Deliverable 2.2.2

Euro-Mediterranean Market Model for the evaluation of the impact of basic scenarios and expected energy flows on the Euro-Mediterranean Electricity Grid

Complementarities of the load curves (daily and seasonal), around the Mediterranean and within sub-regional groupings

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“Mediterranean Project”

Task 2 “Planning and development of the Euro-Mediterranean Electricity Reference Grid ”

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Euro-Mediterranean Market Model: complementarities around the Mediterranean

Basic Principles

The worldwide energy transition and the evolution of the whole industry involve the Northern and Southern banks of the Mediterranean basin in the same direction but with different peculiarities.

The Northern bank is engaged in ambitious decarbonization 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 markets are still in evolution.

These circumstances appear to be sufficient to capture synergies between the two banks. Moreover, the push towards cooperation is reinforced by the political willingness to use the electricity as a vehicle of progress and welfare.

This task will be undertaken using, in a first step, the data gathered from TSO-members, especially regarding hourly curves for both load and renewable generation, and in the second step, using results from the Market Studies.

Description of the Market Study:

The aim of the market study is to develop market scenarios suitable for the evaluation of network investments to increase exchange capacity among countries. Four scenarios, designed by the Med-TSO Working Group Economic Studies and Scenarios (WG ESS) with year 2030 as target date, are the object of the activity. The four scenarios are based on distinctively different assumptions, thus the actual future evolution of parameters is expected to lie in-between:

1. Business as usual and security of supply improvement
2. Green future based on gas and on local integration of renewable energies (and management of the complexity of this kind of grids)
3. High economic growth which supports high interconnection development and free carbon thermal plants development in the South of the Mediterranean area
4. Green future and market integration at an international level

The scenario definition was applied only to Med-TSO member countries while for ENTSO-E countries a match with TYNDP 2016 Visions (which is also spanning until 2030) has been made.

The model of each country 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 system and allows economic exchanges of electricity. Med-TSO BTCs for year 2030 have been provided by the Med-TSO Technical Committee 1 (TC1), while for ENTSO-E countries TYNDP 2016 public data have been used.

The study was accomplished through the application of a simulation model on a Mediterranean/European wide basis.

The market software tool carries out an optimal coordinated hydrothermal scheduling of the modeled electric system generation set, over a period of one year on an hourly basis. 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.

1 Demand side complementarity

When assessing electric systems complementarities in the Mediterranean area, the first and obvious aspect that comes to mind is the demand. Indeed, since electricity loads depend on industrial production patterns, temperatures, day/night cycle but also on people habits, all of these parameters vary significantly within the entire Mediterranean area and this offers synergy opportunities.

1.1 Annual overview and duration curves

The load duration curve is the curve plotting sorted hourly loads from annual peak load to annual min load. And the load factor is given by the formula:

$$LF = \text{Annual Energy}_{MWh} / (\text{Peak Load}_{MW} * 8760_{hours})$$

Both load duration curve and load factor can give a preliminary idea about power plants fleet utilization. The higher the load factor, the better the utilization of power fleet.

The objective of this part is to show, on an annual scale, the Mediterranean load duration curve compared to individual country ones.

The following figure shows normalized load duration curves for Turkey and Tunisia, comparing them with that of the Med-Tso area for scenario 1. These two countries have been chosen for illustrative purpose because they have the highest (Turkey) and the lowest (Tunisia) annual load factors.

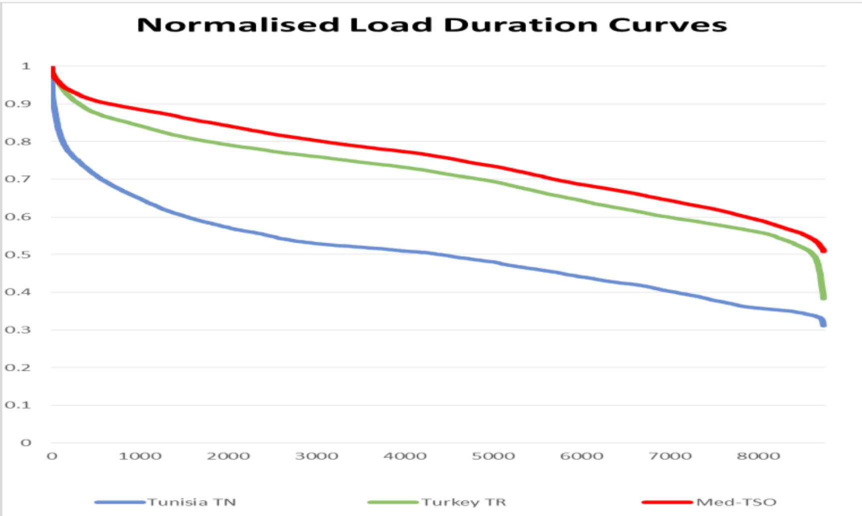

Figure 1: Normalized Load Duration Curves for Med-TSO and several countries

The resulting Load factor is 50% for Tunisia and 70% for Turkey. For the Med-TSO area, the load factor reaches 75%. In other words, and taking into account that load curves with high load factors are better, we can say that the global load curve is better than single country ones, even better than the best single country load curve.

The global load duration curve shows that the minimum annual load for the whole Med-TSO area never goes under 50% of annual peak load, while it goes until 30% for Tunisia and 38% for Turkey.

Another preliminary result is that base load power plants should represent at least 50% of annual peak load when considering the whole area demand.

1.2 Peak load

In fact, this finding is the consequence of not having a synchronous single country peak and off-peak loads. The figure below shows for Med-TSO country members, the date of annual peak loads.

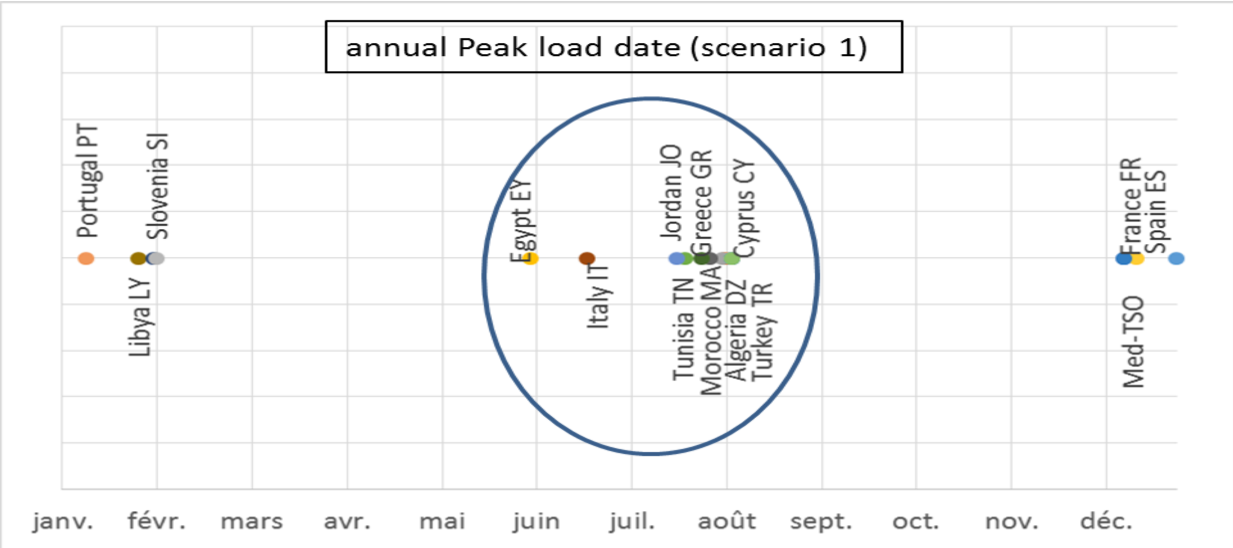

Figure 2: national peak load date

It can be noticed that countries' peak loads spread all over the year, with summer and winter peaks.

When summing all the load curves, the obtained global peak load is very different from the sum of national peak loads. The next table shows a comparison between the obtained values for Scenarios 1 and 4 (the two more extreme scenarios adopted by Med-TSO).

Peak load (GW)	Scenario 1	Scenario 4
Self-sufficient	440 GW	481 GW
Copper-plate	380 GW	414 GW
Difference	*60 GW*	*67 GW*

Figure 3: Mediterranean peak load comparison between self-sufficient and copper-plate principles

A very important finding is that the whole Med-TSO load instead of single country loads shows a saving of 60 GW in scenario 1 and 67 GW in scenario 4. **Mutualizing the complementarity within the Med-TSO Power System area is worth around 15% of the sum of all national needs,** which translates in a corresponding saving in generation plants avoided investments of at least the same amount. Indeed, the saving is somewhat higher due to the proportional reserve margin needed by the system for adequacy criteria. Considering a 10-20% reserve margin, the saving in avoided generation investments can be estimated prudentially in around 70 GW in the range of the envisioned scenarios. This in turns translates in around 70-100 G€ of avoided investment costs, to be compared with the investments in transmission facilities to realize the copper plate. A typical optimization exercise (static analysis, out of scope of this complementarity analysis), entailing OPEX, CAPEX and financial parameters, would provide the optimal balance level between investments in transmission and in generation. In any case, the total savings should be several tens of G€.

It is important to remark that these savings in capital costs are additional to those on variable costs (mainly fuel) stemming from the market prices algorithm, i.e. the maximization of the use of the cheapest generation plants (extending the merit order optimization to a larger area); these savings are duly.

1.3 Seasonality of Demand

The Mediterranean area is a very large zone that covers countries with very different weather conditions.

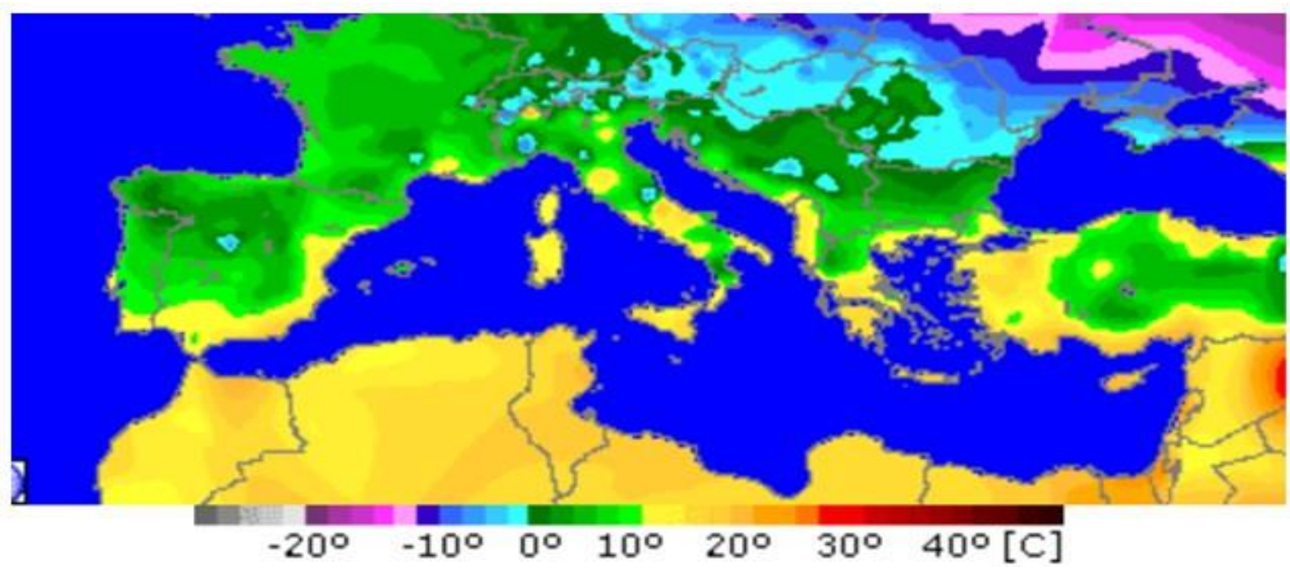

Figure 4: example of temperature contrast within Mediterranean area

The Northern area is characterized by low temperatures, while in the Southern bank, temperatures are quite high. As a consequence, we obviously expect annual demand to depend on this parameter and follow its pattern.

The following figure shows normalized monthly load profile for Scenario1 of the Market Study.

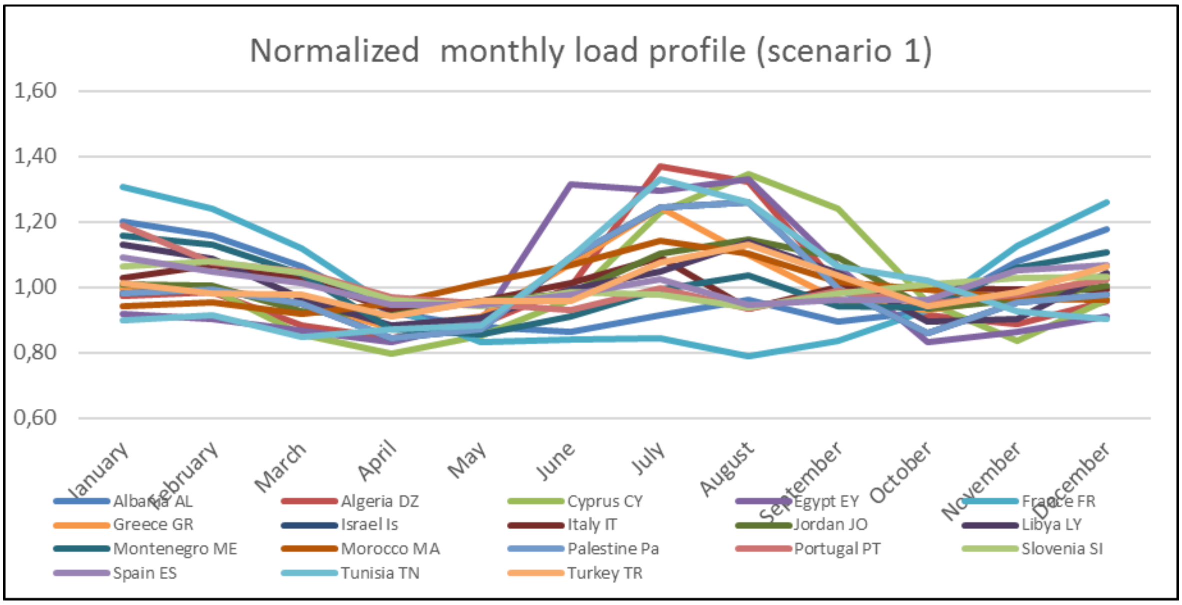

Figure 5: Normalized monthly load profile of each Med-TSO members

It can easily be seen that profiles can be split into three categories:

- Flat profile (i.e. similar winter and summer peak)
- Winter profile
- Summer profile

When aggregated according to these three groups, the result is shown in the following figure:

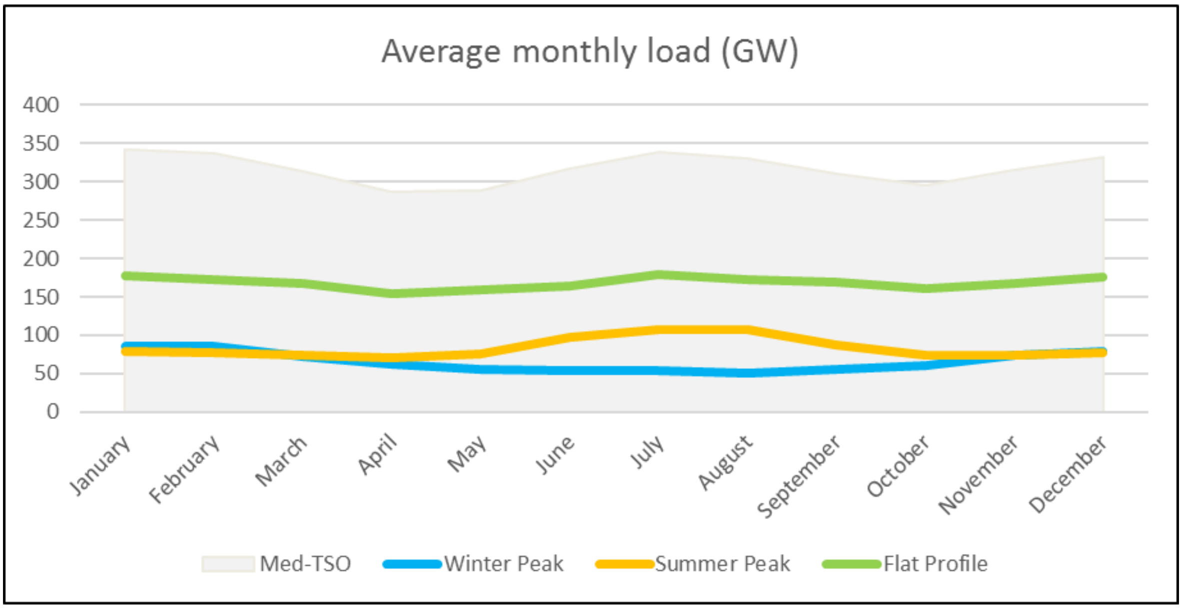

Figure 6: aggregated monthly load profile

The resulting Med-TSO monthly load has two peaks: in January and July and two off-peaks: in April and October.

The next figure gives dominant season for each country of the Med-TSO area:

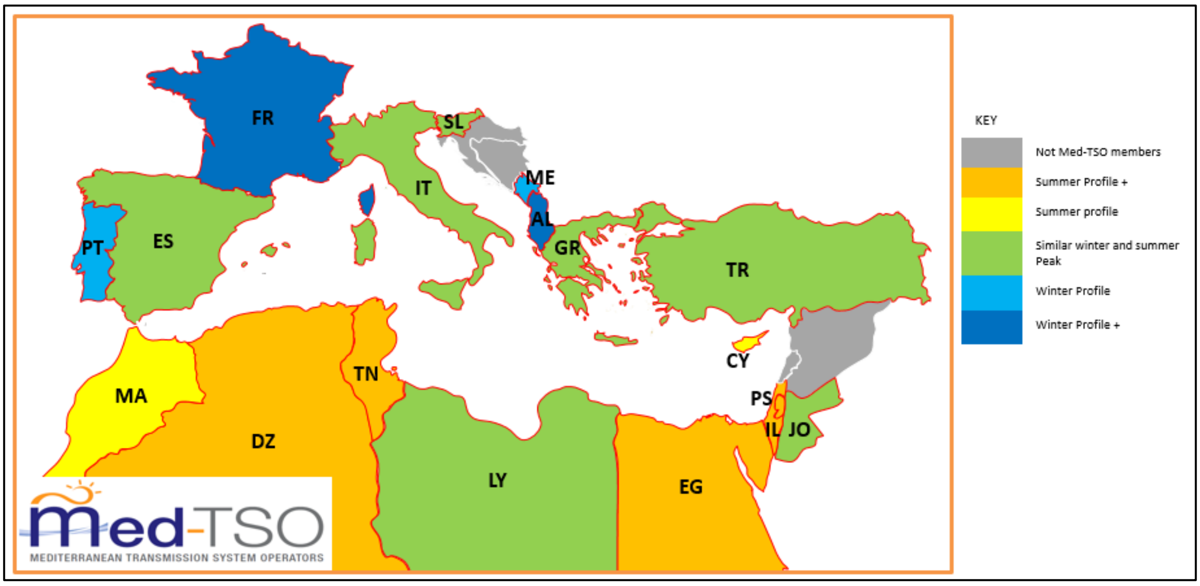

Figure 7: Map of Mediterranean countries depending on annual profile

1.4 Weekly scale complementarity

The weekly complementarity relates to the effect of different holidays and different working days in the countries within the Mediterranean pool.

In fact, the weekend takes place on Saturday-Sunday in some countries and on Friday-Saturday on some others (especially Arab countries). This means that these days, with low load level, will be shifted accordingly.

While the load seasonal complementarity implies peak loads-shaving, supporting the interconnected system adequacy and providing a clear and substantial saving in generation fleet, the load weekly complementarity conversely implies a minimum peaks-shaving. Since the minimum peak does not constitute a cost for the system, no direct economic saving (in terms of market prices) stems from smoothening the minimum peaks; however, in general, it is well established that a smoother load curve means easier operation, and therefore also the weekly complementarity gives a positive contribution to the system (for example reducing the need of fast and expensive ramping services).

A qualitative example is given in graphic form in Figure 8, assuming three countries of similar size with an average daily consumption of 1 TWh in weekdays and 50% in weekends. If the three countries have the same weekly pattern, the minimum peak and more important the downward/upward ramps are steeper. If the three countries have different a weekly pattern (as mentioned in the previous paragraph), the minimum is higher and the ramps are smoother. This effect in the reality shall be combined with hourly (and sub-hourly) profiles and thus become less evident; but for the sake of study, it is useful to consider the different effects separately in order to extract some common mode observations.

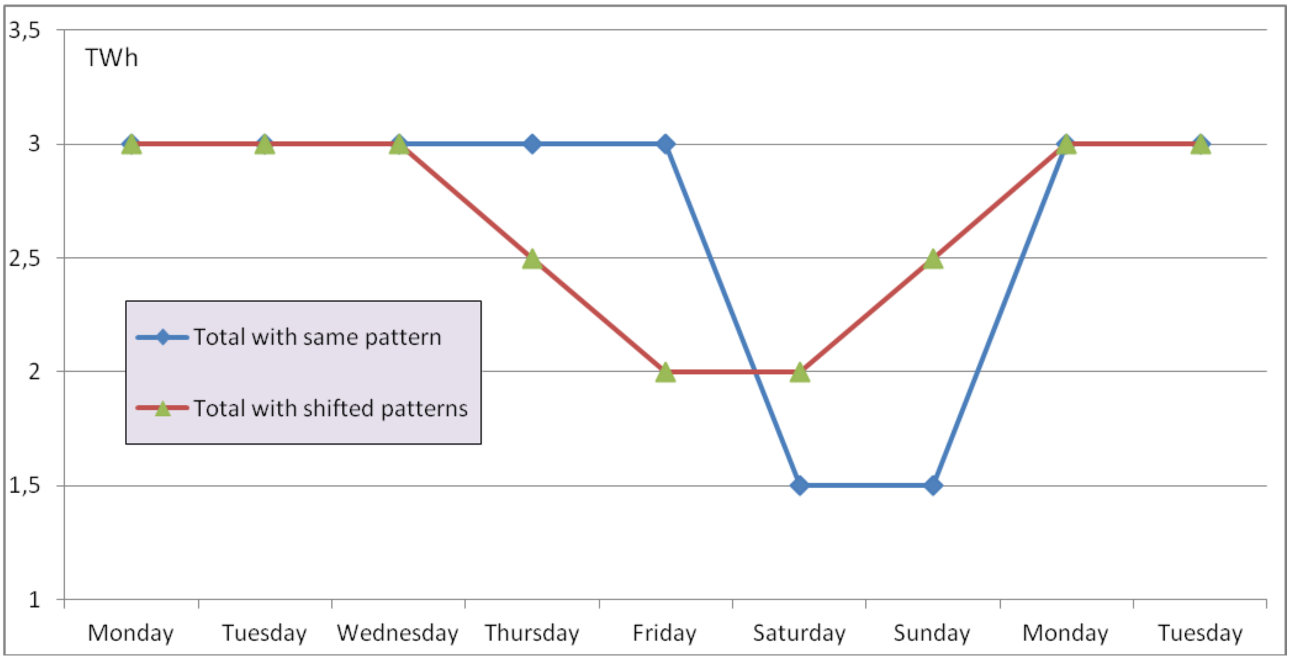

Figure 8: normalized weekly load profile

1.5 Hourly scale complementarity

1.5.1 Hourly load curves

Based on previous findings, the objective of this analysis is to determine at an hourly scale, the synergy between Med-TSO members when it comes to load curves. Since the number of countries is too high to permit an illustrative and clear analysis, we choose to divide the area into three corridors: Western corridor, Central corridor and Eastern corridor; the comparison between individual and global loads will be made within each corridor.

The Western corridor contains Spain, Portugal, Morocco and Algeria, the central corridor contains Italy, Algeria, Tunisia and Libya and the Eastern corridor contains Albania, Cyprus, Greece, Egypt, Israel, Montenegro and Turkey.

The following figures show, for the three corridors, normalized (to annual peak load) hourly loads for June 4th 2030 in Scenario 1.

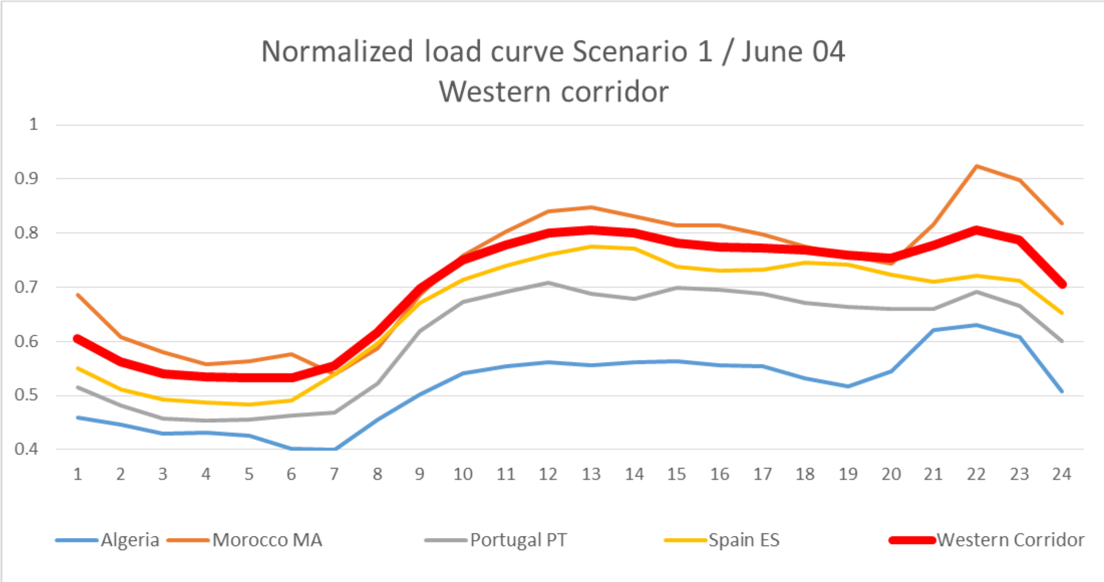

Figure 9: western corridor load profile – summer – working day

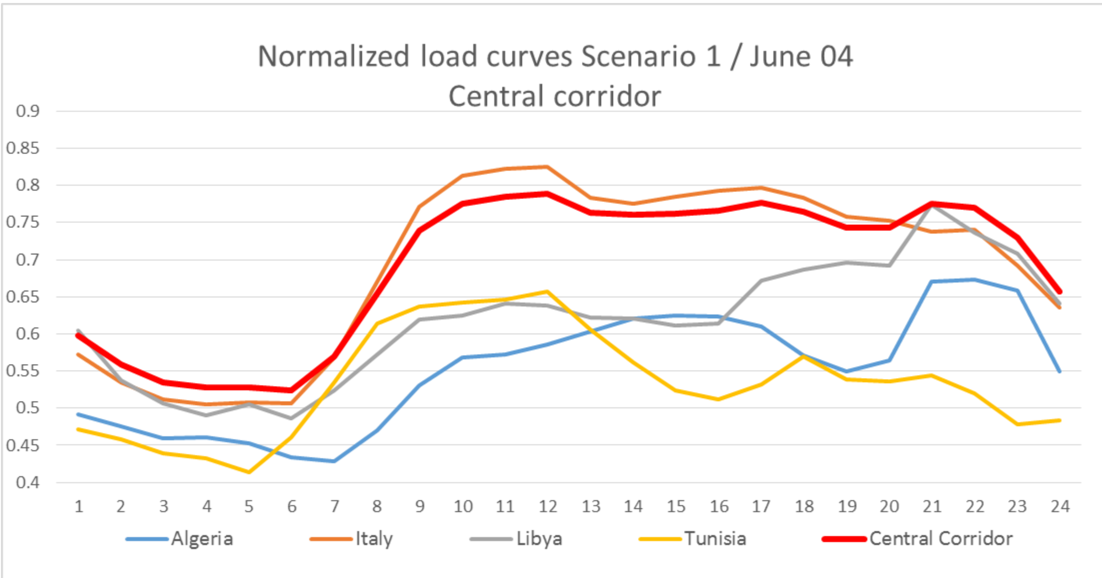

Figure 10: central corridor load profile – summer – working day

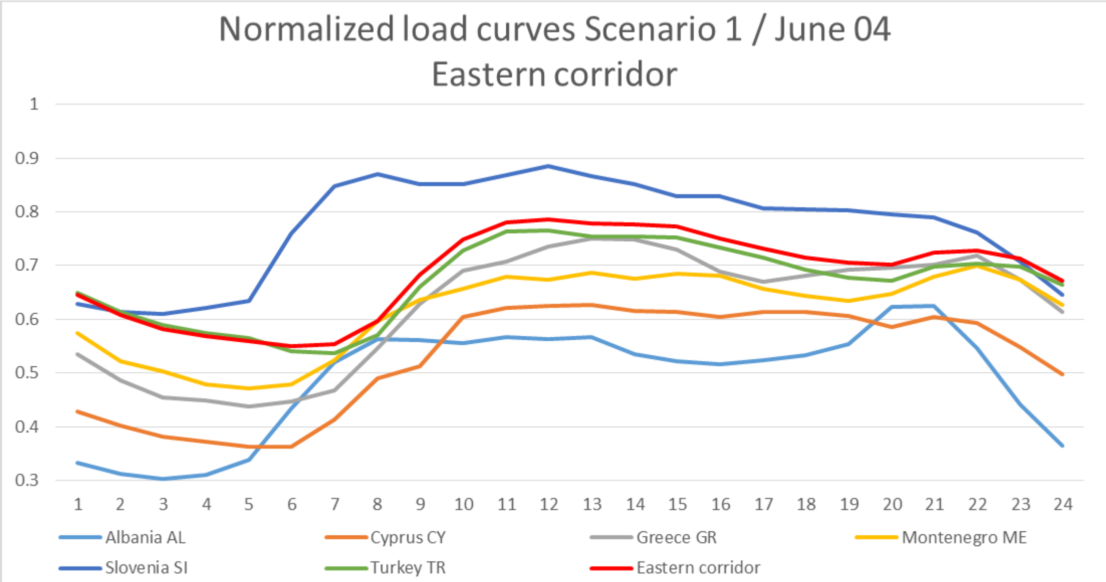

Figure 11: eastern corridor load profile – summer – working day

As shown in all corridor figures, two profiles can be noticed: evening peak load and mid-day peak load profiles.

Regarding aggregated load curve, and for all corridors, two effects can be noticed. The first effect is a higher off peak level and the second one is a relatively flat load curve for most part of the day.

This aggregation effect doesn't depend on selected scenario: the same analysis was conducted for Scenario 4 with similar results.

1.5.2 Hourly residual load curves

The residual load curve is the remaining load after deducting renewable generation from demand load curve. Even though demand synergy analysis is very important, it can be noticed that the real synergy is about residual demand. In fact, being a non dispatchable resource, renewable generation is considered by TSOs as fatal energy, equivalent to a negative load.

The present analysis was made keeping the same corridors as considered before. The following figures illustrate, for these three corridors, individual and global residual load curves for a typical day in Scenario 1 (June 16th).

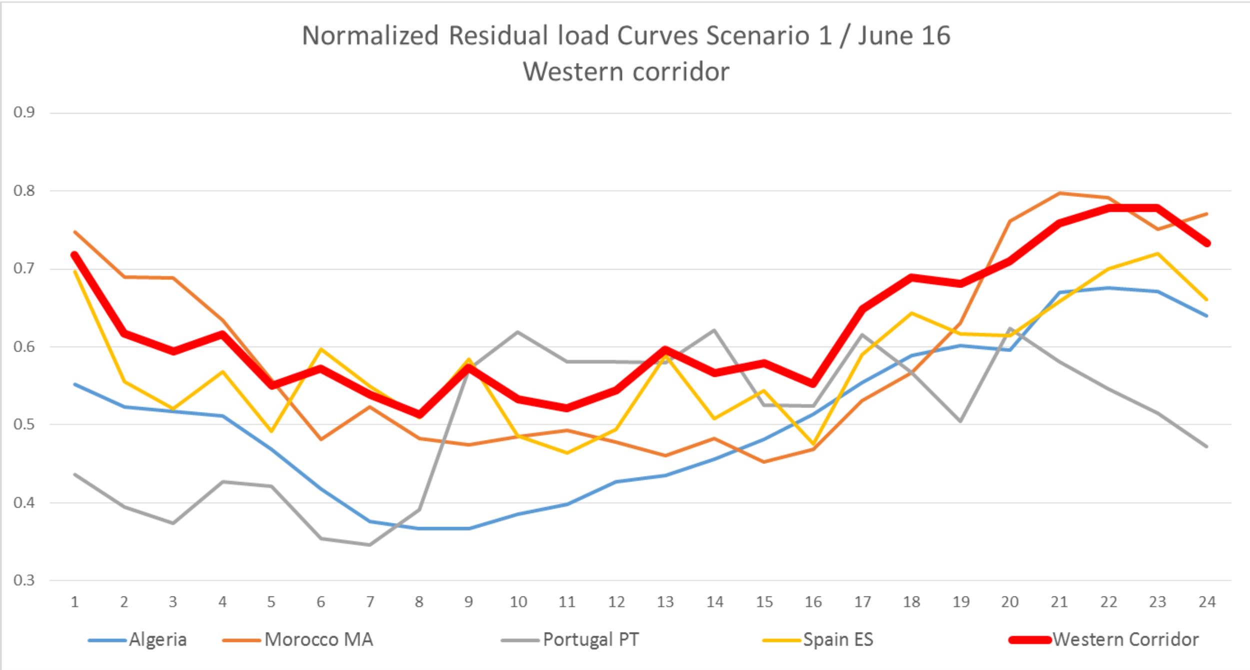

Figure 12: western corridor residual load profile – summer – working day

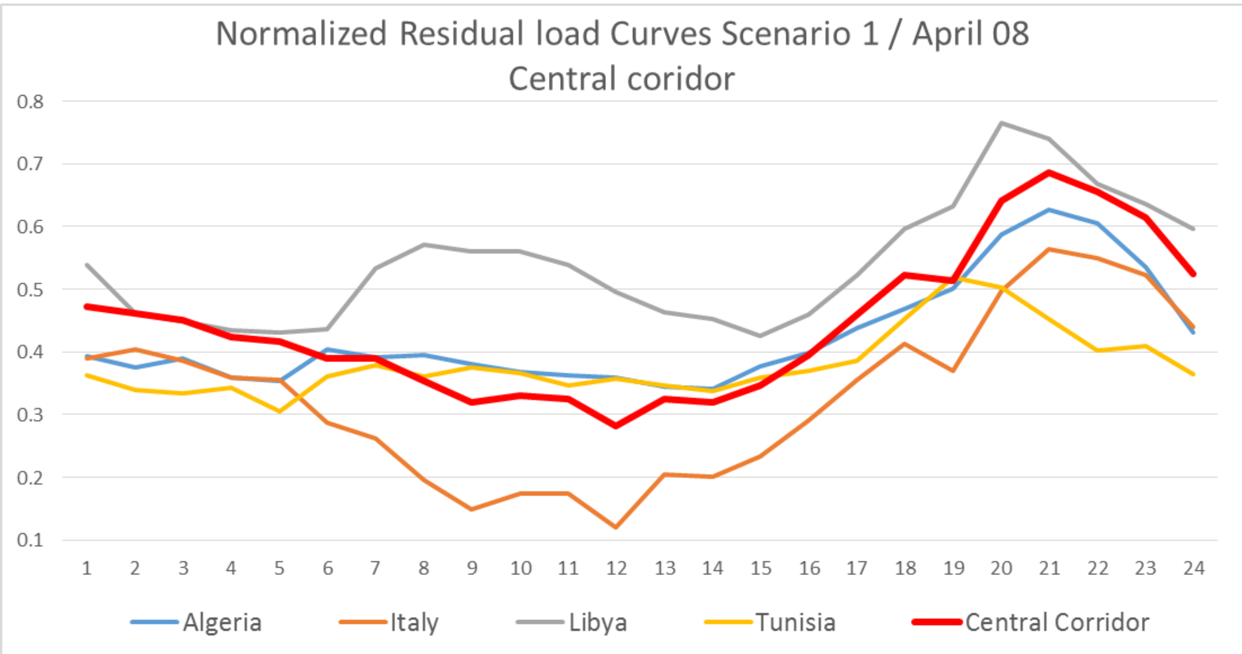

Figure 13: central corridor residual load profile – spring – working day

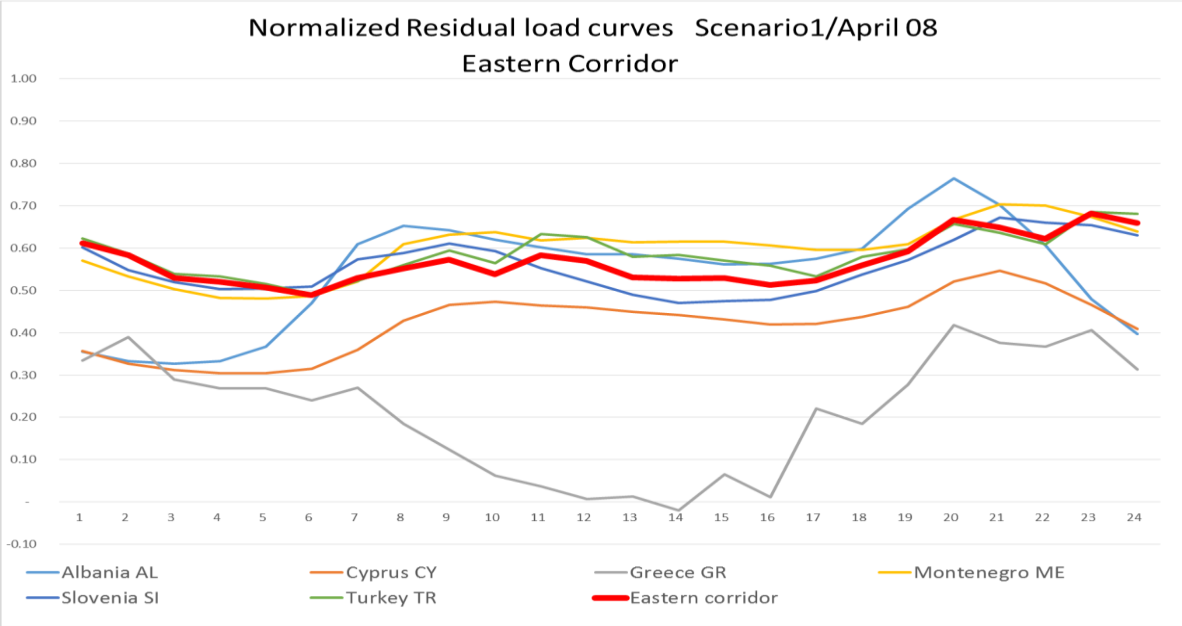

Figure 14: eastern corridor residual load profile – spring – working day

The figures show that Countries have very contrasted residual load curves according to their renewable share in the energy mix. For some countries, and depending on metrological conditions (wind and sun), residual demand can reach very low levels, and its variation from one hour to another can be quite high. In Scenario 1 for example, the annual lower residual load is about -12% for Greece, 1% for Spain and 2% for Portugal.

These results are scenario-dependent since renewable share in the energy mix varies from one scenario to another. For Scenario 4, in which renewable integration is the highest among other scenarios, residual demand reaches lower levels for Portugal (-28%) and Spain (-22%). For illustrative purpose, the next figure shows, for the Western corridor, the residual demand on June 20th for Scenario 4.

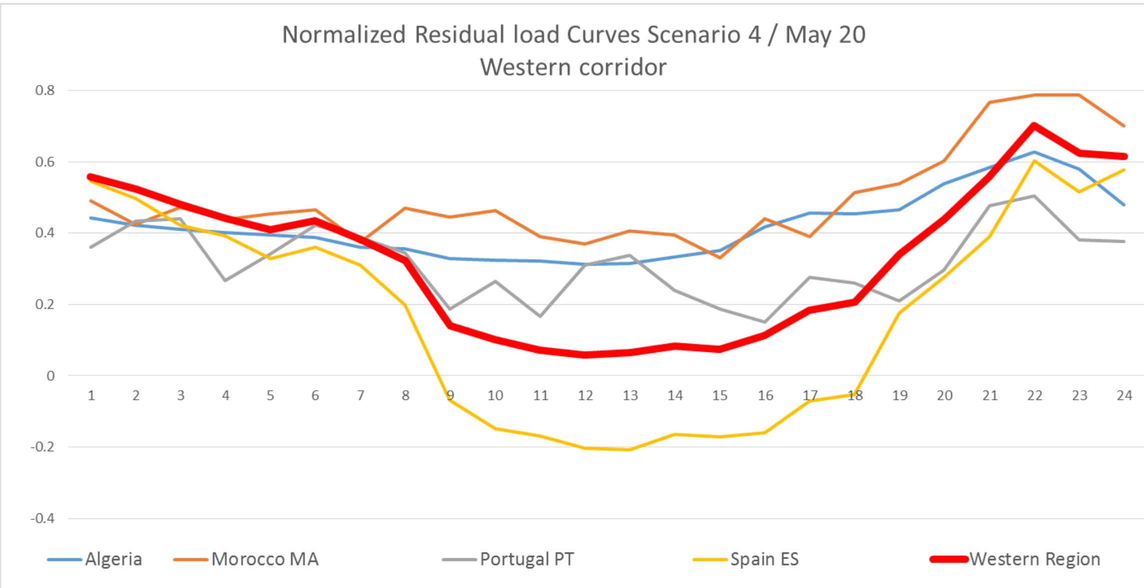

Figure 15: western corridor residual load profile – spring – working day

As finding, and due to RES intermittence, residual load is even more variable than load itself; but when considering larger areas (corridor or whole Med-TSO zone), the mitigation of both load and renewable generation results in a smoother and flatter global residual load curve. The effect is more important in scenarios where renewable share is higher.

2 Generation complementarity and flows at a regional level

Based on the analysis of the national load curves and the generation fleets showing a high diversity of load profiles, renewable shares, and generation technologies within Med-TSO area, and using results from the market study, the aim of this analysis is to assess the benefit coming from the usage of existing interconnections.

The analysis is performed considering a zonal approach through splitting the Med-TSO area into three corridors.

Figure 16: Map of the corridor location

2.1 Western corridor

The annual profile of exchanges between Spain and Morocco (to be considered as representative of the regional exchanges between Iberia Peninsula and Maghreb) are mainly driven by the seasonal complementarity. The following graph shows the U-shaped, annual curve of the average monthly exchanges for the scenarios 1 and 4. It is to be noticed that exchanges are well-balanced in the greenest scenario 4, where flows are going more from South to North in winter and in the opposite direction in summer.

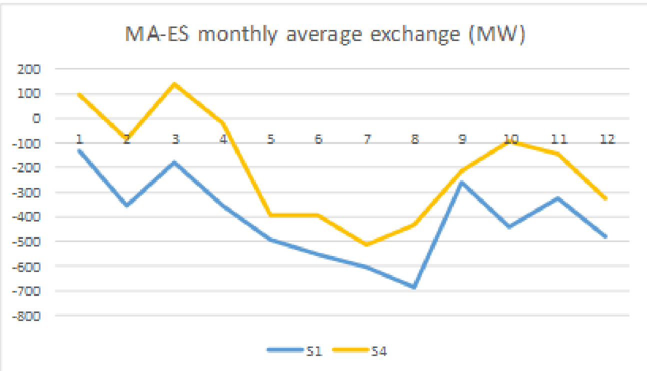

Figure 17: Spain-Morocco monthly exchanges

A detailed analysis for this corridor can be done by focusing on one typical day (4th June 2030) of Scenario 4.

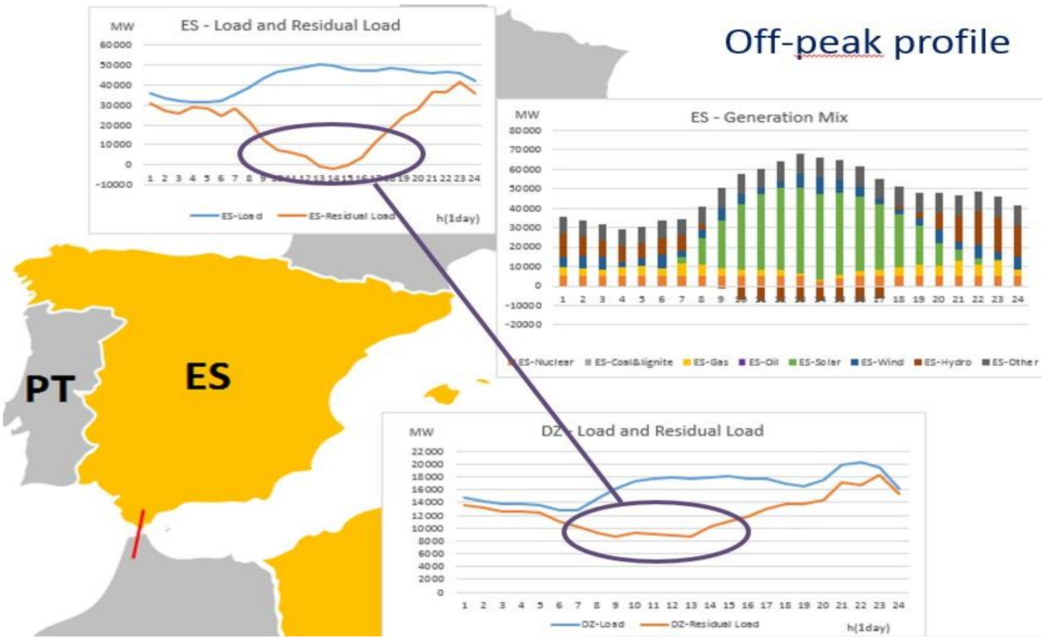

Figure 18: focus on the western corridor

At single country scale, episodes of high renewable generation could result in low residual load demand. To handle such situations, both thermal and pumping plants contribute to system adequacy. The following figure shows residual loads in Spain and in Algeria that are lower during the day due to PV generation. The most noticeable effect is the usage of hydro generation that lead to turbine in the night and pump within the day.

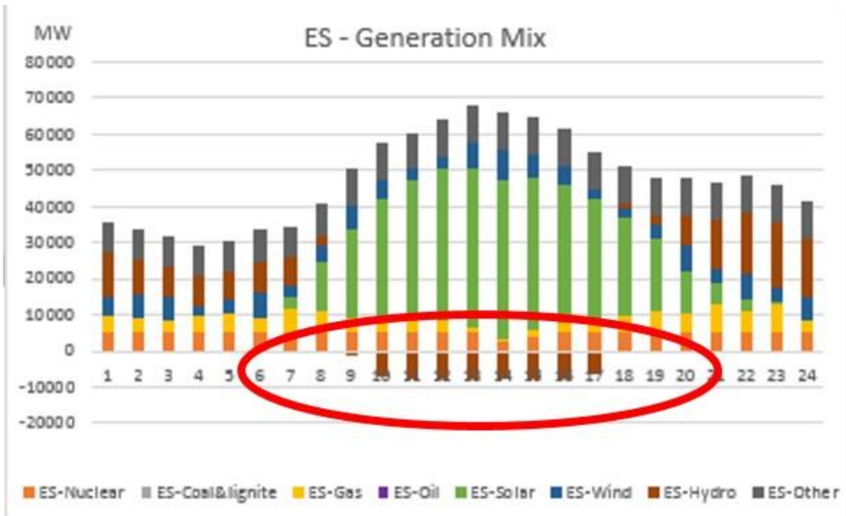

Figure 19: impact of PV on hydro in Spain

Another effect of the massive development of the PV generation is noticeable on the South shore: modulation of the CCGT generation in Algeria during the day.

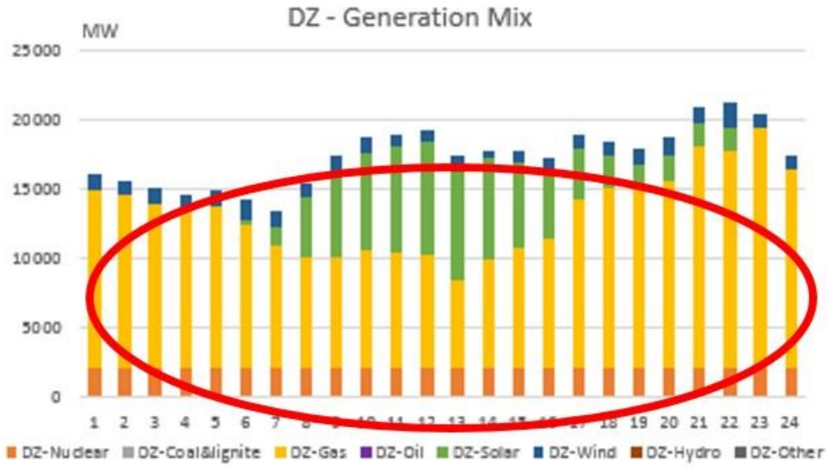

Figure 20: impact of PV on CCGT in Algeria

On the other hand, episodes of renewables over generation can translate into exchanges opportunities with neighbouring countries. Even better, RES over generation can offer long distance exchanges opportunities. In the following graph, generation surplus is seen in Spain when the peak of PV generation is mitigated by exporting at the maximum capacity simultaneously to France and to Morocco.

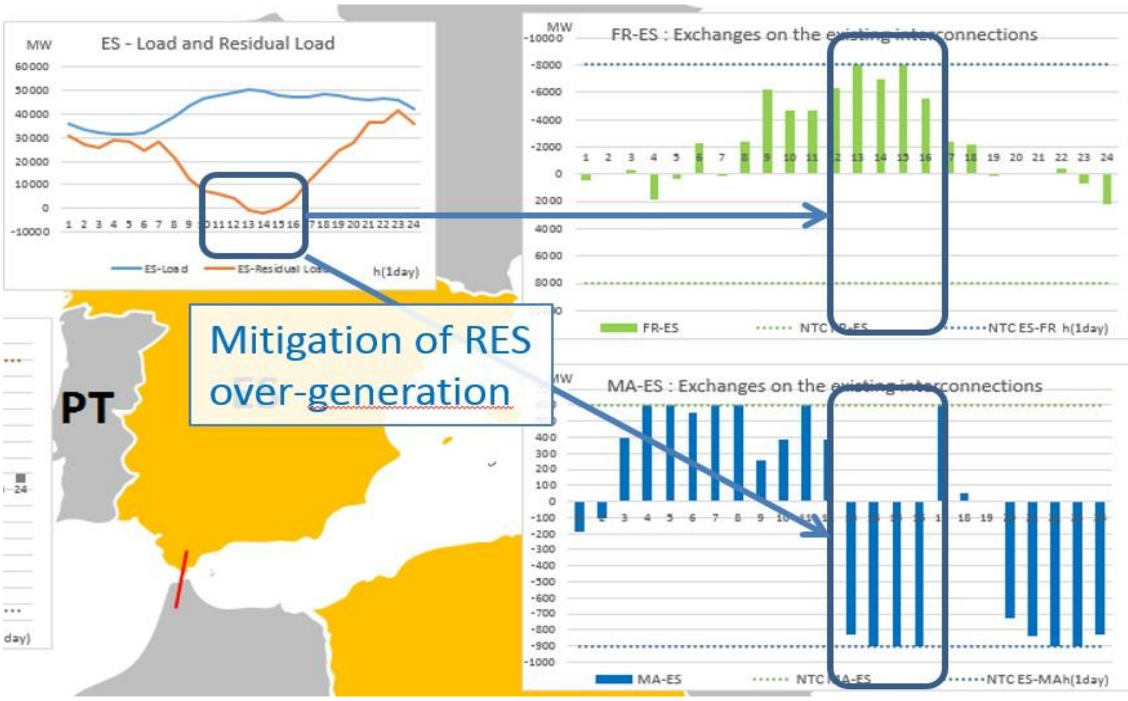

Figure 21: mitigation of PV generation in Spain with exportation

Additionally, it can be noticed that a high volatility of exchanges and interconnections can be saturated in both directions in one single day. For example, the following figure shows in the same day that exchanges between Spain and Morocco can alternate four times in 24 hours, as an illustration of the high volatility resulting from the Market optimization.

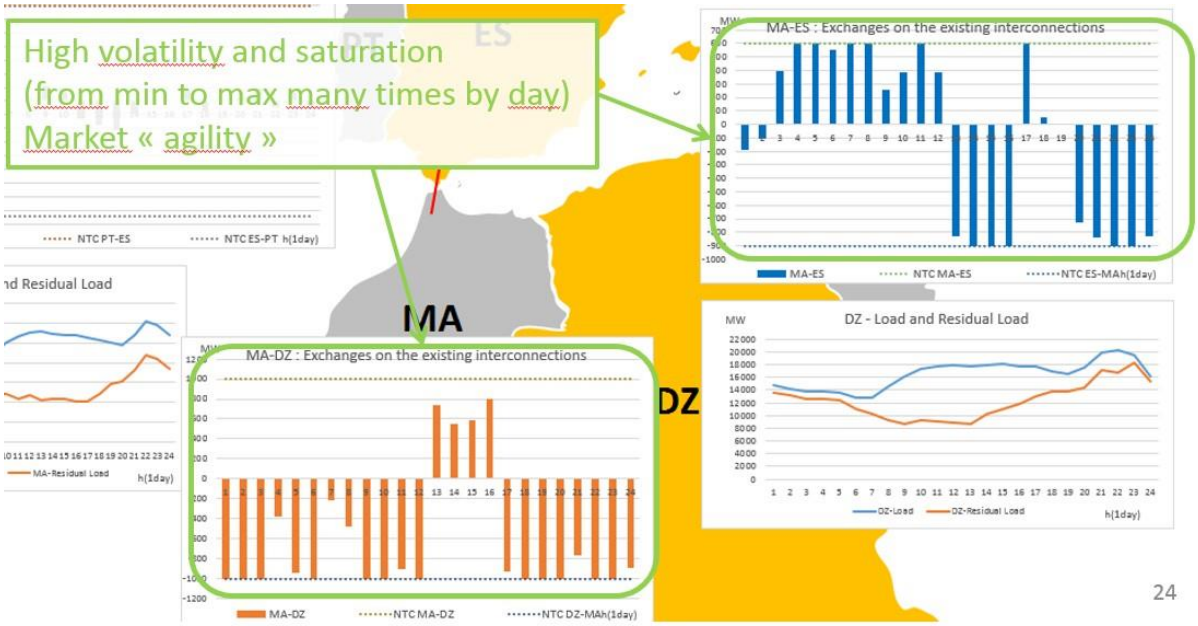

Figure 22: volatility of the exchanges within the western corridor

Finally, the following figure illustrates how regional flows affect several interconnected countries. Since Morocco is importing from Algeria in the summer example, the flows reverse when Spain is saturating exportation capacity due to PV generation.

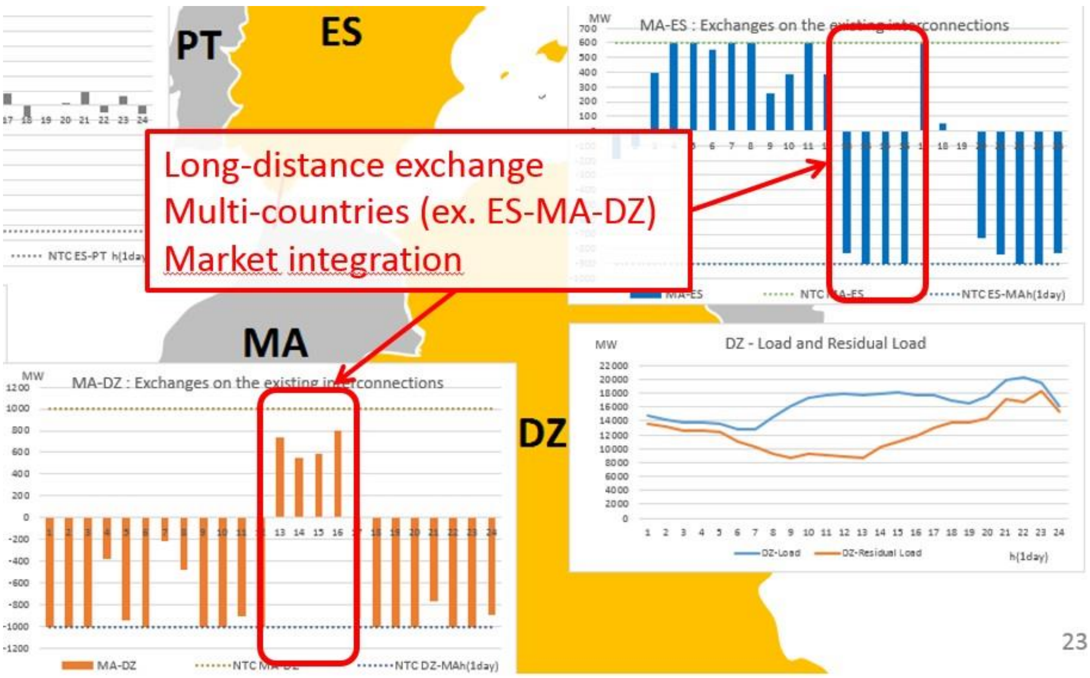

Figure 23: multi-country exchanges within the western corridor

In this example, flows from Spain between 2 and 6 pm are going through Morocco to Algeria as a result of the Market optimization. It does provide an illustration of a coordinated market in order to capture all the benefit of the interconnections.

2.2 Central corridor

The annual profile of exchanges between Italy and Tunisia (to be considered as representative of the regional exchanges within the central corridor) are mainly driven by the seasonal complementarity. The following graph shows the U-shaped, annual curve of the average monthly exchanges for the scenarios 1 and 4. It is to be noticed that, like for the western corridor, exchanges are well balanced in the greenest scenario 4, flows going more from South to North in winter and in the opposite direction in summer.

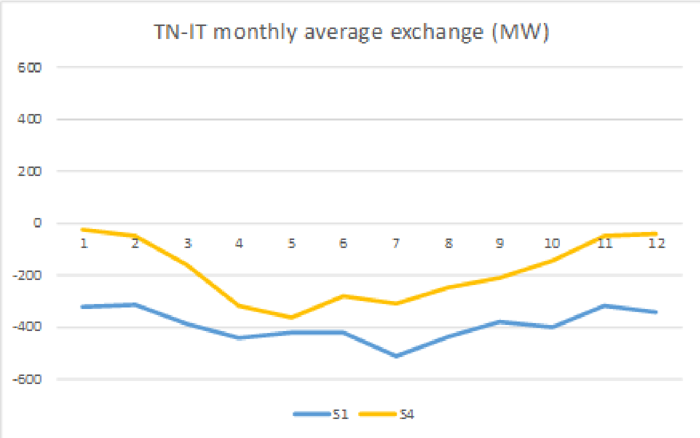

Figure 24: Tunisia-Italy monthly exchanges

Although in scenario 1 less renewables are developed in the southern bank of that corridor, interconnections are almost saturated from north to south, especially in summer time. Energy flows come from north bank through Italy-Tunisia interconnector to Tunisia but also to Algeria and Libya. This is due in part to high solar development in Italy and high demand in southern countries in summer season. Even for the other scenarios, flows are still mainly from the north to south.

The following analysis will focus on one typical day (June 4th) and scenario 1. As a consequence of a less developed PV generation compared with the scenario 4, the residual off-peak remains during the day, except in Libya.

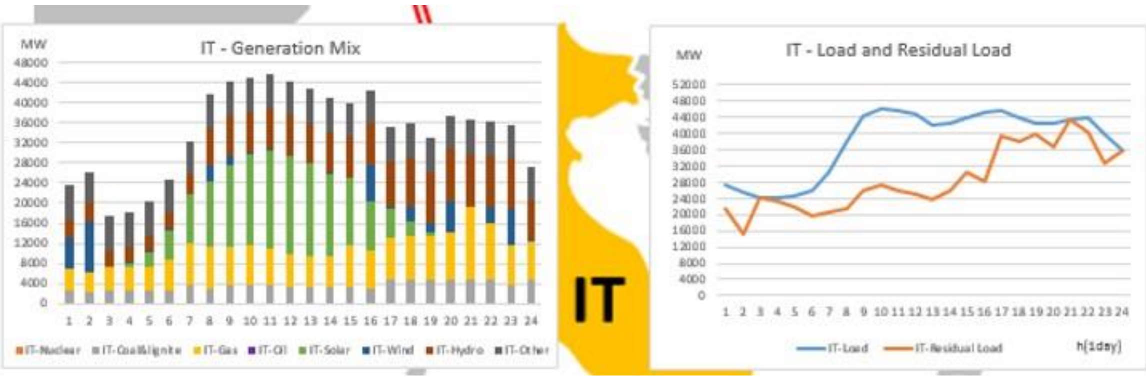

Figure 25: Load and residual load in Italy – Scenario 1 in summer

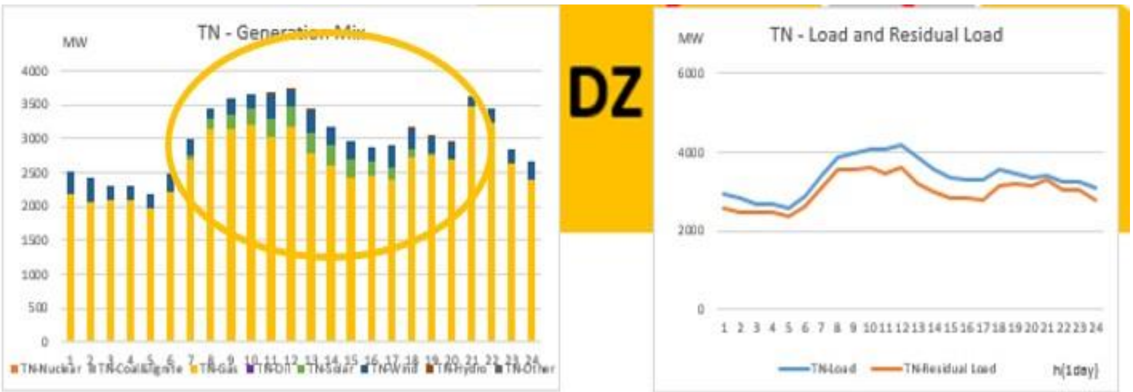

Figure 26: Load and residual load in Tunisia – Scenario 1 in summer

The next figure shows that interconnections are almost saturated from North to South in summer time in the scenario 1. Energy flows coming from North bank through Italy-Tunisia interconnector to Tunisia is also wheeled further to Libya. This is due in part to high solar development in Italy and high demand in Southern countries in summer season. However flows are going from Algeria to Tunisia.

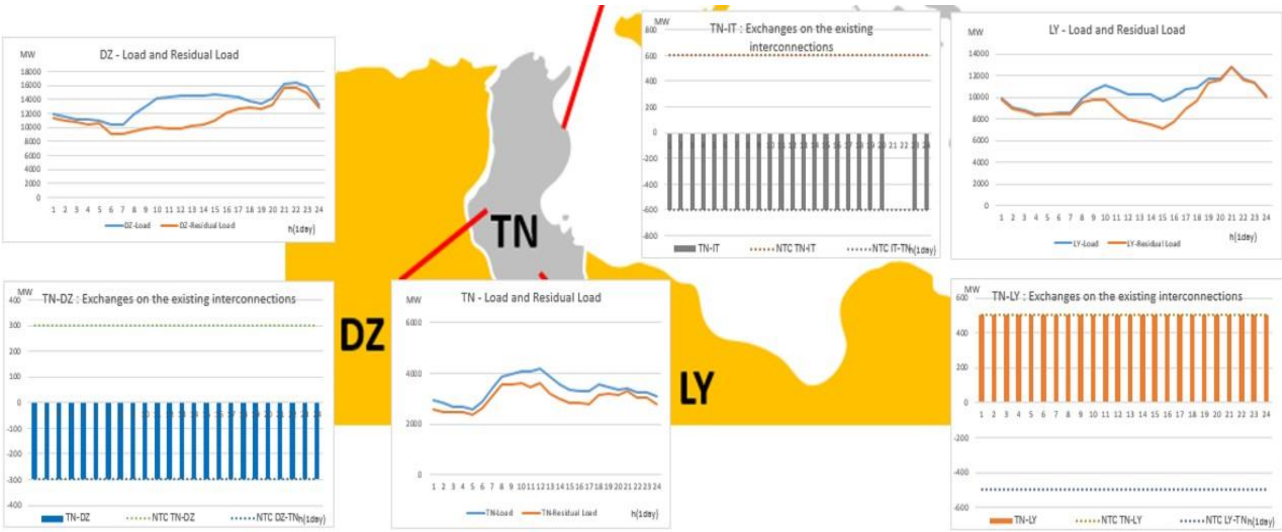

Figure 26: Flows within central corridor in summer in scenario 1

2.3 Eastern corridor

The annual profile of exchanges between Bulgaria, Greece and Turkey (to be considered as one of the regional exchanges within the central corridor) are mainly driven by the seasonal complementarity. The following graph shows the W-shaped, annual curve of the average monthly exchanges for the scenarios 1 and U-shaped for the scenario 4. Instead of the western corridor, it is to be noticed that exchanges are well balanced in the scenario 1 when flows going more from East to West in the greenest scenario 4, especially in summer.

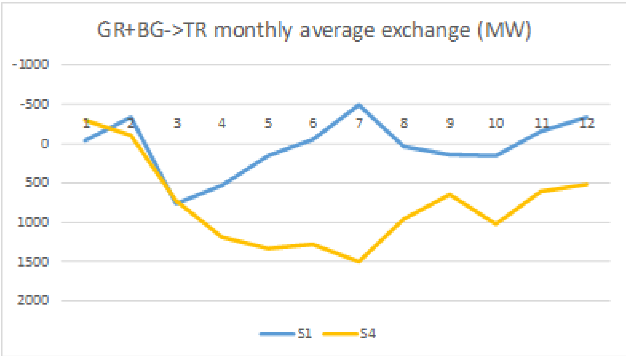

Figure 28: Bulgaria and Greece to Turkey monthly exchanges

It can be noticed that in the greenest scenario 4, flows in summer are almost saturated from Turkey to Bulgaria and Greece due to the PV generation in Turkey.

A detailed analysis for this corridor can be done by focusing on one typical day (4th June 2030) of the Scenario 1.

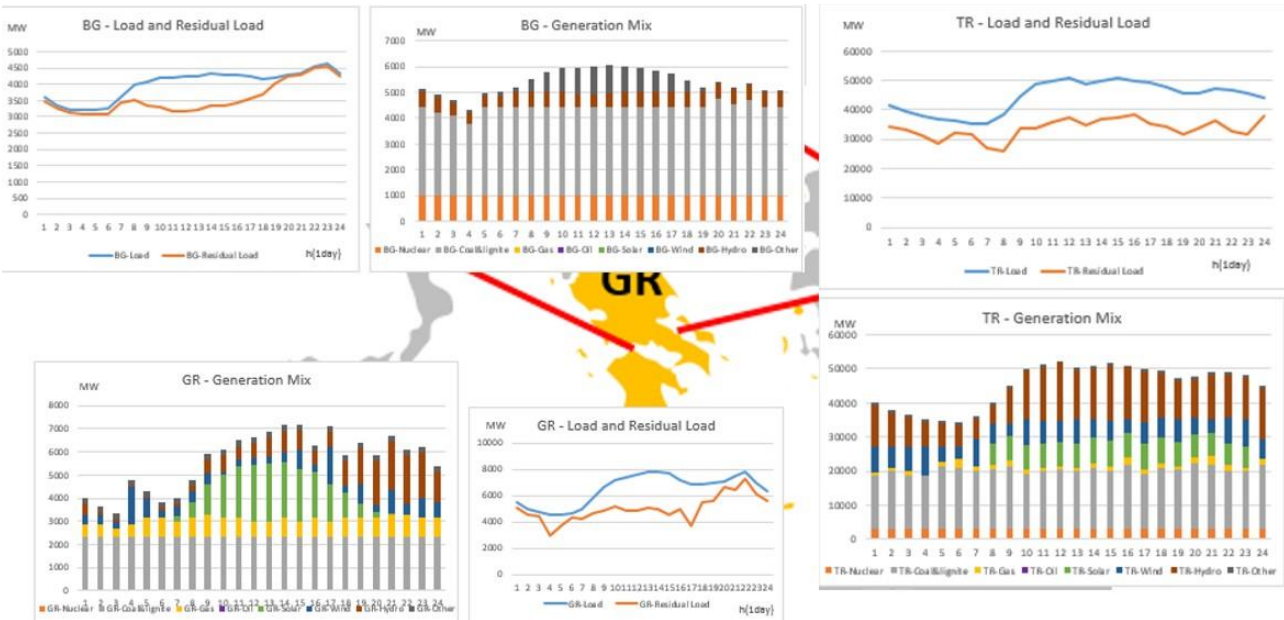

Figure 29: Load and residual load in Bulgaria, Greece and Turkey on 4th June 2030 scenario 1

As a consequence of a less-developed PV generation compared with the scenario 4, the residual off-peak remains during the day, leading to an almost flat daily profile and an evening peak in Bulgaria and Greece.

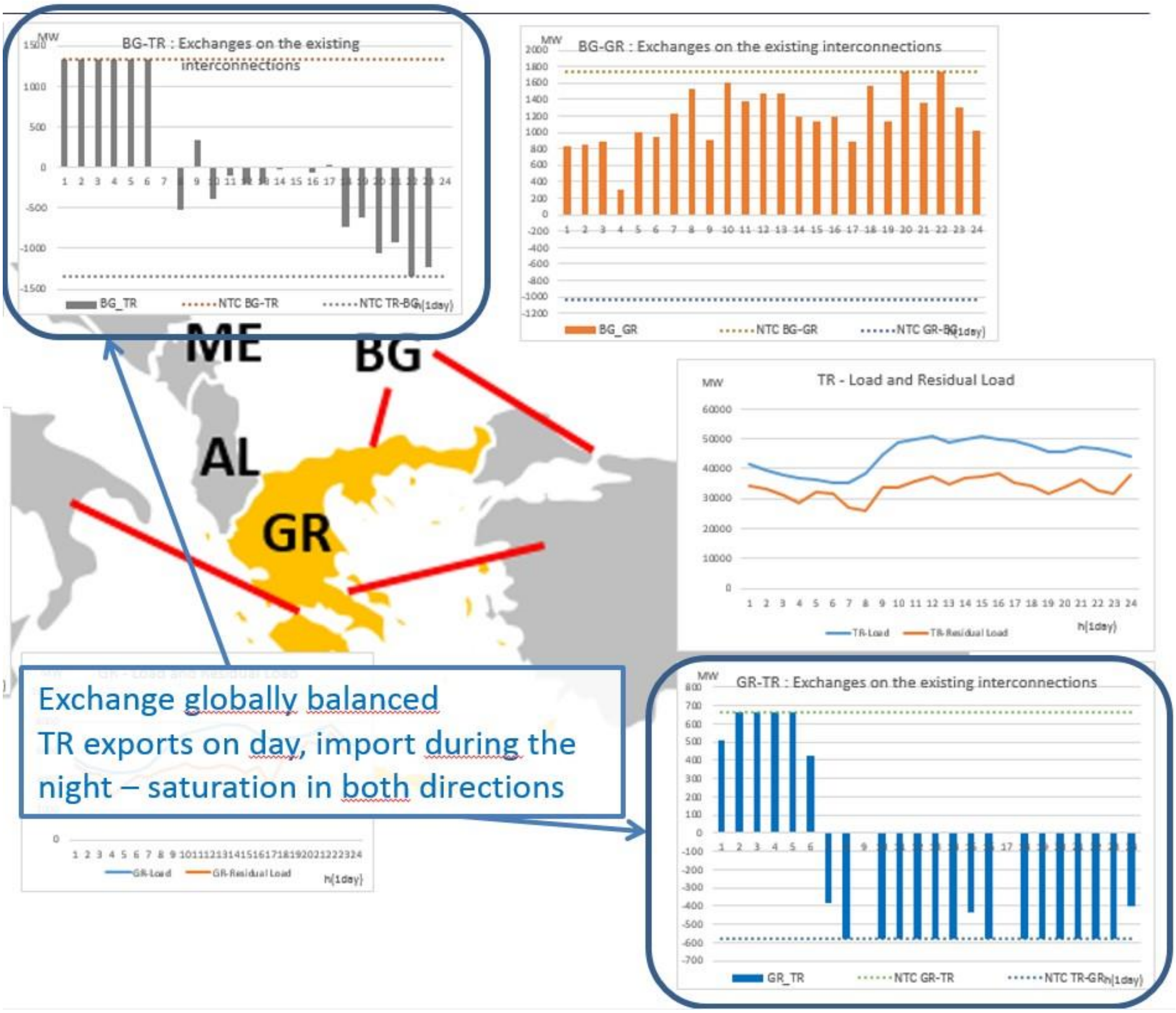

Figure 30: Flows within eastern corridor in summer in scenario 1

In this example, Turkey is importing from both Bulgaria and Greece during the night. As a result of the market optimization, Turkey is exporting during the day due to its PV generation and the residual evening peak in Bulgaria and Greece.

3 Conclusion

The aim of this report is to assess synergies and complementarities between Mediterranean pool countries. The Northern bank is engaged in ambitious decarbonization targets and market integration within a general stagnation of the electricity demand, while the southern bank is characterized by large potentiality of renewable generation and by a fairly high rate of growth of the demand.

This analysis permitted to demonstrate a considerable complementarity potential and was led in two parts. The first part was a data oriented analysis and only relied on data provided by member countries. The second part of the analysis was results oriented and used the results of the Market Study.

In the first part of the analysis, an important finding is that the complementarity relates to electricity demand mitigation and is taking benefit from seasonality effect in an annual scale and shifted daily load curves due to sun time differences.

The second part of the analysis showed that with high renewable targets in both banks, the fact of taking into account larger areas allow more mitigation of renewable variability and results in less curtailment and flatter renewables curves.

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