Deliverable 1.1

Mediterranean Network Development Plan at 2020

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“Med-TSO—Mediterranean Project II”

Task 1.1 “Sustaining the Planning capabilities and enhancing quality: the Mediterranean Network Development Plan (MNDP)”

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1. AIM AND SCOPE

Cooperation amongst the TSOs in the Mediterranean Region

The first Mediterranean Project (MPI, 2015-2018) has shown for the first time the intention of 20 TSOs from 18 countries around the Mediterranean to build up, as an added benefit, a valuable network of relations and cooperation. Starting from this successful result, not only in terms of intention but also in terms of deliverables and results, the second Mediterranean Project (MPII, 2018-2020) intended to continue and extend as much as possible the areas of cooperation amongst the TSOs in the Mediterranean Region. At the beginning of 2017, Med-TSO launched the second Mediterranean Project, a three-year lasting action, funded by the DG NEAR of European Commission (Grant Contract: ENI/2018/397-494). The objective is proceeding towards the integration of the Mediterranean electricity systems, in line with the objectives of EU's Neighborhood policy on Energy and Climate Change. The Mediterranean Project II was developed in the frame of the initiatives aimed at reducing the cost and the environmental footprint of electricity in the Mediterranean region and in the connected neighboring regions. All these initiatives have as beneficiaries the final customers/citizens and the planet, in the context of climate change and economical and societal development. The creation of security, stability and prosperity, shared at a regional level, represents a common objective of the Mediterranean countries. Adequate electricity infrastructures, integrated and efficient, constitute one of the basis for the achievement of development and security goals.

2. Background

How face the challenges of the energy transition

Among the several deliverables the **Mediterranean Project 2** (MP2) addresses the Regional periodic Ten-Year Mediterranean Network Development Plan (TYMNDP) or Mediterranean Master Plan (MMP); this plan identifies the necessary investments in grid infrastructures, of which analytical justification has been based on:

- harmonized methodologies among Members and in line with ENTSO-E practices;
- agreed procedures that prescribe an annual revision cycle of the Master Plan, like the TYNDP for ENTSO-E;
- reference energy scenarios;
- market and grid studies;
- benefits and costs as a result of market and network studies.

The MMP includes the reinforcements of the existing grids to accommodate reliable transit flows in the Med-TSO Region and keep the security of operation standards at adequate levels. The main infrastructure investments have been identified in cross border interconnection projects, regardless to their maturity levels with the specific objective to:

a) increase energy security and reliability;

b) favor greater RES penetration, thus reducing the environmental impact of the electricity generation, by facilitating their integration in the Mediterranean Region, especially encouraging cost-effective RES exchanges both on the North-South and South-South axes;

c) increase the overall system efficiency;

d) generate economies of scale in investments and operations.

Meeting the above-mentioned objectives is a need for the Mediterranean countries, in order to face the challenges that the energy transition (with its high RES penetration) is posing to the TSOs everyday business and long-term planning activities. The MP2 will be an appropriate context where the achieved experience of more developed countries could be put in common with other less advanced countries.

In the Action Plan 2018-2020, Med-TSO's efforts concentrate on sustaining and enhancing this process in terms of quality of deliverables and cooperation. In this regard, Med-TSO increased the efficiency by reinforcing the bottom-up approach through a more effective participation at regional level. The improvement of the process also concerned the quality of the studies, through a better harmonization of the National Development Plans (NDPs) with the MMP. For both sustainability and improvements, more competences and more tools were adopted, in particular:

- more sophisticated network analyses were carried out in order to evaluate grid constraints, (e.g. quality and security of supply, etc.);
- the Mediterranean Database (DBMED) was enriched with more sections in order to have a better representation of the relevant electricity system in the prospective scenarios;
- systematic data quality check was performed from secretariat in order to increase the level of analysis;

- communication tools were developed to manage remote meeting conferences, due to travel restrictions during the COVID-19 emergency.

The MP2 has required multilateral cooperation, between Institutions and Companies, and a strong political will. In fact, Med-TSO's initiative is based on multilateral cooperation as instrument of integration of the Mediterranean Electricity Systems, whose benefits result from the sharing of their resources (primary energy sources, power generation, know-how), costs and risks of infrastructure investments. During the next ten years, the TSOs forecast an increase in the generation capacity in the Mediterranean of about 150 GW[1], of which 15% from RES, corresponding to an expected increase in electricity demand of about 90 GW. The related investments amount to 220 - 250 billion €. This requires the HV network strengthening and integration of the two shores of the Mediterranean. The TSOs estimate the construction of about 33,000 km of HV lines, with around 20 billion € of investments.

[1] Source: Med-TSO website October 2020

3. MED-TSO VISION

Security of supply, integration of market and RES development will characterize the prospective regional energy scenarios at 2030 time horizon

As commonly agreed, the multi-dimensional integration of the Euro-Mediterranean Region has to be seen no longer as an opportunity, but an unavoidable requirement to bring the two shores of the Mediterranean closer and thereby tackle the shortcomings together, especially considering the current phase of instability. The social and work-related problems are severe on both shores, and the development of infrastructure (energy, water, transport, etc) is the key to a new development path, based on employment, job creation and innovation. In this respect, energy plays a vital role for the security and the development of the Mediterranean countries. Ensuring of security, stability and prosperity, shared at a regional level, represents a common objective of the Mediterranean countries. Adequate electricity infrastructures, integrated and efficient, constitute one of the basis for the achievement of development and security goals. Multilateral cooperation must be promoted, through a "bottom-up" approach that improves complementarities and provides a global response to the ongoing changes in the Mediterranean. The impact of recent policies entered into force after Paris Agreement have changed dramatically the mid-term scenarios in the region, with a significant impact on the assessment of costs and benefits for the planned interconnection projects.

Security of supply, integration of market and RES development will characterize the prospective regional energy scenarios at 2030 time horizon, with a growing demand for flexibility, adequacy and efficiency and the need for new regulation framework at regional level. The Euro-Mediterranean region has globally the resources (both in terms of know-how and primary energy sources) to support the regional development. In order to achieve these goals, reducing constraints and valorizing complementarities becomes a must that requires converging rules and interconnection infrastructure to integrate the national power systems.

In this context, a group of Mediterranean TSOs and Utilities decided to establish Med-TSO - the Association of Mediterranean TSOs - on 19 April 2012 in Rome, with the objective to set up a framework for multilateral cooperation in the Mediterranean electricity sector. Members of the Association are currently 21 electricity companies operating the transmission grids of 19 EU and non-EU Mediterranean countries, as shown in Figure 1.

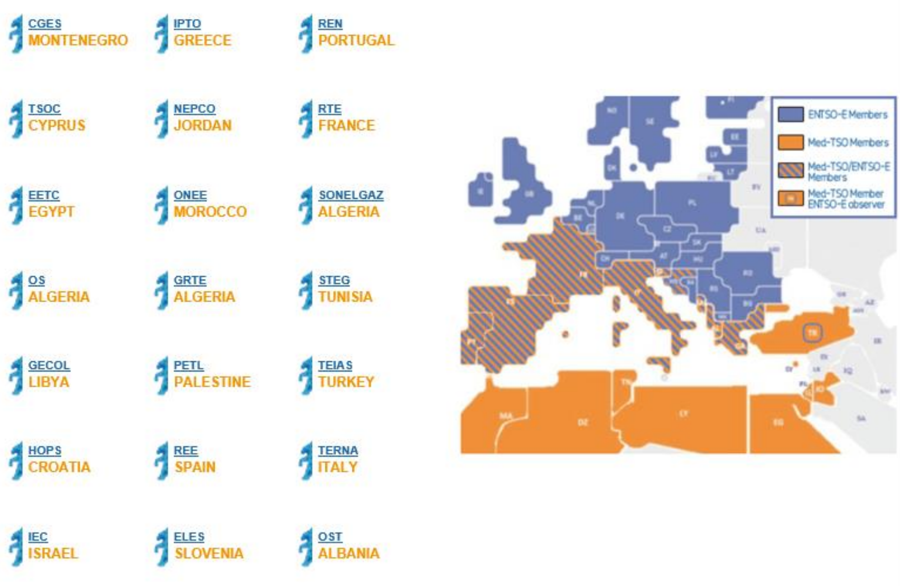

Figure 1. Med-TSO members

3.1 Impact of Climate Change and Energy Transition

Climate change has become one of the major concerns in today political agenda. Therefore, transitioning to a carbon neutral economy is increasingly being considered of paramount priority.

The adoption of the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) marked an unprecedented step in the global action against climate change, establishing the objective to limit global warming in this century to less than two degrees Celsius above pre-industrial levels.

Furthermore, at the end of 2019, the EU reset the Commission’s commitment to tackling climate and environmental-related challenges, setting out the EU Green Deal, the new growth strategy for the European Community. The strategic objectives of the Green Deal include zero net emissions of greenhouse gases by 2050; and economic growth decoupled from resource use.

The successful limitation of the impacts of climate change requires a profound transformation of the global energy landscape, namely through a fast-pace deployment of low-carbon technologies to replace conventional fossil fuel-based technologies. This applies both to the supply and to the demand side. Consequently, not only do we have to change our sources of energy, but also the technologies for using that energy, namely through the electrification of fuel-based sectors (mobility/transport is a good example).

As far as the electrical sector is concerned, delivering the energy transition at the necessary pace and scale requires an almost complete decarbonization of the sector by 2050, which leads to an urgent scaling up of electricity production from renewable sources.

Furthermore, the energy transition process also focuses on a more sustainable consumption, both by promoting the use of more efficient technologies on the demand side, but also by promoting the adoption of more responsible behaviors in using energy.

The Mediterranean region currently emits lower levels of greenhouse gases (GHGs) compared to other areas in the world. According to 2018 data of the Global Carbon Atlas, the Mediterranean countries together emitted around 6.2% of the world's global emissions. But on the other hand, the demographic dynamics observed in the South Shore of the Mediterranean, lead to a more challenging situation in the coming years, as with a growing population - and with an expected simultaneous economic growth -, comes a growing consumption of energy (and specifically of electricity).

On the generation side, the Southern and Eastern Mediterranean region is endowed with a huge solar and wind energy potential, which has been estimated to be largely higher than that of the North Shore. However, and despite the existence of government commitments, regulatory and institutional frameworks and a lowering cost of renewable energy technologies, the deployment of renewable generation projects is evolving at a relatively slow pace and the degree of penetration in the region is still low when compared to other regions in the world, namely to some of the North Shore countries.

The differences currently observed between the realities of the North Shore countries and the South and Eastern countries, coupled with the different trends expected in the consumption evolution among these countries and with a generalized expected increase in renewables integration, all drive the need for a robust infrastructure, not only at national level but also in terms of interconnections. In fact, these different realities between Mediterranean countries pose complementarities which, in order to be exploited, require a capable transmission infrastructure.

Furthermore, interconnections between national markets represent the hardware for promoting properly functioning electricity markets, ensuring security of supply and reaping the full potential of renewable energy sources.

4. THE FRAMEWORK OF PREVIOUS STUDIES

Med-TSO is a cooperation platform for identifying and analyzing potential infrastructure projects

Med-TSO started its operational activities in 2013, in the frame of the EU-funded project "*Paving the Way for the Mediterranean Solar Plan*", by developing "*Master Plan of the Mediterranean Electricity Interconnections*" in four deliverables on the basis of two main objectives:

- Sharing criteria among the Mediterranean TSOs, consistent with ENTSO-E experience, of a coordinated rolling planning of transmission infrastructures;
- Analyzing projects of interconnections and related reinforcements of internal grids planned at short-term, whose feasibility studies are available and, where applicable, eligible for European PCI (Projects of Common Interest) and ENTSO-E coordinated planning procedures.

This Plan highlighted the need of huge investments in new transmission infrastructures, both for strengthening and integrating the networks on the southern shores of the Mediterranean and integrating them with the networks of the northern shore[2].

Afterwards, Med-TSO proposed to the European Commission to set up a cooperation platform for identifying and analyzing potential infrastructure projects. A trilateral Memorandum of Understanding with the European Commission and MEDREG, the Association of the Mediterranean Energy Regulators (MEDREG), was signed in Rome on November 18, 2014 at the Euro-Mediterranean Conference on Energy. With this cooperation framework, the EC recognized Med-TSO as a "long term partners of the EC", acknowledging the proposed Med-TSO platform as an efficient instrument for cooperation.

At the beginning of 2015, Med-TSO launched the Mediterranean Project 1 (MP1), a three-year lasting action, funded by the EC (Grant Contract ENI/2014/347-006), aimed at supporting the assessment of infrastructural projects in the Mediterranean Region. The project was structured according to the following five main streams of activities.

- **Rules** - basic rules for international electricity exchanges, in cooperation with MEDREG.
- **Infrastructure** - the planning process for setting up a Mediterranean Reference Grid.
- **International Electricity Exchanges** - case studies and feasibility demonstration of interconnection projects.
- **Knowledge Network** - a network for exchanging knowledge and experiences, in cooperation with Universities of the Med-TSO Area.
- **Med-TSO Database** - sharing information (data and market projects) for the development of electricity exchanges at regional level.

The first edition of the Mediterranean Master Plan (MP1) 2030 defines the feasibility of fourteen (14) main interconnection projects (within three corridors) between regional electric systems and the necessary internal reinforcements to guarantee proper security standards. The MP1 plays a key role for consolidating a secure and sustainable electricity infrastructure through the development of interconnections, while facilitating the integration of RES in the Mediterranean

[2] The Plan estimated the construction of 33,000 km of new High Voltage transmission lines, for about 17 BEUR of investment in the reference period (2013-2022).

Region. Fourteen interconnection projects have been identified and assessed (9 of them supposed to be deployed in HVDC technology), according to the different energy scenarios elaborated at the year horizon 2030 (target year). Five of these projects link countries never interconnected before and, in addition, one of the outcomes is the end of the electrical isolation of Cyprus.

In concrete terms, the MP1 has depicted:

- almost 18 000 MW of new interconnection capacity;
- limited needs of reinforcements (2 200 km of new lines, 840 km of reconductoring and less than 40 new bays and transformers);
- about 16 bn€ of additional investments.

5. THE PROCESS OF THE MASTER PLAN ELABORATION

The general process used by Med-TSO for coordinated planning is based on a consolidated procedure for the elaboration and assessment of a development plan of interconnection projects between the transmission systems of Med TSO countries, envisaged by the TSOs, with the aim to address the challenges of energy transition in the Mediterranean area.

To make such energy transition happen in a cost effective and secure way, this portfolio of interconnection projects is assessed for a range of possible energy futures, in terms of load and generation evolution, represented by the development of adequate long-term scenarios.

Setting the path from the present situation to the reference time horizon, those scenarios shall provide a robust framework for grid development studies, based on which the interconnection projects of the MMP shall be assessed, with the implementation of a technical-economical approach taking as input the results of Market and Network Studies.

Towards this goal, a "Methodology for the Long-term Network development Plan" includes the following main actions:

- Definition of Mediterranean scenarios;
- Definition of the list of future interconnection projects;
- Creating reference models of power system at regional level to perform market studies;
- Analyzing the network behavior (load flow calculations) and the investments needed to fulfil the security requirements;
- Performing the Cost Benefits Analysis (CBA) for the new investments.

5.1. Scenarios development investigating the energy landscape in the region on the 2030 horizon

These Med-TSO 2030 Reference scenarios explore possible future situations of load and generation, interacting with the Euro-Mediterranean Power system. The aim of these scenarios is to build the path from the present to several possible futures (trends on load and generation) to give a robust framework for grid development studies. The Euro-Mediterranean region is characterized by wide contrasts and complementarity in terms of load growth and of RES development.

Contrasts first of all in the dynamics of the evolution of electricity demand between countries which are experiencing regular growth of 4 to 5% per year, and others which have shown stability or even a decrease over the past ten years.

Contrast then in national energy and environmental policies and in the importance given to any regional regulation, the most comprehensive of which concerns European countries. If these disparities also affect the way the states address their commitment to the Paris Agreement, a form of convergence is found on the other hand in the massive development of renewable energies, mainly solar and wind, among all Mediterranean countries.

Finally, contrasts in the way of organizing electricity exchanges between countries, from a fully integrated and fluid market to other configurations that give priority to mutual assistance considerations, while the infrastructures themselves also offer very contrasting exchange possibilities. Needless to say, all of these questions involve such a level of uncertainty that it must itself be taken into account in the method and has led to the construction of three contrasting scenarios which are as many possible futures of the Mediterranean electricity system by 2030.

Which rationales for defining scenarios for the future of the Mediterranean power system

Globally speaking, the scenario definition and storylines building in the Mediterranean context shall be based on a series of parameters that constitute the main drivers of the scenarios: Renewable share, GDP & population, Transport (Electric vehicle and other electric public transport), Energy efficiency, storage, Energy prices, cooling and heating systems, market integration, policies & targets, Security of supply.

An overview of the Med-TSO scenarios' drivers is shown in Figure 2.

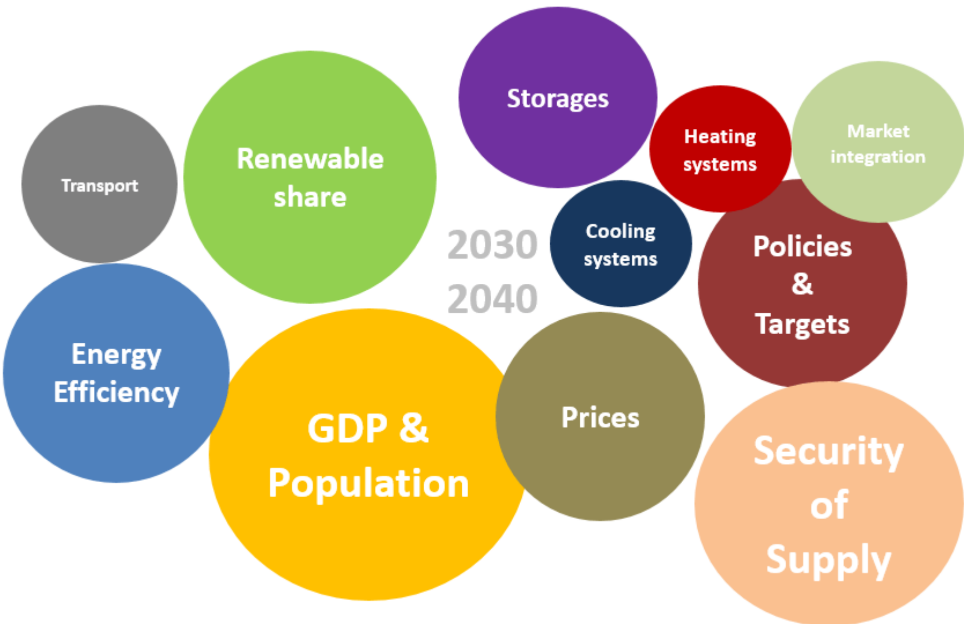

Figure 2. Overview of the Med-TSO scenarios' drivers

Naturally, these parameters are not completely independent from each others, and can be gathered in more coherent categories (sets). Med-TSO scenarios are defined with reference to five sets of drivers:

- Macro-Economic Trends (GDP growth, population growth, demand forecast, and primary resources price): these are used to assess the gross demand forecast; based on GDP trend, the consumption can be estimated.
- Regulation, Policies and Cooperation, Mediterranean integration (internal, regional or global market integration, policies and targets, security of supply, convergence on technology): the higher this driver is, the higher the network transfer capacity within Mediterranean area increases and performing technologies spread.
- Generation, RES development and GHG emission reduction (the main parameters are renewable share, prices, policies and political targets, and security of supply): it is used for the renewable energy generation share and the ambitions for GHG reduction.
- New demand and energy efficiency (main parameters are transport, energy efficiency, and cooling and heating systems, water de-salinization): New demand represents the extra load can be added to the conventional consumption trend.
- Technology development (storage, load management, demand response, smart grid): this driver is about flexibility; this driver can have effect in generation mix with the increase of storage facilities, and also load management; the storage should be considered as one solution to achieve the most ambitious RES targets.

Three scenarios proposed to address the Mediterranean power system in 2030

On the basis of these most essential parameters in the context of the Mediterranean electricity system, the three different long term scenarios are the subject of a first description intended to give the main principles, as following:

National Development scenario

The National Development (ND) is a storyline based on a positive yet conservative option for long-term economic growth and decarbonization in the Mediterranean region, accompanied by a moderate population growth. The extent of development of renewable energy generation corresponds to commitments already made plus already approved national energy policies. Energy efficiency, as well as electrification of other sectors present a limited development.

Green Development scenario

The Green Development (GD) storyline describes a Mediterranean region that benefits from a good development of macroeconomic trends. Emphasis is placed on the development of RES, especially with the construction of large generation facilities, but also with the development of decentralized generation and the growing role of prosumers. Efforts to improve energy efficiency focus on the residential sector and industry, resulting in the emergence of new uses of electricity.

Mediterranean Evolution scenario

The Mediterranean Evolution (ME) is a storyline that embraces a regional approach to the energy transition. It is based on a strong population growth, especially on the South and East coasts, accompanied by a dynamic economy based on a strong development of industrial sectors and services. The ambitions for the development of RESs and the reduction of GHGs are increased and can rely on regional cooperation and enhanced interconnection between countries. New uses of electricity are developing significantly, while at the same time efforts are being made to improve energy efficiency.

The Table 1 shows how the three most impacting drivers and their metrics are qualitatively defined and combined in storylines as building blocks of three contrasted scenarios with the aim of providing a wide spectrum within which the realistic future is expected to fall with high probability.

Drivers	Criteria	National Development	Green Development	Mediterranean Evolution
Macro-Economic Trends	**GDP/Population**	+	++	+++
New demand and energy efficiency	**Energy efficiency**	+	++	++
	New demand	+	++	+++
Generation, RES development and GHG emission reduction	**RES/GHG reduction target achieved**	++	+++	+++

Table 1. Med-TSO scenarios' drivers settings

Where the legend is:

Legend	2030 compared to today
+	Low growth
+ +	Moderate growth
+ + +	High growth

It is important to note that the three Med-TSO long-term scenarios do not aspire to give a forecast of the future, nor is there any quantification of probability associated to any of the scenarios. The scenarios do not intend to show that future shall be alike, but rather to give a wide spectrum within which the realistic future will fall.

The need for a set of common technical parameters and principles

In addition to the scenario description through drivers and storylines, the coherency on market studies is ensured with the determination of a common set of technical and economical parameters and principles:

- The principle of an efficient day-ahead market, i.e. in which electricity exchanges will go from one less expensive price zone to another more expensive price zone, independently for each hour of the day.
- The principle of equal fossil fuel wholesale prices across all Euro-Mediterranean countries. While several countries in the region are or plan to become producers and exporters of natural gas, sales mechanisms at regulated prices may exist within such countries (generally a low price that benefits the residential consumers), which can be qualified as subsidies. However, thanks to the adopted principle of equality in fuel prices, the competition between thermal power plants, and therefore the international electricity exchanges which result from it, are based solely on the type of fuel and on the technical performance (efficiency) of each plant. Indeed, correct economic assessment must consider the opportunity cost of the fuels, which correspond to international market prices where they exist, as it is the case for oil and gas products.
- The principle of an economic value for CO2 emissions resulting from the electricity generation, common to all Mediterranean countries, which ensures, despite the absence of a shared regulation, the integrity of regional mechanisms for controlling greenhouse gases emissions.

Finally, the last step that makes it possible to ensure the overall consistency of the scenarios, is to take into account the countries which are not members of Med-TSO and which are directly or indirectly connected to compose the Euro-Mediterranean power system. In practice, this involves on one hand the coordination with the TYNDP2020 scenarios of ENTSOs, and on the other hand the exchange assumptions in the eastern Mediterranean between Jordan, Egypt and the GCCIA member countries.

How are Med-TSO scenarios linked with other available scenarios

Power system modelling aims to represent all the interconnected countries. For the Euro-Mediterranean Power system, there is therefore a key issue in retaining assumptions for all countries in the perimeter of ENTSO-E, for each of the three scenarios. This consistency is facilitated because the scenario building methodology used by Med-TSO is similar to the one adopted in ENTSO-E, in particular for the scenarios proposed to be used for Ten-Year Network Development Plan (TYNDP 2020)[3].

Then the principle is to examine to what extent these drivers coincide and to proceed with the coupling of the scenarios, favoring as much as possible the coherence of the drivers.

[3] https://www.entsos-tyndp2020-scenarios.eu/

The comparison of the choice of drivers shows that, because of the different economic and energy contexts between the European countries and the Mediterranean countries, the following three common drivers are the most relevant for matching the scenarios:

- The total demand trend (also considering the development of new usages for electricity)
- The development of renewable generation (mostly solar and wind)
- The option for RES development in terms of centralized vs. distributed, and the growing role of the prosumers.

Following this driver-based method, the matching of Med-TSO scenario with the most similar one of ENTSO-E scenarios for European countries is as follows in Table 2.

Med-TSO **Mediterranean Scenarios**	**ENTSO-E** **TYNDP2020 Scenarios**
National Development	National Trends
Green Development	Distributed Energy
Mediterranean Evolution	Global Ambition

Table 2. Adopted matching for Med-TSO and ENTSO-E TYNDP2020 scenarios

The scenarios presented in this report were built collectively by the members of Med-TSO on the basis of the context and the prospects for the evolution of electricity systems in Mediterranean countries. Assuming this common framework, the data collection is performed following a bottom-up approach for the three scenarios.

For European countries, data collection was carried out according to the principle described in chapter 3.3, i.e., through the construction of the TYNDP2020 scenarios of ENTSO-E. As the data exchange between Med-TSO and ENTSO-e took place in early 2020, some minor differences may exist between the final versions of the scenarios of the two associations, resulting from changes made after the data-sharing step.

The following Mediterranean countries have not directly contributed to the data collection: Egypt, Israel, Syria and Lebanon. For these countries, the detailed data were set up based on public documents, for the three scenarios, while respecting their definition. Thus, it is expected that the lack of a direct contribution for these countries does not weaken the quality and accuracy of the scenarios as a whole.

How to address the value of CO_2 emissions in the Mediterranean region for the purpose of the Power System modelling

The economic value of CO2 is an important parameter for forming the variable generation price of thermal power plants. The setting of this parameter at the scale of all Euro-Mediterranean countries presently reveals contrasting contexts of regulation. While many non-European countries have not set up a mechanism for setting the price of CO2 emissions, Med-TSO has made a strong choice to adopt a common CO2 value for all the interconnected countries in the 2030 horizon.

This choice does not require that each member country of Med-TSO, and even more generally any country connected to the Euro-Mediterranean power system, is integrated into any CO2 market mechanism leading to the formation of a common CO2 price, which would be binding on all electricity producers.

On the other hand, this choice assumes that any exchange of electricity between the interconnected countries must ensure that generation-induced CO2 emissions have a similar socio-economic value, leading to not favoring one plant over another because of a distortion on the CO2 emissions regulation.

Firstly, conceived as a means of evaluating electricity exchanges between Mediterranean countries in a context of a fair and undistorted market, this strong choice is supported by the Carbon Border Adjustment Mechanism project. The European Green Deal adopted by the Commission on 11 December 2019 includes the goal of enshrining the long-term objective of climate neutrality by 2050 in legislation and increasing the EU's climate ambition to reduce greenhouse gases emissions by 50-55% from 1990 levels by 2030. In this context, the European Green Deal emphasized that "should differences in levels of ambition worldwide persist, as the EU increases its climate ambition, the Commission will propose a carbon border adjustment mechanism, for selected sectors, to reduce the risk of carbon leakage".

While fuel prices are common to all three scenarios, the choice of the CO2 value offers an opportunity to differentiate from a reference value, 28 €/tCO2, common to the PRIMES EUCO2030 and WEO2018 models for the 2030 horizon.

Concerning the assumption of ensuring coordination with the TYNDP2020 scenario building, ENTSO-E decide to adopt the 28 €/tCO2 price for the National Trend scenario, which is matched with the National Development scenario of Med-TSO (cf. chapter 3.3).

However, this price level is considered too low in the context of European countries to reach the environmental objectives associated with TYNDP's Distributed Energy and Global Ambition scenarios for the 2030 horizon. The high value adopted for DE2030 and GA2030 scenarios is respectively 53€ and 35 € per ton CO2.

For the Med-TSO scenario building, the choice of the CO2 price not only addresses a value compatible with the fulfilment of an emissions cap target, but it also addresses the regulation and mechanisms for price setting and regional regulation convergence. The important contrasts that currently exist among the countries of the Mediterranean basin must not be neglected, nor the path to achieve an integrated, or at least compatible CO2 regulatory framework.

This issue is explicitly addressed in the definition of Med-TSO scenarios, especially in Mediterranean Evolution scenario, which states the following concerning Regulation, Policies and Cooperation, Mediterranean Integration: "The regulation on GHG reduction should go beyond the already established targets. For this purpose, a regional emission trading mechanism is foreseen".

Thus, the definition of the Mediterranean Evolution scenario is in favor of the adoption of a CO2 price common to all countries of the Euro-Mediterranean power system, considering a value that should be favorable to achieving the highest ambitions for the development of renewable energies.

The following Table 3 presents the set of CO_2 prices for the three Med-TSO scenarios:

Scenario	National Development (matched with TYNDP2020 NT2030)	Green Development (matched with TYNDP2020 DE2030)	Mediterranean Evolution (matched with TYNDP2020 GA2030)
CO2 price for UE-regulated countries	28 €/t CO2	53 €/t CO2	35 €/t CO2
CO2 price for non UE-regulated countries	28 €/t CO2	28 €/t CO2	35 €/t CO2

Table 3. CO_2 prices for Med-TSO scenarios

With this choice, it is assumed in the Green Development scenario the coexistence of two different CO2 values within the interconnected countries, with the reference price coming from the WEO2018 and PRIMES EUCO2030 models for non-European countries, and a higher price, 53 € per ton, for the countries concerned by the European regulation.

Variable generation costs adopted by Med-TSO for modelling the Euro-Mediterranean power system

Table 4 presents the summary of fuel value for the three Med-TSO scenarios:

		Med-TSO Mediterranean Projet 2		
2030		National Development	Green Development	Mediterranean Evolution
Fuel prices (€/net GJ)	Nuclear	0.47	0.47	0.47
	Lignite	1.1	1.1	1.1
	Steam coal	4.30	4.30	4.30
	Gas	6.91	6.91	6.91
	Light oil	20.51	20.51	20.51
	Heavy oil	14.63	14.63	14.63
	Oil shale	2.3	2.3	2.3

Table 4. Summary of the fuel prices for Med-TSO scenarios

Considering the sets of fuel prices and CO_2 prices, the unit commitment of each thermal generation is depending on its variable generation cost (in € per MWh) and starting cost (in € per startup).

The following Table 5 presents the variable generation cost of some of the most common technologies for the three Med-TSO scenarios:

		Variable Generation Cost (€/MWh)			
		National Development	Green Development		Mediterranean Evolution
Fuel	Type (efficiency range)		Non-European countries	European countries	
Nuclear	NPP	14.1	14.1	14.1	14.1
Lignite	Steam turbine (30% - 37%)	43.7	43.7	69.7	51.0
Gas	Combined Cycle New (53% - 60%)	54.4	54.4	63.2	56.9
Gas	Combined Cycle Old (45% - 52%)	65.4	65.4	76.1	68.4
Hard Coal	Steam turbine (38% - 43%)	65.7	65.7	86.8	71.6
Gas	Open cycle (39% - 44%)	74.5	74.5	86.7	77.9
Gas	Steam turbine (39% - 42%)	75.8	75.8	88.3	79.3
Heavy oil	Steam turbine (25% - 37%)	176.2	176.2	196.3	181.8

Table 5. Variable generation cost for the three Med-TSO scenarios

The prices used for fuels and CO2 lead to very similar variable generation costs between coal and gas plants. Very close prices between gas and coal-based generation tend to reduce the benefit assessment of interconnection projects, given that it would be based on a competition between plants based on these two fuel types.

More specifically, the main difference lies in the performance of the plants, with very significant differences in efficiency for a given fuel between old and more recent facilities.

In a context where the long-term relative evolution between gas and coal price is uncertain, as evidenced by the price dispersion in the two sources of information considered (WEO 2018 and EUCO2030), it seems appropriate that the new interconnection projects impact assessment relies less on the relative fuel price and more on the performance of the generation facilities. This means that, in a context of strong development of renewable energies, most of the valorization of interconnection projects corresponds to the competition between very different generation types: renewable energies, nuclear, recent thermal power stations, and finally old (and lower efficiency) thermal power plants.

5.2. Envisaged investment clusters proposed by TSOs, their rationale and maturity level.

The actual Mediterranean electrical system presents, in one hand, a wide variety of available resources dedicated to the electricity generation, and in the other hand some limited transfer capacity due to the heterogeneity of regulations and the lack of a fully integrated market covering the whole area. This may lead to the fact that several bottlenecks have been detected as it is the situation in the south-western region with an incomplete backbone of 400 kV lines going from Morocco to Tunisia and extended to Libya under several 225 kV overhead lines which are not fully operated.

Covering a very wide area of more than 5000 km from Portugal to Turkey, a detailed analysis of the Mediterranean electrical system, as shown in the Deliverable 2.2.1: “Description of the Reference Energy Scenarios” of the actual Mediterranean Project showed a great potential of electrical exchanges that still untapped and highlighted several complementarities between the interconnected electrical systems related to the differences in terms of load and renewable generation profiles due to the seasonal effect but also the time shifting and the difference in working days between the countries.

Those aspects are part of the non-exhaustive list of what we called projects merits, given in the following table, and showing the most relevant needs of the Mediterranean electricity system that the actual Mediterranean Project helps to solve.

Table 6 describes the projects’ merits categories as well as associated with System needs. Besides, symbols are introduced which will be used in the assessment later.

Category	Project Merits	Associated system NEEDS	Symbol
Market	Reduce high price differentials between different market nodes and/or countries	Power studies at 2030-time horizon can highlight significant differences in average marginal prices between countries, groups of countries or bidding zones. These differences are generally the consequence of structural differences in the composition of production fleets. The increase in the exchange capacity between these zones allows an economic optimization of the use of the generation plants and will be accompanied by electricity flow massively oriented in one direction, from the lower price country to the higher price's country, then reducing the price differential.	
Dispatch, Adequacy and Security of Supply	Positively contribute to the integration of renewables	Infrastructure to mitigate RES curtailment and to improve accommodation of flows resulting from RES geographic spreading.	
	Contribute to solving adequacy and security of supply issues	Infrastructure that presents a benefit for the security of supply or system adequacy, in general by allowing additional importation at peak hours, in countries and areas presenting current of future risk of deficiencies	
Operation	Fully or partially contribute to resolving the isolation of countries in terms of power system connectivity or to meeting specific interconnection targets	Infrastructure to connect island systems or to improve exchange capacity of countries showing low level of connectivity	
	Introduce additional System Restoration mechanisms	Infrastructure that could provide capability for Black Start & Islanding Operation thus decreasing the need for generation units with such capabilities	
	Improve system flexibility and stability	In countries were expected changes in the generation fleet may raise concerns in those specific issues. Infrastructure to improve system flexibility and stability, by increasing sharing possibilities. Decreasing levels of dispatchable generation can be compensated by infrastructure and/or market design to provide balancing flexibility at cross-border level (international pooling / sharing of reserves, coordinated development of reserve capacity). The large increase in penetration of asynchronous renewable generation is leading to Higher Rate of Change of Frequency (RoCoF) on the system, creating transient stability issues and causing voltage dips. This can be compensated through infrastructure designed to contain frequency during system events.	
	Increase system voltage stability	Reactive power controllability of converters can be used to increase system voltage stability	
	Enable cross-border flows to overcome internal grid congestions	Infrastructure to facilitate future scenarios and enable cross border flows, accommodating new power flow patterns, overcoming internal grid congestions	
	Mitigate loop flows in bordering systems	Infrastructure to mitigate the loop flows occurrence in the borders between Mediterranean countries, contributing to exchange capacity improvement.	
	Contribute to the flexibility of the power systems through the control of power flows	Contribution to flexibility of power system operation by controlling power flows and optimizing usage of existing infrastructure	

Table 6. Project merits categories and description

For these reasons, in the beginning of the actual Master plan, members proposed a list of 15 projects to be studied, assessed and analyzed. Below Table 7 presents the list of the 15 proposed projects within the actual version of the Master Plan.

NO.	INTERCONNECTION PROJECT / CLUSTER	Nominal Capacity [MW]
1	MA-PT (Morocco – Portugal)	1000 MW
2	ES – MA (Spain – Morocco)	900 MW
3	DZ- ES (Algeria – Spain)	1000 MW
4	IT – TN (Italy – Tunisia)	600 MW
5	DZ – TN – LY (Algeria – Tunisia - Libya)	1000 MW/2000 MW
6	EG – TR (Egypt – Turkey)	3000 MW
7	IL – TR (Israel – Turkey)	2000 MW
8	EG – JO (Egypt – Jordan)	550 MW
9	JO – SY (Jordan – Syria)	800 MW
10	SY – TR (Syria – Turkey)	600 MW
11	BG – TR – GR (Bulgaria – Turkey – Greece)	500 MW/500MW
12	GR - CY- IL (Greece – Cyprus – Israel)	1000MW/1000 MW
13	CY – EG (Cyprus – Egypt) in addition to Project 12	1000MW
14	JO – PS (Jordan – Palestine)	100 MW
15	DZ- IT (Algeria – Italy)	1000 MW

Table 7. Interconnection projects studied at MP2

5.3. Market studies assessing the benefits of the different investment clusters and the exchanges within the area

Scenario building process provides for Med-TSO members a common framework aiming to quantify national assumptions for the load and the Generation fleet, for each Med-TSO 2030 scenario. Because of the development of renewable energy and considering all the hazard impacting the load and generation fleet, market studies are strongly designed in a probabilistic approach, focusing on the weather conditions impacts (wind, temperature, insulation, etc.) and using available weather data base.

The market model is based on an economic optimization of the overall generation cost of the full Euro-Mediterranean Power system, not considering the network except international interconnection exchange capacities, but also internal constraint if relevant.

Based on the scenario's definition, Med-TSO members have performed a data collection in order to build a set of three market models. A model is an equivalent bus-bar without the detail of the transmission grid; the models of the load and the generation (thermal power plants, not dispatchable productions such as other non-RES and RES generators, run of river units and hydro pumping power plants, wind farms and photovoltaic power plants) are specified.

Every country has a defined Bilateral Transfer Capacities (BTC) with interconnected neighboring countries that helps to guarantee the security of the electricity supply power system and allows economic exchanges of electricity. Med-TSO BTCs for year 2030 have been addressed by Med-TSO members, while TYNDP 2020 data have been used for BTCs between ENTSO-E non-Mediterranean countries.

The study is accomplished through the application of a Monte Carlo simulation model on a Mediterranean/European wide basis. The Market Studies software tool carries out an optimal coordinated hydrothermal scheduling of the modelled electric system generation set, over a period of one year. The simulation tool implements a day-ahead energy market, characterized by a system marginal cost and by a congestion management based on a zonal market-splitting.

The market simulator used in the scope this study by Med-TSO members is ANTARES, a sequential 'Monte-Carlo' multi-area simulator developed by RTE, the French TSO, whose purpose is to assess generation adequacy problems and economic efficiency issues. This power system analysis software is characterized by these following specifications:

- Representation of several interconnected power systems through simplified equivalent models. The European electrical network can be modelled with up to a few hundred of region-sized or country-sized nodes, tied together by links whose characteristics summarize those of the underlying physical components;
- Sequential simulation with a time span of one year and a time resolution of one hour;
- 8760 hourly time series based on historical time series or on stochastic ANTARES generated time-series;

- For hydro power, a definition of local heuristic water management strategies at monthly and annual scales;
- A daily or weekly economic optimization with hourly resolution.

The implementation of Market model makes it possible to obtain a global and detailed vision of the Mediterranean power system behavior for each of the scenarios through a large number of indicators and physical quantities, at hourly time steps, and on average over one year: power and energy produced by each type of generation plant for each country, border exchanges, marginal production price, national balance, unsupplied energy expectation, RES curtailment, CO_2 emissions.

It is with the same market studies that Med-TSO carries out the Cost Benefit Analysis (CBA) of the projects. The CBA methodology[4] has been developed by Med-TSO as adaptation of the same proposal submitted to ACER by ENTSO-E in July 2016 and compliant with the Regulation (EU) 347/2013 on guidelines for trans-European energy infrastructure.

The CBA methodology is developed to evaluate the benefits and costs of new interconnection projects from a Mediterranean perspective, providing important input for the assessment of the interconnection projects considered in the Mediterranean Region. The main objective of this CBA methodology is to provide a common and uniform basis for the assessment of these projects.

The cost-benefit impact assessment criteria adopted reflect each project's added value for society. Hence, economic and social viability are displayed in terms of increased capacity for exchange of energy and balancing services between market areas (market integration), sustainability (RES integration, CO_2 emissions variation) and security of supply (secure system operation). The indicators also reflect the effects of the project in terms of costs and environmental viability. They are calculated through an iteration of market and network studies. It should be noted that some benefits are partly or fully internalized within other benefits, such as avoided CO_2 and RES integration via socio-economic welfare, while others remain completely non-monetized.

This set of common indicators forms a complete and solid basis for project assessment across the Mediterranean area within the scope of the Mediterranean Project. The multi-criteria approach highlights the characteristics of a project and gives sufficient information to the decision makers as presented in Figure 3.

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[4] Source: Med-TSO Mediterranean Project 1 – Deliverable 2.2.3 Proposal of a CBA Methodology for transmission projects assessment.

https://www.med-tso.com/publications/Deliverable_2.2.3_Proposal_of_a_CBA_Methodology_for_transmission_projects_assessment.pdf

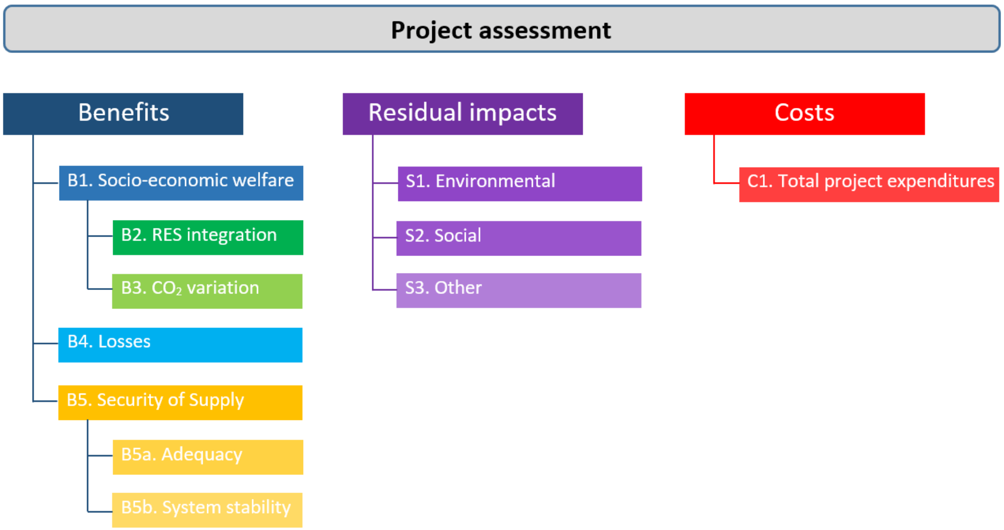


Figure 3. Cost Benefit Assessment indicators

The main benefit indicators assessed in Med-TSO studies are defined as follows:

B1. **Socio-economic welfare** (SEW) or market integration is characterized by the ability of a project to reduce congestion. It thus provides an increase in transmission capacity that makes it possible to increase commercial exchanges, so that electricity markets can trade power in a more economically efficient manner.

B2. **RES integration**: Support to RES integration is defined as the ability of the system to allow the connection of new RES plants and unlock existing and future "green" generation, while minimizing curtailments. Although this indicator is economically accounted for in the calculation of SEW (a variation of the RES integration will result in a variation of the energy from conventional sources and thus affect the system costs.), the RES integration is one key target in the Mediterranean region and is therefore displayed separately.

B3. **Variation in CO_2 emissions** is the characterization of the evolution of CO2 emissions in the power system due to the new project. It is a consequence of B1 and B2 (the unlocking of generation with lower carbon content). Although this indicator is economically accounted for in the calculation of SEW (a variation of the CO_2 emission and the resulting change in emission costs will affect the system costs), the CO_2 indicator is one key targets in the Mediterranean region and is therefore displayed separately.

B4. **Variation in losses** in the transmission grid is the characterization of the evolution of energy losses in the power system due to the new project. It is an indicator of energy efficiency.

B5. **Security of supply**: Adequacy to meet demand characterizes the project's impact on the ability of a power system to provide an adequate supply of electricity to meet demand over an extended period of time. Variability of climatic effects on demand and renewable energy sources production is taken into account.

5.4. Networks Studies

The purpose of the Network Studies is to assess the security of operation of the interconnected Mediterranean network, including all Med-TSO countries and ENTSO-E perimeter, at the target year 2030 with three contrasting scenarios to evaluate the effect of several different interconnection clusters on the exchanges among countries.

There are several stages to the planning process based on:

- The time-frame for decisions (e.g. the implementation time for the construction of lines differs from that for reactive power compensation measures)
- The detailed nature of analysis:
  - Technical-economic pre-feasibility
  - Feasibility
  - Work plans

The present study is focused on a long term horizon (2030) where the purpose is the selection of the most attractive alternatives (investment clusters selection, voltage level definition, sizing) starting from a load forecasting and a generation expansion plan provided from each involved countries.

The level of details of the analyses performed in order to assess the Transmission network planning is adequate to the objective of the screening of different investment alternatives and includes:

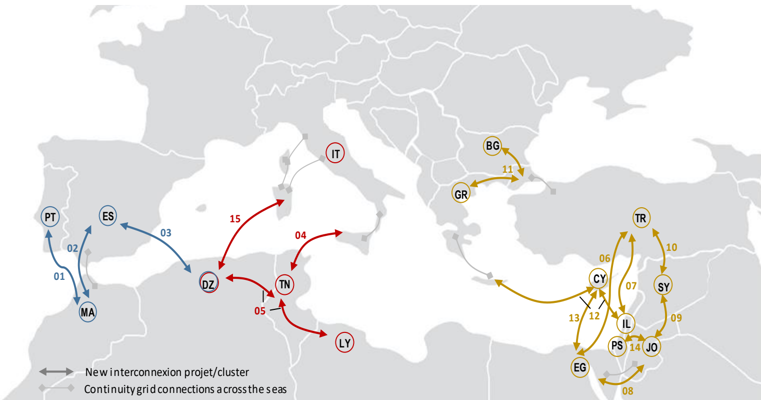
- **Market analyses** to evaluate the economic profitability of an interconnection cluster not considering a network detail but only a market area approach where generation and load are connected to a single bus bar equivalent; a whole year of operation is analysed with an hourly detail
- **Load flow** to verify the consistency of the interconnection clusters with possible network constraints; planned reinforcements of current network should be considered in accordance with the year horizon and additional reinforcements could be evaluated to allow system functioning foreseen from Market studies
  It is possible to have Load Flow with AC (Alternate Current) or DC (Direct current) detail:
  - *AC Load Flow* includes a complete analysis of active and reactive power flows over the network together with the evaluation of voltage profile,
  - *DC Load Flow* is instead a simplified methodology focusing only on active power flows to obtain a quick solution

The above-mentioned analyses enable a comparison between economic benefits of an investments (in terms of the overall electrical system) and its costs (considering possible additional network reinforcements needed).

The present study is articulated in different steps:

- collection of National grid models data and Med-TSO documentation on planning methodology, in the framework of the present study few countries interested in a new interconnection have not provided network detail (Libya, Egypt, Israel, Syria, Palestine) and an equivalent derived from Market Studies has been adopted;
- building of the reference network model of the interconnected Mediterranean system;
- selection of significant Point In Time (PIT) from the hourly analysis of Market Study to obtain demand and generation figures to be applied in the analysis of interconnection clusters; a Point in Time in the analysis, represents, in fact, one single hour from the electricity market simulation with specific characteristics in terms of load, generation and import/export of electricity with neighboring countries.
- execution of AC load flow calculations, with the aim to assess the fulfillment of security criteria, both in normal situations and in cases of disturbances;
- assessment of possible internal reinforcements to allow a safe operation of the network in presence of the new interconnections;
- evaluation of system losses for each hour of the year, with a simplified DC load flow, to monetize a possible variation of the losses in presence of a new interconnection;
- comparison of calculated benefits associated to interconnection clusters to all the costs associated to each studied interconnection.

The perimeter of the network studies includes all Med-TSO countries, the network detail has been considered for the market area directly involved in an interconnection cluster (Figure 4), but in case of missing data for countries included in the study perimeter an equivalent has been implemented considering market data detail in order to obtain the level of exchanges derived from Market studies.



NO.	INTERCONNECTION PROJECT / CLUSTER	Capacity [MW]
1	MA-PT (Morocco – Portugal)	1000 MW
2	MA – ES (Morocco – Spain)	900 MW
3	DZ- ES (Algeria – Spain)	1000 MW
4	TN – IT (Tunisia - Italy)	600 MW
5	DZ – TN – LY (Algeria – Tunisia - Libya)	1000 MW/2000 MW
6	TR – EG (Turkey - Egypt)	3000 MW
7	TR – IL (Turkey – Israel)	2000 MW
8	EG – JO (Egypt – Jordan)	550 MW
9	JO – SY (Jordan – Syria)	800 MW
10	SY – TR (Syria – Turkey)	600 MW
11	GR- TR – BG (Greece - Turkey - Bulgaria)	500 MW/500MW
12	IL- CY- GR (Israel – Cyprus – Greece)	1000MW/1000 MW
13	EG- CY (Egypt – Cyprus), joint with project 12	1000 MW
14	JO – PS (Jordan – Palestine)	100 MW
15	DZ- IT (Algeria – Italy)	1000 MW

Figure 4. Clusters definition

5.4.1. PIT Selection process

AC load flow analyses requires time to analyze network detail and it is not possible to perform it for all hourly results of the Market Studies, it is therefore necessary to operate a selection of significant Point In Time to verify possible network constraints.

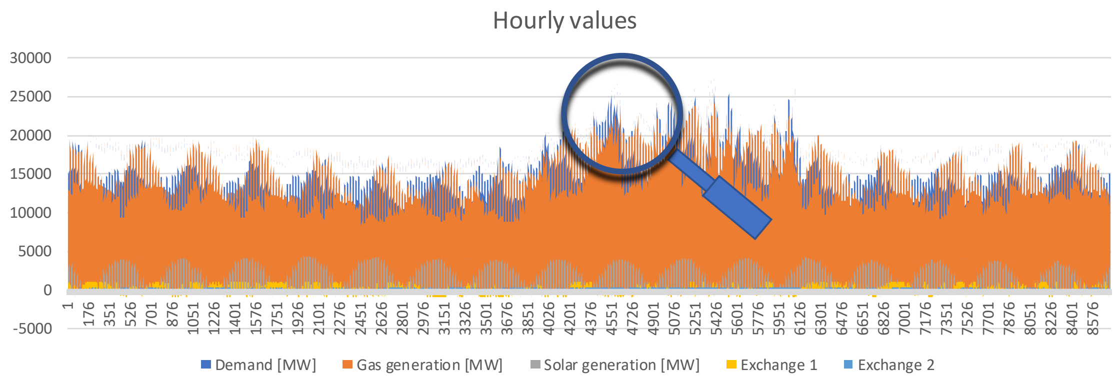


Figure 5. Selection of a PIT starting from hourly results of Market studies

PITs definition is crucial to verify a wide variety of dispatching conditions that may result stressful for the network and in particular for the interconnection clusters under analysis.

Med-TSO Market Study has covered 3 economic scenarios for the target year 2030 and 15 clusters analyzed; the total number of PITs is equal to 126: 8-9 snapshot per clusters.

The selected PITs should be significant to understand the possibility of the network to manage different dispatching and load situations in safe network conditions or under contingencies with AC load-flow calculations.

The CBA methodology includes also losses evaluation (not available from the Market Studies), but they will be calculated for each single hour of the year using a DC load-flow and therefore it is not necessary to save some PITs dedicated only to significant hours for losses evaluation (e.g. night hours with low demand).

To define the distribution of PITs among different scenarios and clusters an initial screening has been done focusing on: exchanges, demand, balance, production from RES, conventional production. For each scenario and project, the analysis performed includes:

- analysis of possible correlation among variables listed above
- distribution of variables values during the year subdivided by range
- duration curve for exchanges
- radar chart with the values of main variables in a number of significant PITs during the year to examine the relative values of the variables for a single data point (PIT) and to locate similar points or dissimilar points
- histogram graphs representing in detail each PIT of the data chart.

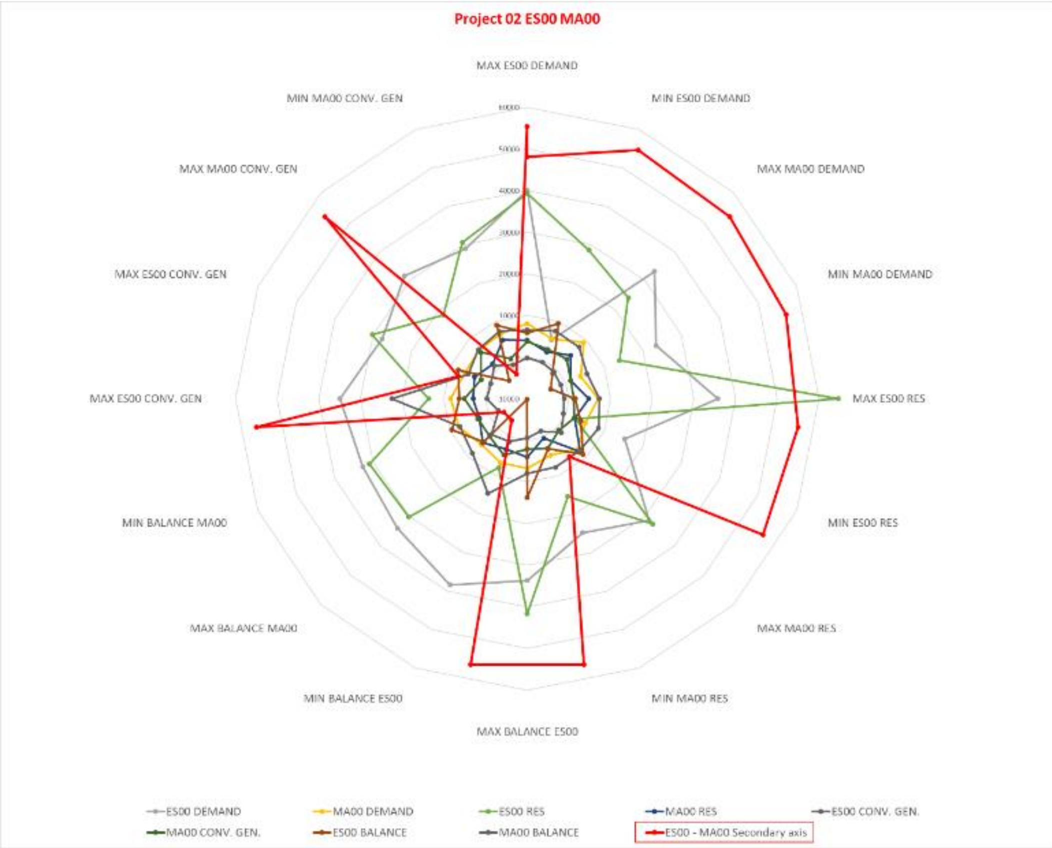


Figure 6. Radar chart with the values of main variables in a number of significant PITs

After this preliminary screening each TSO has provided indication regarding the most significant criteria to be applied for each cluster.

An automatic procedure has been developed to transfer PITs data from market analyses to the reference network model previously obtained (Figure 4)..

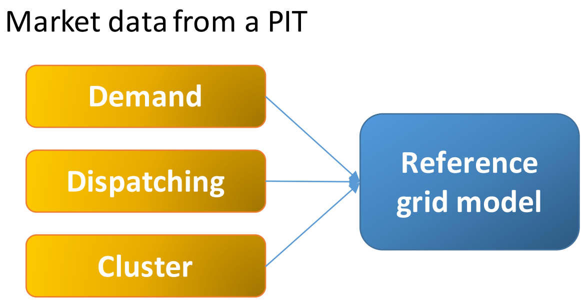


Figure 7. Data transfer from Market results and network

To operate the matching, it is necessary to have an alignment between market and network data and to consider possible constraints (must run, merit order strategy).

It should be clear that Market analysis are carried out with equivalent bus-bar model representing a country where all generation and demand is concentrated in a single node connected to other countries by an interconnection capacity: the power flows calculated in these conditions are normally named as commercial/economic flows different from physical ones, that are obtained applying load-flow analysis on a real electric network. This mean that applying PIT to the reference model the respect of the balance of each country should be the same of the Market study (neglecting losses that load-flow analysis should consider) while the distribution of the exchanges on the borders in a meshed system may be different from the ones obtained in Market simulations (this effect can be reduced for the mainly radial interconnection system that characterize north Africa and from the presence of active elements such as HVDC).

Market and Network studies are normally focused on different level of detail, in accordance to their objective, in table below it is highlighted the different detail in network representation and contemporary the different number of snapshot examined from the two approaches (example derived from ENTSO-E perimeter).

Consistency	Market	Network
NODES	56	19599
TRANSFORMERS	0	9683
LINES	270	19454
STATIONS	0	8740
GENERATORS	21129	
LOADS	56	10258
Number of hours	8760 hours for Climatic years (35) x Monte Carlo sampling (100)	PiT selection (e.g. 126)

Table 8. Differences between Market and Network studies in numbers

5.4.2. Load Flow Analysis in normal situations (N) and in cases of contingencies (N-1 or N-2).

Load-flow studies compute the power flows and the bus voltages in an assigned electric system subject to the regulating capability of generators, reactive power sources, and on load tap-changer transformers. Moreover, the net interchange between individually operating systems is determined.

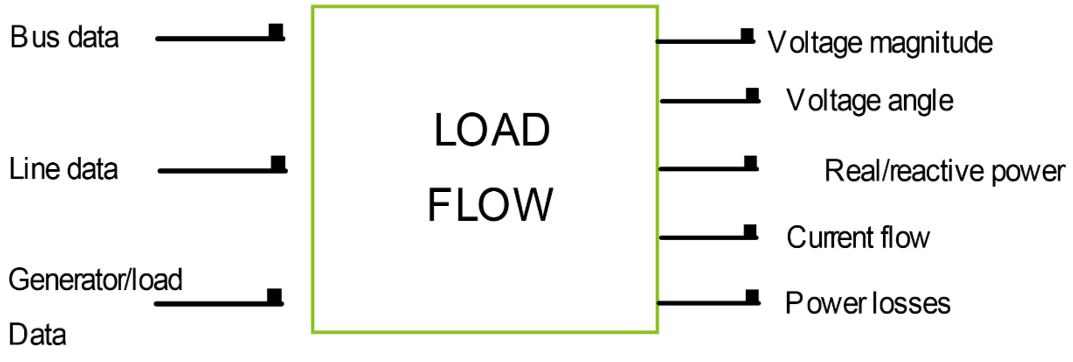


Figure 8 Load flow input & output

A simple parallel can be made with water flow in a meshed pipelines with different inflow (generators) and outflow (load), a load flow describes how the water flow is distributed in the pipeline helping to detect if is there any problem in water distribution (e.g. overloads).

Load flow output is essential for the evaluation of the current performance of a power system in operation studies, and for analyzing the effectiveness of alternative plans for system expansion to meet increased load demand.

The load-flow solution consists of the knowledge of all the electrical quantities in each bus of the system, or, at least, the knowledge of a set of state variables, from which all the others can be easily derived.

These analyses require the calculation of considerable numbers of load-flow cases for both normal and emergency operating conditions. Considering that the network includes a certain number of lines and transformers (N), N-1 and N-2 criteria are defined to verify the ability of the system to operate even facing the lack of one element (N-1) or two elements together (N-2).

The ability of a system to face N-1 or N-2 conditions depends from the soundness of the system and from the faulted elements, figures below highlight how two different systems (simplified as a plan in equilibrium over 4 legs with different spacing among them) may become unstable without one element or two, or remain stable depending on the elements selected and their spatial distribution. A similar behavior can be observed in an electric network where the lack of one element can be easily faced in a well meshed network while it is not sustainable in weaker part of the system.

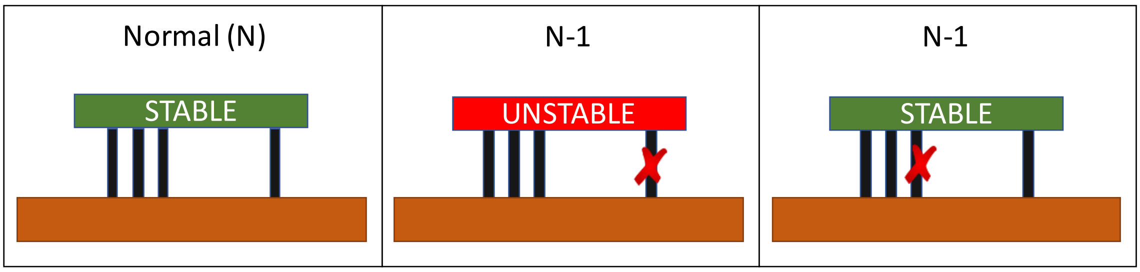


Figure 9 Simplified example of N-1 application

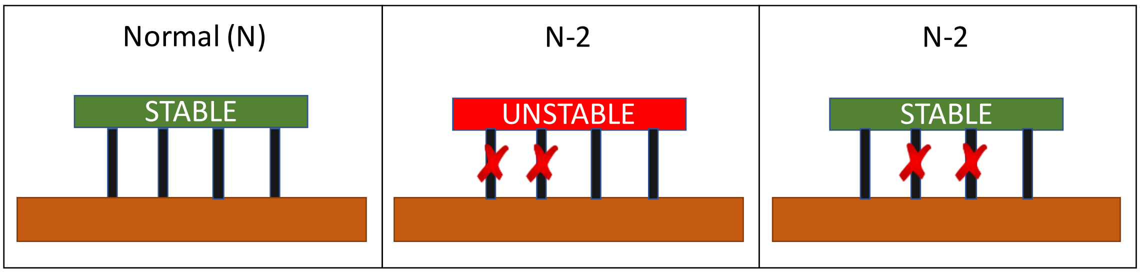


Figure 10. Simplified example of N-2 application

Network simulations aim at:

- Evaluating the adequacy of the interconnected Mediterranean network by assessing its ability to transfer the bulk power flows resulting from the economic studies while ensuring the secure operation of the system;
- Identifying possible criticalities related to the interconnections and the internal grids, in terms of bottlenecks and voltage issues;
- Assessing the need of internal reinforcements due to the new interconnections.
- For each selected snapshot, the following analyses will be conducted with and without the cluster:
  - Full AC load flow analysis to identify overloads of transmission elements and violations of voltage limits in normal conditions;
  - Static security analysis (N-1 and N-2 where applicable) to identify violations of security criteria.

A description of the security criteria includes:

- acceptable voltage range in normal and contingency situations (i.e. ±5% in normal and ±10% in contingency or in general for generation buses)
- threshold for admissible overloads of network elements (i.e. 20% for lines,5-10% for transformers)
- contingency criterion (N-1, identification of N-2, loss of a substation, remedial actions, ..)

Security criteria requires the network to be planned and operated to withstand at any moment in time the loss of one or more production unit or element of the transmission network.

The security analysis will consider N-1 contingency conditions, whereas N-2 conditions will be taken into account if required by the practice of a Country.

The resulting overloads of lines, cables, transformers and three winding transformers, as well as voltage variations at nodes, will be analysed against the contingency operation criteria applied from Med-TSO countries.

The static security analysis allows the identification of limitations of the power flows due to grid constraints, with respect to the bulk power flows calculated in the framework of the Market Studies.

Considering that most of the clusters are HVDC, the technology selected will be considered in order to define possible additional analysis to verify the strength of the network in presence of HVDC devices.

5.4.3. Optimal Reactive Power Flow (ORPF)

Market study results provide an economic dispatching of active power all over the network to meet the demand respecting exchange capacities among market areas.

In order to obtain a network model with an acceptable voltage profile in the country, it is necessary to optimize transformer tap positions and the reactive power output of generation units, STATCOM, static VAr compensators (SVC), and capacitor banks through an ORPF algorithm is fundamental for simulating a realistic operating point of the interconnected network.

Simulating a large non-optimized interconnected power system will result in high reactive power flows across the AC interconnections and the internal networks, eventually producing violations of the operational criteria that are not representative of a realistic operation of the future interconnected network. In addition, maximizing the reactive power margins of the generating units and the SVC improves the security of the system by increasing its stability margin.

For these reasons, an ORPF algorithm is run to obtain a realistic operating point of the reference network, enabling the identification of investments required for steady state reactive compensation such as shunt capacitor banks or shunt reactance.

Generally, common constraints adopted for network studies are the following:

- Voltage limits;
- Generators should operate within their reactive power limits;
- The SVCs and synchronous compensators should operate within their reactive power limits;

These first results might highlight limitations of the transfer capacity across borders and provide an initial indication on internal reinforcements needed. System losses are also an output of the simulation. These results will be refined in the static security analysis.

5.4.4. Assessment of the reinforcements required by evaluating the performance of plans produced according the technical and economic criteria

Starting from the results of previous analysis possible need of internal network reinforcements to cope with operational security constraints will be identified.

The proposed reinforcements should consider all the snapshots analysed for the cluster and the interaction with other clusters: the aim is to define the minimum set of reinforcement to solve possible security problems minimizing the cost for the system.

Some reinforcements could be not necessary in all the scenarios: in order to get a better evaluation of the costs of the project, each scenario will consider the reinforcements strictly needed (e.g. Scenario 1 needs reinforcements A and B, Scenario 2 needs only reinforcement A: reinforcement B will not be considered in Scenario 2).
Some reinforcements could be not necessary in all the PiT (same scenario): in order to guarantee the security of supply, all the reinforcements will be considered in each PiT (e.g. PiT 1 needs reinforcements A and B, PiT 2 needs only reinforcement A, but reinforcement B will be considered also in PiT 2).
Table below includes an example where for all the PiTs of Scenario 1 and 2 the reinforcements A, B, C, D will be considered and in Scenario 3, only reinforcements A and B will be considered, in both PiTs

Project X								
	Scenario 1			Scenario 2			Scenario 3	
	PiT1	PiT2	PiT3	PiT1	PiT2	PiT3	PiT1	PiT2
Criteria/ Reinforcement	max export Y	max export Z	max import Y	max export Z	max export Y	max import Z	max export Y	max import Z
	max RES Y	min demand Z	max demand Y	max RES Z	min demand Y	max demand Z	max RES Y	min demand Y
			max RES Z			max RES Y		
A	X		X			X		X
B			X			X	X	
C			X			X		
D			X			X		

Table 9. PiT selection criteria and reinforcements – each criteria refers to a specific country (Y or Z) – here just for illustrative purpose

Once defined the reinforcements a second iteration of the load flow and security analysis will be conducted to verify the compliance of security criteria. Consistency with the National Development Plans will also be verified.

5.4.5. Losses variation calculation (with and without the project)

Losses calculation will be derived from load flow analysis for the different PITs in normal condition (N).

Normally when a new interconnection is operated the exchanges increases and consequently the losses; it is also necessary to consider that HVDC interconnections due to their length and technology are characterized from a not negligible level of losses.

In a Cost Benefit Analysis, it is important therefore to consider the amount of losses all over the year as an additional cost that may lower the benefit of a new interconnection.

To estimate the losses starting from single hours of the year (PITs) a common methodology is to associate to each situation analysed an equivalent number of hours calculated considering the occurrence of hours with similar characteristics to the ones analysed with load flow calculation. This association can be obtained starting from Market Study results and clustering technics applied to PITs selection. The results are better if the need to use PITs for the losses is taken into account during PITs selection process.

An alternative methodology for losses evaluation has been applied for this master plan based on losses calculation of for each single hour of the year, using a DC load-flow to analyze both the situation with and without the interconnection cluster. Losses calculated from DC load-flow will be also compared with AC losses obtained from selected PITs analyses.

Finally, the monetization of the losses is obtained directly from market simulation marginal price for each area (or an average for interconnections lines).

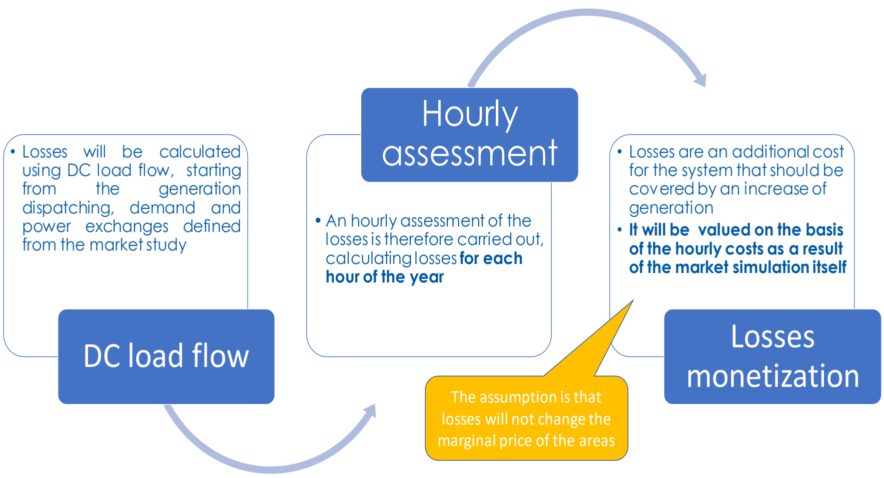


Figure 11. Losses evaluation and monetization

5.4.6. Analysis of the results of the network studies and investment costs

The planning of an electrical transmission system involves financial choices among different technically feasible solutions; at this end the costs of the various system components have to be available.

The chief components to be considered are the transmission lines and the transformer substations.

The cost of the main components of a transmission network may usually be shared into the following two well-known classes:

- cost of installation (investment costs – CAPEX): design, construction and erection, spares,;
- costs of maintenance and personnel and operating costs - (OPEX).

Additionally, since the scope of an electrical system is that of supplying the load with satisfying quality and continuity of service, a further cost is the one relevant to the "energy not supplied" to the load.

With reference to the costs stated hereinbefore, the following remarks have to be made:

a) The average or standard costs of the components are suitable for financial comparisons between different solutions.

b) The homogeneity among the costs adopted for the different components of the different solutions to be compared is compulsory.

c) Costs estimated by comparison with the real costs of similar components already installed must be stripped of any peculiar market condition and reported to the same date. It is also advisable for the estimate to be the result of a statistical investigation on a number of installations sufficient to form a significant sample.

The following task has as main goal the analysis of investment and operational cost estimation. In particular, the cost analysis will be aimed at estimating the capital expenses associated to each interconnection project, including a breakdown of the costs associated to the related internal reinforcements.

An indicative cost for each cluster shall be provided based on industry standard equipment and standard costs.

An indicative list of cost items for the assessment of network investments is provided below:

- AC transmission lines per type and voltage level [k€/km]
- AC equipment (busbar and line bay) [k€/unit]
- DC transmission line standard cost per type, voltage level and rating [k€/km]
- DC converter station per type, voltage level and rating [M€]

Costs may vary from country to country. Standard costs may be applied in the absence of data from TSOs. Concerning the operation costs, the network studies integrate market ones including the assessment of the costs associated to active power losses.

6. THE MASTER PLAN OF INTERCONNECTIONS

6.1. Overview of the 2030 Mediterranean power systems

An examination of recent trends in electricity consumption in the Mediterranean countries reveals very marked contrasts, between West European countries which have experienced stable demand for the last ten years, or even a decrease, and on the other hand, certain countries in the south and east of the Mediterranean where the growth in demand is around or even exceed 4 to 5% per year over a long period. Naturally, the reasons for these differences can be found in several underlying indicators such as economic and demographic growth, the deployment of energy efficiency measures, and the development of new uses of electricity. It is the consideration of all of these factors, described in three scenarios that leads to the development of forecasts for 2030.

Electricity consumption evolution for 2030 remains dynamic, mainly driven by economic and demographic growth

The following Table 8 shows the annual demand forecasts for all Mediterranean countries up to 2030 for the three scenarios.

	2018	2030		
	Mediterranean countries	National Development	Green Development	Mediterranean Evolution
Electricity Demand (TWh)	**1980**	**2470**	**2540**	**2630**
Demand increase (12 years)	-	*+ 25%*	*+ 28%*	*+ 33%*
Compound annual growth rate (CAGR)	-	*+ 1.9%*	*+ 2.1%*	*+ 2.4%*

Table 8. Electricity demand forecast in 2030

The underlying storyline drivers show that by 2030 Green Development scenario (+28%) is centrally positioned in terms of growth between National Development (+25%) and Mediterranean Evolution (+33%) scenarios compared with the historical reference in 2018. The main reason is the predominant importance of economic and demographic growth in the future trend of evolution of electricity consumption in the majority of Mediterranean countries. On a global scale, the development of energy efficiency measures, stronger in the Mediterranean Evolution scenario, does not manage to offset the growing effect of economic growth.

Expressed in terms of average annual growth rate, the three scenarios National Development, Green Development and Mediterranean Evolution are respectively at +1.9%, +2.1% and +2.4% per year between 2018 and 2030.

This global growth includes contrasting dynamics between Mediterranean countries

While past trends in consumption are very contrasted among the Mediterranean countries, the forecasts for 2030 also show very strong differences, illustrated below in Figure 12.

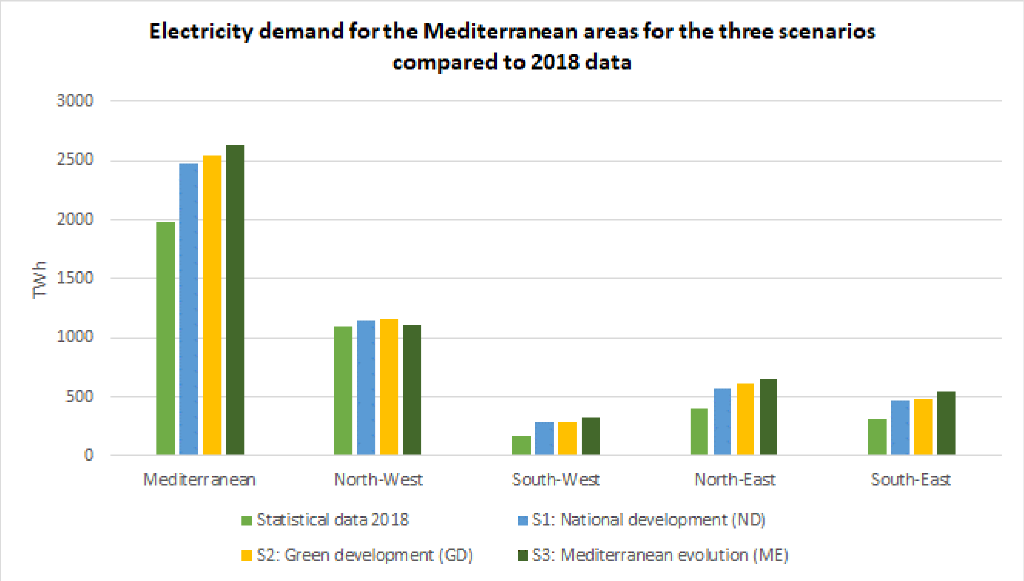


Figure 12. The electricity demand by region and for the Mediterranean area in 2018 and for the three 2030 scenarios

Where the distribution of Mediterranean countries in sub-regions is as following in Table 9.

South-West		North-West		South-East		North-East	
MA	Morocco	**IT**	Italy	**EG**	Egypt	**TR**	Turkey
DZ	Algeria	**MT**	Malta	**JO**	Jordan	**CY**	Cyprus
TN	Tunisia	**FR**	France	**PS**	Palestine	**GR**	Greece
LY	Libya	**ES**	Spain	**IL**	Israel	**AL**	Albania
		PT	Portugal	**SY**	Syria	**ME**	Montenegro
				LB	Lebanon	**BA**	Bosnia and Herzegovina
						HR	Croatia
						SI	Slovenia

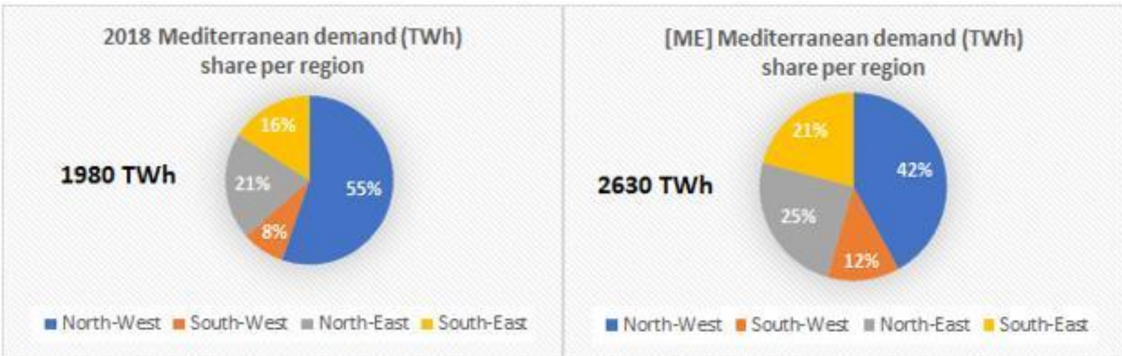
Table 9. Distribution of Mediterranean countries in sub-regions

It is expected for the north-western region the evolution rate should not exceed 0,5% per year while the rate is more than 3% in the three other regions with a maximum 6% foreseen in the Maghreb region in the Mediterranean Evolution scenario.

Unlike the Mediterranean countries as a whole, the graph above shows that Mediterranean Evolution scenario is the less growing scenario for the countries located to the north-west of the region, almost stable compared with the 2018 reference. The main reason is due to the fact that

Mediterranean Evolution (matched with the Global Ambition scenario of TYNDP2020) has the strongest level of energy efficiency that is the most impacting driver for these countries when the economic growth has a fewer effect.
Conversely, in all the countries where economic and demographic growth is the main driver of the growth in electricity consumption, the Mediterranean Evolution scenario presents the highest growth rates, up to + 6% per year in Average for countries located in the south-east of the region.

Consequently, while the electricity consumption of the countries located in the north-west of the region represented in 2018 more than half (55%) of the consumption for the entire Mediterranean, this proportion should drop significantly below 50% by 2030 in the three scenarios, similarly compensated by the other three regions. It is the Mediterranean Evolution (figure below) scenario that shows the greatest decline, in proportion, for the north-west countries, the electricity demand of the other countries being driven by a high assumption of economic and demographic growth.



(a) *(b)*

Figure 13. Distribution of electricity demand among Mediterranean sub-regions in 2018 (a) and in scenario of Mediterranean Evolution (b)

Other complementarities among Mediterranean countries

While the relative evolution of electricity consumption among Mediterranean countries by 2030 provides a first indication of exchange opportunities, a more detailed examination of consumption can provide additional information, starting with the seasonality.

The seasonality of electricity consumption is naturally a direct consequence of the use of electricity for heating in winter and for air conditioning in summer. The excess consumption during these periods is therefore the result of two combined elements: first, the general climatic conditions in a country and the temperature range covered during the year; then the development of heating and air conditioning equipment and building construction techniques. Thus, a rather cold climate does not automatically imply an increase in electricity consumption in winter, especially when the general heating fuel is natural gas.

An accurate modelling of those phenomena is not only important to assess the seasonal demand profile, but above all to measure the effect of the strongest cold or hot waves that can strike any countries in exceptional moments. This question is of prime importance for addressing the security of supply issue and sizing of peak generation capacity.

Figure 14 below illustrates the seasonality of the demand (in the National Development scenarios) for each Mediterranean sub-region.

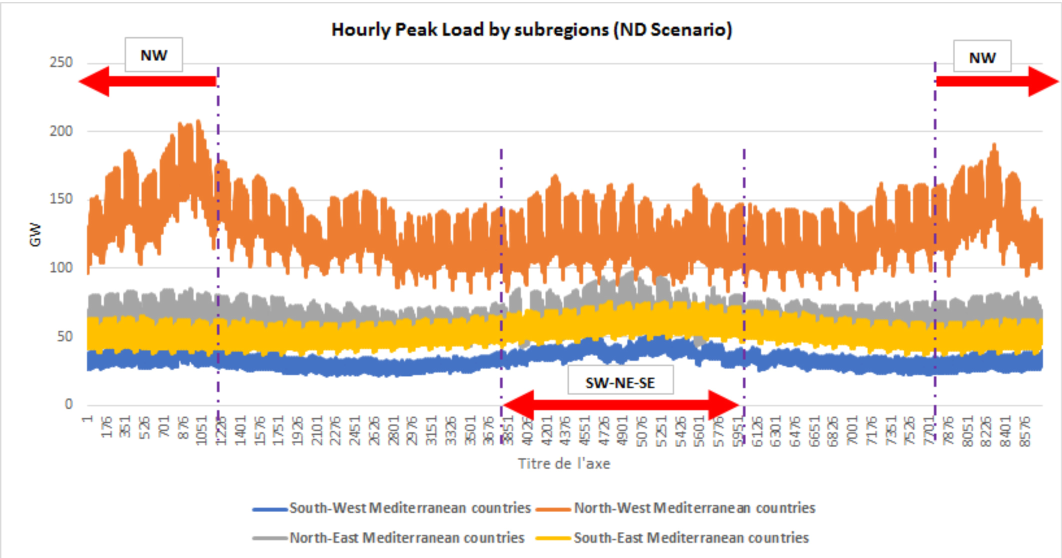


Figure 14. Hourly demand in the National Development scenarios for each Mediterranean sub-region

In north-west countries the peak load is observed during winter where the demands for heating are higher and electric heating well developed. On the contrary the load during summer time is higher in the South Mediterranean countries, including the North-East region as the demand for cooling is imperative and covers a large time period from June to August.

Development of generation capacity that responds to multiple challenges

In the context of growing electricity demand, Mediterranean region is seeing increased production capacity to face the challenges of security of supply and decarbonization of generation. Figure 15 shows the three scenarios represent a significant increase in the total installed capacity from 44% to 54% compared to the installed capacity in the year 2018. The Green Development scenario represents the largest installed capacity due to the high economic growth and the huge ambitions for RES development, while the installed capacity for Mediterranean Evolution scenario is slightly lower.

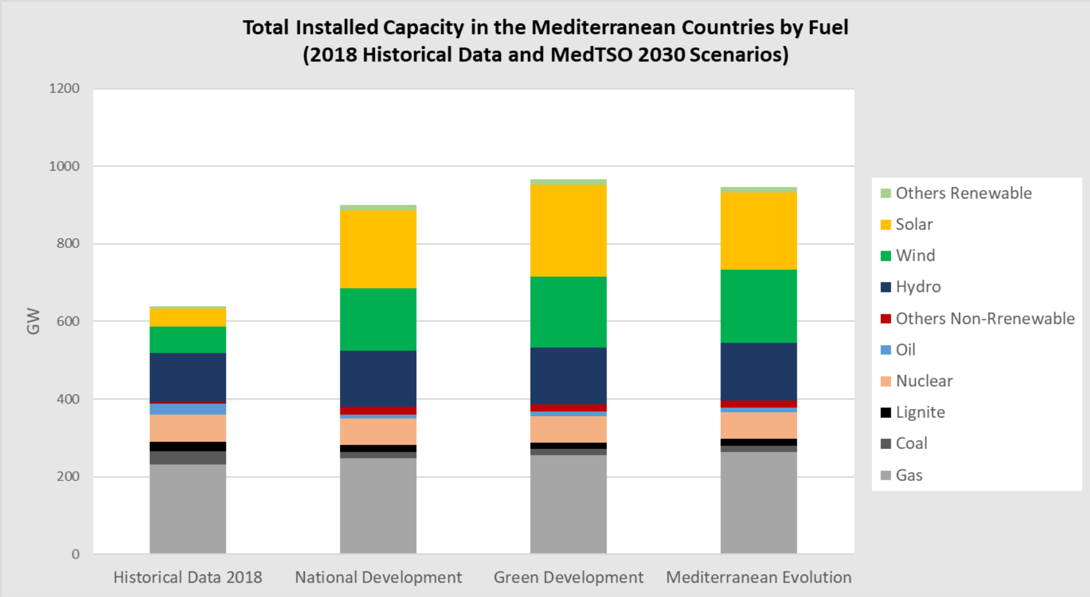


Figure 15. Installed generation capacity in 2018 and for the three scenarios for Mediterranean

The scenarios show a decrease in the capacity of coal and lignite power plants is expected by 2030, respectively 50% and 30% due to coal and lignite decommissioned. About 60% of the installed capacity of oil power plants are retired. Investment in conventional gas power plants is slightly increased (about 10% against 2018), mostly pushed in countries where gas generation is envisaged in substitution of existing coal power plants.

But the most remarkable thing is the development of solar and wind capacity in all Mediterranean countries, illustrated by the following graph in Figure 16.

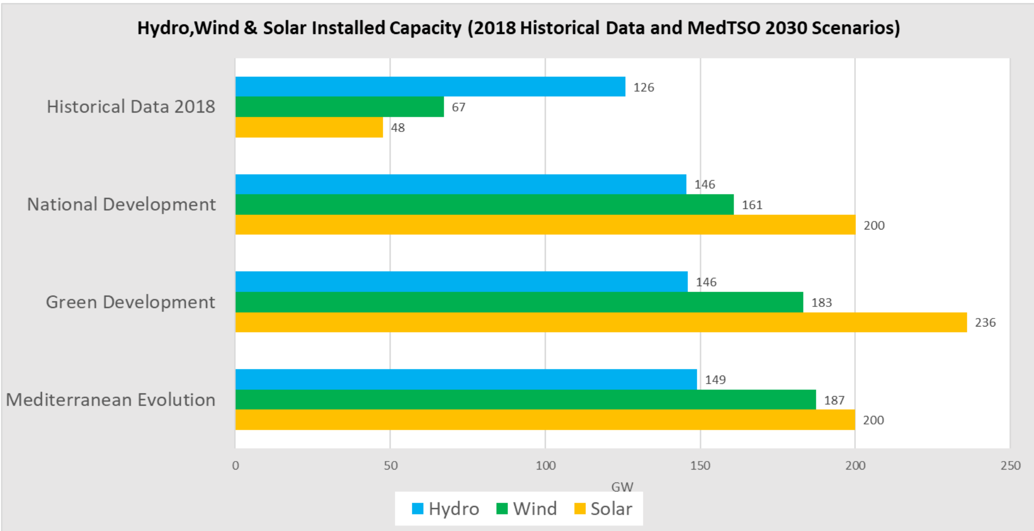


Figure 16. Installed renewable capacity in 2018 and for the three scenarios for Mediterranean

The massive and fast increase in solar development is mostly pushed in Mediterranean countries by the sharpest PV cost decline over the last decade, combined with the good to excellent natural resources. In the Green Development scenario, the installed PV capacity is expected to reach 236 GW that is almost five times the value in 2018, while PV capacity is 200 GW for the two other scenarios.

New RES to meet the increase in electricity demand

While electricity consumption is expected to increase by 25 to 33% by 2030 for the entire Mediterranean region, this excess consumption is fully satisfied by the increase in production from renewable sources.

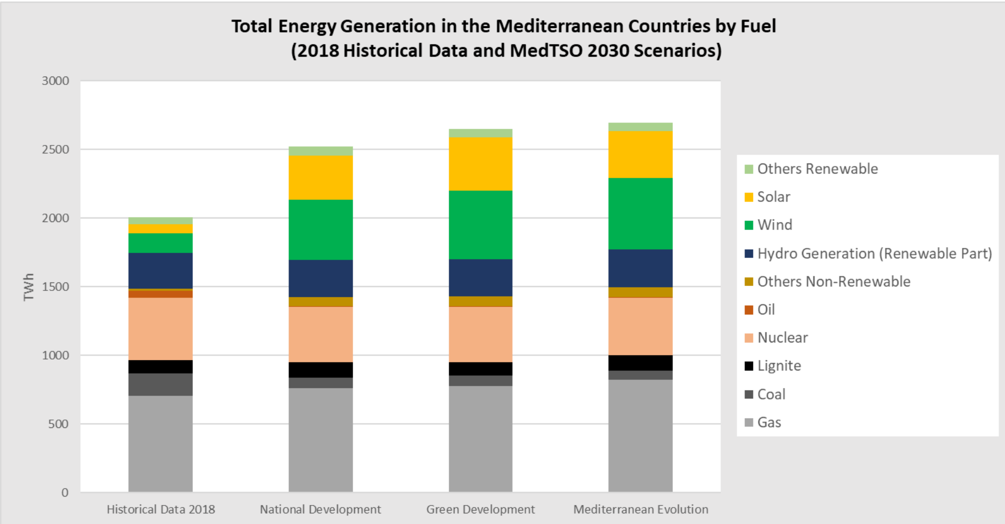


Figure 17. Electricity generation in 2018 and for the three scenarios for Mediterranean

For the Green Development scenario, nearly half (47.5%) of consumption is covered by renewable generation, whereas this proportion was just over a quarter (26.3%) in 2018. The table below indicates these percentages for the three scenarios. The hydro generation is experiencing a small increase in energy, but its overall share is declining. At the same time, wind and especially solar production shows a spectacular increase, covering between them more than 30% of demand, whatever the scenario.

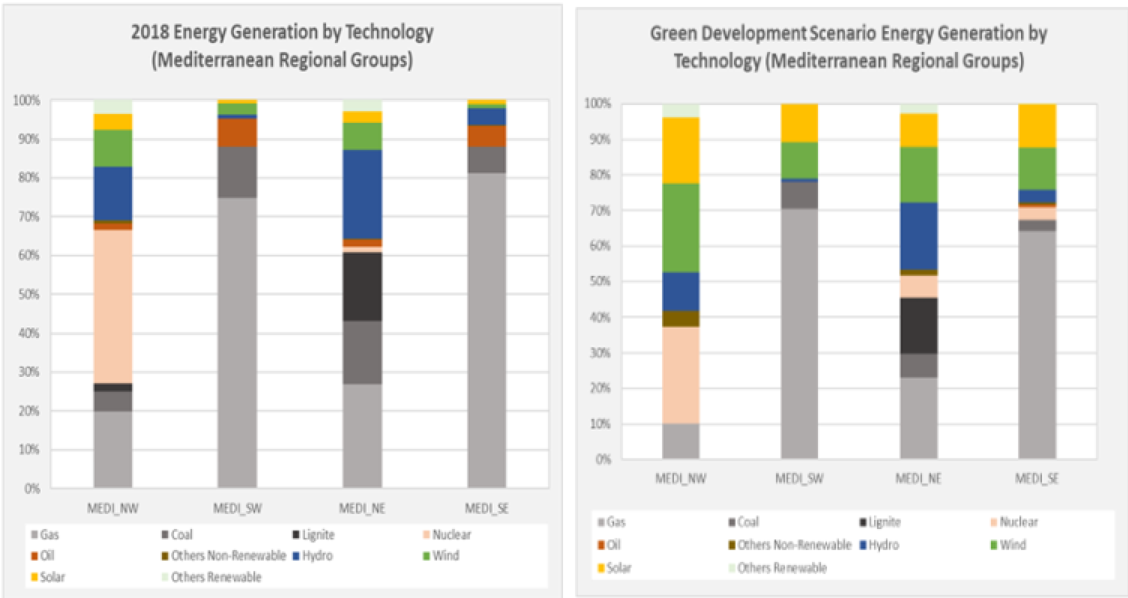
	2018	2030		
	Mediterranean countries	National Development	Green Development	Mediterranean Evolution
Consumption covered by RES	26.3%	44%	47.5%	45%
From which Wind generation	*7.2%*	*17.7%*	*19.7%*	*19.7%*
From which Solar generation	*3.2%*	*13%*	*15.2%*	*12.8%*
*From which Hydro generation**	*13.3%*	*11%*	*10.7%*	*10.6%*

**renewable part*

Table 10. Share of RES in generation in 2018 and for the three scenarios for Mediterranean

While the general trend of massive development of renewable energies is shared by all Mediterranean countries, differences are notable when examining the evolution of the distribution of fuels between sub-regions. This is what the figure below illustrates for the scenario Green Development (2018 for reference).

A common point to all regions is the end of oil generation, and a very sharp decline in the share of coal. In the north-western countries, coal is completely closed and gas is declining very sharply, replaced by renewable energies. In the other regions, the share of gas is maintained, which means an increase in this production to cope with the increase in consumption and the willingness to reduce the share of coal.



(a) *(b)*

Figure 18. Share of generation by fuel in 2018 (a) band for the Green Development scenarios (b)

Toward a more carbon-free power system

For all Mediterranean countries, the reduction in CO_2 emissions from electricity generation is expected between 16 and 20% by 2030 for the three scenarios compared to 2018, which represents a decrease of about 100 million tons per year.

While in the same period, the increase in consumption is expected between 25 and 33%, the decrease in emissions is the consequence of a strong reduction in the average CO_2 content of electricity generation, from 300 gCO_2 / kWh in 2018 to around 185 to 200 gCO_2 / kWh in 2030 depending on the scenarios, i.e. an average decrease of 35%.

	2018	2030		
	Mediterranean countries	National Development	Green Development	Mediterranean Evolution
Reduction of CO_2 emissions (Mt)	(590)	- 17%	- 20%	- 16%
CO2 content of electricity (gCO2/kWh)	298	197	186	188

Figure 19. Expected variation in CO2 emissions in Mediterranean

Contrasts in Mediterranean that create opportunities for electricity exchange

The average marginal price can be seen as an interesting indicator insofar as on the one hand it results from the competitiveness of the national generation fleets and the supply-demand balance, and on the other hand because it constitutes an indicative parameter of the electricity exchanges between countries precisely being a consequence of economic optimizations.Figure 20 below presents the average marginal price by country for the National Development Scenario (unit is €/MWh).

As a result of the highest renewable energy generation share, and other relatively low-cost generation, Portugal and Spain have the lowest marginal price among Mediterranean countries (around € 24 / MWh), followed by mainland France (27 € / MWh).Conversely, Syria, Lebanon and Libya show in this scenario the highest marginal price (in the range 70-90 €/MWh) in the region, which is explained by a tight supply-demand balance and by a significant use of electricity generation from oil.Turkey also shows one of the highest marginal prices (72 €/MWh) which results on the one hand from a relatively inefficient thermal generation fleet and on the other hand from a low import capacity which limits opportunities on its western border for importing electricity at lower price.

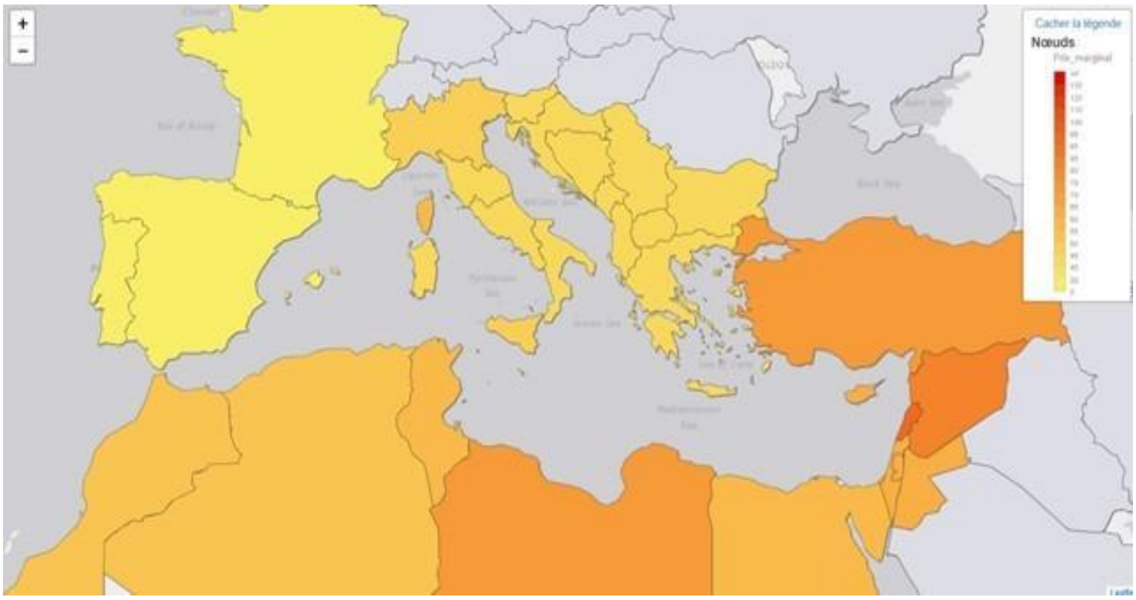


Figure 20. Marginal price in the Mediterranean for the scenario National development

The total number of projects and the total number of countries involved in these projects, for each scenario, are given in the table below. For each project, three different scenarios were examined and a total number of 126 Points in Time. In each scenario the same interconnections are studied, hence the total line length for the interconnections and the overall cost for the interconnection have the same value in all three scenarios. In the table the overall line length of the reinforcements is presented and the total cost for all projects associated to the reinforcements. In addition, the percentage of the internal reinforcements from the total investment cost is given and the total losses and their monetization for each scenario.

In the second table the more detailed cost breakdown of the reinforcements is presented. The total reinforcement cost is shown by element.

KPI*	Scenario 1	Scenario 2	Scenario 3
N° of countries involved	16	16	16
N° Projects	15	15	15
N° Point in Times	41	48	37
Overall interconnection lenght (km)	5538	5538	5538
Overall reinforcements lenght (km)	2440	2680	2600
Aggregated investment costs (M€)	10640	10640	10640
Aggregated reinforcements costs (M€)	710	810	760
% reinforcement cost over total investment	6.7	7.6	7.1
Total losses (GWh)	3942.0	3754.4	3736.3
Total losses (M€)	232.3	221.2	214.1
Reinforcements costs by element (M$)	**Scenario 1**	**Scenario 2**	**Scenario 3**
Lines	680	780	750
Transformers	10	10	10
Stations	0	0	0
Compensators	4	4	4

* The aggregated investment costs are indicative as they average different technological solutions for the same project.

6.2. Presentation of the transmission projects

Interconnectors may contribute to increasing the trade of electricity, it can help integrate more renewables into the systems and in certain cases ensuring security of supply and stability of grids. The overall objective of studying a new interconnection is trying to reduce the final electricity bills.

The reduction of the marginal prices is one of the main drivers for the development of the interconnections since it gives the non or poorly interconnected countries the opportunity to access a less expensive energy, TSO's proposed several interconnection projects to be evaluated. As mentioned in chapter 5, a total of 15 new interconnection projects have been analyzed and benefices have been assessed (the appendix 1).

Having the same drivers and being located in the same area, through the 15 proposed projects, some of them can be clustered, grouped and analyzed in the same way. The following Table 118 proposes a grouping of the new projects based on expectancies from them and the impact that they have on the regional interconnected electrical system. Moreover, the mapping of the corridors is depicted in figure 21.

Actually, the new projects are grouping in six groups according to common geographic and network characteristics.

- **West Mediterranean corridor**
- **Central Mediterranean corridor & North Africa Backbone**
- **East Mediterranean interconnectors**
- **South East Mediterranean hub**
- **Eastern Balkan corridor**
- **Mediterranean Middle East reinforcement**

Projects groups	Projects composing the group	Additional BTC (MW)	Potential Expected benefit from the cluster
West Mediterranean corridor	Project 1: Morocco – Portugal	+1000	
	Project 2: Spain – Morocco	900	
	Project 3: Algeria – Spain	+1000	
Central Mediterranean corridor & North Africa Backbone	Project 4: Italy - Tunisia	+600	
	Project 15: Algeria – Italy	+1000	
	Project 5: Algeria – Tunisia - Libya	+750/+1250	
East Mediterranean interconnectors	Project 6: Egypt – Turkey	3000	
	Project 7: Israel – Turkey	2000	
	Project 12: Greece – Cyprus – Israel	1000/1000	
	Project 13: Cyprus - Egypt in addition to Project 12.	1000	
South East Mediterranean hub	Project 8: Egypt – Jordan	550	
Eastern Balkan corridor	Project 11: Bulgaria – Turkey – Greece	500/500	
Mediterranean Middle East reinforcement	Project 9: Jordan – Syria	800	
	Project 10: Syria – Turkey	600	
	Project 14: Jordan – Palestine	100	

Table 11. Projects groups and expected merits

Where the legend is:

PROJECT MERITS	SYMBOL
Reduce high price differentials between different market nodes and/or countries	
Positively contribute to the integration of renewables	
Contribute to solving adequacy and security of supply issues	
Fully or partially contribute to resolving the isolation of countries in terms of power system connectivity or to meeting specific interconnection targets	
Introduce additional System Restoration mechanisms	
Improve system flexibility and stability	
Increase system voltage stability	
Enable cross-border flows to overcome internal grid congestions	
Mitigate loop flows in bordering systems	
Contribute to the flexibility of the power systems through the control of power flows	

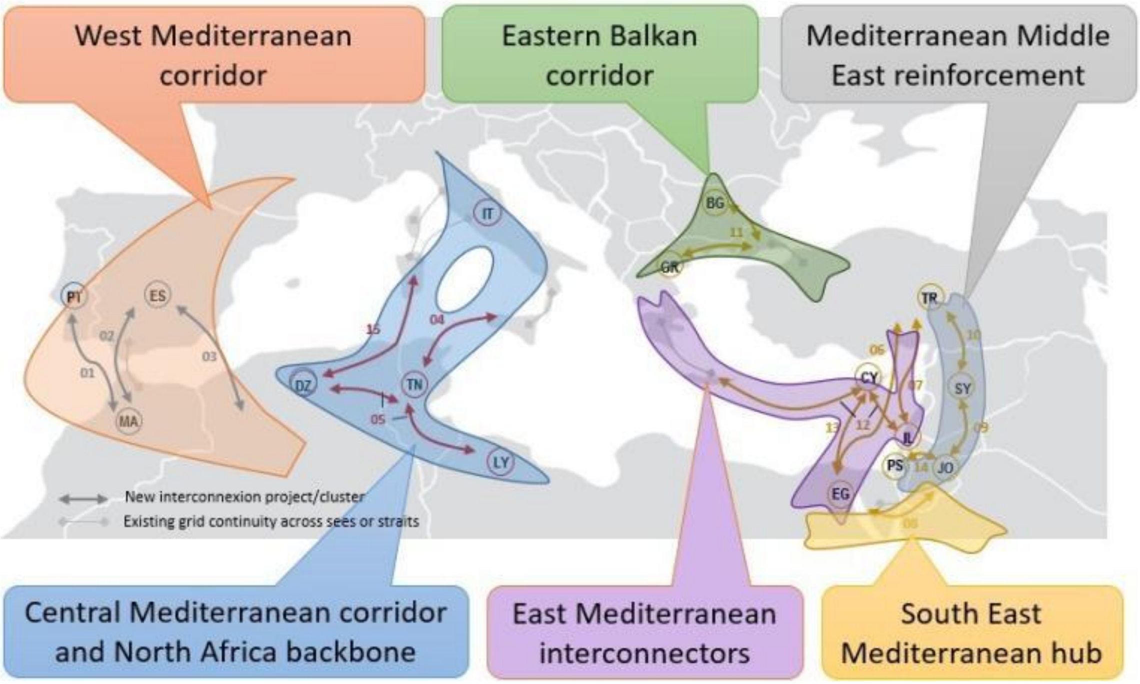


Figure 21. Project grouping mapping in the Mediterranean Area

6.3. The West Mediterranean Corridor

The West Mediterranean corridor comprises three projects, involving Algeria, Morocco, Portugal and Spain. Therefore, not only do these projects involve countries in a naturally well-defined geographical perimeter, but they all also contribute to reinforcing the already existing interconnection between the Iberian Electricity Market and the Maghreb region. As a consequence, the expected benefits of these three projects are all aligned, and in all the three cases we see a clearly positive contribution for: 1) reducing the electricity price differential between the Iberian Market and the Maghreb countries taking benefit from the lower prices observed in Portugal and Spain; 2) increasing the integration of renewables, namely through the avoided curtailment in Portugal and Spain that can be channeled to the Maghreb countries via the envisaged projects, leading to a reduction in gas generation in Algeria and Morocco; 3) meeting specific interconnection targets, which are quantitatively set in the case of the European Countries; and 4) adding additional operational possibilities through the technical characteristics of the technologies at use, namely those associated to VSC-HVDC technology, such as black-start capability and voltage control

The analysis performed for projects composing this corridor was using PINT methodology, the benefices generated from each of the three projects were interesting and it became more interesting when simulations have been pushed further considering all the projects together. Calculations have shown that the mutual effect was not high and no project panelizes the others.

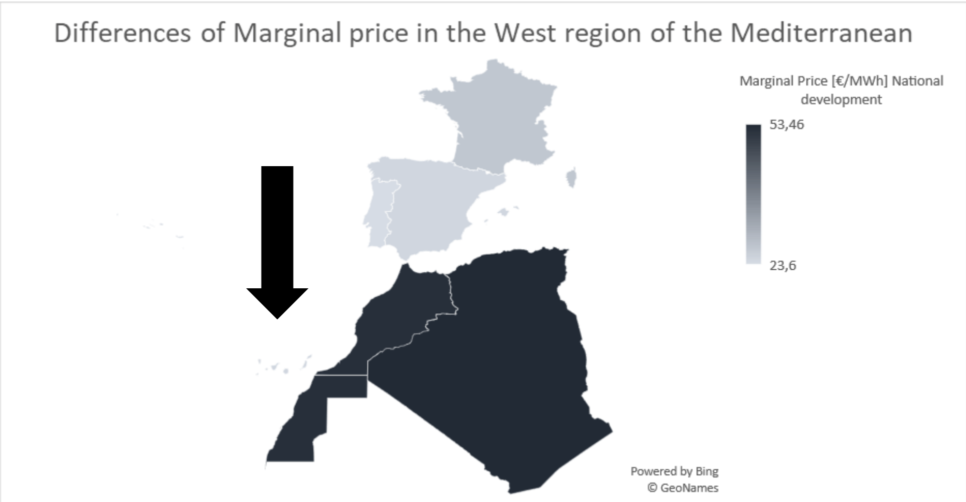


Figure 22. Marginal price in western Mediterranean region countries

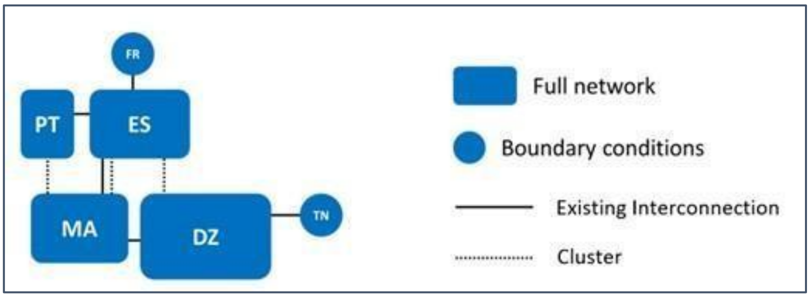


Figure 23. Grid topology with western corridor projects

PROJECT N°1: MOROCCO – PORTUGAL (MA-PT):

This project consists of a new interconnection between Morocco and Portugal based on an HVDC link, with an envisaged capacity of 1000 MW and a total length of c.265 Km, of which approximately 220 Km consist of a submarine cable. This new link is expected to be based on a configuration of two circuits (bipolar converter) of 500 MW each. This project is promoted by the governments of both countries, who have jointly launched the elaboration of a Feasibility Study, presently under development. Figure 24 depicts the project located in the Mediterranean map.

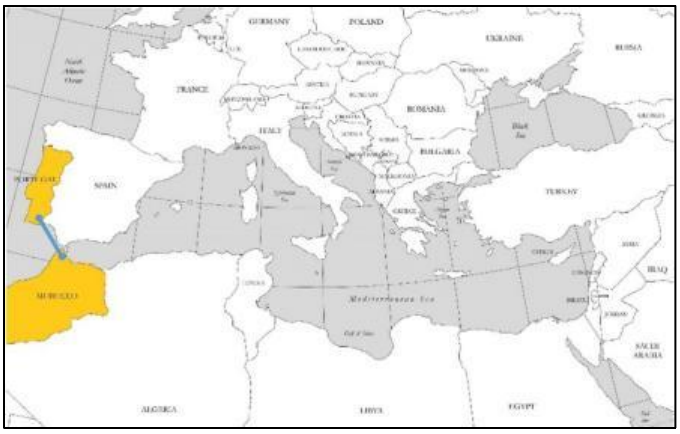


Figure 24. Morocco – Portugal interconnection project

PROJECT N°2: SPAIN - MOROCCO (ES-MA):

This project consists of a new interconnection between Morocco and Spain. In addition to the two-existing links, the project consists of a third link, based on HVAC technology, which will increase the NTC between both countries by 600 MW or 650 MW (Morocco – Spain and Spain – Morocco respectively). The total length of the interconnection line is estimated at around 60km, corresponding to a 30km subsea cable and a 30km overhead line. This project is promoted by ONEE and REE. Figure 25 depicts the project located in the Mediterranean map.

Figure 25. Morocco - Spain interconnection project

PROJECT N°3: ALGERIA – SPAIN (DZ-ES):

This project consists of a new interconnection between Algeria (Ain Fatah) and Spain (El Carril) to be realized through an HVDC submarine cable. The HVDC interconnection will have a capacity of 1000MW and a total length of around 240km. The maximum depth for the installation of the undersea cable will be around 2000m. In addition, in the Algerian side, the connection of the HVDC converter station to the national grid will require a 2x50 km 400 kV AC overhead line.

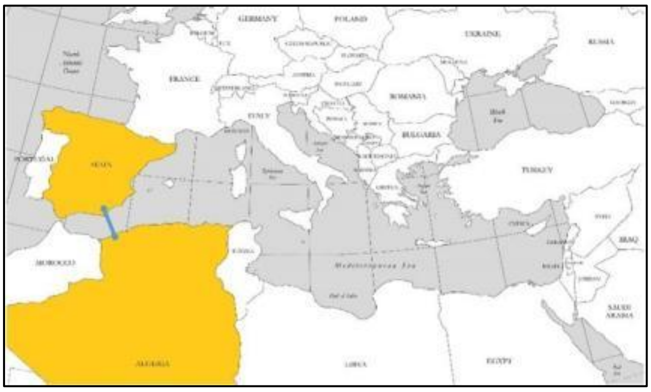


Figure 26. Algeria - Spain interconnection project

Figure 26 depicts the project located in the Mediterranean map.

6.4. Central Mediterranean corridor & North Africa backbone

This group includes 3 interconnection projects strengthening Maghreb countries interconnections and linking them to the Italian Network which presented a high integration rate of renewables in its energy mix together with an overcapacity of the thermal power plants. Demand in Tunisia and Algeria is expected to double within the coming ten years whereas the Italian TSO is expecting a saturation of its demand and who is looking for new markets in order to optimize the renewables power flows to and from his islands Sicily and Sardinia.

From the other side, Libya is presenting one of highest Mediterranean marginal prices which justifies any new interconnection trying to satisfy the Libyan demand using abundant Gas resources of Algeria and well-developed renewables in both Italy and Tunisia. Preliminary results of the actual master plan have shown one of the highest numbers of saturation hours in the interconnections linking Tunisia to Libya. For this reason, the North African backbone project linking the Algerian system to the Libyan system throw the Tunisian grid generated more benefices than the sum of the two segment of the project (Tunisia – Algeria) and (Tunisia – Libya) which justified our theory and reinforced the position of considering the backbone as one project.

New interconnection means also more flexibility and being able to increase the share of renewable in both coasts of the Mediterranean Sea. This is the reason why this cluster is expected to reduce the total amount of curtailed renewables. In addition, STEG is expecting that it will avoid for her the constant need for new investments in power production units and give her access to a guaranteed electricity at a lower cost.

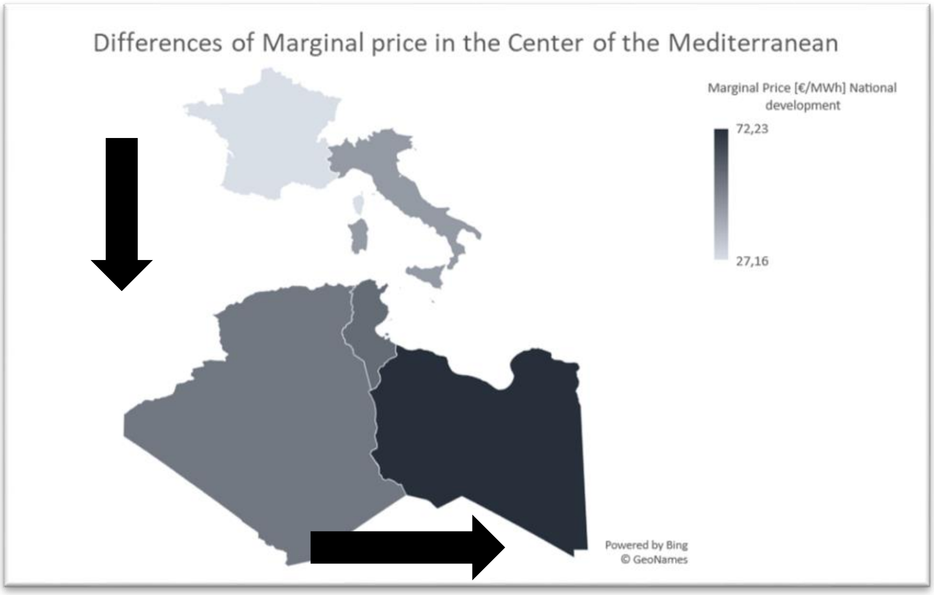


Figure 27. Marginal price in central Mediterranean region countries

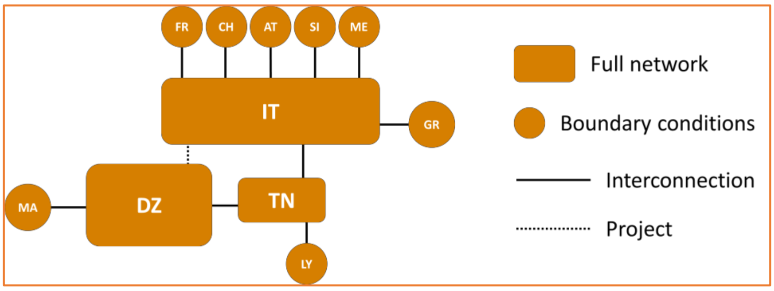


Figure 28. Grid topology with central corridor projects

PROJECT N°4: ITALY – TUNISIA (IT-TN):

The Tunisia-Italy interconnection will be the first link between these two countries, as well as in the central corridor between the North and the South bank of the Mediterranean. This project, which is expected to be completed by 2027, has been intensely promoted by Terna and STEG, with full support of the European Commission, which included the interconnection in the list of Projects of Common Interest (PCI). The potentials of this interconnection are considered deeply strategic for both countries. Considering its maturity, the Tunisia – Italy project is the only that is already included in the reference grid considered for the base case of Med-TSO studies. Figure 29 depicts the project located in the Mediterranean map.

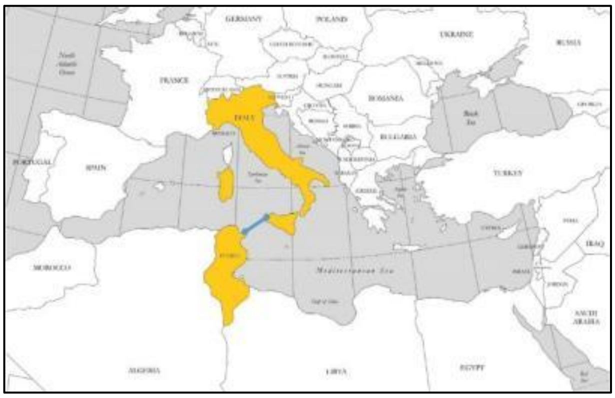


Figure 29. Italy – Tunisia interconnection project

PROJECT N°15: ALGERIA – ITALY (DZ-IT):

The exploratory study consists of a new interconnection between Algeria and Italy - Sardinia through an HVDC submarine cable. The HVDC interconnection will have a capacity of 1000MW and a total length of around 350 km. The maximum depth for the installation of the undersea cable will be over than 2000m. On the Algerian side, the connection of the HVDC Converter Station to the national grid will comprise two 50 km 400 kV AC overhead lines. Figure 30 depicts the project located in the Mediterranean map.

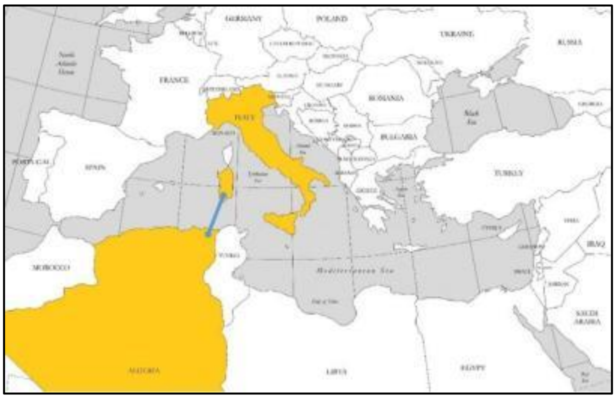


Figure 30. Algeria - Italy interconnection project

PROJECT N°5: ALGERIA – TUNISIA – LIBYA (DZ-TN-LY):

The new interconnection project between Algeria, Tunisia and Libya, it will increase the total expected NTC between Algeria and Tunisia with an additional 750 MW and between Tunisia and Libya with an additional 1250 MW.

The project comprises the following infrastructure:

- A second 400 kV interconnection line between FKirina (Algeria) and Kondar (Tunisia) through an AC overhead line with a 1000 MW capacity and total length of around 250 km (80 Km in Algerian side and 170 Km in Tunisian side);
- A 400 kV interconnection between Bouchemma (Tunisia) and Sorman (Libya) through a double-circuit AC overhead line, with a 2*1000 MW capacity and total length of around 2*300 km (2*250 Km in Tunisian side and 2*50 Km in Libyan side)

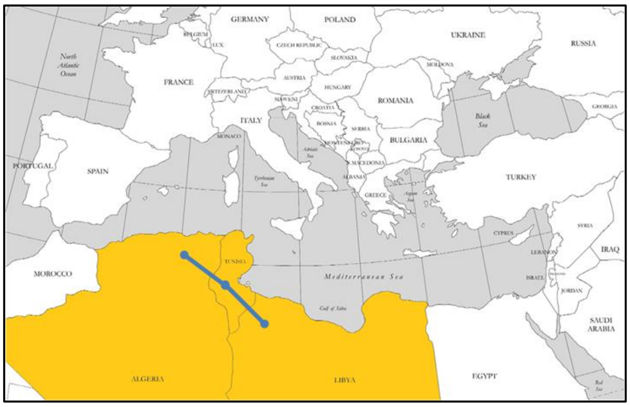


Figure 31. Algeria - Tunisia - Libya interconnection project

Figure 31 depicts the project located in the Mediterranean map.

6.5. The East Mediterranean Interconnectors

This group includes four interconnection projects foreseeing HVDC submarine cables for the connection of the countries of the two banks of Eastern Mediterranean region, with the aim to develop new electricity corridors in the Eastern Mediterranean, providing mutual benefits according to the complementary characteristics and energy prices of the countries involved. More specifically, this cluster includes:

- two interconnection projects linking the Turkish System to Egypt and Israel

- two interconnection projects linking the System of Cyprus to Egypt and Israel and also to the Greek System.

The two most populous countries in the eastern Mediterranean, Turkey and Egypt, are experiencing significant growth in their electricity consumption which could lead them to 450 TWh and 300 TWh respectively by 2030. Both projects connected to Turkey show benefits linked to marginal price differences between countries.

The system of Cyprus which is currently in autonomous operation is expected to be interconnected with Greece, Israel and Egypt with HVDC interconnections of high capacity, which expected benefits cover security of supply issue, the opportunity for higher RES integration in the island and a reduction in fossil fuel dependency.

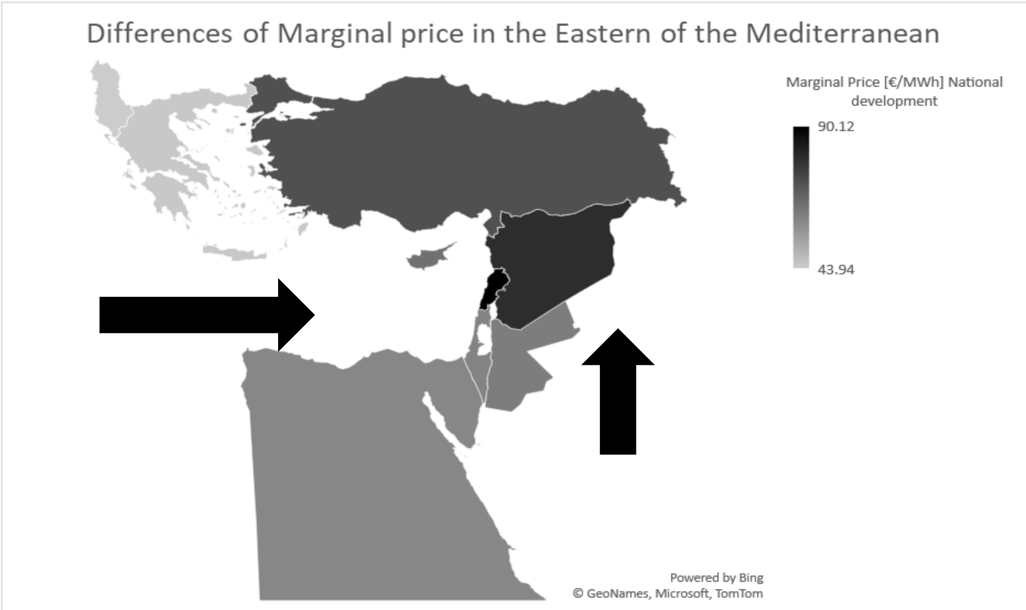


Figure 32. Marginal price in central Mediterranean region countries

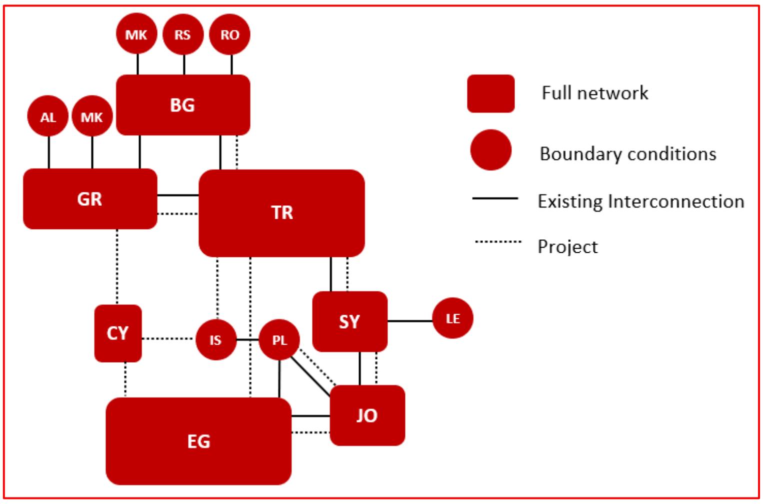


Figure 33. Grid topology with eastern corridor projects

PROJECT N°6: EGYPT – TURKEY (EG-TR):

The exploratory study consists of an interconnection between Turkey and Egypt, to be realized through a submarine 3000 MW HVDC link of about 700km of length.

The project is aiming to increase the interconnection capacity between the two countries to 3000 MW and develop a new corridor in the Eastern Mediterranean. Figure 34 depicts the project located in the Mediterranean map.

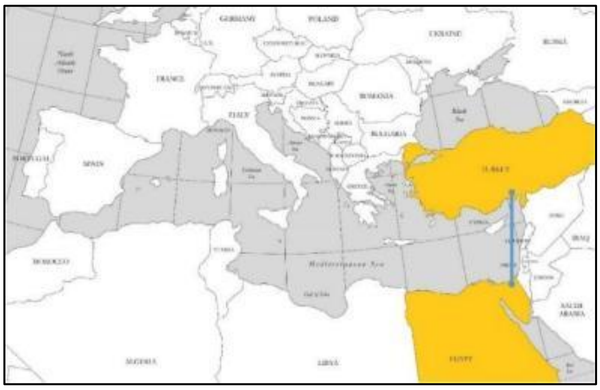


Figure 34. Egypt - Turkey interconnection project

PROJECT N°7: ISRAEL – TURKEY (IL-TR):

The project consists of a new interconnection between Israel and Turkey to be realized through HVDC submarine cable of about 600 km of length. The new HVDC submarine link is expected to be implemented using VSC technology considering the advantages over LCC.

The project is aiming to increase the interconnection capacity between the two countries to 2000 MW and develop a new corridor in the Eastern Mediterranean. Figure 35 depicts the project located in the Mediterranean map.

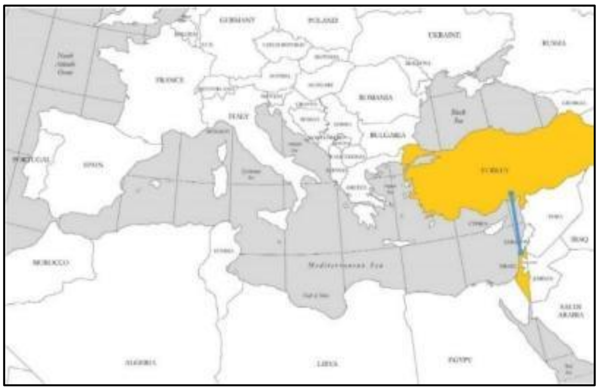


Figure 35. Israel - Turkey interconnection project

PROJECT N°12: GREECE – CYPRUS – ISRAEL (GR-CY-IL)

The project consists in two new interconnections: one between Greece (Crete) and Cyprus and one between Cyprus and Israel. The major driver of the project is the interconnection of the system of Cyprus, which is the last member of the EU remaining fully isolated without any electricity or gas interconnections. Additionally, the project is expected to unlock the integration of high percentage of RES in the island and also create a new transfer route between Israel-Cyprus-Crete-Greece providing mutual benefits to the countries involved.

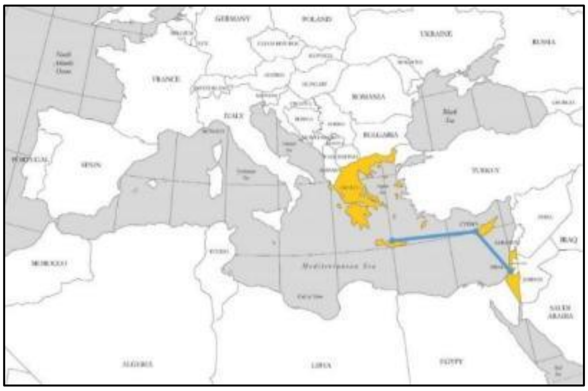


Figure 36. Greece - Cyprus - Israel interconnection project

The project comprises the following infrastructure:

- One new interconnection between the substations of Damasta in Crete (Greece) and Kofinou in Cyprus, to be realized with HVDC submarine cables with a length of about 894 km
- One new interconnection between the substations of Kofinou in Cyprus and Hadera in Israel, to be realized with HVDC submarine cables with a length of about 314 km

The two HVDC links with a capacity of 1000 MW shall be of VSC technology and allow for transmission of electricity in both directions. Nevertheless, because of stability reasons the import/export capacity seen from Cyprus power system is limited at 500 MW. Figure 36 depicts the project located in the Mediterranean map.

PROJECT N°13: CYPRUS – EGYPT (CY-EG) IN ADDITION TO PROJECT N°12

This project is studied as a consequent step to Project N° 12 and consists additionally of one new interconnection between Cyprus and Egypt. It comprises the construction of two submarine cables (2×500MW) of 500km length between the substations in Cyprus (Kofinou) and Egypt (connection point currently not defined). In the area of the project (especially Egypt) large quantities of Natural Gas have been discovered. The project provides an opportunity to transfer electrical energy generated from Natural Gas towards EU. However, because of stability reasons, import and export capacity for Cyprus will be limited totally to 500 MW.

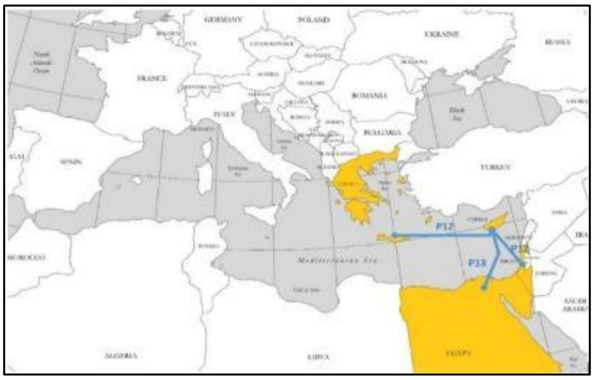


Figure 37. Cyprus - Egypt interconnection project joint to Greece - Cyprus - Israel project

Figure 37 depicts the interconnection project joint to the foregoing Project 12 located in the Mediterranean map.

6.6. The South East Mediterranean hub

The 'South East Mediterranean hub' is the infrastructure that should support significant exchanges between Saudi Arabia (and more globally the interconnected gulf countries power system, GCCIA) and South-East Mediterranean countries. At 2030 time horizon, this this group of projects includes:

- The reinforcement of the existing Egypt – Jordan interconnection (AC submarine cable)
- The development of a HVDC interconnection between Egypt and Saudi Arabia (3 GW)
- The development of a HVDC interconnection between Jordan and Saudi Arabia (1 GW)

The interest of these projects is to benefit from regional complementarities and to promote the massive integration of renewable energies.

The Egypt-Jordan project is studied in the Med-TSO Master Plan while the two projects linked to Saudi Arabia are taken into account in both Market and Network studies but have not been the subject of a study in this framework.

PROJECT N°8: EGYPT – JORDAN (EG-JO):

The project consists of a second interconnection (550 MW) between Jordan and Egypt to be realized through a 13 km 400 kV AC submarine cable. It is expected to increase the current transfer capacity between the two countries to reach about 1100 MW, aiming to mitigate possible overloads in the path of the interconnection.

Figure 38 depicts the project located in the Mediterranean map.

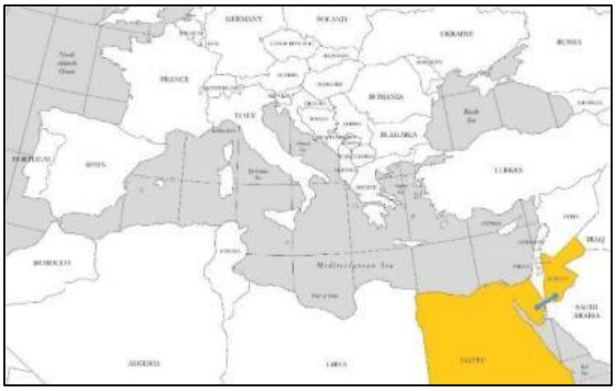


Figure 38. Egypt - Jordan interconnection project

6.7. The Eastern Balkan corridor

This corridor includes one interconnection project linking Turkey with two Balkan countries, Greece and Bulgaria, which are part of the Continental Europe Synchronous Area (CESA) to Turkey transmission corridor. The project aims to further increase the interconnection capacity between Turkey and the CESA of about 1000MW.

While the scenarios for 2030 show significant growth in consumption in Turkey, this project constitutes a strengthening of the corridor located in south-eastern Europe, the main benefit of which is linked to the opportunity provided by differences in marginal price, and therefore to an improvement in economic optimization to benefit the consumer.

PROJECT N°11: BULGARIA – TURKEY – GREECE (BG-TR-GR):

The project consists of two new interconnections: one between Greece and Turkey and one between Bulgaria and Turkey to be realized through AC overhead lines. The realization of the project is aiming to further increase the interconnection capacity between Turkey and the CESA of about 1000MW totally. Figure 39 depicts the project located in the Mediterranean map.

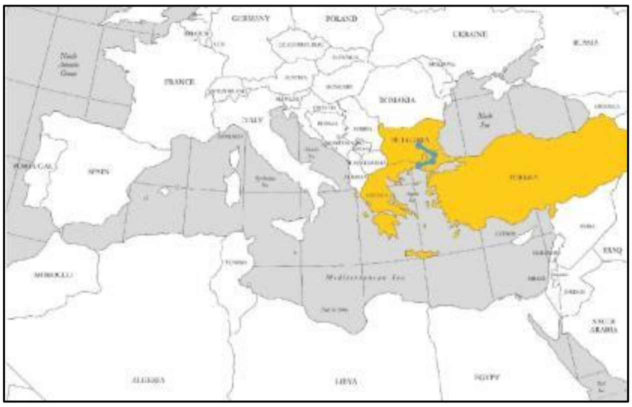


Figure 39. Greece - Bulgaria - Turkey interconnection project

The project comprises the following infrastructure:

- A new 400 kV AC overhead interconnection line between N. Santa (GR) and Babaeski (TR) of about 130km of length and 500MW GTC.
- A new 400 kV AC overhead interconnection line between Maritsa Iztok (BG) and Vize (TR) of about 140km of length and 500MW GTC.

6.8. Mediterranean Middle East reinforcement

This cluster includes four interconnection projects foreseeing new OHL for the reinforcement of the connection of the countries of the Eastern Mediterranean region, with the aim to further increase the existing NTC between the involved countries.

The main merit of those projects is the Security of Supply improvement for the benefit of Syria and Palestine, which should take profit from increased import capacity from Turkey and from Jordan.

PROJECT N°9: JORDAN – SYRIA (JO-SY):

The project consists of one new interconnection between Jordan and Syria to be realized through a 400 kV AC overhead line of about 102km, connecting Hassan_Ind substation (JO) and Der Ali substation (SY). It is expected to increase the current transfer capacity between the two countries of about 800MW and 102km length. This will allow mainly meeting the Syrian demand as well as to integrate more renewable resources and base load units in the region.

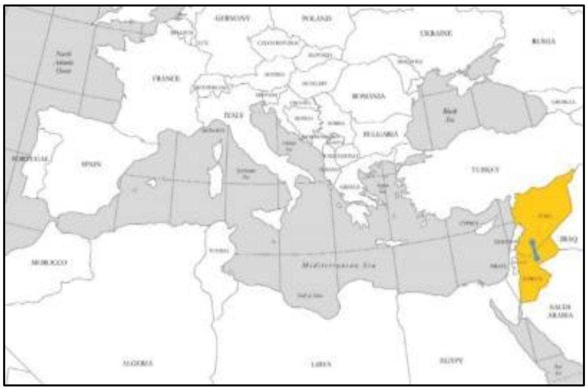


Figure 40. Jordan - Syria interconnection project

Figure 40 depicts the project located in the Mediterranean map.

PROJECT N°10: SYRIA – TURKEY (SY-TR):

The project consists of one additional interconnection between Syria and Turkey to be realized through AC overhead lines. The realization of the project is aiming to further increase the interconnection capacity between the two countries of about 600MW.

The project comprises the following infrastructure:

- A new 400 kV AC overhead interconnection line of about 115km between Birecik HPP in Turkey and Syria
- Upgrading of the B2B converter station at the Turkish side to 1200 MW (it is already in the investment plan of TEIAS).

Figure 41. Syria - Turkey interconnection project

Figure 41 depicts the project located in the Mediterranean map.

PROJECT N°14: JORDAN – PALESTINE (JO-PS)

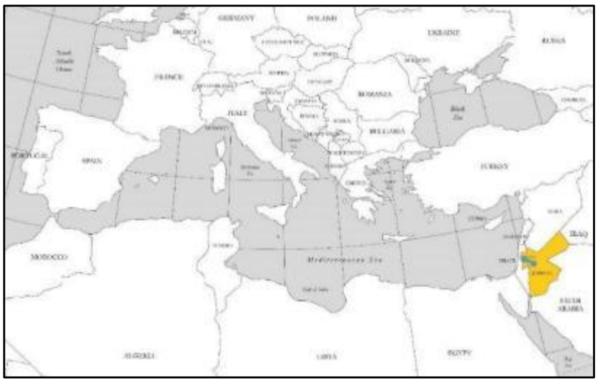


Figure 42. Jordan - Palestine interconnection project

The project consists of one new interconnection between Jordan and Palestine to be realized through an AC 132kV overhead line of about 47km of length, expecting to increase the transfer capacity between the two systems of about 100MW. Although the aim of the project is for Jordan to contribute in feeding the demand in Palestine, the market study was performed following the general rules adopted for the Mediterranean Master Plan, assuming electricity exchanges in both directions driven by market mechanism in the limits offered by the interconnection, with consequent effects in the exchanges between neighboring countries.

Figure 42 depicts the project located in the Mediterranean map.

6.9. Conclusions

Thanks to the three scenarios as designed and developed in this second edition of the Mediterranean Master Plan, it is possible to provide a detailed picture of the Mediterranean electricity system by the year 2030. Those scenarios helped to show how much renewable capacity each country intends to integrate into its system while understanding which are the "urgent" needs in terms of investments. Several challenging barriers were identified such as Market design and market integration which will allow more renewable integration together with a guaranteed access to a cheaper greener and more stable electricity.

Besides the European countries already organized under the umbrella the ENTSO-e and the EC, all the southern Mediterranean countries are evolving and planning the development of their systems by their own and in a self-sufficient way. This master plan represents an attempt to confront the different Med-TSO countries National Development Plans in order to raise together the challenges of diversification of the electrical mixes and increasing the overall flexibility of the systems by enhancing Market integration and assessing new interconnection projects. The total list of 15 interconnection projects that were identified and promoted by the members (TSOs) were studied and assessed in compliance with the requirements of the EU Regulation (EU) 347/2013 as a direct application of ENTSO-e CBA methodology.[5] Figure 43 depicts the project assessment framework.

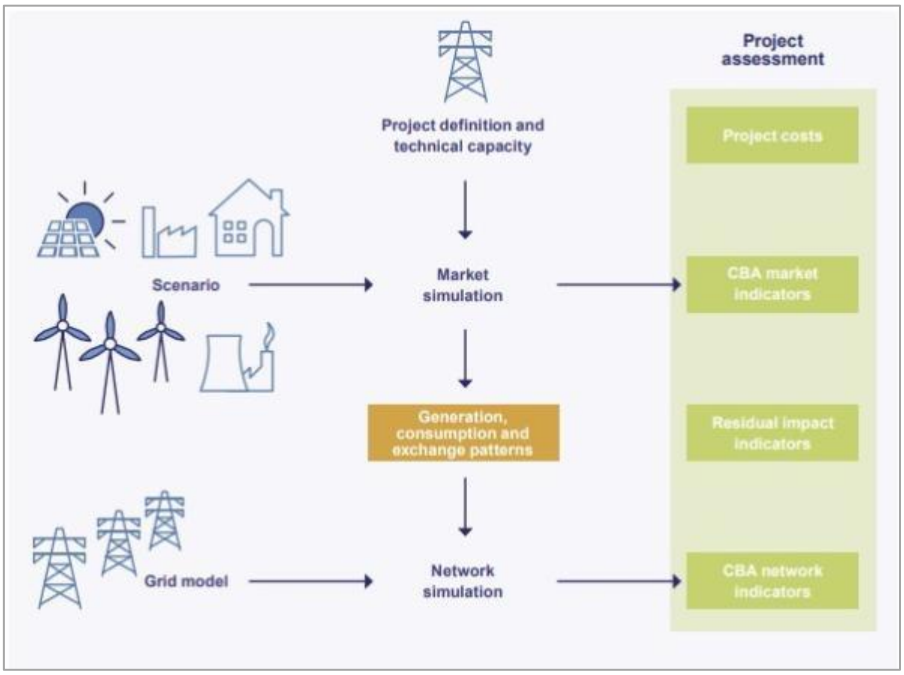


Figure 43. Project assessment framework

[5] 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects

The Mediterranean Master Plan identifies 15 clusters of cross-border interconnections assessed at the time horizon 2030. A cluster is defined as a set of investments - new lines, new substations, other equipment for active and/or reactive power control, generally comprising both cross-border interconnections and local reinforcements

Network analysis assesses feasibility and standard costs of such clusters, whose sustainability is previously proven by market studies.

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