Deliverable 2.2.1
Description of the
Reference Energy Scenarios

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NOTE	

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Med-TSO 2030 Reference Energy Scenarios Report

Introduction

This Scenario Report explores possible future situations of load and generation, interacting with the Euro-Mediterranean Power system. These Med-TSO 2030 Reference scenarios will be the baseline on which the interconnection projects of the Mediterranean Master Plan are to be assessed.

This set of four scenarios will focus on the year 2030. The Northern bank is engaged in ambitious decarbonisation targets and market integration within a general stagnation of the electricity demand. The southern bank is characterized by large potentiality of renewable generation and by a fairly high rate of growth of the demand, supported by concrete examples of plans and deployment of RES. While the market is still in evolution.

The aim of this report is to provide insight in how Med-TSO 2030's scenarios for the Mediterranean Master Plan are developed, highlight how infrastructure needs are linked with the evolution of the power system as a consequence of the choices in energy policies.

This activity has been performed by the Working Group Economic Studies and Scenario, with the contribution of all the Med-TSO members. Since end-2015 and 2016, the work was mainly focus on defining the scenarios, performing the data collection and running of the Market Model. The scenarios have been updated in 2017, taking into account several new national Energy Plan following the COP21 involvements.

1 Development of Mediterranean area scenarios

The aim of those Med-TSO 2030 scenarios is to build the path from now 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 renewable energy development. It results a high level of uncertainty regarding the long-term load forecast in the countries where growth rate remains significantly positive. Moreover, many areas show a very good potential in terms of wind or irradiation that could offer opportunity of a massive RES development.

In this context of high uncertainty, a set of four long-term Med-TSO 2030 Scenarios has been built.

The aim of the scenario building process was also to ensure a Mediterranean framework and overall consistency. For that, the first step was to determine commonly a set of drivers (economic, demographic, technology, …). Those drivers have been later converted into national parameters by each Member, including the specificities of its country.

In parallel, the Market Model has been completed to include the "Rest of the World", meaning in practical word all non-Med-TSO European countries in coherency with ENTSO-E TYNDP.

In the following chapters it will be analysed: the methodology used for scenario definition and data ghatering, the storylines for the four scenarios, a brief introduction on the current situation (2015-2016) in the MedTSO countries, the Macroeconomic Model considered for the studies, the results and the next steps.

2 Scenario Building Methodology

In general terms scenarios are based on a storyline, assumptions, data collections, quality checks, and final market simulations to quantify energy outputs.

Basically the activity has been organized in a two steps approach.

The first phase (Round A) has included the definition of the scenarios to be used and the associated key drivers (phase A1), the data collection performed by each Med-TSO member and completion for the missing countries (phase A2) as well as the characterization of the market

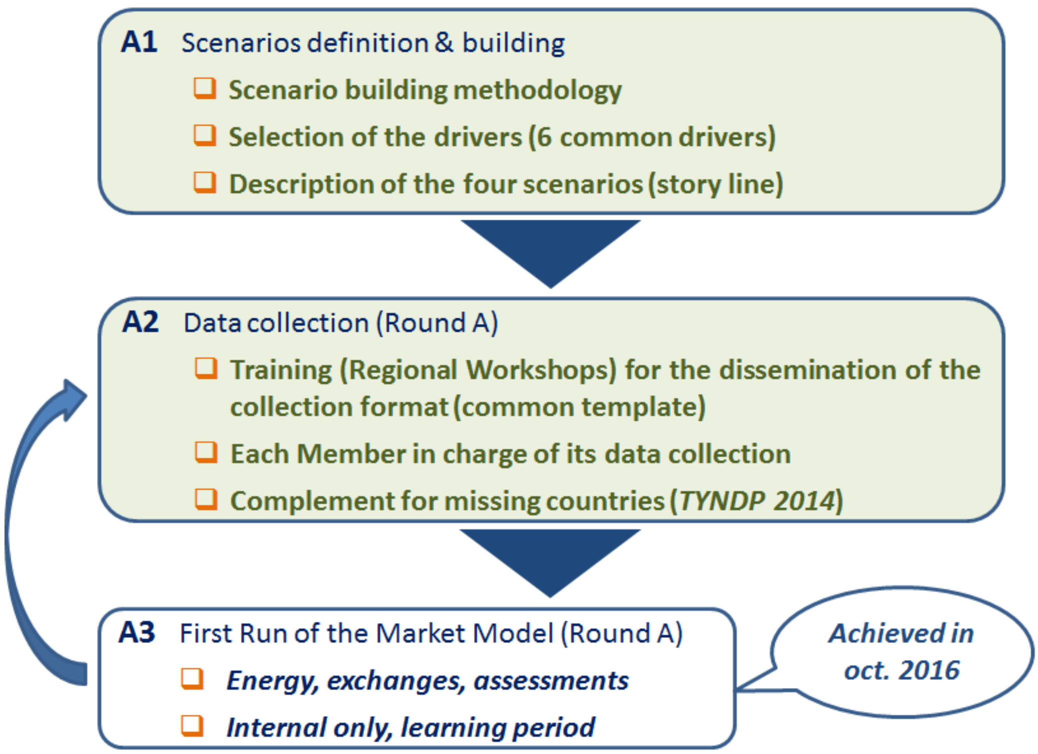

Figure 1 – Round A

model to be used for the analyses and a first run of the model (phase A3).

The second phase (Round B) has been dedicated to the refinement of the hypotheses on the basis of the results obtained in Round A. However it is important to notice that the effect of the COP21 on the Energy policy of several members has led to some significant evolution in RES and load assumptions.

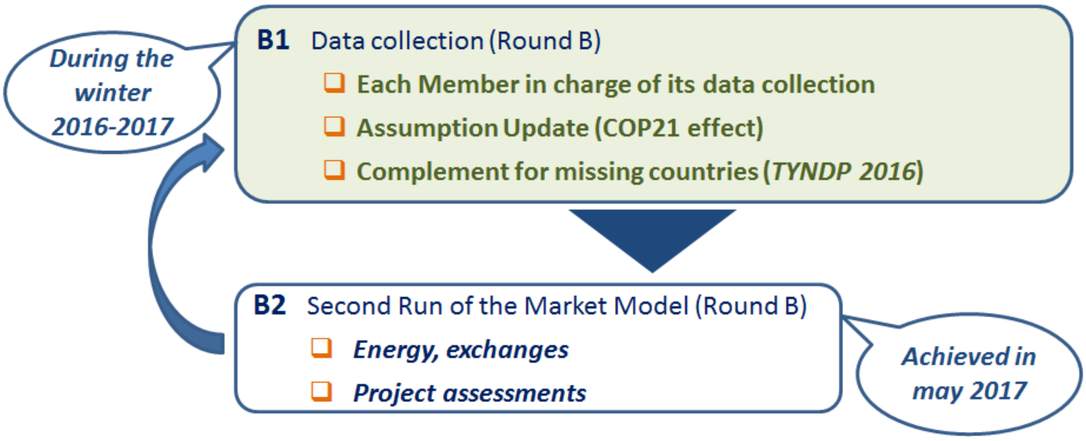

Figure 2 - Round B

It is important to note that the four Med-TSO 2030 scenarios do not have ambition to give a forecast of the future, nor is there any quantification of probability attached to any of the 2030 scenarios. The scenarios do not pretend to show the future shall be alike, but rather give a wide spectrum within which the realistic future will fall.

3 Main storyline for the Med-TSO scenarios

Med-TSO scenarios are defined with reference to six sets of drivers:

- **Economy and population** (GDP growth, population growth, demand forecast, primary resources price): it is used to assess the Gross Demand Product (GDP) forecast; base on GDP trend, the consumption can be estimated;
- **Renewable energy development**: it is used for the amount of renewable energy generation power plants (generally if this driver is 2, the percentage of renewable generation is the same by 2030 than today, if it is 3, an increase of this production has to be figure out based on government forecast);
- **Technology development** (storage, load management, 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;
- **New load** (water de-salinization, electric cars, public transportation, energy efficiency) represents the extra load can be added to the consumption;
- **Market integration** (internal market, regional market, or global market): the higher is this driver, the higher the network transfer capacity increase will be introduced in the model;
- **Thermal carbon free technologies** (i.e. nuclear development in the South of the Mediterranean area): this driver is linked to the nuclear power plants used in the energy mix (if the driver is 0, no more nuclear power plants, if it is 3, the maximum power plan generation has to be introduced in the model).

In particular four scenarios have been developed:

- **Scenario 1 – Business as usual**
- **Scenario 2 – Green Future**
- **Scenario 3 – High interconnection development**
- **Scenario 4 – Green Future & Market Integration**

3.1 Scenario 1 - Business as usual and security of supply improvement

This scenario is a conservative medium scenario.

The load consumption increases with the observed trend in each MED TSO country. The development of new use of electricity is considered at low level and the effort on improving energy efficiency is limited.

The hypothesis on the economic environment is one of the partial cash-up phase of global demand in the North (development up to 3%). The development in south and East of Mediterranean is between 4 and 7%.

Energy policy is marked by the continuation of the current trend in each country. The policy of supporting renewable energies is pursued but their growth remains well short of the level seen in other countries like Spain and Italy.

Interconnection and internal grid in the South is based on the improvement of the security of supply.

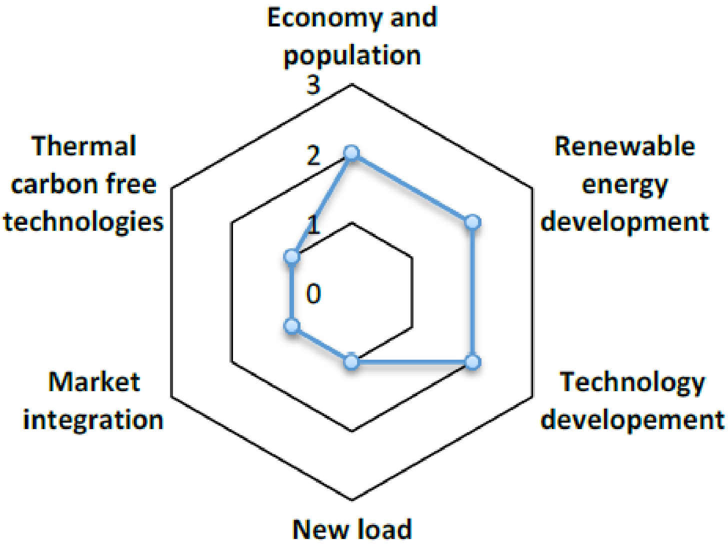

Figure 3 - Business as usual and security of supply improvement

3.2 Scenario 2 - Green future based on gas and on local integration of renewable energies

This scenario is a green scenario based on a bottom-up approach. Each country has decided a common politic tool to integrate RES and minimize climatic changes.

The CO_2 price is high in the whole Euro-Mediterranean power system. South shore countries policy is based on an attentive use of primary resources and the development of renewable energy funds with primary resources incomes.

Gas power plants, that represent the higher percentage of total installed capacity, are built in the South for the adequacy of supply and to minimize CO_2 emissions since the price of CO_2 is high enough to have a Merit Order with gas before coal. These gas power plants will have also to be flexible to deal with a new energy mix based on renewable energy.

The load consumption increases higher than the same medium trend in each MED TSO country because of the development of new electricity uses like public transportation.

The hypothesis on the economic environment is one of the partial cash-up phase of global demand in the North shore. The development in the South and East of Mediterranean is between 3 and 7%.

Interconnection development in the South is based on the improvement of the security of supply and exportation of RES.

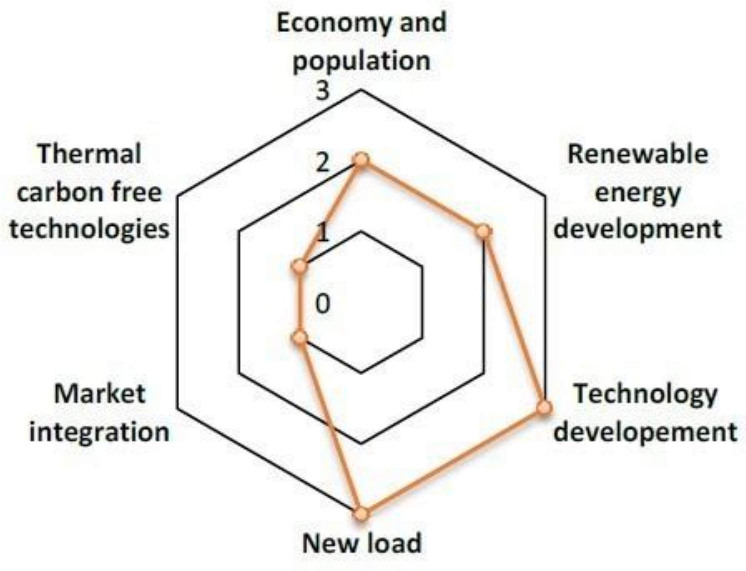

Figure 4 - Green future based on gas and on local integration of renewable energies

3.3 Scenario 3 - High economic growth which supports high interconnection development

This scenario assumes that following new primary resources discovered the economy of the Mediterranean area goes up especially in the South. A higher GDP growth could be expected in the South (more than 3%) and a lower growth (less than 3%) for the European countries.

South countries decide to develop free carbon thermal power plant to support the electricity demand and RES development.

New interconnections are necessary to share the low cost electricity of this kind of power plants and to support the relevant energy exchanges.

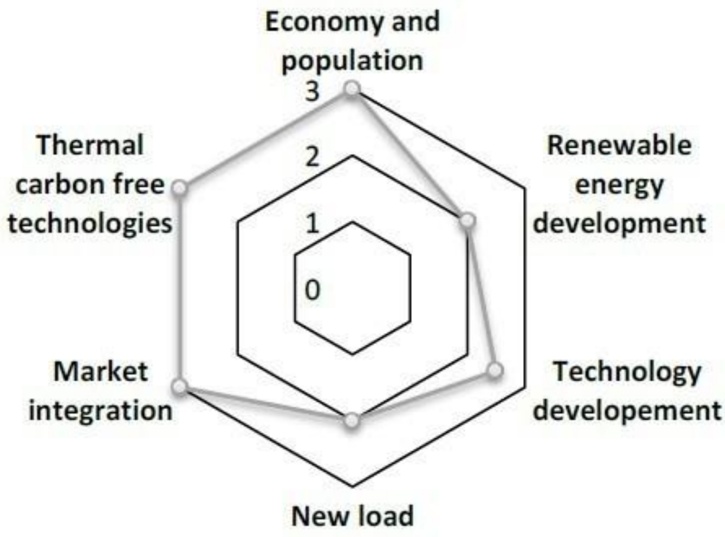

Figure 5 - High economic growth which supports high interconnection development

3.4 Scenario 4 - Green future and market integration at an international level

This scenario is based on a top-down approach with three issues:

- The CO_2 reduction for electricity production but also for transportation (new electricity uses)
- High technology development for load and generation management especially in the north bank.
- The RES and Nuclear investment in the South to support electricity demand, to limit the consumption of primary resources and to export the surplus of electricity.

This scenario is linked to the necessity to develop many multinational interconnections to support a global electricity market all around the Mediterranean area.

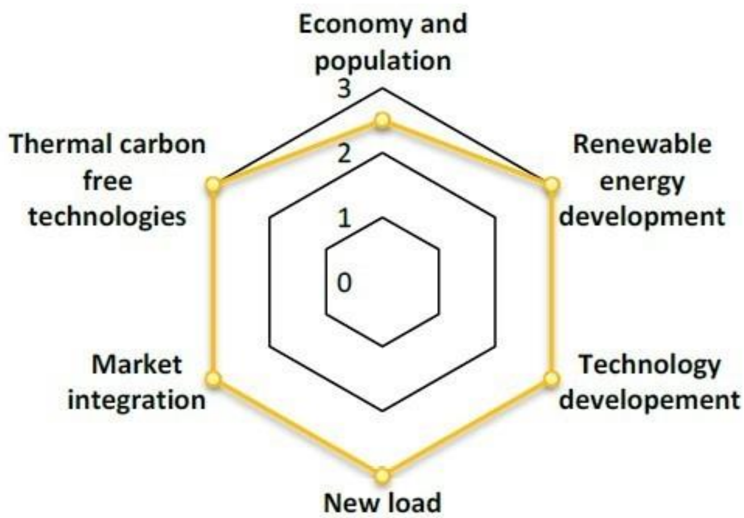

Figure 6 - Green future and market integration at an international level

The **Table 1** below summarizes the level of the 6 drivers for each scenario, the minimum value being 1 and the maximum value 3.

Table 1 – Drivers for scenario

Drivers/Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Economy and Population	2	2	3	2
Renewable energy development	2	2	2	3
Technology development	2	3	2.5	3
New Load	1	3	2	3
Market Integration	1	1	3	3
Thermal carbon free technologies	1	1	3	3

It is important to note that, for all scenarios, the "RES development" driver is always at least equal to 2. Indeed, all the questioned experts consider for their country a “Medium to Strong” evolution of the RES development, and generally in acceleration by comparison with the past trend.

In a global vision, the scenarios can be presented according to several general characteristics: consumption in 2030, development of renewable energies, market Integration and development of interconnection, etc.

The following figure proposes to plot the 4 scenarios according to their level of development of RES in horizontal axis and the development of interconnections on the vertical axis. As the scenarios 3 & 4 are the two with the highest development of RES, it can be noted that they are also the ones that lead to the highest consumption forecast as they present due to the cumulative effect of the "Economy and Population" and "New Load" drivers.

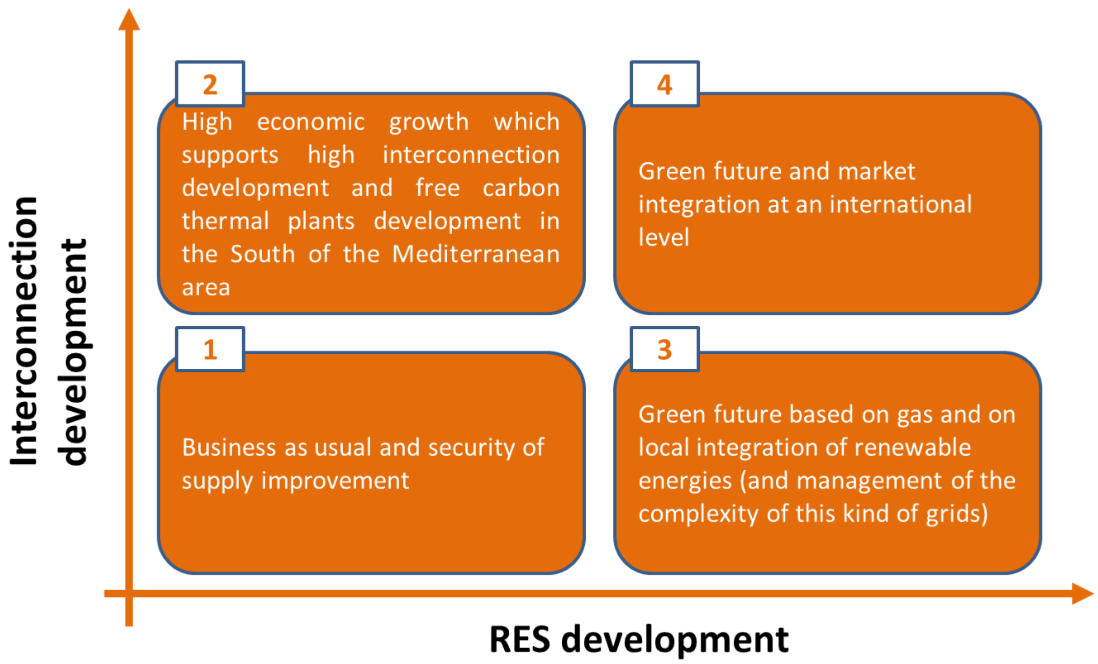

Figure 7 – Interconnection and RES development levels for each scenario.

3.5 How are these scenarios linked with other available scenarios

Power system modeling claims to represent all the interconnected countries. For the Euro-Mediterranean Power system, there is therefore a key issue to retain assumptions for all countries in the perimeter of ENTSO-E for each of the four scenarios. This consistency is facilitated because the scenario building methodology used by Med-TSO is similar to what adopted in ENTSO-E, in particular four visions are introduced to be used for Ten-Year Network Development Plan (TYNDP 2016[1]) calculation:

- Vision 1: “Slowest progress”
- Vision 2: “Constrained Progress”
- Vision 3: “National Green transition”
- Vision 4: “European Green revolution”

To have a coherent approach between the two TSO associations, the economic model for each Med-TSO scenario are coherent with ENTSO-E Visions for European countries when the adopted matching is as following:

- Med TSO Scenario 1 – ENTSO-E Vision 1
- Med TSO Scenario 2 – ENTSO-E Vision 2

[1] Link TYNDP 2016

- Med TSO Scenario 3 – ENTSO-E Vision 3
- Med TSO Scenario 4 – ENTSO-E Vision 4

However, the detailed comparison of scenarios 2 and 3 of Med-TSO and ENTSO-E reveals a divergence on the use of coal and gas power plants. In fact, Med-TSO has preferred in scenario 2 a control of CO_2 emissions which is based in part on the use of natural gas to the detriment of coal (gas power plants are built in the South for the adequacy of supply and to minimize CO_2 emissions).

For that, Energy and CO_2 price need to be set up to have a Merit Order with gas before coal, that implies a switch of Visions 2 and 3 fuel and CO_2 prices compare to ENTSO-E TYNDP 2016 assumptions.

A synthesis is illustrated in **Table 2**, **Table 3** and **Table 4**.

Table 2 - Fuel price values

IEA Reference Scenario		Current Policies	IEA “450” except coal price IEA “New Policies”	Current Policies	IEA “450” except CO2 price (UK FES High)
Simulation Scenario		Med-TSO 1	Med-TSO 2	Med-TSO 3	Med-TSO 4
		Vision 1 2030	Vision 3 2030	Vision 2 2030	Vision 4 2030
Fuel prices [€/net GJ]	**Nuclear**	0.46	0.46	0.46	0.46
	Lignite	1.1	1.1	1.1	1.1
	Hard coal	3.01	2.8	3.01	2.19
	Gas	9.49	7.23	9.49	7.23
	Light oil	17.34	13.26	17.34	13.26
	Heavy oil	13.7	9.88	13.7	9.88
	Oil shale	2.3	2.3	2.3	2.3
CO2 price [€/ton]		17	71	17	76

Table 3 - Fuel price values [€/MWh]

Fuel	Type	Med-TSO 1	Med-TSO 2	Med-TSO 3	Med-TSO 4
Nuclear	-	14.02	14.02	14.02	14.02
Hard Coal	old 1	50.70	100.75	50.70	99.31
	old 2	44.77	88.57	44.77	87.31
	New	39.36	77.44	39.36	76.35
	CCS	36.63	39.45	36.63	34.12
Lignite	old 1	32.27	88.37	32.27	93.57
	old 2	28.65	77.74	28.65	82.28
	New	25.35	68.03	25.35	71.98
	CCS	18.65	23.81	18.65	24.29
Gas	conventional old 1	105.69	113.87	105.69	116.72
	conventional old 2	92.94	100.12	92.94	102.62
	CCGT old 1	95.73	103.09	95.73	105.66
	CCGT old 2	80.04	86.18	80.04	88.32
	CCGT new	66.52	71.60	66.52	73.36
	CCGT CCS	70.87	57.09	70.87	57.29
	OCGT old	109.18	117.59	109.18	120.52
	OCGT new	91.25	98.26	91.25	100.70
Light oil	-	193.09	194.45	193.09	198.46
Heavy oil	old 1	157.85	161.89	157.85	165.90
	old 2	138.53	142.06	138.53	145.57
Oil shale	old	52.96	119.99	52.96	126.20
	new	40.22	90.07	40.22	94.68
Gas	CCGT new	64.35	69.26	64.35	70.97

Table 4 - Comparison between Med-TSO and ENTSO-E scenarios

Med-TSO	ENTSO-E TYNDP 2016
Scenario 1 **Business as usual** and security of supply improvement	**Vision 1** **Slowest progress**
Scenario 2 **Green future** based on gas and on local integration of renewable energies (and management of the complexity of this kind of grids)	**Vision 2** **Constrained Progress** (CO_2 and fuel price of Vision 3)
Scenario 3 High economic growth which supports high **Interconnection development** and free carbon thermal plants development in the South of the Mediterranean area	**Vision 3** **National Green Transition** (CO_2 and fuel price of Vision 2)
Scenario 4 **Green future and market integration** at an international level	**Vision 4** **European green revolution**

4 Historical evolution

In the following a brief overview of the Med-TSO countries will be given. Indeed, the Mediterranean region is made up of countries that have experienced, over the last 15 years, contrasting evolutions of their Power System. Some, in the North, show a very slow, even stabilized, evolution of consumption, while growth is very strong in other countries. The contrasts can also be very significant on the composition of the generation fleets and the development of renewable energies.

This is why it seems relevant, before discussing the 2030 scenarios, to present the current state of electricity systems of Med-TSO member countries, as well as their recent evolution.

In particular it is investigated: the historical load evolution, the generation installed capacity and the energy produced with a focus on RES penetration, the interconnection with other countries and the annual balance for each country[2].

This map shows the growth rate of electricity consumption in each Med-TSO member country during the period 2000-2015. A “low development” means that the average annual load growth rate is lower that 1.5%, when “high development” is higher than 4.5 %.

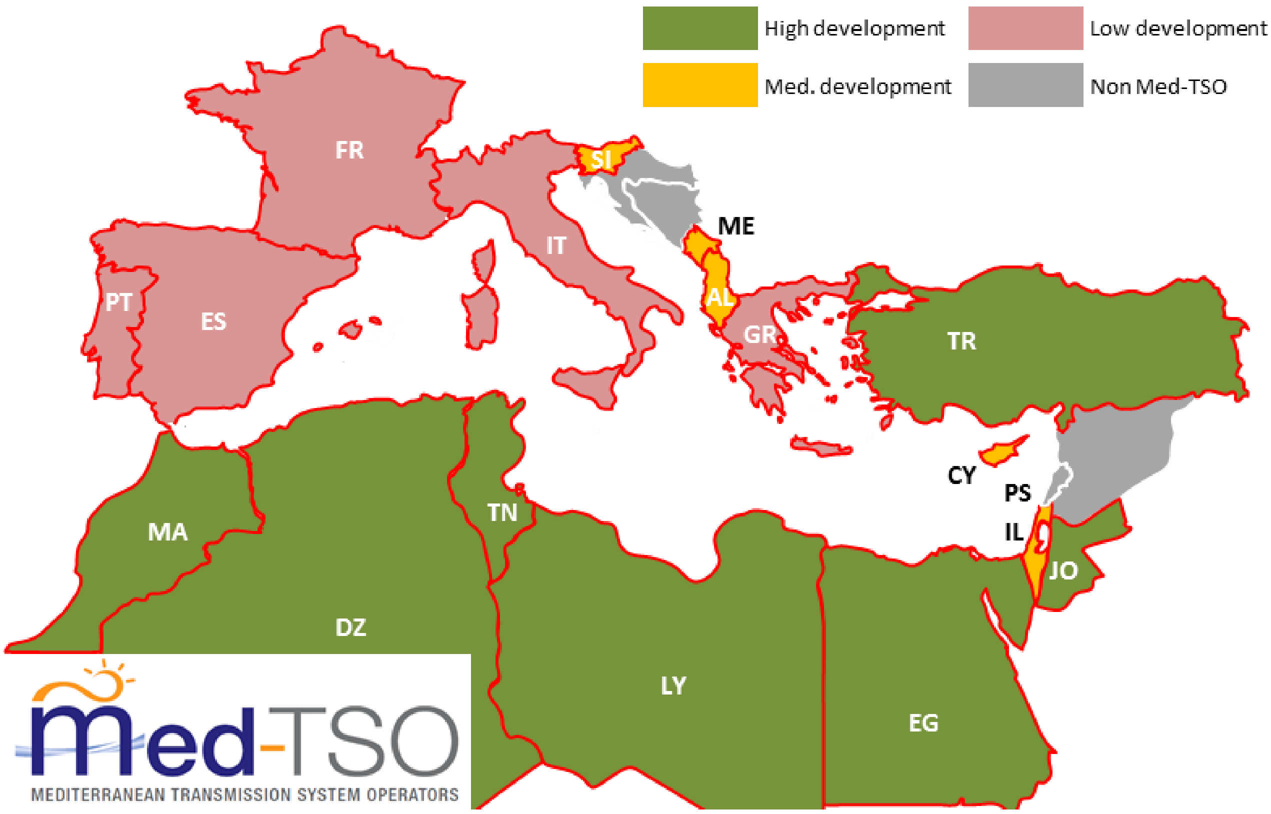

Figure 8 - Historical load evolution 2000 – 2015

[2] Figures from Spain are related to mainland power system (not including Balearic and Canary islands)

In **Figure 8**, the historical load evolution is displayed. According to that, in the Northern bank could be detected countries with a medium/low development rate instead Southern and Eastern shore (except Israel) with a higher development rate. Detailed data are available in appendix.

The Euro-Mediterranean region is also characterized by strong differences in the composition of the national generation mix. To illustrate these differences, the following figures show, for the year 2016, the installed capacity and the production by type of production. The share of Renewable generation is summarized, country by country.

In **Figure 9** and **Figure 10** are shown the ratio of the total installed capacity and a focus on hydro and other renewable power plants for each country. Albania and Montenegro have the higher ratio for what concerns hydro power plants (respectively 95% and 75%), Greece, Portugal and Spain the higher ratio for what concerns the other RES (around 30%).

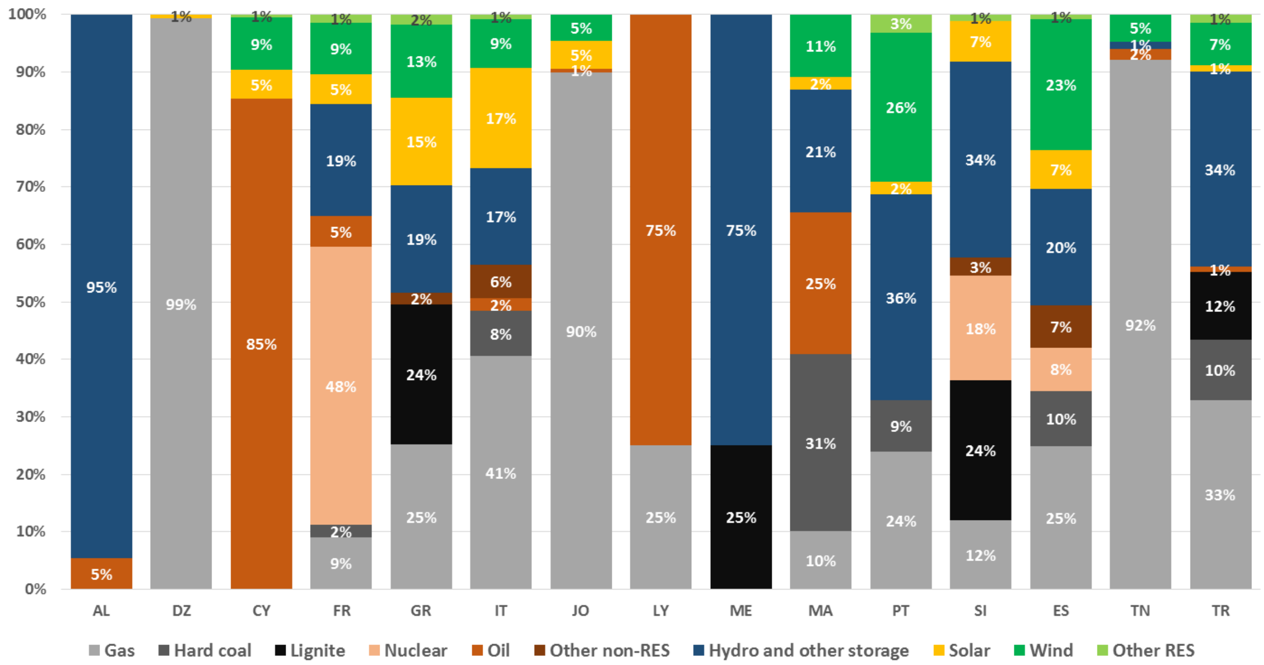

Figure 9 -Installed capacity 2016

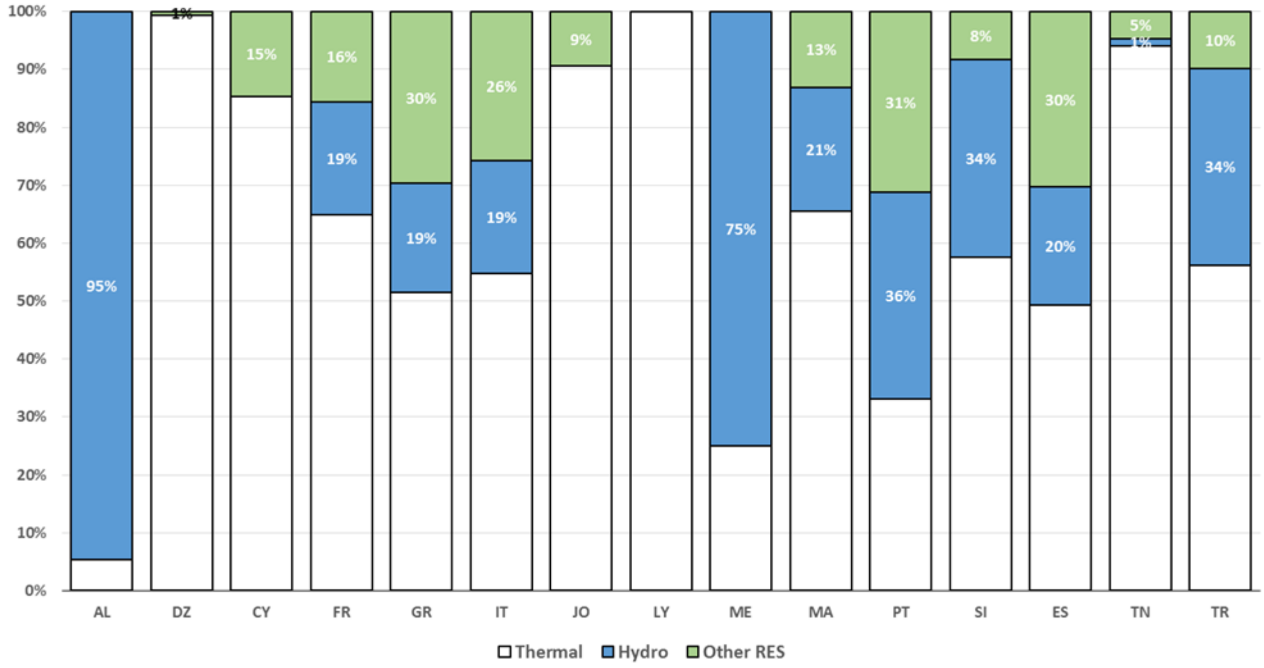

Figure 10 - Installed capacity 2016, RES share.

Same considerations could be done for produced energy (cf. **Figure 11** and **Figure 12**).

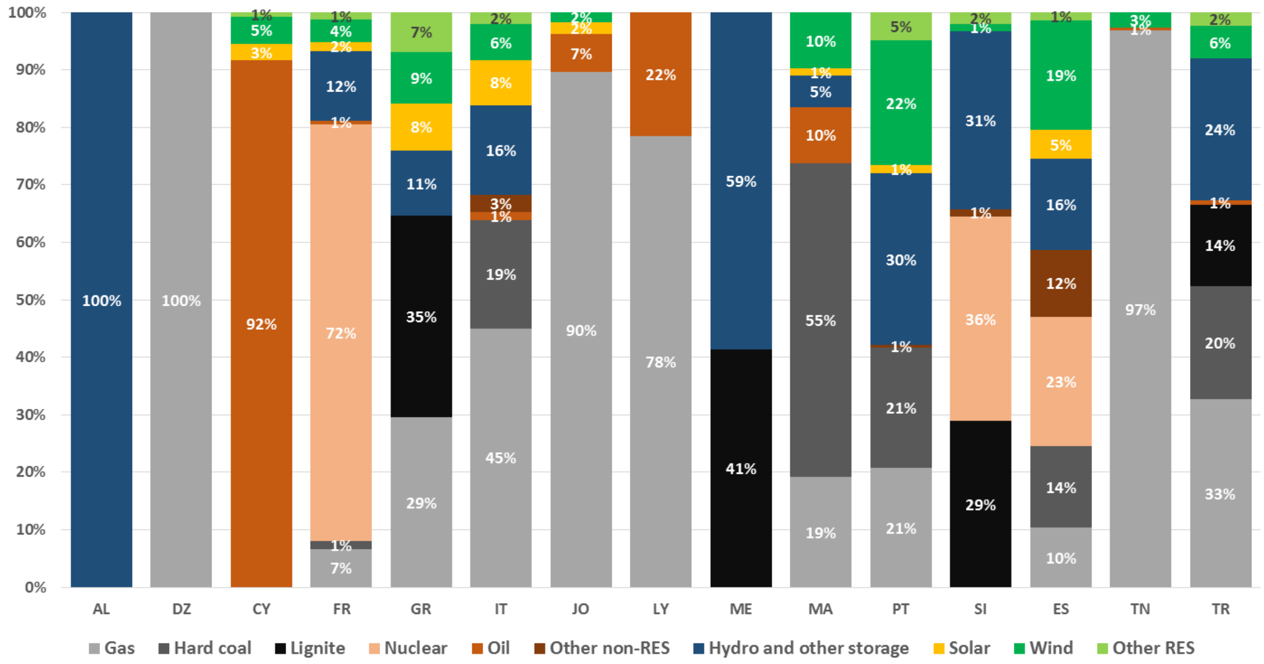

Figure 11 - Generated energy 2016

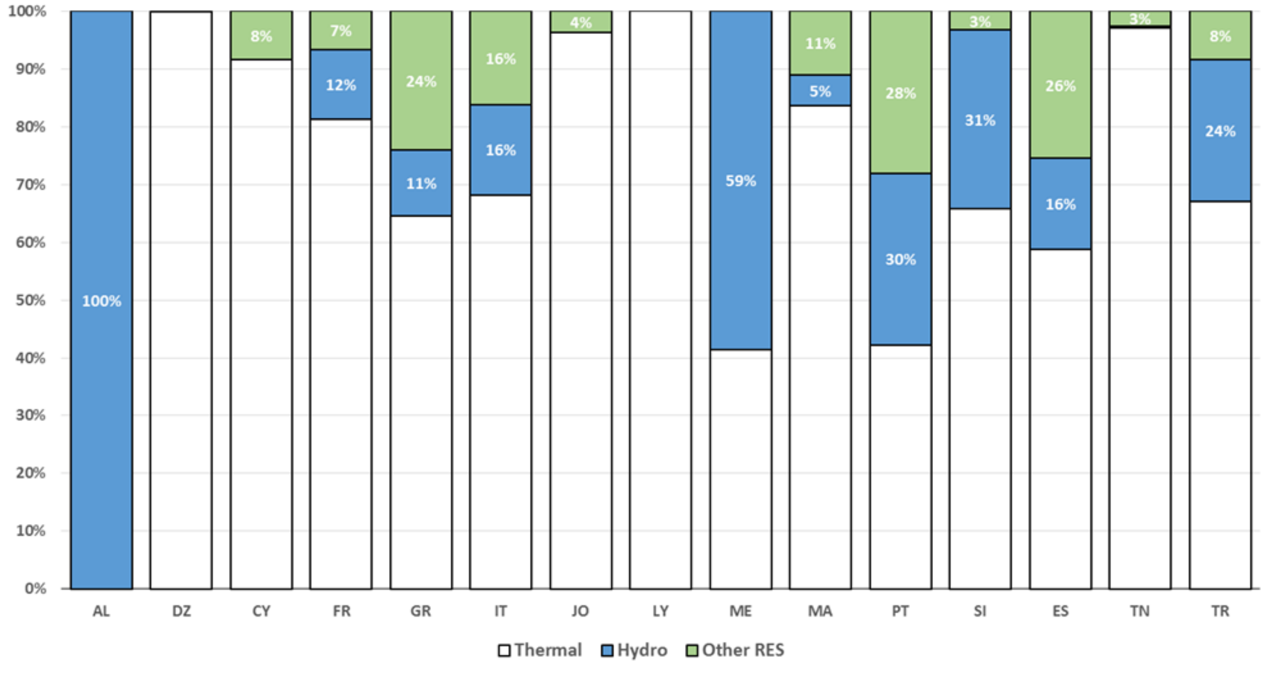

Figure 12 - Generated energy 2016, RES share

In **Figure 13** and **Figure 14** a global picture for Med-TSO countries is given both in terms of RES installed capacity and RES generated energy.

In the perimeter of Med-TSO, the overall generation capacity was aroud 550 GW at end-2016. From that total, RES capacity is 39%, from which 11% of Wind generation and 7% of solar generation.

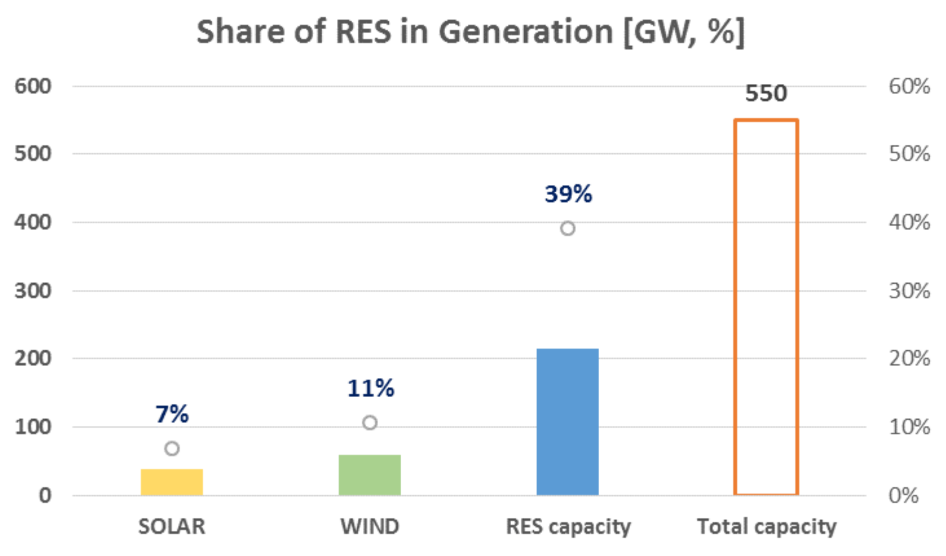

Figure 13 - Installed capacity 2016, RES share.

Solar and wind represent the 18% (around 97 GW) of the total installed capacity.

When looking on yearly generation, the total for Med-TSO perimeter is 1820 TWh, from which one quarter is from renewable generation. Globally, 10% of the electricity produced in Med-TSO countries is provided by wind and solar generation.

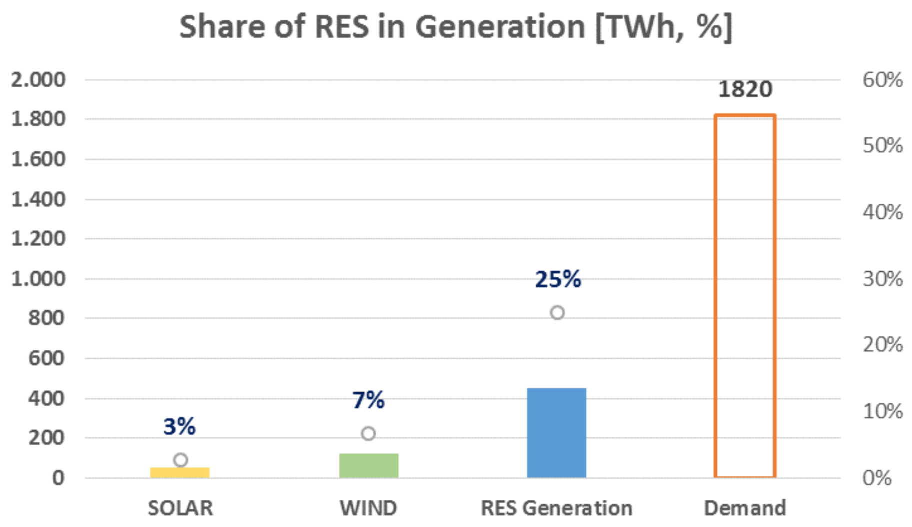

Figure 14 - Generated energy 2016, RES share

To complete the description of the Mediterranean power system, the case of interconnections and exchanges of electricity needs to be addressed. The first point concerns the exchange capacities between countries.

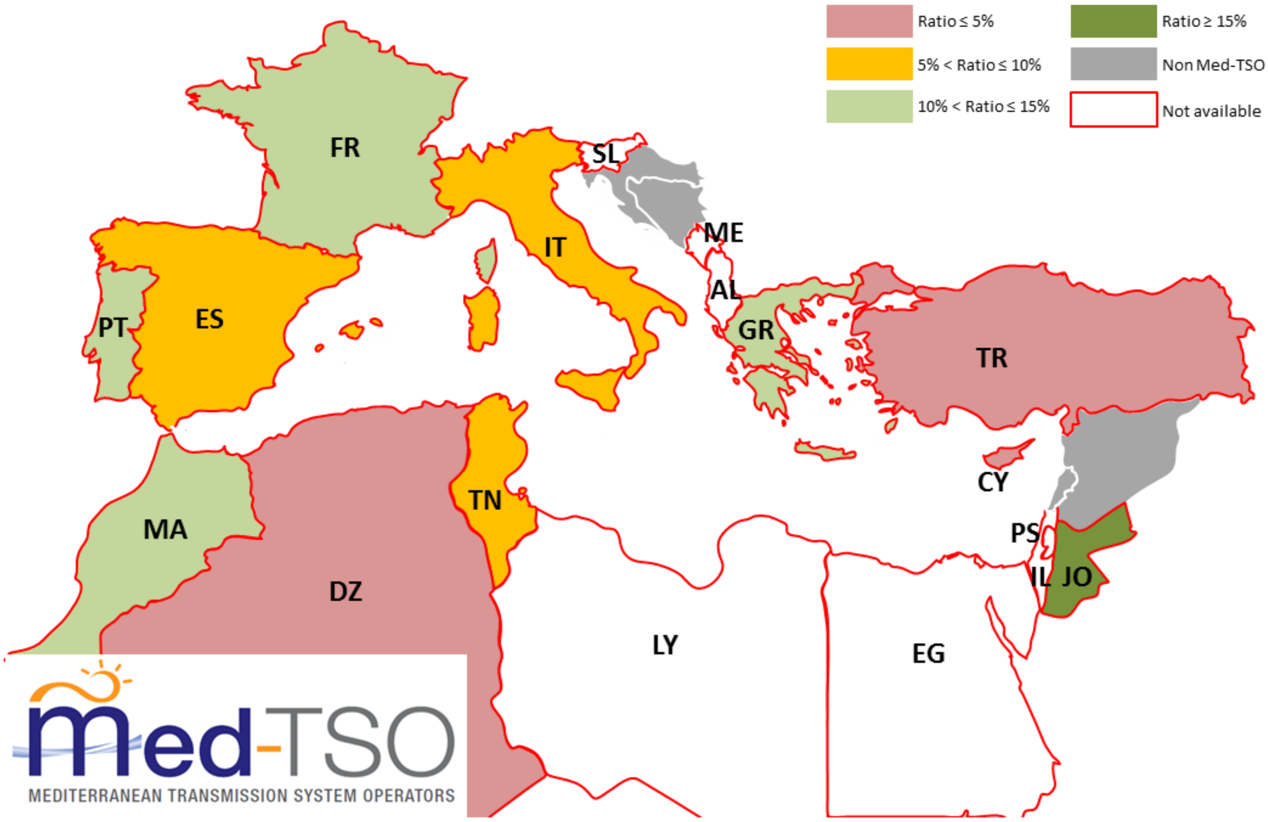

Figure 15 - NTC against total installed capacity, 2016

The **Figure 15** shows the Net Transfer Capacity (NTC) between countries compared to the national installed generation capacity for each country as of 2016.

The second point adresses the use of interconnections during the year 2016 in order to give a global picture of importing and exporting countries.

The **Figure** shows the net country balance for 2016 according to data available in **Table 5**. A threshold of 5% was taken into consideration meaning that countries in which the exchange with other countries is between -5% and +5% respect to the total load are labelled *balanced*, countries with an exchange that is over than +5% are labelled *exporter* and countries with an exchange that is lower than -5% are labelled *importer*.

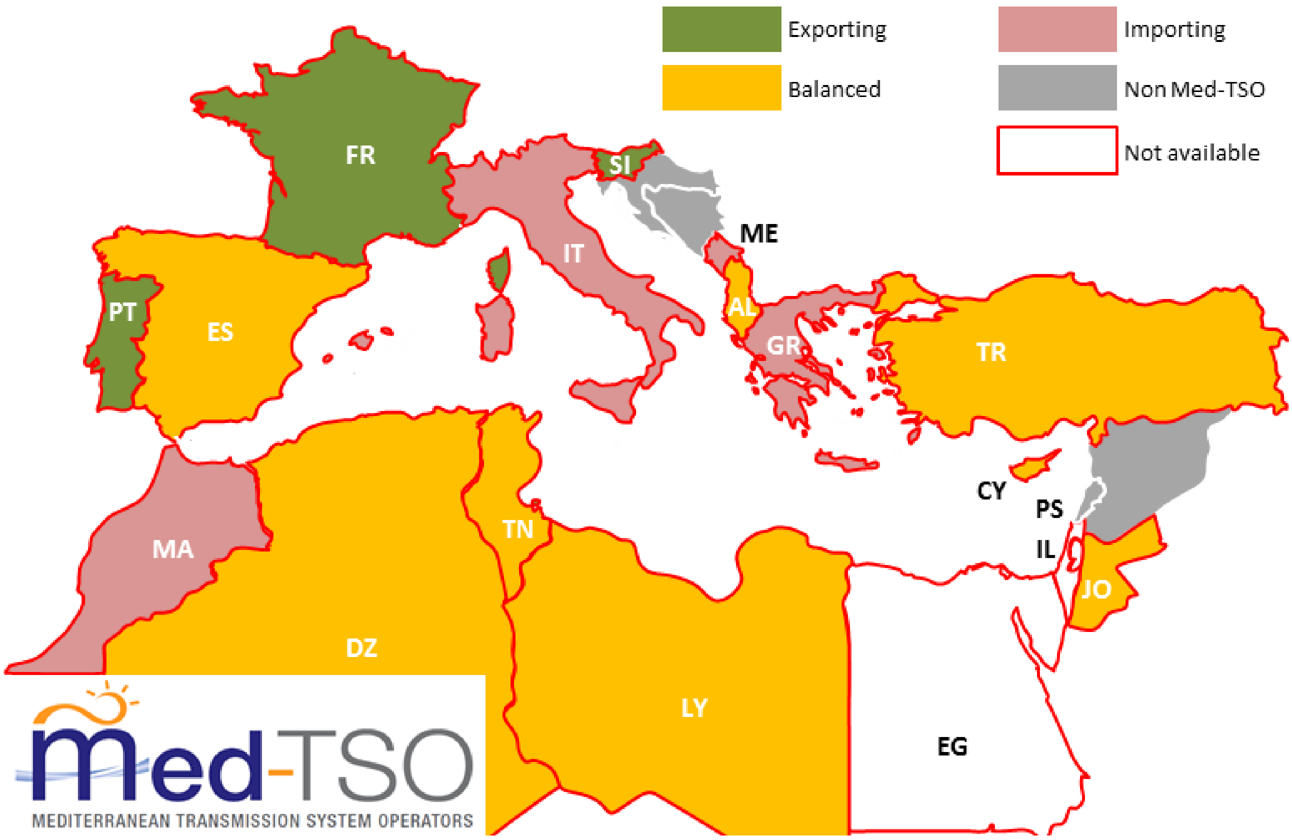

Figure 16 - Balances 2016[3].

For what concerns Spain 2016 has been the first year (since 2003) in which the country has not been a net exporting country due to the new interconnection with France and the increase in the energy coming from Portugal (evolution in Market rules).

[3] Exchanges relate to economic merit order assessments. Importing countries do not necessarily have lack of generation capacity.

Table 5 - Generation – Load – Balances 2016

2016	TOTAL GENERATION (TWh)	Load [TWh]	Pump consumption [TWh]	Exchange balance (Export - Import) [TWh]	Exhange VS Load [%]
Albania AL	6,6	6,6	0,0	0,0	1%
Algeria DZ	64,1	63,9	0,0	0,2	0%
Cyprus CY	4,9	4,9	0,0	0,0	0%
France FR	531,3	482,9	6,8	41,6	9%
Greece GR	42,4	51,2	0,0	-8,8	-17%
Italy IT	279,7	314,3	2,5	-37,1	-12%
Jordan JO	18,3	18,6	0,0	-0,3	-2%
Libya LY	36,4	36,4	0,0	0,0	0%
Montenegro ME	2,9	3,2	0,0	-0,3	-9%
Morocco MA	30,8	35,4	0,6	-5,2	-15%
Portugal PT	55,9	49,3	1,5	5,1	10%
Slovenia SI	15,2	13,8	0,4	1,0	7%
Spain ES	248,4	250,0	4,8	-6,4	-3%
Tunisia TN	18,2	18,1	0,0	0,1	1%
Turkey TR	274,4	279,3	0,0	-4,9	-2%

5 Input dataset at 2030 target year

In the following a brief overview of the input dataset will be given. In particular for each scenario it is investigated: the load evolution, the generation installed capacity and the interconnection with other countries.

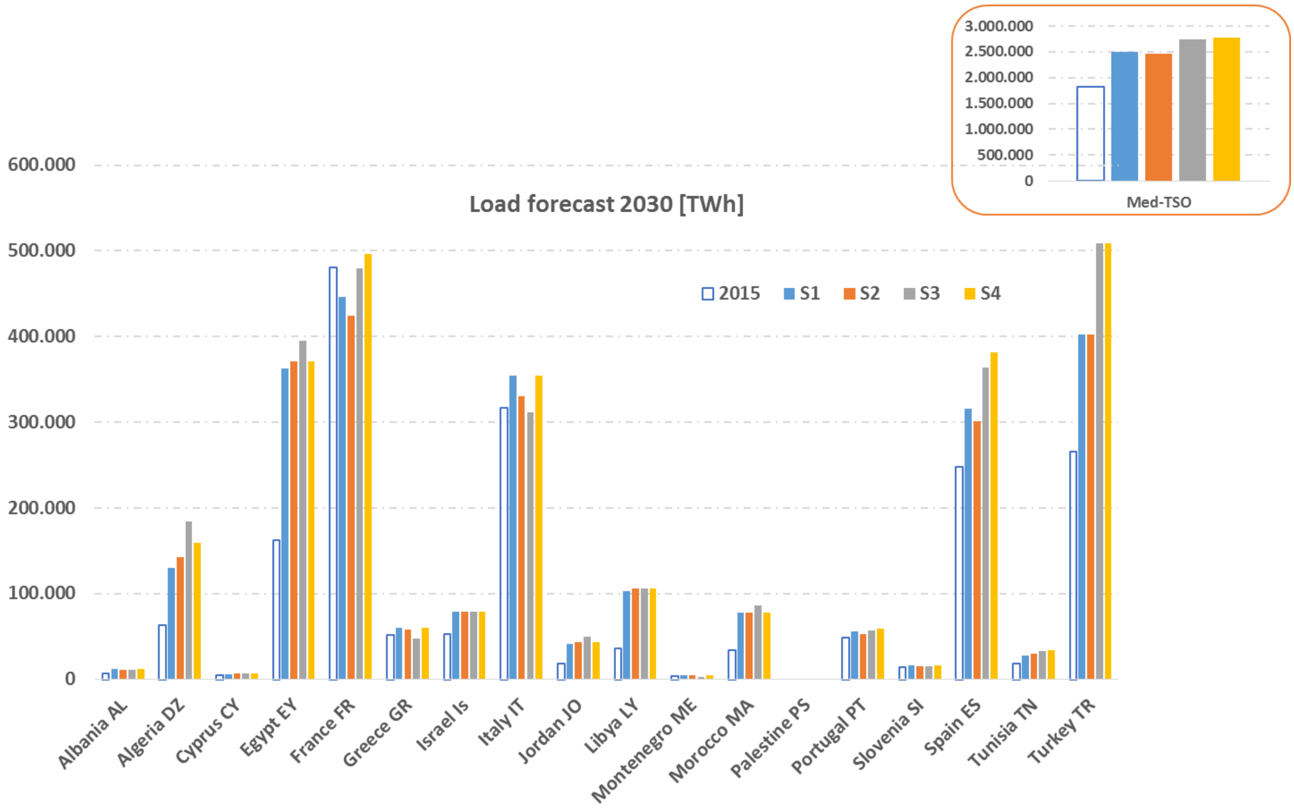

Figure 7 - Load forecast per scenario at 2030 target year.

The **7** shows the load values for each country and each scenario: 2015 value are given just for reference. Globally the scenarios 3 and 4 consider a higher development of electricity sector because of new electricity uses like public transportation. CAGR against 2015 value are between 2% and 3%. More details are given in **Table 6** and **Table 7**.

Table 6 - Load evolution

Annual Load (TWh)	2015	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Med-TSO	***1825***	**2496**	**2457**	**2737**	**2772**
Albania AL	*7*	12	11	11	12
Algeria DZ	*63*	130	143	185	160
Cyprus CY	*5*	6	7	7	7
Egypt EY[4]	*162*	363	371	395	371
France FR	*481*	446	425	479	496
Greece GR	*51*	60	57	48	60
Israel IS	*524*	78	78	78	78
Italy IT	*317*	354	330	311	355
Jordan JO	*19*	41	43	49	43
Libya LY	*36*	103	106	106	106
Montenegro ME	*3*	5	4	3	5
Morocco MA	*34*	78	78	86	78
Portugal PT	*49*	56	53	57	59
Slovenia SI	*14*	16	15	15	16
Spain ES	*248*	316	301	364	381
Tunisia TN	*18*	28	30	33	34
Turkey TR	*266*	403	403	509	509

Table 7 - CAGR at 2030 target year

CAGR 2015-2030	Med-TSO	AL	DZ	CY	EY	FR	GR	IS	IT
S1	2%	3%	5%	2%	5%	0%	1%	3%	1%
S2	2%	3%	5%	3%	5%	-1%	1%	3%	0%
S3	3%	3%	7%	2%	6%	0%	0%	3%	0%
S4	3%	3%	6%	3%	5%	0%	1%	3%	1%
CAGR 2015-2030	**JO**	**LY**	**ME**	**MA**	**PT**	**SI**	**ES**	**TN**	**TR**
S1	5%	7%	2%	5%	1%	1%	2%	3%	3%
S2	5%	7%	1%	5%	1%	1%	1%	3%	3%
S3	6%	7%	-1%	6%	1%	1%	2%	4%	4%
S4	5%	7%	2%	5%	1%	1%	3%	4%	4%

[4] For Egypt and Israel the last available data is for 2014.

In the following it is presented a focus on RES development in terms of installed capacity (**Figure 18**, **Figure 19**).

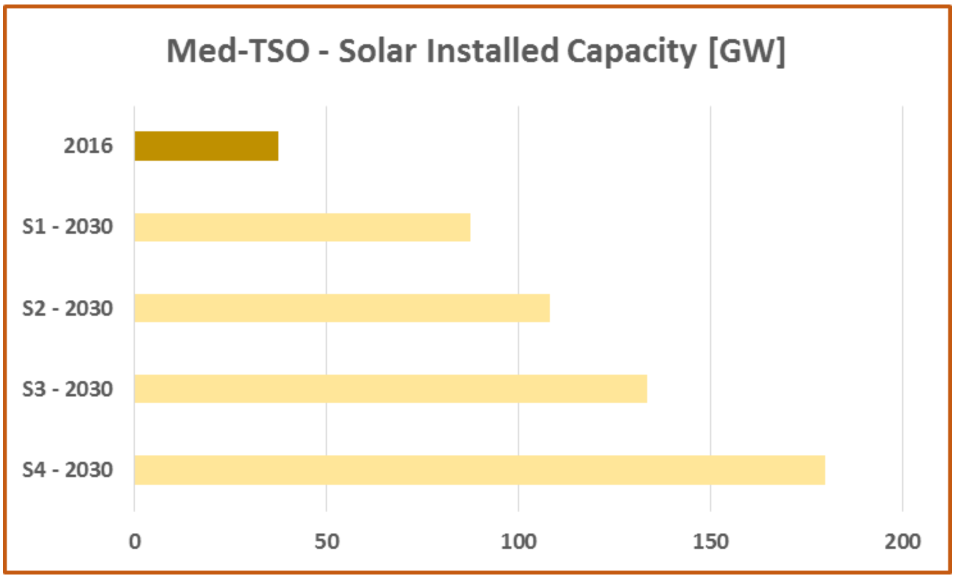

Figure 8 - Solar Installed capacity 2016 VS 2030 scenarios

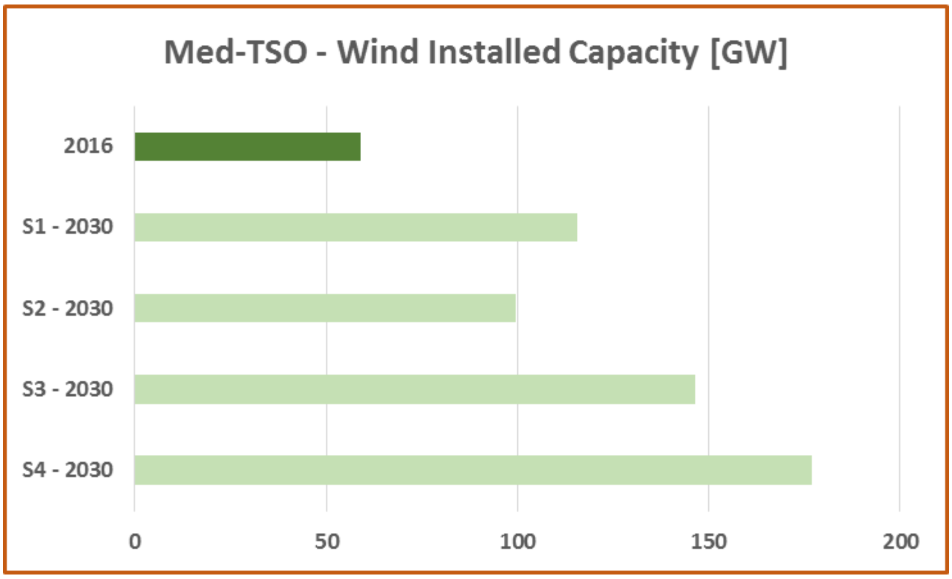

Figure 9 - Wind Installed capacity 2016 VS 2030 scenarios

In term of installed capacity solar increases from 2016 between 2 and 5 times and wind between 1,7 and 3 times, depending on the scenario.

The **Figure** 20**20** shows the share of RES in Generation Capacity for the whole Med-TSO permimeter.

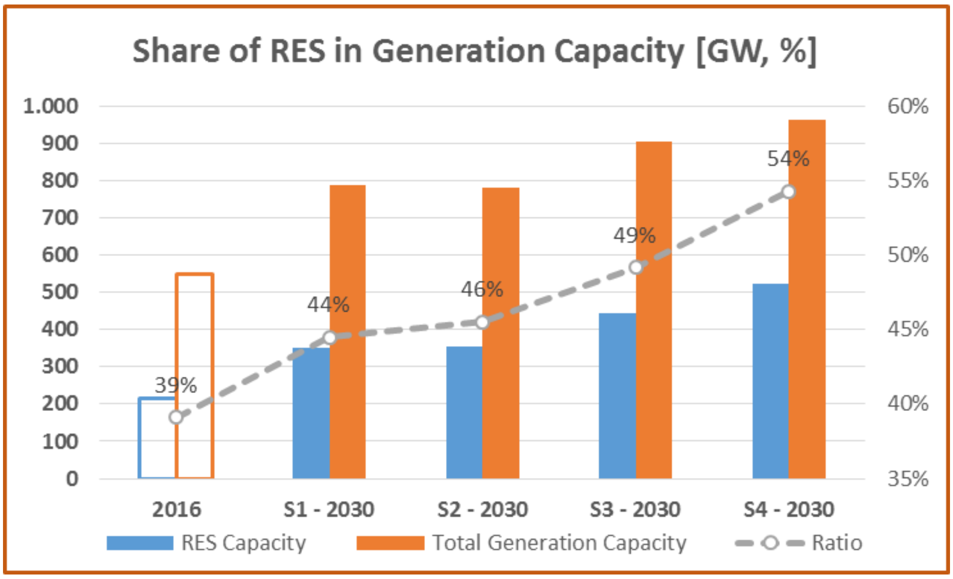

Figure 20 - Installed capacity 2016 VS 2030 scenarios, RES share against total installed capacity

Total share of RES installed capacity increases from 39% of 2016 up to 54% of S4-2030.

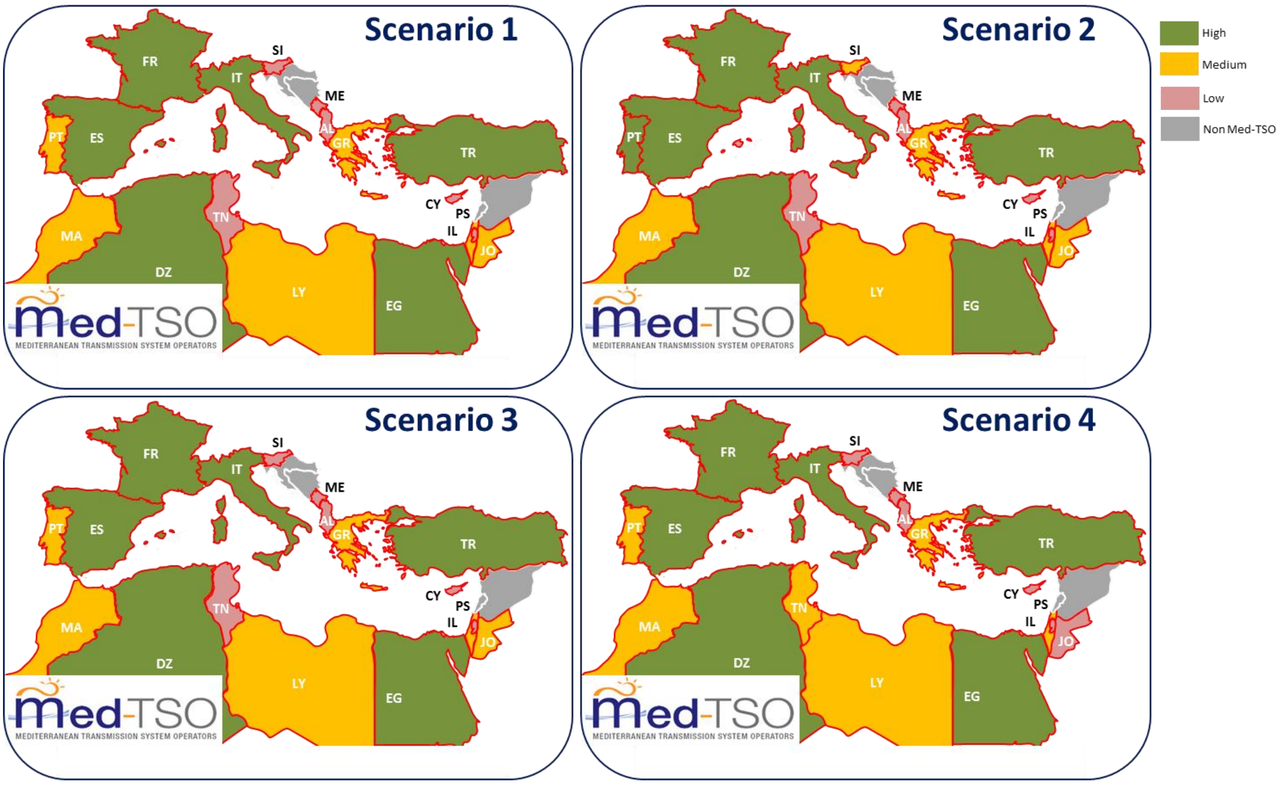

Figure 16 - Installed Capacity at 2030 target year

In the **Figure 16** it is shown the total installed capacity for each scenario and each country. In particular, the color code is according to the distribution of installed capacity in each scenario: red is for countries with an installed capacity less or equal to 35°, yellow for an installed capacity higher than 35° and up to 65°, green for an installed capacity higher than 65°. In particular, the figure illustrates countries with higher installed capacity (e.g. France, Algeria and Turkey) against countries with lower installed capacity (e.g. Montenegro and Albania). The choice of percentile instead of a simple percentage is due to the high differences in installed capacity country by country (e.g. for scenario 1, France has an installed capacity of about 130 GW rather than Montenegro that has an installed capacity less than 2 GW). More detail are showed in the **Table 8**.

Table 8 - Percentile for each scenario, GW

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
35° Percentile	10,6	11,5	10,9	12,9
65° Percentile	25,6	25,0	29,0	34,6

The detailed description of Generation capacity by country and by scenario is available in appendix.

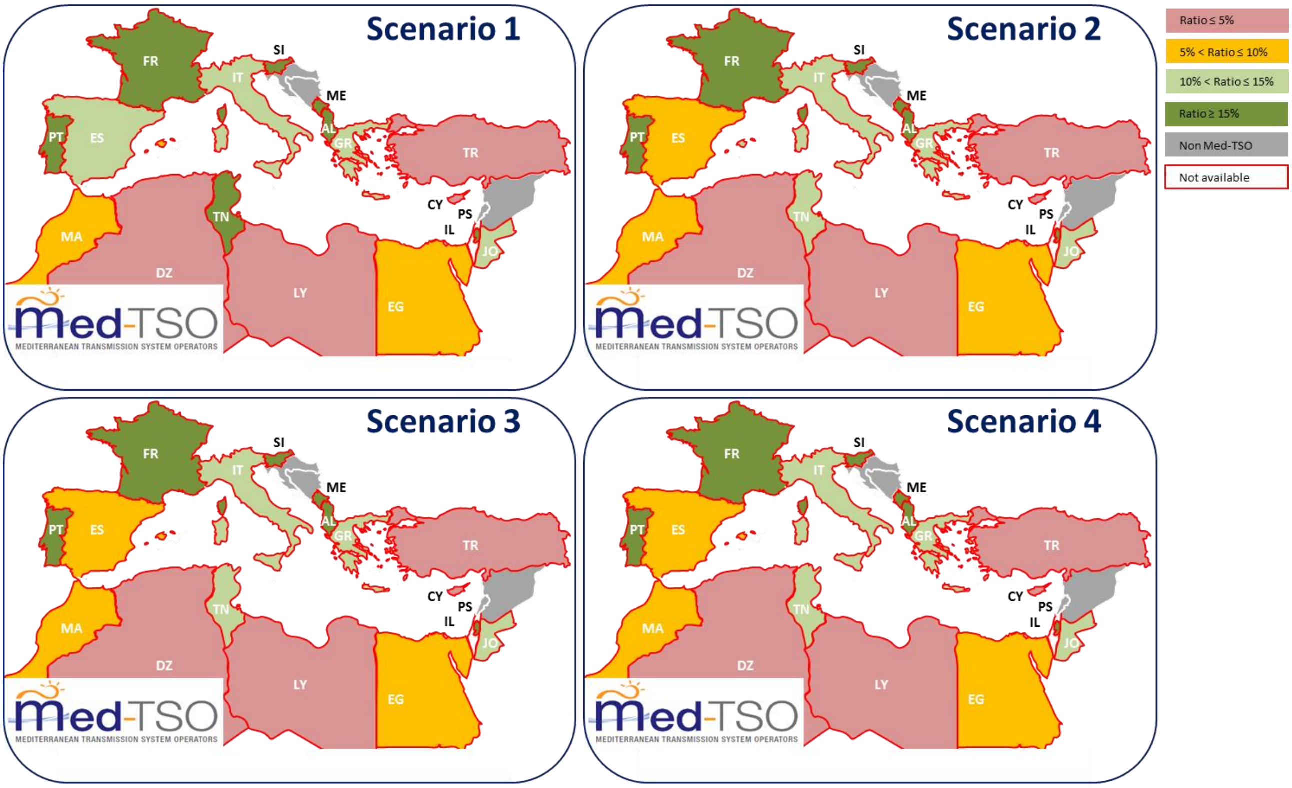

Figure 17 - NTC against total installed capacity, 2030

The **Figure 17** shows the NTC against total installed capacity for each country at the target year 2030 for each scenario. Globally, comparing the same data of **Figure 15** for the year 2016, interconnection will develop more than the installed capacity.

6 Macroeconomic Model building and results

The analysis of the scenarios has to quantify possible benefits related to investment projects, focusing on the Med-TSO member countries in order to improve transmission capacity and achieve benefits for the transmission system as a whole. The methodology used to calculate the benefits and its share between systems is based on:

- The assumptions that are adopted for future generation costs (CAPEX&OPEX, in particular fuel and CO2 emission prices)
- The assumptions that are adopted with respect to the regulatory model governing the electricity interchanges; a perfectly concurrent market is assumed.

The target has be accomplished through the application of simulation models carrying out an optimal coordinated hydrothermal scheduling of the modeled electric system generation set (after having considered solar and wind production as 100% pass through in the merit order), over a period of one year. The simulation tool implements an efficient energy market for the whole Med-TSO area, characterized by a zonal market and by a congestion management based on a zonal market-splitting. In order to simplify the calculations, market zones has been reduced to one per country.

An adequate tool to simulate competition in future market scenarios has been adopted considering thermal generation units, pumped-storage hydro power plants, and several equivalents for reservoir and for run-of-river hydro power plants, depending on data availability.

Considering both technical constraints for generation units and transmission constraints between market zones the method has provided robust quantitative outputs on generation dispatching and market prices.

For all generation units the market simulation tool has provided total production, cost, and number of hour of service and CO_2 emissions.

Possible over generation problems due to RES integration are assumed to be managed by the minimal curtailments in production (once all storage and export possibilities have been used up).

A Monte Carlo approach applied to the availability of generating units and to interconnection capacity has been considered suitable for the evaluation of the security of supply for the electric system under study and to provide information about limiting elements, contingencies, and main security of supply indicators.

6.1 Methodology to build the complete model

The model for year 2030 includes the following Med-TSO countries: Albania, Algeria, Cyprus, Egypt, France, Greece, Israel, Libya, Montenegro, Italy (which is split between North and South), Jordan, Morocco, Palestine, Portugal, Slovenia, Spain, Tunisia, and Turkey.

The model includes also the following non Med-TSO countries to complete the European model: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark Dke, Denmark DKw, Estonia, Estonia, Finland, FYROM, GB Northern Ireland, Germany, Great Britain, Herzegovina, Hungary, Ireland, Latvia, Lebanon, Lithuania, Luxemburg Lub, Luxemburg Luf, Luxemburg Lug, Norway, Poland, Romania, Serbia, Slovak Republic, Sweden, Switzerland, Syria, and The Netherlands.

The model of each country is an equivalent bus-bar without the detail of the transmission grid. For each country 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, photovoltaic power plants) are specified.

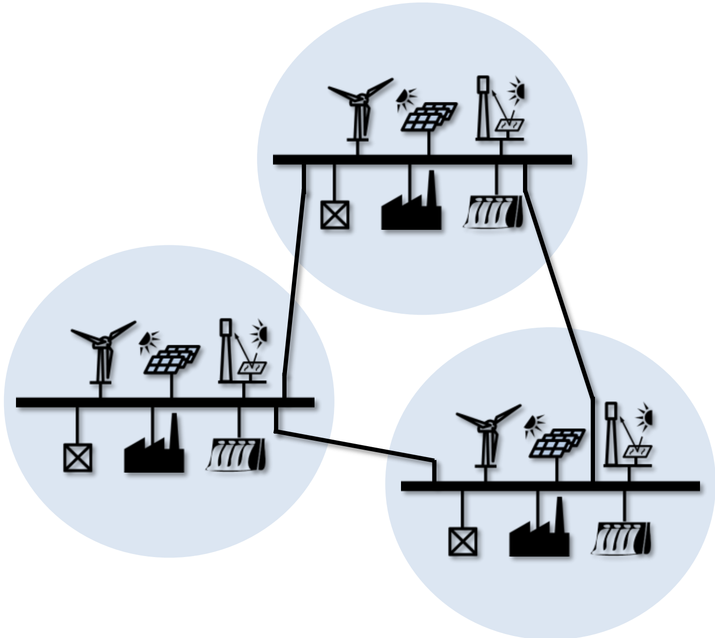

Figure 18 - Example of bus-bar model

Every interconnected country has a bilateral transfer capacity with neighboring countries that helps to guarantee the security of the electricity supply power system and allows economic exchanges of electricity.

6.2 Load model and weekly diagrams

The load model for the probabilistic analysis is based on the data provided by the member TSOs.

The variation of the system load during the year is represented by means of a succession of weekly curves on an hourly basis. The year has been divided into 52 weeks, each composed by 168 steps (one of each hour of the week).

The yearly load distribution of each country is obtained considering a single year calendar that associates a specific load diagram to the i-th week of the year.

6.3 Generation

In the probabilistic model adopted for the analyses, the generation is divided in four macro-categories: dispatchable power plants, imposed, wind farms and photovoltaic power plants. The first one includes units with cost functions that determine their optimal dispatching with the minimum costs criterion, while the second one includes units modeled with production profiles imposed over the year. Instead, wind and photovoltaic power plants, characterized by the uncertainty of production, exploit producibility curves and random draws by Monte Carlo method. The random draws of power productions from the probability curves allow to consider many different production figures for the same analyzed week. In this way the system reliability is less affected by imposed profiles, especially in systems with large amounts of PV and wind installed capacities.

This model has been adopted for all the Med-TSO countries; on the contrary, for the ENTSO-E non Med-TSO countries, RES production has been considered by imposed profiles.

6.3.1 Dispatchable generation

The dispatchable generation has been modeled with its overall installed capacity and the fuel type: a linear curve of power production cost, needed to evaluate the units turned on (dispatched), has been assumed, together with the rate of forced unavailability and the maintenance duration.

The economic operation and the management of the generation fleet during the year are achieved by the program in order to provide a minimum cost production. In particular, about the planned outage (maintenance) of generation units, the probabilistic model allows an optimized maintenance plan on the basis of the number of weeks during the year. In the optimization tool, for every week, the comparison between the available power generation and the peak load, considering also a reserve margin together with the type of energy source and the maximum percentage of overall plants, returns the period in which the units can be put out of service for maintenance. Instead the forced outage rate is considered by a Monte Carlo approach on a random basis.

6.3.2 Not-Dispatchable generation

The imposed generation production takes into account the economical dispatching as well as the availability of the primary source and the particular dispatching contracts.

The types of not-dispatchable power plant simulated in the study are the following:

- hydro power plants;
- wind on-shore and off-shore farms;
- photovoltaic e solar thermal power plants;
- other RES and other Non-RES.

Hydro Power Plants

The hydro power plants have been modelled as follow.

- Run of River plants refer to imposed profiles;
- the other hydro units production is optimized taking into account the volume of the tank, the inflow and the pumping capacity. The optimization of Morocco hydro generation refers also to three different hydro conditions provided by the country (wet, normal and dry), that are defined with a different probability of occurrence.

Wind Power Plants

Wind power plants have more complex models to take into account the uncertainty in power production.

Wind generation is modelled using producibility diagrams, and applying a Monte Carlo approach to extract the production values.

The power availability and its randomness are represented by a sequence of a maximum of 10 typical weekly diagrams showing the cumulative power availability function. The "standard weeks" are distinguished by the average power availability value and its variance. The sequence of weekly diagrams allows seasonal variability to be modelled.

Photovoltaic Power Plants

Photovoltaic and solar thermal generation is modelled with an approach quite similar to the wind generation. The typical curves shown in **Figure 19** are applied at each power plant together with their producibility distribution functions that allow to model the unpredictability of power production by means of Monte Carlo extractions.

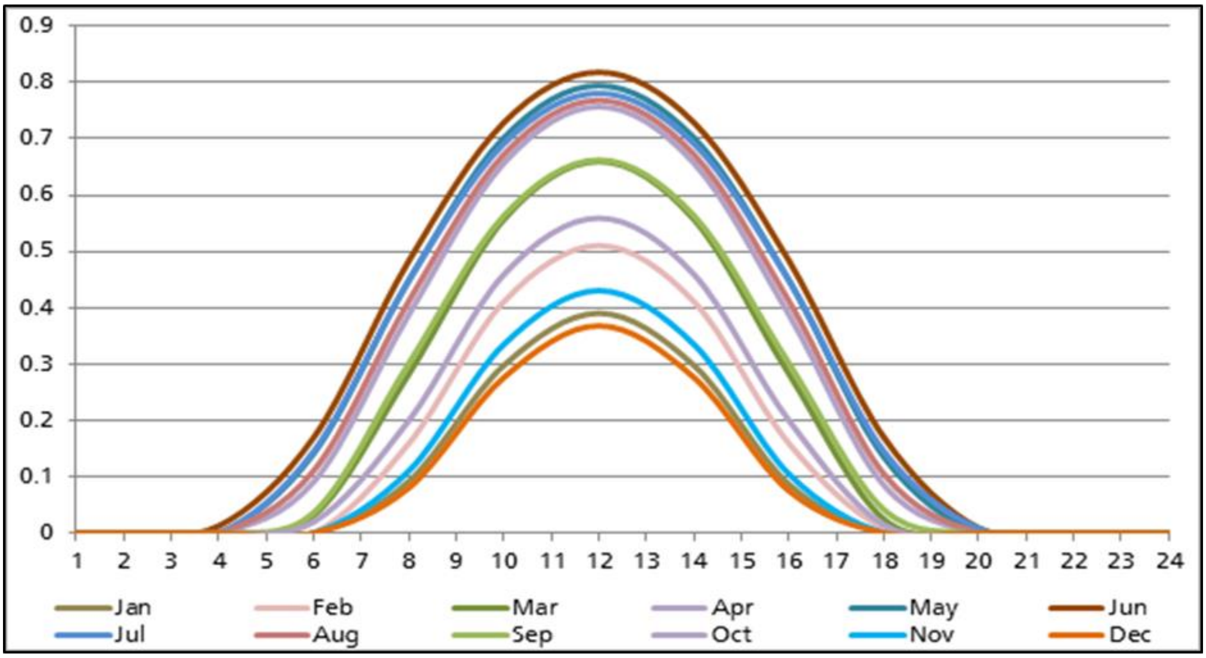

Figure 19 - Typical monthly average daily PV productions (p.u.)

Other RES and other Non-RES

The other RES and other Non-RES power plants have been modelled with yearly production curves that refer to the provided data. The yearly production distribution of each power plant is obtained considering a single yearly calendar that associates a specific production diagram to the i-th week of the year.

Reserve model

The reserve adopted for the analyses consider the data provided by the countries. A fixed value of reserve is imposed during unit commitment phase to allow the system to face unexpected unavailability of generating units.

7 Scenario quantification results

Based on the storyline and the assumptions of the scenarios, and the methodologies previously summarized, quantification of the final Med-TSO 2030 Market model is described in this section.

The **Figure 20** shows the net country balance for 2030 for each scenario. As of in the **Figure ,** a threshold of 5% was taken into consideration meaning that countries in which the exchange with other countries is between -5% and +5% respect to the total load are labelled *balanced*, countries with an exchange that is over than +5% are labelled *exporter* and countries with an exchange that is lower than -5% are labelled *importer*.

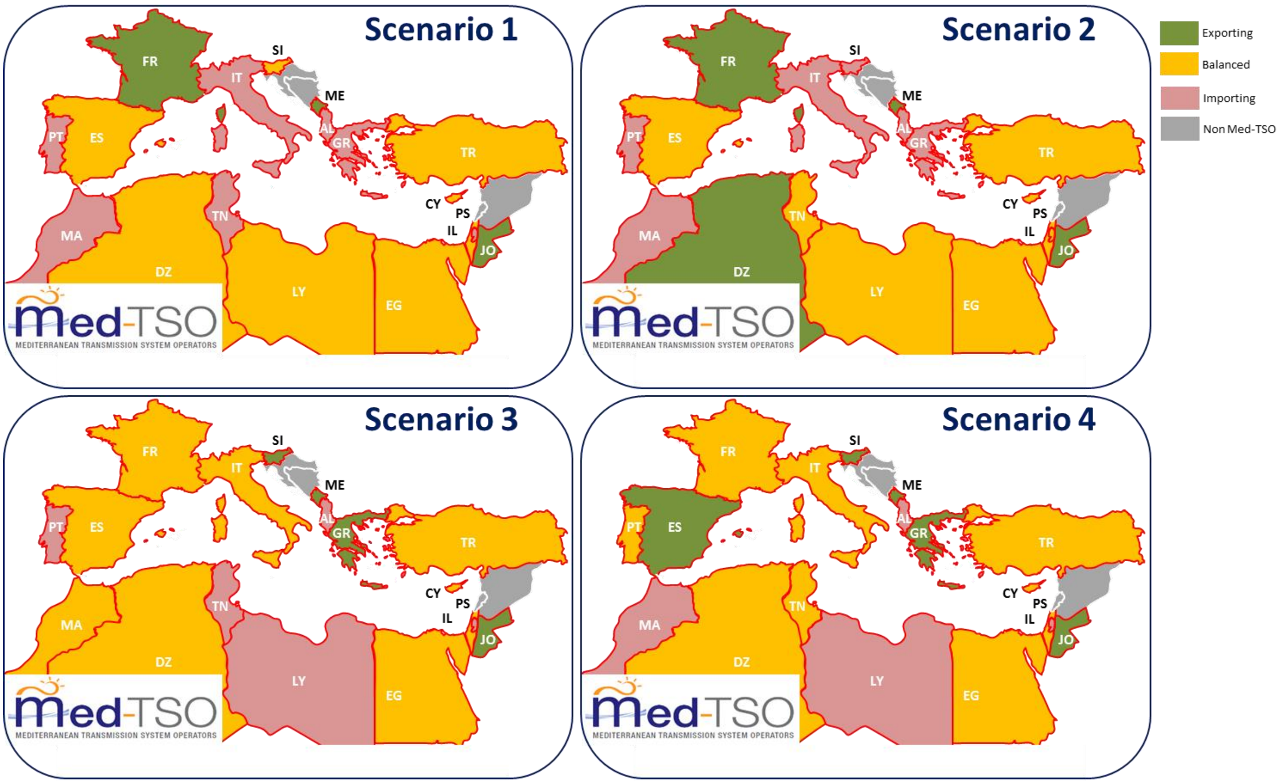

Figure 20 - Balances 2030

The **Figure 20** shows that Italy is an importing country in Scenario 1 and 2 and a balanced country in Scenario 3 and 4 due to the fact that there is a huge increase in both installed capacity and generated energy from RES.

France is an exporting country in Scenario 1 and 2 and a balanced country in Scenario 3 and 4 due to the fact that there is an increase in demand with a lower production from nuclear power plants.

The **Figure 21** to **Figure 24** show in detail for each scenario the border exchanges, in annual energy (arrows in the two directions) and in saturation time (hours by year in the two directions).

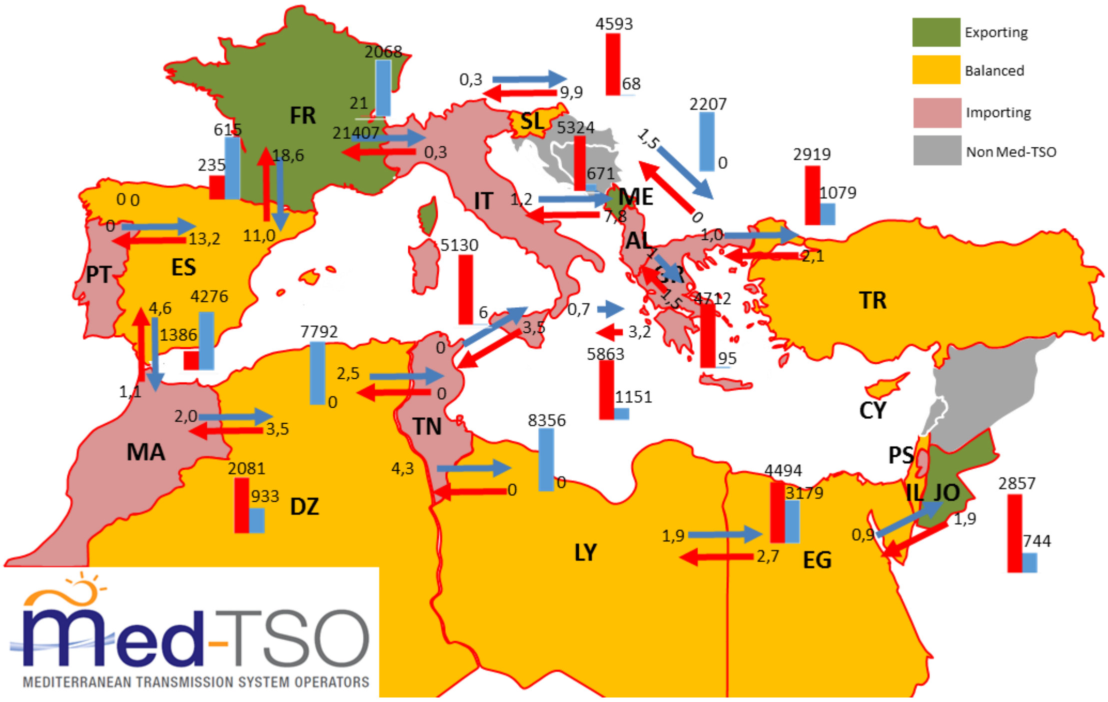

Figure 21 - Exchanges [TWh] and saturation hours [hh], Scenario 1

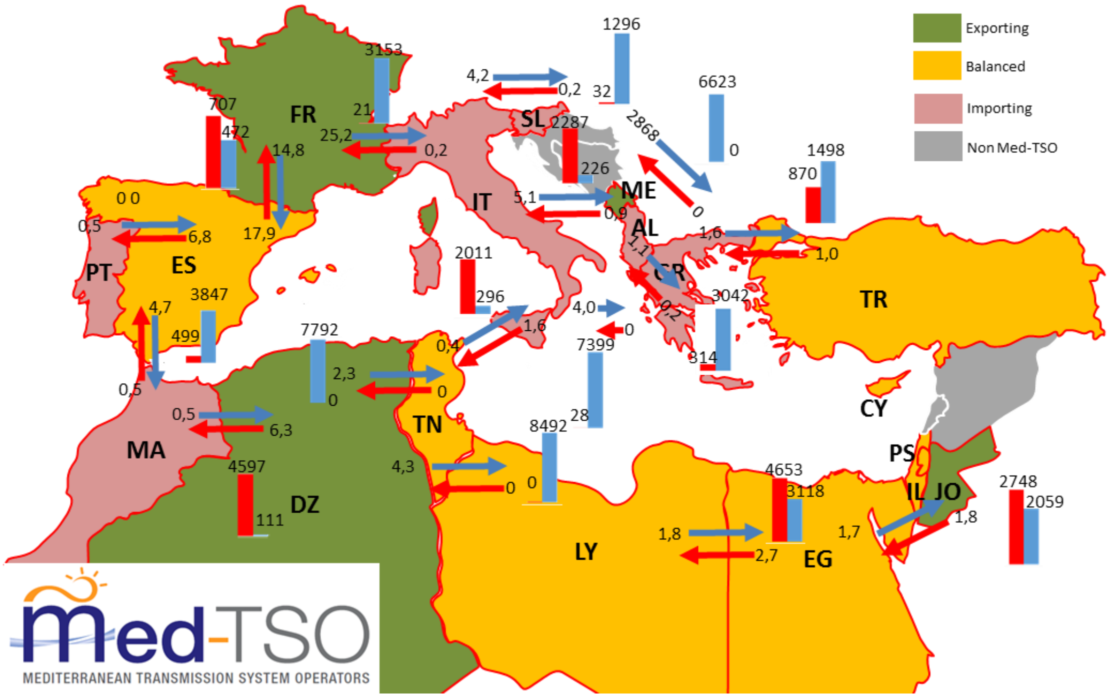

Figure 22 - Exchanges [TWh] and saturation hours [hh], Scenario 2

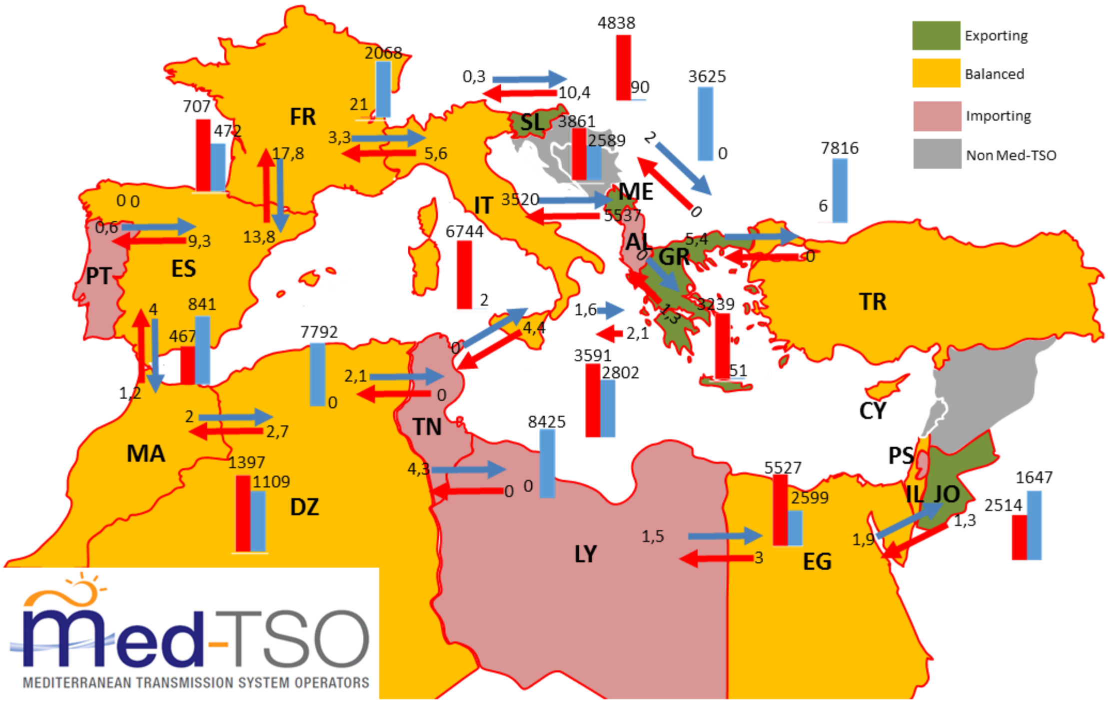

Figure 23 - Exchanges [TWh] and saturation hours [hh], Scenario 3

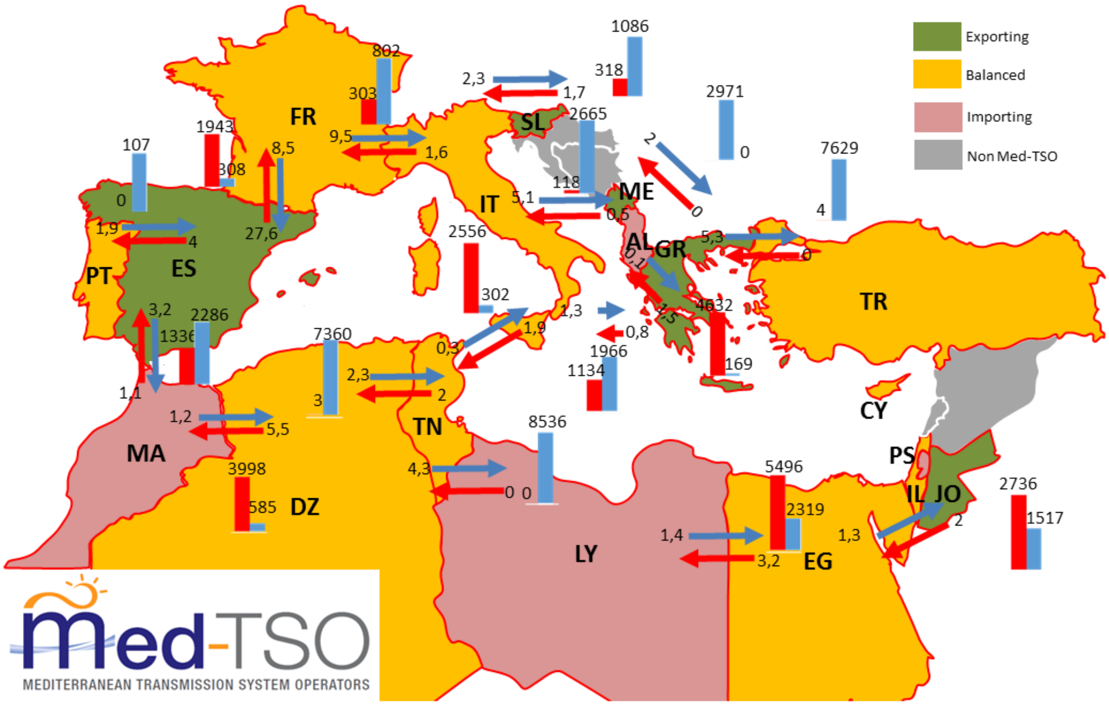

Figure 24 - Exchanges [TWh] and saturation hours [hh], Scenario 4

In the **Figure 30** are showed the price bands for each scenario and each country. In particular, the color code is according the distribution of prices in each scenario: green is for countries with a price less or equal to 35°, yellow for a price higher than 35° and up to 65°, red for a price higher than 65°.

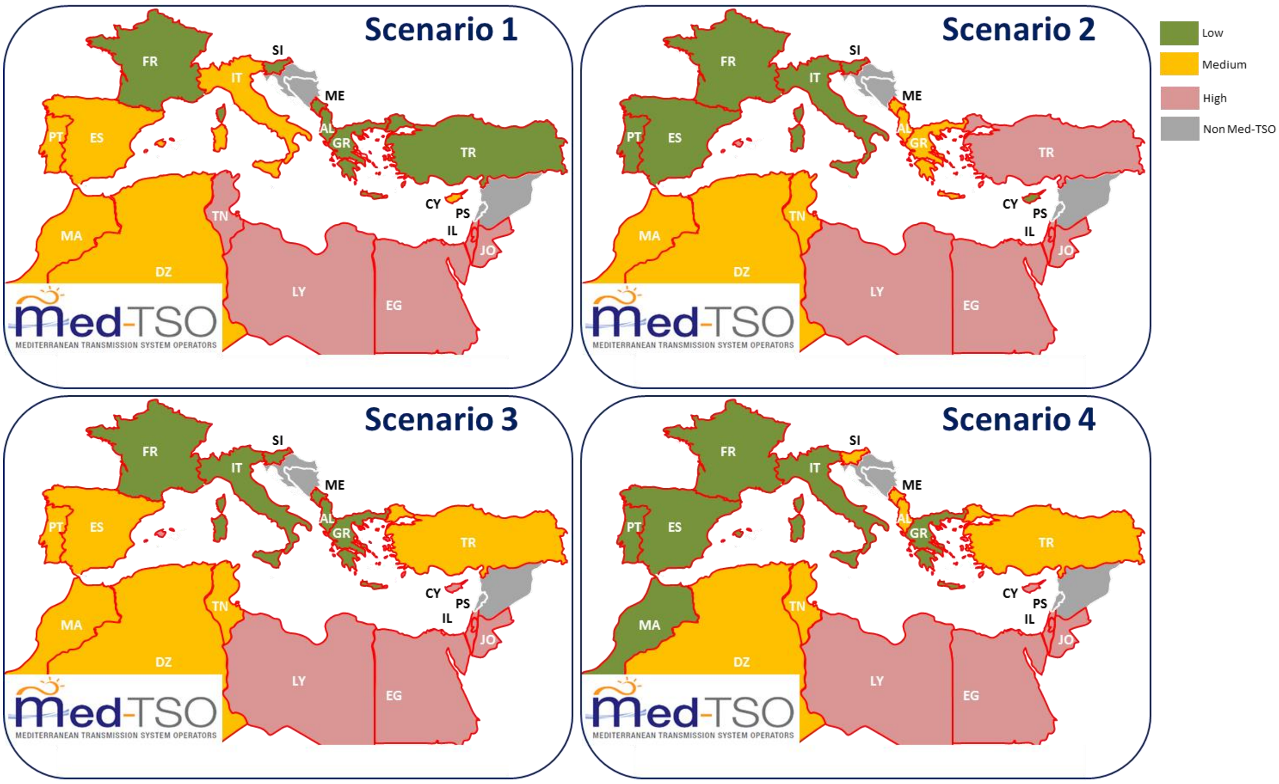

Figure 30 - Prices 2030.

More detail are showed in the **Table 9**.

Table 9 - Percentile for each scenario, €/MWh.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
35° Percentile	**52,5**	**67,5**	**53,6**	**69,0**
65° Percentile	**65,8**	**76,6**	**68,6**	**80,4**

In the following is presented a focus on RES development in term of generated energy (**Figure 25**, **Figure 26** and **Figure 27**).

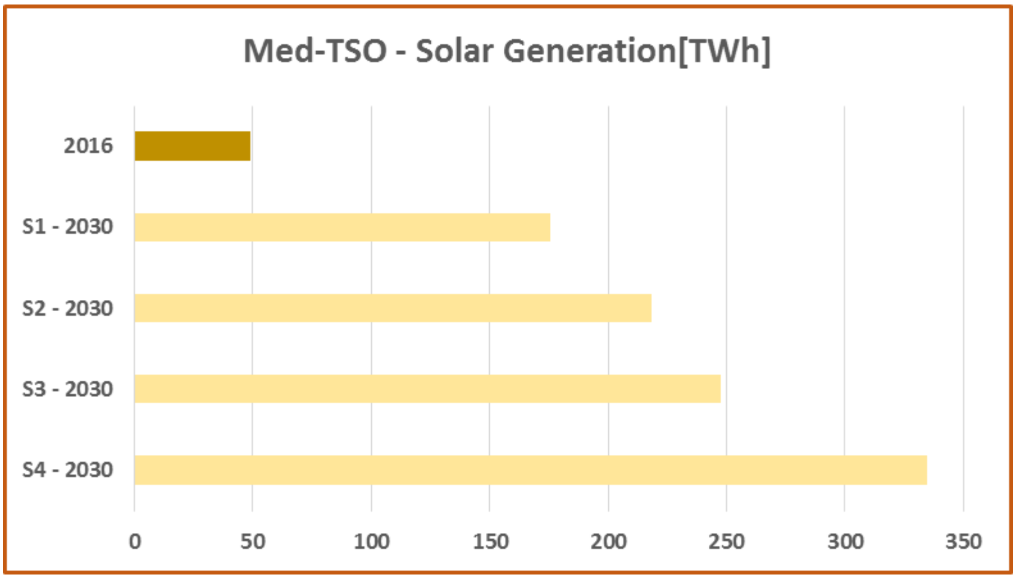

Figure 25 - Solar generation 2016 VS 2030 scenarios

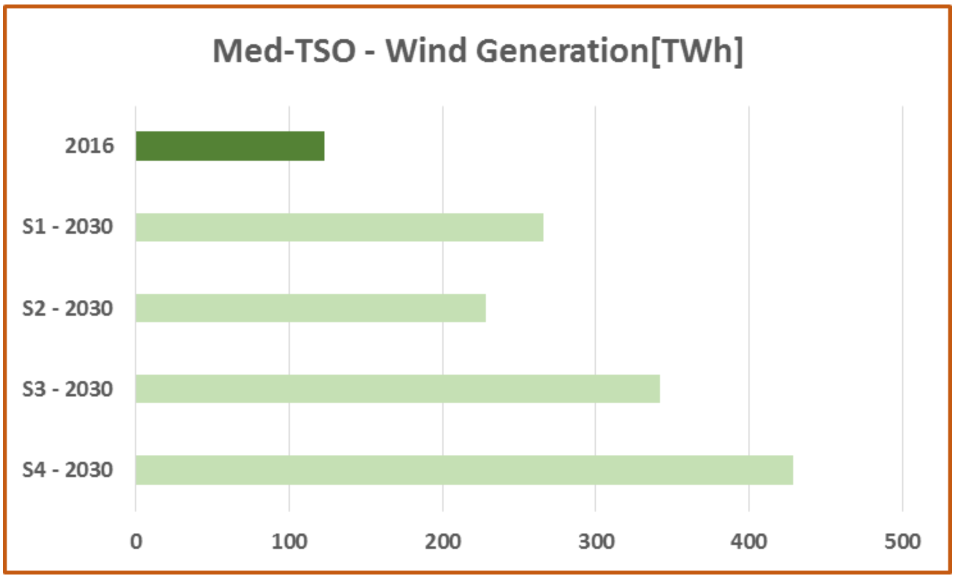

Figure 26 –Wind generation 2016 VS 2030 scenarios

In term of generated energy Solar increases between 3 and 7 times and Wind between 2 and 4 times. The growth in energy is higher than the growth in installed capacity. This is due to two effect: i) new technologies will be developed with a higher efficiencies; ii) Southern countries have naturally higher load factor than the Northern bank.

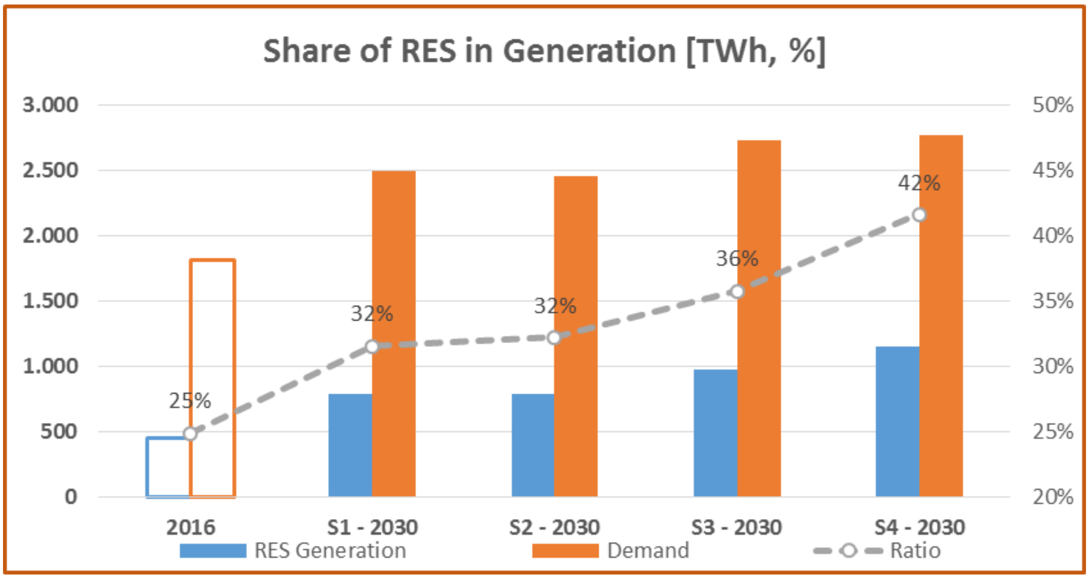

Figure 27 - Generation 2016 VS 2030 scenarios, RES share against demand

Total share of RES generated energy increases from 25% of 2016 up to 42% of S4-2030.

8 Conclusions and next steps

This Scenario Report is the illustration that cooperation between Mediterranean TSO have been able to commonly build long term scenario and setup a common Model in the framework of the Mediterranean project, and ability to use it for interconnection development assessment.

The worldwide Energy transition and the evolution of the Energy Sectors involve the northern and southern banks of the Mediterranean basin in the same direction but with different peculiarities.

Experiences acquired during this process of Market Model has also created opportunities of further improvements of several issues : the climate data base to be enriched for the model of RES generation and weather sensitivity of electricity consumption ; to improve consistency with gas development scenarios, especially in the eastern part of the Mediterranean basin ; development of a mid-term scenario for the assessment of the most mature interconnection projects ; connection and exchange model with other African and middle-East countries.

Appendix

Table – Historical load

LOAD (TWh)	Med-TSO	AL	DZ	CY	EY	FR	GR	Is	IT	JO	LY	ME	MA	PT	SI	ES	TN	TR
2000	1.355	6	25	3	74	440	53	38	299	7	11	-	14	41	12	195	9	128
2005	1.587	6	33	4	102	480	54	44	330	10	22	-	20	50	13	246	12	161
2010	1.745	6	44	5	137	490	53	51	330	15	33	4	27	52	12	261	15	210
2011	1.773	7	48	5	147	488	53	52	335	15	26	4	29	50	13	256	15	230
2012	1.795	7	53	5	155	483	51	55	328	17	34	4	31	49	13	252	17	242
2013	1.790	8	55	4	158	480	50	53	318	17	38	5	32	49	13	246	17	246
2014	1.797	7	59	4	162	478	51	52	311	18	38	3	34	49	13	244	18	257
2015	-		63	5	-	481	51	-	317	19	36	3	34	49	14	248	18	266

Table – Historical CAGR

CAGR %	Med-TSO	AL	DZ	CY	EY	FR	GR	Is	IT	JO	LY	ME	MA	PT	SI	ES	TN	TR
CAGR 2000-2005	3,2%	0,7%	5,7%	5,3%	6,6%	1,8%	0,3%	2,8%	2,1%	8,1%	14,6%	-	7,0%	3,9%	1,5%	4,8%	5,4%	4,6%
CAGR 2005-2010	1,9%	0,9%	6,0%	3,8%	6,1%	0,4%	-0,2%	3,0%	0,0%	8,6%	7,8%	-	6,3%	0,9%	-0,8%	1,1%	4,3%	5,5%
CAGR 2010-2011	1,6%	17,4%	8,7%	-5,5%	7,1%	-0,4%	-0,6%	1,4%	1,3%	6,2%	-19,4%	3,4%	8,4%	-3,3%	2,5%	-1,9%	2,4%	9,4%
CAGR 2011-2012	1,2%	1,0%	11,1%	-5,1%	5,3%	-1,0%	-3,7%	5,8%	-1,9%	7,2%	29,1%	-6,8%	8,0%	-2,8%	0,6%	-1,4%	10,5%	5,2%
CAGR 2012-2013	-0,3%	3,6%	3,2%	-9,9%	2,2%	-0,6%	-0,9%	-3,3%	-3,0%	0,8%	13,1%	19,3%	3,1%	0,2%	0,2%	-2,2%	1,4%	1,6%
CAGR 2013-2014	0,4%	-2,6%	7,1%	1,3%	2,3%	-0,4%	2,2%	-1,1%	-2,5%	5,1%	-2,0%	-30,1%	4,7%	-0,7%	4,0%	-1,1%	3,4%	4,4%
CAGR 2014-2015	-	-7,2%	7,2%	4,6%	-	0,6%	-0,3%	-	2,0%	5,6%	-4,1%	5,1%	2,6%	0,3%	3,5%	2,0%	3,0%	3,3%

Scenario 1 – Generation Capacity (MW)

Generation Capacity (MW)	Gas	Hard coal	Lignite	Nuclear	Oil	Other non-RES	Hydro and storage	Solar	Wind	Other RES
Med-TSO	**269967**	**36195**	**19144**	**73860**	**9812**	**28000**	**133695**	**87334**	**115686**	**13580**
Albania AL	500						3152	50	150	
Algeria DZ	40180							6000	3000	
Cyprus CY	921				530			609	251	30
Egypt EY	74450				1552		2800	4900	3588	
France FR	6051	1740		57644	819	5400	25200	12300	21700	1400
Greece GR	6252		2876				4259	4250	6200	480
Israel IS	12037	4675			1571			64	38	
Italy IT	38974	7926			1394	10160	22635	24580	13400	7240
Jordan JO	5451		600		2195			1490	951	
Libya LY	19746				500			3000	300	
Montenegro ME			450				1215			
Morocco MA	3836	5792			577		3094	3880	4000	
Palestine PA	135							1		
Portugal PT	4156					1340	7858	720	5300	720
Slovenia SI	505	45	545	696		120	1929			60
Spain ES	24948	5900		7120		10480	23450	16800	35750	2400
Tunisia TN	7410						66	690	890	
Turkey TR	24415	10117	14673	8400	674	500	38036	8000	20168	1250

Scenario 2 – Generation Capacity (MW)

Generation Capacity (MW)	Gas	Hard coal	Lignite	Nuclear	Oil	Other non-RES	Hydro and storage	Solar	Wind	Other RES
Med-TSO	**259667**	**39195**	**15144**	**73860**	**9812**	**28000**	**134295**	**108173**	**99704**	**13580**
Albania AL	400						3152			
Algeria DZ	40930							8000	4000	
Cyprus CY	1036				530			771	275	30
Egypt EY	74450				1552		2800	4900	3588	
France FR	6051	1740		57644	819	5400	25200	8500	13900	1400
Greece GR	3111		2876				4259	4050	4884	480
Israel IS	12037	4675			1571			64	38	
Italy IT	34886	7926			1394	10160	22635	27147	13400	7240
Jordan JO	5451		600		2195		200	1960	1250	
Libya LY	19746				500			3000	300	
Montenegro ME			450				1215			
Morocco MA	3836	5792			577		3094	3880	4000	
Palestine PA	135							1		
Portugal PT	3693					1340	7858	2014	5300	720
Slovenia SI	505	45	545	696		120	1929			60
Spain ES	21572	5900		7120		10480	23450	33145	27650	2400
Tunisia TN	7410						466	740	950	
Turkey TR	24418	13117	10673	8400	674	500	38036	10000	20168	1250

Scenario 3 – Generation Capacity (MW)

Generation Capacity (MW)	Gas	Hard coal	Lignite	Nuclear	Oil	Other non-RES	Hydro and storage	Solar	Wind	Other RES
Med-TSO	**299446**	**33085**	**22720**	**64818**	**9304**	**29960**	**140836**	**133686**	**146381**	**23500**
Albania AL	500						3162	100	200	
Algeria DZ	49910			2000				11000	5000	
Cyprus CY	660				530			771	275	30
Egypt EY	74450			4656	1552		2800	5850	4300	
France FR	14051	1740		37646	819	5400	27200	24100	36600	4800
Greece GR	6252		2212				4699	5300	7800	650
Israel IS	12037	4675			1571			64	38	
Italy IT	37993	7056			1386	10160	23535	40400	18990	10750
Jordan JO	3951		600	2000	1695		200	1490	950	
Libya LY	19746				500			3000	300	
Montenegro ME			450				1271			
Morocco MA	5036	5792			577		3094	4880	5000	
Palestine PA	135							1		
Portugal PT	3717					1560	9717	910	6400	850
Slovenia SI	425	45	545	1796		130	2005			70
Spain ES	29208	4160		7120		12210	25050	25000	39300	5100
Tunisia TN	8460						66	820	1060	
Turkey TR	32915	9617	18913	9600	674	500	38036	10000	20168	1250

Scenario 4 – Generation Capacity (MW)

Generation Capacity (MW)	Gas	Hard coal	Lignite	Nuclear	Oil	Other non-RES	Hydro and storage	Solar	Wind	Other RES
Med-TSO	**287301**	**31196**	**18338**	**63618**	**9304**	**29960**	**141488**	**179839**	**177068**	**23500**
Albania AL	500						3162	449	175	
Algeria DZ	46495			2000				11000	5000	
Cyprus CY	660				530			1081	352	30
Egypt EY	70570			4656	1552		2800	6800	5000	
France FR	14051	1740		37646	819	5400	27200	18200	44851	4800
Greece GR	6252		1070				4366	8384	12335	650
Israel IS	12037	4675			1571			64	38	
Italy IT	37993	5667			1386	10160	23535	42169	23459	10750
Jordan JO	3951		600	2000	1695		200	2350	1500	
Libya LY	19746				500			3000	300	
Montenegro ME			450				1271			
Morocco MA	3836	5792			577		3094	4880	5000	
Palestine PA	135							1		
Portugal PT	3717					1560	9717	3281	8572	850
Slovenia SI	425	45	545	1796		130	2005			70
Spain ES	29208	4160		7120		12210	25635	54130	40604	5100
Tunisia TN	8310						466	1550	2560	
Turkey TR	29415	9117	15673	8400	674	500	38036	22500	27322	1250

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