zones are determined based on the copper plate concept.[137] Bidding zones should therefore reflect major congestions in the network. Currently, offshore areas are included in the bidding zone of the country in which exclusive economic zone (EEZ) they belong to. Offshore renewable generation currently participates in its home market. **Why:** An offshore grid could result in important offshore congestions that are not reflected through the current bidding zone arrangement. In addition, offshore renewable energy in an offshore grid could be located in the EEZ of one country but connected to the offshore grid in the EEZ of another country if that is optimal from a planning perspective.[138] These developments would require an analysis regarding suitable bidding zone configurations for the Mediterranean region.	**Strong**

[135] (RES Legal, 2020)
[136] (WindEurope, 2019d)
[137] (ENTSO-E, 2018c)
[138] (PROMOTioN, 2017a), (PROMOTioN, 2019c)

	Barrier	Description and rationale barrier	Rank
Offshore RES generation			
1	**Aligned balancing responsibility of offshore renewable generators**	**What:** Balancing responsibly defines which market players are responsible for maintaining the balance between supply and demand in the electricity market.[139] Balancing responsibility rules can vary between markets and impact the business case of generators if they cause or alleviate an imbalance and whether they have access to markets after day-ahead to adjust their forecasts and mitigate their own imbalances.[140] **Why:** National differences and uncertainties regarding the responsibility of offshore renewable generators balancing responsible parties and how remuneration and penalties are organised could hamper offshore renewable development. Offshore renewables could also be limited to being balancing-responsible parties in the market they are located in rather than on a regional level in an offshore grid.	**Strong**
2	**Aligned requirements and standards for RES grid services**	**What:** Grid services include frequency control, reactive power, and voltage control, among others. Grid services are determined by the Network Code on Requirements for Grid Connection Applicable to All Generators (RfG) (art. 21)[48],[141],[142]. For HVDC, this is specifically addressed in the HVDC Network Code (art. 37 and 38) from ENTSO-E (2014), which was delivered to ACER, who recommended it for adoption by the EC. Some ancillary services are to be provided by offshore renewables following national grid codes. **Why:** National grid codes for ancillary service provisions for offshore renewables can differ. When offshore renewables are connected to multiple countries in an offshore grid, these rules should be aligned to ensure compliance of renewable operation with the grid codes of the different connected countries.	**Moderate**

[139] (ACER, 2020)
[140] (PwC, 2016)
[141] (3E and Project Partners, 2015)
[142] (PwC, 2016)

	Barrier	Description and rationale barrier	Rank
3	**(Aligned) renewable energy support schemes and support allocation mechanisms**	**What:** Development of offshore renewables—in particular, starting the scale up of offshore renewables developments in the Mediterranean—would benefit from appropriate support scheme design and support allocation mechanisms. Support could be important to strengthen the business case of offshore renewables. Several types of support schemes exist, including feed-in tariffs, feed-in premiums, contracts for difference, or quotas with green certificates.[143,144] Other state support is also possible, such as subsidies or tax incentives. Levels of state support will depend on the ambition level of the targets of each state and technology cost learning curves among other factors and can be awarded in a technology-neutral or technology-specific context. There is a clear trend towards auctioning of support for renewables in Europe; the EU State Aid guidelines mandate that energy subsidies are granted through competitive bidding processes from 2017.[145] **Why:** Discrepancies in the level of support for offshore renewable technologies and in the support scheme design and allocation mechanisms between countries might hinder optimised development of renewables and an offshore grid in the region. Developers might be incentivised to develop in markets with the highest level of support (combined with lower grid connection costs; see **Cost level barriers**) rather than developing in sites with the overall highest renewable potential. Furthermore, this approach might result in some countries not meeting their RES targets. In addition, rules around support allocation mechanisms for renewable generation often specify the requirement of feeding in renewable energy to the market to receive the support available in that market.[146] This should be aligned and defined for an offshore grid with joint or hybrid projects, where it could become unclear if and what type of support would apply for a renewable asset (i.e., policy uncertainty hampers developments). In addition, for hybrid projects, the possibility exists that renewable generation units could receive multiple support streams leading to over-subsidising and hampering of international strategies. Alignment should occur on a region-specific level to facilitate the development of an offshore grid in the Mediterranean.	Strong

[143] (RES Legal, 2020)

[144] (CEER, 2018)

[145] Communication from the Commission, 2014. Guidelines on State aid for environmental protection and energy 2014-2020 (2014/C 200/01). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014XC0628%2801%29

[146] (PROMOTioN, 2019c; PROMOTioN, 2019a)

	Barrier	Description and rationale barrier	Rank
Offshore grid operation			
1	**Aligned priority dispatch regulation for offshore renewable energy**	**What:** Renewables Directive 2009/28/EC (Article 16) specifies priority dispatch for renewable energy under certain conditions.[147,148,149] This priority dispatch for renewable energy over conventional fossil-fuel based energy is adopted in some countries in the Mediterranean.[150] Priority dispatch depends on the location of the congestion in the grid. In an offshore grid, this situation might not apply due to only offshore renewable electricity being exported to the onshore areas, and congestions might occur in the onshore grid requiring curtailment of onshore renewable generators.[151] **Why:** A framework is required for curtailment of offshore renewable energy connected to an offshore grid but located in different countries. Compensation for curtailment might differ between countries—potentially part of the support conditions. If offshore renewables are only seen to be part of the market they are located in, this barrier is minimal.[152]	**Moderate**
2	**Alignment on cross-border CACM in offshore grid operation**	**What:** An offshore grid not only connects offshore renewable energy plants to shore but also increases interconnection (cross-border capacity) between countries (hybrid function) that might not be connected yet through point-to-point interconnectors.[153] National and regional rules are required for cross-border CACM. The European Guideline on CACM defines the methodology to determine what part of interconnector capacity can be used by the market while ensuring measures for secure network operation. In addition, it provides harmonisation on cross-border markets on a European level (auction type implicit/explicit, flow based). This is of major importance to facilitate the European single electricity market. [154] The 2019 recast of the European Electricity Market Regulation (EU) 943/2019 (Art 16, 8b) stipulates that at least 70% of the physical capacity of each interconnector must be used for cross-zonal trade. Congestions can also occur in the offshore grid with a hybrid function requiring part of the capacity to be reserved for the transport of offshore renewable electricity to shore and part for cross-border exchange, which might challenge this regulation. **Why:** Regulations are already in place for point-to-point interconnectors but not for hybrid projects and meshed offshore assets. Hybrid functions of an offshore grid are not yet aligned with the EU regulation 2009/714, which stipulates that interconnector capacity needs to be allocated without discrimination while offshore renewable generators need guaranteed output injection in the offshore grid.[155] Therefore, sizing of hybrid interconnectors poses a challenge due to the balance between interconnection and renewable connection functions.	**Moderate**

[147] (3E and Project Partners, 2015)
[148] (RES Legal, 2020)
[149] (Emissions-EUETS, 2020)
[150] (RES Legal, 2020)
[151] (PwC, 2016)
[152] (PwC, 2016)
[153] (PROMOTioN, 2019c)
[154] (ENTSO-E, 2018b)

	Barrier	Description and rationale barrier	Rank
3	**Regional offshore grid maintenance strategy**	**What:** To ensure optimal operation and adequacy of an offshore grid, a joint maintenance and repair strategy needs to be developed.[156] This includes determining the responsible parties, funding sources, frequency, and infrastructure required to perform maintenance and contract maintenance operators. **Why:** Without joint strategy for an offshore grid, costs might not be optimised, higher levels of forced outages of equipment could occur, and delays in repair activities could take place since there is no clear allocation of responsibilities and cost.[157]	**Moderate**
Administrative/governance process			
1	**Development of national and joint regional marine spatial plan and integrated coastal zone management**	**What:** The Marine Spatial Planning (MSP) Directive obliges all coastal EU member states to develop an MSP by March 31, 2021.[158] MSPs will have different levels of enforceability and different formats following general guidelines in the directive. MSP is defined in the directive as "a process by which the relevant member state's authorities analyse and organise human activities in marine areas to achieve ecological, economic, and social objectives."[159] It is "aimed at promoting the sustainable growth of maritime economies, the sustainable development of marine areas, and the sustainable use of marine resources." The MSP includes an integrated approach, including multiple sectors. On an EU level, there is also an Integrated Maritime Policy.[160] **Why:** Currently the coastal member states of the Mediterranean are in different phases of developing their MSP. In addition, member states can freely decide on the format, content, and level of legal enforceability (e.g., binding, non-binding vision, strategies, guidelines[161]). This scenario could delay or hinder the development of offshore grid infrastructure or offshore renewables in the region. In addition, there should be alignment on the development of marine offshore energy and the allocation and use of high potential renewable sites. Harmonisation and alignment of MSPs between Mediterranean member states could more readily facilitate regional cooperation for offshore grid developments.	**Moderate**

[155] (PwC, 2016)
[156] (3E and Project Partners, 2015)
[157] (3E and Project Partners, 2015)
[158] (European MSP Platform, 2018a)
[159] (European Commission, 2014)
[160] (European Commission, 2020a)
[161] (European MSP Platform, 2018a)

	Barrier	Description and rationale barrier	Rank
2	**Alignment of licensing, permitting, and consenting procedures for development of offshore renewable energy**	**What:** Offshore renewable energy developers need to obtain appropriate permits, licences, and leases by the relevant state bodies to develop their projects. Consenting procedures include a timeline and process for applications and are typically in the form of open-door policies (open applications), application rounds, or competitive tenders.[162] **Why:** Consenting procedures can present a high level of complexity for developers due to a high number of permitting and licensing applications with different state bodies and unclear application and award timelines. Offshore renewable energy consenting procedures are not yet defined for each member state in the Mediterranean and not regionally aligned in terms of process and lead times. This situation introduces uncertainty for developers due to varying application timelines, processes, and complexity levels between countries.[163] These challenges decrease developer confidence in the market and could hamper the development of renewable and joint projects in addition to optimised and timely development of offshore renewable energy in the region.	**Moderate**
3	**Legislative issues on a national level to clarify mandates for offshore grid development by the national TSO**	**What:** Developments in the offshore area require involved stakeholders such as the TSOs to have the mandate (legal status) to start developing transmission system infrastructure in the offshore area, including the EEZ. National legislative frameworks should be adapted to new practices and users. **Why:** Bureaucratic and legislative issues and complexity can introduce uncertainty for developers, TSOs, and other stakeholders, which might delay the development of an offshore grid.	**Strong**
4	**Regulatory framework for islands on a national and regional level regarding renewables and fossil fuel support**	**What:** The Mediterranean includes many islands, some of them grid connected and others non-interconnected. Islands can experience seasonal demand patterns due to high influxes of tourists over the summer.[164] Some islands use specific tax relief for fossil fuels to ensure security of supply or restrictions for the development of larger-scale renewable generation due to insufficient demand.[165,166] These regulations often differ from national regulations and regulations on other islands in the region. **Why:** To optimise renewable energy development in the region, islands can play a critical role in the Mediterranean area due to their high potential for solar PV (high solar irradiation). Support for fossil fuels or restrictions on renewable energy developments can hamper the optimal development of renewables on islands. It can also hinder the development of interconnections between islands that have a high potential for RES development and low population densities, islands with higher population densities and less RES potential, or with the mainland. Increased interconnections could increase sharing of renewable energy in the region. Therefore, ensuring appropriate and more aligned regulatory frameworks on islands in the Mediterranean remains important.	**Strong**

[162] (WindEurope, 2019c; Simas, 2015); (PwC, 2016)

[163] (WindEurope, 2019d); (PwC, 2016)
[164] (Navigant & E3 Modelling, 2017)
[165] (Navigant & E3 Modelling, 2017)
[166] (RES Legal, 2020)

	Barrier	Description and rationale barrier	Rank
5	**Jurisdictional definition regarding grid development within EEZs**	**What:** Member states have jurisdiction in their territorial sea. Beyond the territorial sea in the EEZ, member states have jurisdiction for economic exploitation.[167] Jurisdiction needs to be established in the EEZ regarding the development of grid infrastructure such as interconnectors. **Why:** Without legislation for grid development in the EEZ, offshore grid development will not be easily facilitated.	**Strong**
Cost allocation			
1	**Aligned grid charges/grid connection costs for renewable generation units**	**What:** Grid connection costs are the costs paid by grid users to obtain and maintain a grid connection.[168] Across Europe, these costs are often carried by the developer applying for a grid connection. The charge can be based on the capacity of the connection (per MW) or on the injection (per MWh). **Why:** Discrepancies in the level of grid charges for offshore renewable technologies between countries could hinder the optimised development of renewables in the region or distort site selection. Developers might be incentivised to develop generation in those markets with the lower grid connection costs rather than developing in the overall highest renewable potential sites. This approach might result in some countries with higher charges not meeting their RES targets or congestions for renewable feed-in markets with lower charges resulting in possible curtailment.	**Moderate**

[167] (PROMOTioN, 2017a)

[168] (WindEurope, 2019d); (PwC, 2016)

	Barrier	Description and rationale barrier	Rank
2	**Cross-border cost allocation (CBCA) method for offshore grid infrastructure (cost-benefit sharing)**	**What:** An offshore grid not only increases connections between countries but also connects offshore renewable energy generation units. It could contribute to increasing societal benefits in the region, not only to all directly connected countries (through price convergence, reduction of CO_2 emissions[169]) but also to countries removed in the first and second degree from the sea and possibly further. The development of an offshore grid of offshore hybrid projects comes with a high investment and O&M cost. Transmission infrastructure between countries could qualify as projects of common interest (PCI) on a European level if they bring benefits to multiple countries and help to integrate the European electricity market. PCI projects could receive funding from the Connecting Europe Facility fund.[170] The remaining costs are carried by the respective countries relative to the benefits they obtain (For TEN-E projects CBCA rules exist[171]). For offshore grids with hybrid infrastructure, there is currently no clear methodology to allocate costs to the respective stakeholders.[172] On a regional level, Med-TSO published preliminary criteria for the implementation of a CBCA process in April 2020. [173] **Why:** Hybrid infrastructure such as offshore grids bring multiple benefits beyond increasing market integration (connecting renewables).[174] Without frameworks for cost sharing, the offshore grid in the Mediterranean would face a development barrier. Current rules stipulate that countries receiving a "significant positive net benefit"[175] of a project should contribute to the costs.[176] However, in an offshore grid system, there might be a case where benefits are spread out between countries, resulting in a few countries bearing all costs. The current methodology thus requires adaptation.	Strong

[169] (ENTSO-E, 2018d)

[170] (INEA, 2020; European Commission, 2020b; ACER, 2020)

[171] (WindEurope, 2019d)

[172] (PROMOTioN, 2019a)

[173] MedTSO, 2020. Med-TSO defines preliminary criteria for the implementation of a Cross Border Cost Allocation process. Deliverable 4.2 "Procedure for Cross Border Cost Allocation Application". https://www.med-tso.com/publications/Deliverable_4.2_Procedure_for_Cross_Border_Cost_Allocation_Application.pdf

[174] (WindEurope, 2019d)

[175] Around 10%: https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Recommendations/ACER%20Recommendation%2007-2013.pdf; PROMOTioN

[176] (PROMOTioN, 2019c)

	Barrier	Description and rationale barrier	Rank
3	**Cost information of new technologies**	**What:** Meshed offshore grid developments are only beginning in Europe and are mainly at early development stages.[177] Offshore grids connect countries and offshore renewable energy over longer distances and require new technologies, such as HVDC protection devices[178], to be developed and marketed. In addition, the unique characteristics of the Mediterranean require the use of emerging technologies such as floating wind turbines. **Why:** Some novel technologies are not yet commercially produced (e.g., HVDC protection devices), resulting in uncertainty regarding the cost evolution in the market for these components. Cost uncertainty complicates cost estimates for offshore grid developments, and any discussions on cost sharing and revenue requirements by involved stakeholders introduces uncertainty on the level of support required.	**Moderate**
Financing			
1	**Availability and cost of capital for offshore grid and renewable energy generation assets**	**What:** Development of an offshore grid requires significant investments and capital to finance offshore assets.[179] Financing offshore assets might come at a high cost depending on the risk level of the country, required returns on investment, and availability and cost of capital. Uncertainty relates to the presence of a stable regulatory framework, the strength of the business case, or the participation of public or private investors. **Why:** Unavailability of and high cost of capital in a country could decrease confidence from private investors and hamper the development of offshore assets in a country. Differences in capital cost and availability of capital between Mediterranean countries might result in a non-optimised offshore infrastructure due to investors focusing on countries with the lowest uncertainties to decrease perceived risks in financing assets.[180]	**Moderate**
2	**Common (and sharing of) financing mechanisms/financing rules for joint offshore renewable projects**	**What:** An offshore grid could encompass multiple joint infrastructure assets and potentially joint renewable energy projects. Currently, there are no standard mechanisms for financing joint offshore renewable projects.[181] For joint projects, government agencies need to define cooperation mechanisms and possibly joint support schemes. **Why:** Rules for financing hybrid projects and joint offshore renewable projects could increase investor confidence and ensure timely development of assets in the region rather than relying on bilateral and case-by-case agreements.	**Strong**

[177] PROMOTioN project, https://www.promotion-offshore.net/

[178] PROMOTioN project, https://www.promotion-offshore.net/

[179] (WindEurope, 2019d)

[180] (Intelligent Energy Europe, 2016); (WindEurope, 2019d)

[181] (PROMOTioN, 2019a)

	Barrier	Description and rationale barrier	Rank
3	**Tailored and sufficient investment incentives for offshore grid and renewables**	**What:** The development of large-scale grid infrastructure and renewable generation units in the Mediterranean will require significant investments. It is important that investment risks are mitigated as much as possible to ensure enough availability of capital and interest from developers. **Why:** One risk lies in the high levels of investment required for currently emerging technologies such as HVDC and floating offshore. This could require targeted funding sources for growth of technologies in the region.[182]	Moderate
Social constraints			
1	**Public acceptance of offshore renewable energy developments**	**What:** International experience with transmission infrastructure and offshore renewable energy developments has shown that public opposition can significantly hinder and delay developments.[183] Public opposition from coastal communities and tourism industries in the Mediterranean area could result from onshore landing points and the visibility of offshore renewable energy units from shore. Offshore renewable energy is key to achieving renewable energy targets in the region due to high potential renewable energy sites located offshore. **Why:** Public acceptance is key to ensuring optimal and timely development of the offshore grid in the Mediterranean. It is a highly touristic area, which increases risks of acceptance of coastal and visible infrastructure.	Strong
2	**Availability of skilled personnel and targeted training and education programs**	**What:** Large-scale development of an offshore grid and offshore renewable energy requires skilled technical personnel to design, develop and construct the required infrastructure.[184] The skills required relate to new components and technologies would necessitate new targeted training and education programs on innovation, specialised technological skills, expertise, and sharing of skills and experiences across the region. These skills relate to the offshore wind farm value chain, the development of marine offshore energy and offshore grids, socioeconomic assessments, laws and regulations, and energy system modelling, among others.[185] **Why:** Without locally available and sufficient numbers of skilled personnel, the large-scale development of an offshore grid in the Mediterranean could be delayed. Currently, experience is being built up in the region through experiences with subsea cable developments (e.g., TERNA ENERGY[186] and RTE[187]). In addition, offshore wind tenders in France will build up experience with grid connection developments of offshore wind and floating technologies in the region.[188]	Moderate

[182] (Interreg, 2017)

[183] (PROMOTioN, 2017b)

[184] (Interreg, 2019)

[185] (Interreg, 2019)

[186] TERNA, 2019. TERNA: new Italy-Montenegro interconnection infrastructure under way. https://www.terna.it/en/media/press-releases/detail/new-Italy-Montenegro-interconnection-infrastructure-under-way

[187] RTE, 2020. Tous nos projects. https://www.rte-france.com/projets/nos-projets

[188] RTE, 2020. Tous nos projects. https://www.rte-france.com/projets/nos-projets

	Barrier	Description and rationale barrier	Rank
Environmental constraints			
1	**Environmental protection areas limiting exploitation of full RES potential**	**What:** Environmental protection areas in the offshore area are marine areas with restrictions for the protection of unique and rare habitats of marine fauna and flora. Protected nature areas are included in the MSPs of each country, nationally designated, and also defined on a European level (Natura 2000[189]). **Why:** Designated environmental protection areas could reduce high potential RES production areas by prohibiting any developments. These protection areas include current environmental protection areas and potential designated environmental protection areas.	**Moderate**
2	**RES development restrictions due to impact on animal migration routes**	**What:** The Mediterranean Sea area encompasses strategic bird migrating routes, mainly twice a year traffic on the African-Eurasian route.[190] **Why:** Bird migration routes specific to the Mediterranean could be impacted by large-scale development of offshore wind farms on the routes.	**Moderate**
3	**Understanding cumulative environmental impact of large-scale offshore grid infrastructure**	**What:** Large-scale developments and potential decommissioning of grid infrastructure (offshore substations, seabed cables, onshore landing points, etc.) and offshore energy will impact local marine flora and fauna in the sea, air, and on the seabed. Research has shown that offshore developments (such as oil rigs and wind farms) could present new habitats (local reefs) for marine fauna and flora around their bases.[191] If hub solutions were part of the offshore grid, these could provide new resting and breeding areas for birds and other animals. **Why:** The full extent of the cumulative environmental impact from the development to decommissioning of an offshore grid and renewable energy assets in the Mediterranean region is not yet understood. Knowledge of the impact's extent would ensure developments balance protection of marine flora and fauna with offshore renewable energy developments and create buy-in from NGOs and the broader public.	**Strong**

(Source: Guidehouse)

[189] (European Commission, 2020c)
[190] (Birdlife International., 2009)
[191] (PROMOTioN, 2019b; Renewables Grid Initiative, 2020; Arvesen et al., 2014)

Appendix E. Stakeholder engagement

To provide additional value, this study has actively engaged stakeholders in the region on several levels:

- By consulting the Advisory Board on the progress of work
- By developing the stakeholder survey
- By consulting with national grid experts regarding proposed grid solutions
- By holding a stakeholder consultation webinar
- By gathering comments from the second interim report from the stakeholder consultation participants
- By presenting the conference results in the final conference and external conferences

E.1 Advisory Board

The Advisory Board consisted of the following experts presented in Table E-1.

Table E-1: Advisory Board

#	Name	Position	Organization	Country
1	Nikos Hatziargyriou	Professor	Division of Electric Power School of Electrical and Computer Engineering National Technical University of Athens	Greece
2	Angelo Ferrante	Secretary General	Med-TSO	Italy
3	Kostas Komninos	General Manager	DAFNI–Network of Sustainable Greek Islands	Greece

(Source: Guidehouse)

The Advisory Board verified this study’s approach and provided a high-level overview of the draft results of the study. Three webinars were held to discuss the work progress:

- Webinar 1: Discussing the detailed approach to work before finalizing the inception report
- Webinar 2: Initial conclusions from Tasks 1 and 2 and verification of the approach for Tasks 3 and 4
- Webinar 3: Draft recommendations

The Advisory Board members will also participate as panellists in the final conference.

E.2 Stakeholder survey

This survey aimed at verifying this study’s view on key challenges and implementation barriers for the development of an offshore grid and offshore renewables in the Mediterranean, as presented in the Longlist of barriers. Table E-2 presents the list of interviewees for the barriers and challenges overview.

Table E-2: Stakeholder interview participants

#	Last Name	First Name	Organization
1	Ozkoc	Hasan	MedReg
2	Pineda	Iván	WindEurope
3	Collombet	Rémi	Ocean Energy
4	Schroeder	Robert	ENTSO-E

(Source: Guidehouse)

E.3 Stakeholder webinar

The authors of this study prepared an online stakeholder webinar, where they presented the draft results of the study. The list of participants is presented in Table E-3.

Table E-3: Stakeholder webinar participants

#	Last Name	First Name	Organization
1	Abedrabbo	Mudar	KU Leuven
2	Airoldi	Davide	Ricerca sul Sistema Energetico
3	Akbas	Tunahan	EKOsinerji
4	Alagialoglou	Nikolaos	Copenhagen Offshore Partners
5	Ayuso	Juan Ramon	IDAE
6	Bakker	Wessel	DNV GL
7	Bates	Charlotte	Commission de Régulation de l'Energie
8	Bennani	Smail	EBRD
9	Biller	Tobias	Ørsted
10	Blanco	Lucía	Miteco
11	Bordenave	Thomas	EOLFI
12	Breyton	Juliette	Schneider Electric
13	Capaldi	Romain	Guidehouse
14	Capra	Marcello	Italian Ministry of Economic Development
15	Cecchinato	Mattia	WindEurope
16	Chomo	Adam	Energy & Water Agency
17	Ciglar	Julien	AD'OCC, the Regional Economic Development Agency
19	De Diego	Carmen	EDPR
20	Demmer	Michael	DG ENER
21	D'Innocenzo	Wolfgang	Permanent Representation of Italy to the EU
22	Durand	Hermine	Government of France
23	Fernández	Manuel	EDPR Offshore
24	Fitton	Jeremy	SkyLifter
25	Fonseca	Manuela	Directorate General for Energy and Geology
26	Fonseca	Manuela	Directorate General for Energy and Geology

#	Last Name	First Name	Organization
27	Foucher	Maud	Government of France
28	Francis	Adam James	Ørsted
29	Frosin	Sorin	Melita TransGas
30	Gaeta	Maria	Ricerca sul Sistema Energetico
31	Galea	Therese	Government of Malta
32	García	Fatima	Ministry for the Ecological Transition and Demographic Challenge
33	Garofalo	Elisabetta	Ricerca sul Sistema Energetico
34	Gaspar	Miklos	European Commission
35	Graham	Shannon	Guidehouse
36	Grosaru	Alex	Cathie
37	Hanif	Adil	EBRD
38	Hatziargyriou	Nikos	NTUA
39	Jimenez	Maria	Government of Croatia
40	Jukić	Vjekoslav	Ministry of Environment and Energy
41	Komninos	Kostas	DAFNI Network of Sustainable Greek Islands
43	Krönert	Frank	Sweco
44	L'Abbate	Angelo	RSE S.p.A
45	Lahdo	Georgina	Cyprian Ministry of **Energy**, Commerce, Industry & Tourism.
46	Lampasona	Alberto	Europacable
47	Laugier	Romain	WWF European Policy Office
48	Lauri	Sandro	Government of Malta
49	Lindroth	Simon	Sweco
50	Logothetis	Georgios	Ministry of Economy and Development
51	López Ocón	Carmen	IDAE
52	Lundholm	Rickard	KU Leuven
53	Major	Hiyaw	KU Leuven
54	Maksijan	Boris	Government of Croatia
55	Maly	Miroslav	EBRD
56	Massaras	Panagiotis	Permanent Representation of Greece to the EU
58	Nicolini	Emilio	Cathie
59	Nikou	Ioanna	Greek Ministry of Environment and Energy/Executive Authority of the Partnership Agreement, Energy Sector
60	Ozkoc	Hasan	MEDREG
61	Panteli	Christos	Permanent Representation of Cyprus to the EU
62	Partasides	George	Ministry of Energy, Commerce, and Industry
63	Pineda	Ivan	WindEurope

#	Last Name	First Name	Organization
64	Psaroudakis	Eleftherios	Ministry of Development and Investments
65	Ramaekers	Lou	Guidehouse
66	Ramirez	Lizet	WindEurope
67	Renedo Williams	Ricardo	ENTSO-E
68	Rundqvist Yeomans	Gustaf	Sweco
69	Sannino	Gianmaria	ENEA
70	Sargin	Okan	Guidehouse
71	Spady	Matthew	Guidehouse Insights
72	Staschus	Konstantin	Guidehouse
73	Stefanoudi	Aliki	Ministry of Development and Investments
74	Tesniere	Capucine	CRE
75	Vailati	Riccardo	ARERA
76	Vasconcelos	António	Directorate General of Energy and Geology
77	Villar Lejarreta	Ainhoa	Guidehouse
78	Vree	Barry	Guidehouse
79	Wang	Mian	KU Leuven
80	Wendt	Volker	Europacable
81	Wilson	Hector	Carbon Trust
82	Wouters	Carmen	Guidehouse
83	Xuereb	Michaela	Government of Malta
84	Yang	Li	Elia
85	Zacharia	Stella	TERNA ENERGY

(Source: Guidehouse)

E.4 List of interviewees for grid options

The following people were interviewed to gain insight into the consequences for the transmission grids around the Mediterranean Sea.

- Angelo Ferrante, Secretary General, Med-TSO
- Prof. Nikos Hatziargyriou from NTUA
- Dimitrios Chaniotis, ENTSO-E System Development Committee Chair
- Gro Waeraas de Saint Martin, Directrice de Programme, RTE

E.5 List of comments provided by stakeholders

Finally, comments to the second interim report were received from the following stakeholders:

- Malta Permanent Representation to the EU
- Greece Permanent Representation to the EU
- France Permanent Representation to the EU
- Italy Permanent Representation to the EU
- Spanish Permanent Representation to the EU

- Portugal Permanent Representation to the EU
- Europacable
- WindEurope
- OceanEnergy
- TERNA ENERGY

E.6 Conferences and events presenting the study results

The initiative of supporting the offshore energy and regional grid developments in the Mediterranean region will be promoted via other key offshore energy-specific events. The following events are proposed:

- European Sustainable Energy Week (https://eusew.eu/), Brussels, 22-26 June 2020
- Med Power 2020 (http://medpower2020.org/), 08-12.11.2020
- Floating Offshore Working Group, Wind Europe, 23.10.2020
- Global Wind Europe Summit, 1-4.12.2020

The final conference will be held online on November 12, 2020. Registration is open at https://guidehouse.com/events/2020/11/12/offshore-power-grid-potential.

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