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flexitranstore

An Integrated Platform for Increased FLEXIbility in smart TRANSmission grids with STORage Entities and large penetration of Renewable Energy Sources

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D2.4 Flexibility assessment study for the SEE region: Greece, Bulgaria, Cyprus

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1.1 Scope of deliverable

In this Deliverable 2.4, advanced flexibility assessment studies in the SEE countries of Greece, Bulgaria and Cyprus are presented, elaborating in certain specific scenarios of system operation and RES integration. This work has been carried out during Task 2.6 and it is building upon the multi-level methodology described and developed during Tasks 2.3, 2.4, 2.5. For the first time in the SEE region, specific scenarios that evaluate adequacy and flexibility metrics alongside with the implementation of technology innovations are studied in simulations, while specific technology solutions are tested in the field of the transmission and distribution countries of 3 European countries (Greece, Bulgaria, Cyprus,).

In this deliverable, for each country, the flexibility requirements, flexibility resources (plants, storage, demand side, interconnections), present flexibility index, renewable energy penetration, LOLE, IRRE and other related indices are calculated and commented, in the context of the existing market and regulatory regime. The near future scenarios of PCI projects realization and the scheduled reforms in the regulatory and market regimes are also studied, mainly regarding the operation of battery storage in daily scheduling.

The objectives of the deliverable can be summarized as follows:

- Improve the WP2 flexibility adequacy methodology to provide more detailed analysis on future innovation scenarios with increased SEE cross-border flows
- Evaluate the impact of PCI projects interconnections in the area and innovation integration in grid operation and markets
- Analyse the impact of forecast errors in flexibility assessments and system operation scheduling
- Propose and implement a unit commitment with real time rebalancing model for reserves optimization
- Study scenarios of increased RES operation with the support of battery storage integration
- Analyse the impact of increased cross-border flows through the future electricity interconnections (PCI projects) on the SEE countries' adequacy and flexibility metrics.
- Develop additional functionalities to enhance the user stories scenarios in FEG

1.2 Concept and methodology

In this chapter, an upgraded flexibility study for the Greek power system is presented, building upon the work conducted previously in Tasks 2.3, 2.4 and 2.5 [1]. In particular, we are dealing with various existing methodological shortcomings, such as the ones addressed by ENTSO-E's Joint Research Committee (JRC) [2], regarding IPTO's previous adequacy and flexibility studies, and provide specific recommendations for improving existing studies by Greek TSO. Overall, FLEXITRANSTORE's recommendations in this deliverable can be highlighted as following:

- An upgraded modeling of forecast errors is presented. In the previous study of deliverable 2.2, forecast errors were modelled by assuming a *normal distribution* and independency between errors from different hours of the day; in this deliverable, forecast errors are modeled extensively, alongside the dependencies between different times of the day based on *historical time series* and utilizing non-parametric statistical tools
- A two-stage stochastic unit commitment (UC) algorithm with balancing actions is implemented. In particular, net load is assumed to be *imperfectly* forecasted when the day-ahead schedule is determined, and different scenarios are used to model the uncertainty in

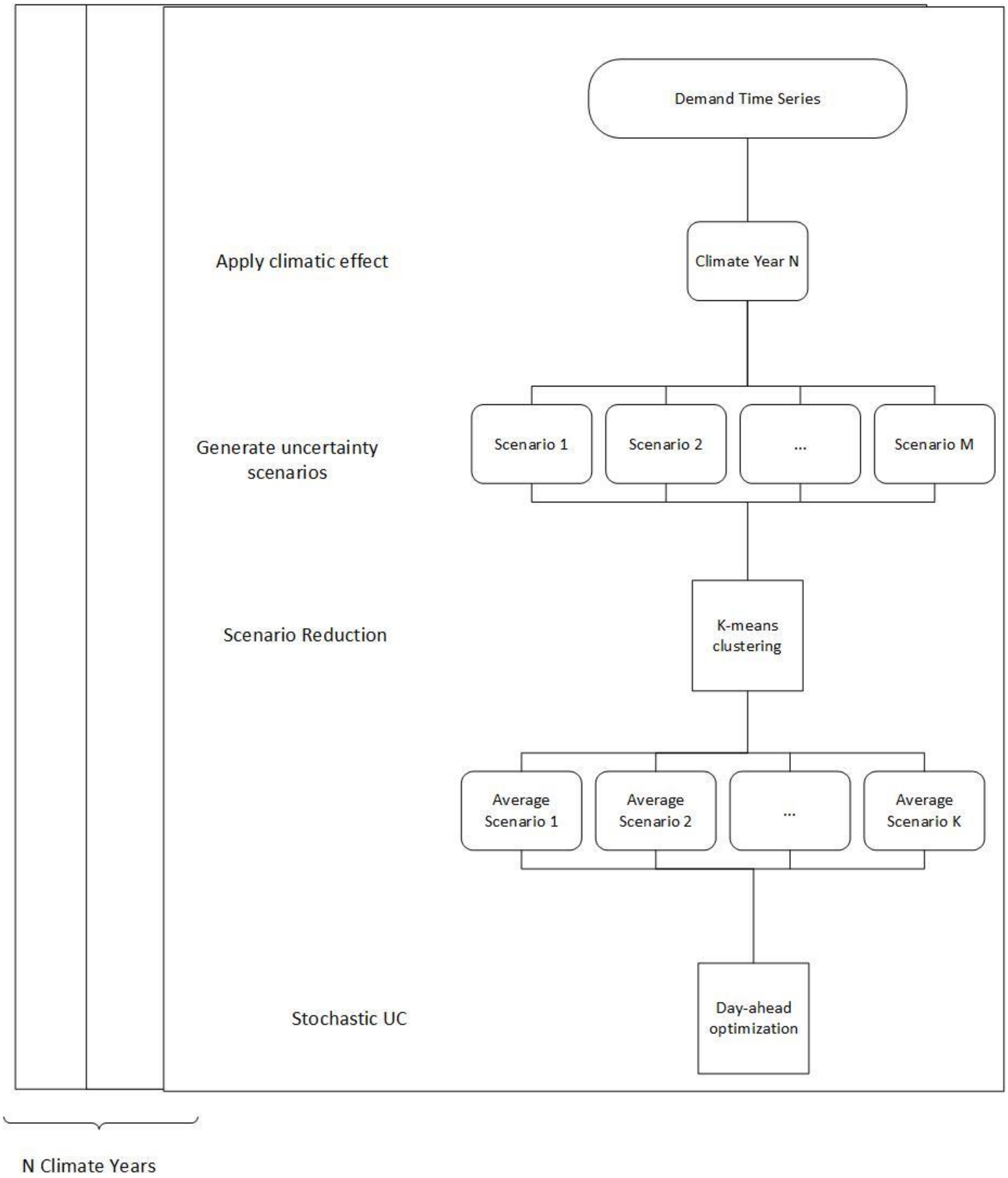
the net load predictions. This adjustment is an improvement upon traditional adequacy studies, including ENTSO-E's mid-term adequacy forecast (MAF) study [3], which assume perfect foresight (no prediction errors) when optimizing the day-ahead schedule. Therefore, the work presented here comprises a true stochastic calculation of the various indices and metrics. Moreover, reserve requirements are also calculated probabilistically in an endogenous way based on the uncertainty scenarios.

- In previous studies included in Deliverable 2.2, hydraulic power plants were only assumed to contribute to peak shaving based on the 'must run' scenario generated by IPTO's proprietary software. In this FLEXITRANSTORE Deliverable 2.4 analysis, their operation is modelled in greater detail by assuming that their generation bids, beyond the must-run quantity offered, are slightly higher than the higher-cost plant in operation
- A novel approach to generate uncertainty scenarios is implemented. First, forecast errors are modeled using non-parametric distributions comprising the marginal error distributions. Afterwards, a copula distribution function is fitted in order to model the dependencies between forecast errors from different hours of the day, thus modelling the underlying multivariate joint distribution. Please note that copula means a multivariate cumulative distribution function for which the marginal probability distribution of each variable is uniform. Finally, Monte Carlo sampling is used to create uncertainty scenarios and a clustering algorithm to reduce their size in order to produce a trackable problem
- After the simulation is conducted, the unit commitment and economic dispatch schedule is obtained for years 2020-2025. Moreover, we obtain the balancing decisions which are required to maintain demand-supply equilibrium based on the realization of the uncertainty scenarios. Subsequently, the results from the day-ahead scheduling are used as input to calculate various reliability (LOLP, LOLE, EENS) and flexibility metrics (IRRE, Flexibility Residual) [4][5].

Regarding Cyprus island power system, the assessment of the *impact of the BESS* on the curtailed RES power, the operating cost, and the reduction of the CO_2 emissions are further studied. For the generation of the scenarios, the estimated gross load and the per unit RES generation provided by the Transmission System Operator Cyprus (TSOC) for April of 2020, 2023, and 2025 were used [12]. Different RES penetration levels ranging from the reference penetration (as it is estimated by the Transmission System Operator of Cyprus (TSOC)) to the very high penetration level of 50%, are evaluated. The different scenarios were created by modifying the capacity of the wind, solar and biomass power.

Regarding the Bulgarian power system, the impact of enhanced interconnection with Greece on flexibility adequacy, through the implementation of relative PCI interconnection project, has been studied. A two-stage stochastic unit commitment (UC) algorithm [14] was developed, which co-optimized both systems jointly.

Additionally, the same approach was implemented for the Greece-Cyprus future interconnection, each power system is represented as an equivalent node in a two-node network and a DC approximation is used for calculating load flows. In each node, however, the detailed power system is included containing all the power plants separately, the VRE sources, and the precise forecasted load. The three interconnection capacity scenarios that were tested are 0MW, 500MW, and 1000MW. In all cases, the designed algorithm minimizes the overall production cost in both systems and co-optimizes energy and ancillary services. For the case of 0MW (no interconnection), each system is optimized autonomously.

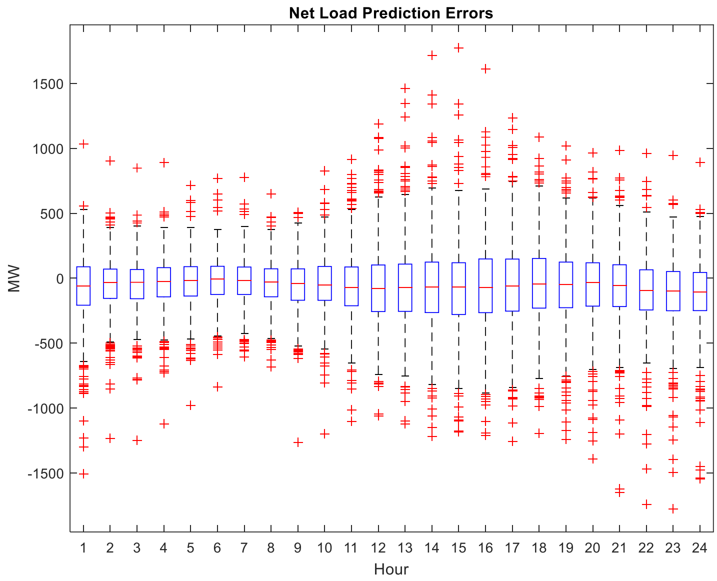


Flowchart of the upgraded flexibility assessment study

1.3 Key activities and results

In this paragraph very few results will be presented from the extensive studies presented in the full deliverable

First, the various forecast scenarios for the time-horizon of the study need to be generated. In this case, the demand time series generated after applying the climatic effect to the normalized load, used in ENTSO-E's MAF analysis, are used as input. These series are comprised of different assumptions regarding load growth, VRE penetration and hydraulic conditions.

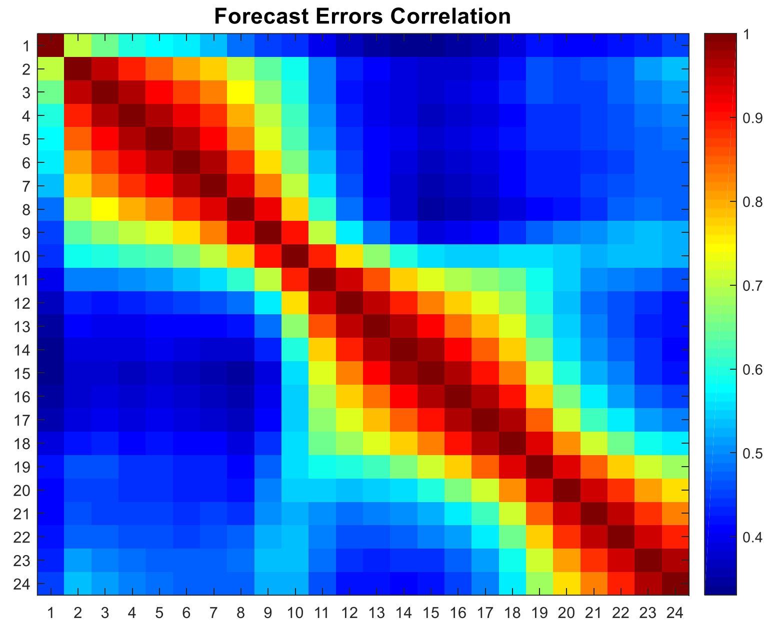


Distribution of Net Load errors for each hour of the day

Analysing forecast errors, overall, day-ahead System Load predictions had a *MAPE* of 3.2%. The predictions for the VRE generation, which comprises mostly of Wind power generators, showcased a *MAPE* of 23%, which is expected given the stochastic nature of wind generation. It should be noted, however, that *MAPE* is a measurement of relative error and thus sensitive to the magnitude of the forecasted series; the same error in absolute values (MW) gives higher *MAPE* the smaller the actual value is. Therefore, it's natural for VRE generation to have a much higher percentage error when compared to System Load, which is orders of magnitude larger, and the two results are not directly comparable. On the other hand, Net Load is similar in scale when compared to System Load, therefore by comparing their respective MAPE one could get a sense of the impact of the uncertainty in VRE generation to Net Load. In this case, Net Load exhibited a *MAPE* of 4.4%.

An interesting observation here is that, while in general VRE generation has highest prediction error as we move farther from the point of origin, Net Load errors are greater during hours 13:00-18:00. This fact underlines the impact that distributed PV generation has in Net Load predictions, as the greater errors occur during noon-afternoon and are related to the uncertainty in PV generation.

Given the above, the following approach was followed in order to effectively model the forecast errors. First, instead of making distributional assumptions, a non-parametric distribution based on Kernel density estimators (KDE) was used, thus obtaining 24 marginal distributions. Subsequently, in contrast to assuming independency between consecutive hours, the correlation matrix of the forecast errors was examined, shown as a heatmap in Figure below. The heatmap indicates extremely high correlations between consecutive hours; what this means in practice is that if for example the forecast error is positive at 14:00 (underestimation of actual net load) then there is very high probability that the error at 15:00 will also be positive, etc. Therefore, forecast errors tend to move together based on whether actual net load was over/underestimated. In order to model these dependencies, we consider the non-parametric distributions obtained as marginal distributions and used a copula distribution function for approximating the multivariate joint distribution between different hours of the day. Finally, a Monte Carlo simulation was used for sampling errors and creating 1000 uncertainty scenarios, which were subsequently reduced to 5 representative scenarios as discussed in the next section.

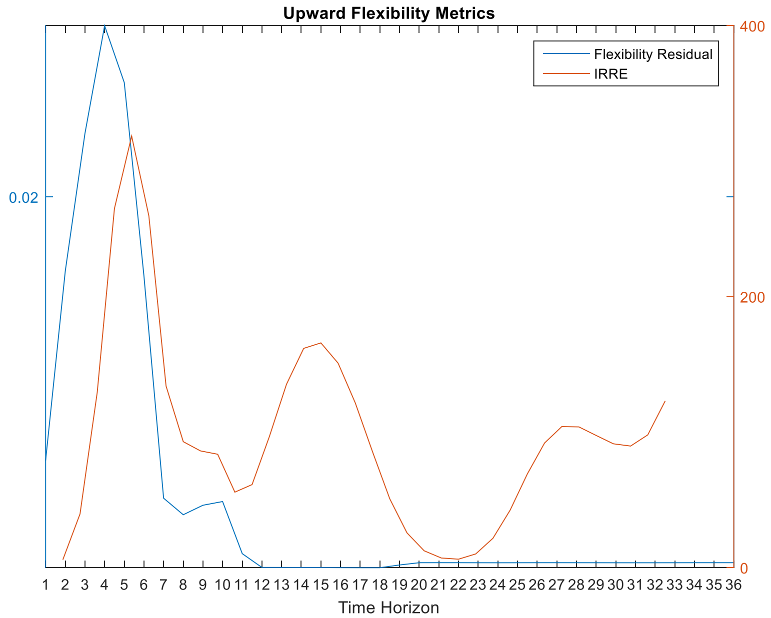


Heatmap of the correlation matrix for forecast errors of different hours.

After obtaining the dispatch schedule, we proceed with an *ex-post* calculation of two indices that quantify the risk of losing a net load ramp, namely Insufficient Ramping Resource Expectation (IRRE) [4] and Flexibility Residual [5]. As also mentioned in the previous deliverable, IRRE does not take into consideration the temporal correlation between the ramping events and the available flexibility at the particular time observation, but rather only compares them ex-post, which in turn may lead to falsely identifying particular time horizons as riskier than they actually are. For example, in the time frame from 5:00 am to 9:00 pm the power system will likely experience the full extent of variability in the net load, resulting to very large upward ramps, but also in that time frame the system is able to provide a lot of upward flexibility since most units at 5:00 am are either operating at the technical minimum (base units) or are offline (peak units). In order to deal with this drawback, the usage of the Flexibility Residual was proposed as an alternative, which considers the temporal correlation between ramping events and available flexibility in the power system.

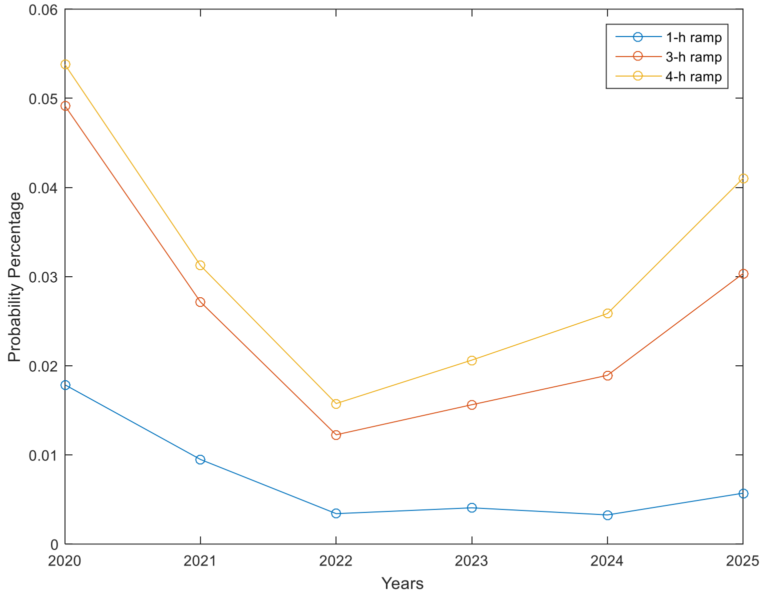
Currently, the SEE TSOs use an analytical approach to conduct adequacy studies. In this work, a Monte Carlo simulation was conducted instead, which offers greater detail in the modelling of the power system. The optimization algorithm implemented solves the day-ahead unit commitment (UC) and economic dispatch (ED) problem, prior to realization of uncertainty scenarios. Subsequently, during the second stage of the stochastic unit commitment algorithm, when uncertainty scenarios are realized, balancing actions are required from plants that have contracted reserve capacity in order to maintain the demand-supply equilibrium. The uncertainty scenarios in this work concerned the case of unexpected outages of the power plants, which were sampled from a uniform distribution given the respective F.O.R. Reserve requirements are set deterministically in accordance with the TSOs' current practices.

The simulation study concerns the year 2025. To the best of our knowledge, no published work concerning the impact of the Eurasia interconnector in the adequacy and flexibility of these two power systems exists. Therefore, the subsequently presented results are of great importance for TSOs and other stakeholders, as they provide a high-level study of the impact of this ambitious project.



Average IRRE and Flexibility residual for the total duration of the study (Greece-year 2025)

A close examination on a yearly basis is provided for some specific horizons of interest, namely 1, 3 and 4 hours ramps. In the figure below the yearly evolution of the risk of losing a ramp at the respective time horizon is shown, as estimated with the Flexibility Residual index. The overall trend observed in other reliability metrics such as LOLE is also evident here, with higher values during 2020-2021, followed by a decrease in 2022. Subsequently, the risk for the 3-hour and 4-hour horizon shows an increase, while the 1-hour horizon showcases a roughly steady risk throughout.



Yearly evolution of the risk of losing a ramp at the respective time horizon is shown, as estimated with the Flexibility Residual index (Greece)

Additional extensive flexibility studies in the SEE region are included in the full deliverable version, resulting in the conclusions presented on the next paragraph

1.4 Conclusions

In this deliverable 2.4, the FLEXITRANSTORE flexibility assessment methodology was elaborated even more to study high uncertainty scenarios stemming from demand and generation forecasting errors, high RES penetration future scenarios in the islanded system of Cyprus using battery storage, future scenarios of higher cross-border capacities and flows through planned PCI interconnection and joint optimization of operation scheduling.

The intention behind these studies is to provide some initial evaluations of the impact that the future SEE market evolution (regarding interconnections, high RES generation, new storage assets connected, market coupling) will have on the flexibility adequacy metrics. The time horizon is the year 2025 and all scenarios relate to the prospects of the SEE market and electricity infrastructure: (a) the PCI projects upgrading Greece and Bulgarian interconnection capacity through a new 400kV OHL Nea Santa (EL) - Maritsa East 1, (b) the HVDC submarine interconnection of Cyprus – Greece – Israel (Euroasia interconnector), (c) the high RES penetration targets, (d) future regulation plans for connecting battery storage onto the grid and participating in the electricity markets, (e) future market coupling and platforms for exchanges of balancing services in European level (PICASSO, TERRE, MARI projects).

The related studies provided some interesting insights in these challenges:

- The forecast errors in net load prediction is an issue that will be of high importance in the years to come, given the increasing distributed RES, the EV charging stations, the storage units on prosumer level. Thus, a two-stage stochastic unit commitment and economic dispatch algorithm with real-time rebalance has enhanced the WP2 flexibility assessment framework, where reserve requirements are being calculated endogenously based on the uncertain scenarios.

- A systematic uncertainty analysis has been presented for the years 2020-2025 for the Hellenic power system, identifying the time zones of high uncertainty in forecasting net load.
- The expected effect of intraday market (IDM) and balancing market (BM) in Greece will limit uncertainty, assuming that gate-closure times would be closer to the actual generation, and prediction errors would be reduced.
- Reserve requirements in Greece are estimated in a probabilistic way by using a two-stage stochastic programming approach that calculates them endogenously
- Based on this probabilistic approach, a detailed presentation of the Flexibility Residual, IRRE and LOLE for the Hellenic transmission system has been elaborated, several findings are depicted and commented, identifying the complementarity of these indices and the need to evaluate them to have an all-around view of the system operation challenges for balancing demand and generation.
- Cost of imbalances in Greece is expected to implicitly affect the prediction error, as it would incentivize producers or aggregators to implement advanced forecasting methods.
- Integration of new technologies such as storage could result in reduction of errors, as the VRE generators or aggregators could utilize storage in the context of Virtual Power Plants in order to match their produced output. However, none of these markets are currently in operation in Greece and therefore the impact cannot be accurately assessed; therefore, constant distribution of errors is assumed throughout.
- The introduction of more RES capacity in the power system of Cyprus as it is now operated is limited by constraints like the must-run thermal units and its isolation since it is not interconnected with other power systems.
- In Cyprus, the increased RES capacity inevitably leads to higher supply than demand on specific occasions. The extra energy cannot be injected into other neighboring systems, while a considerable amount of power should be supplied at any time from the base units resulting in compulsory RES generation curtailment to maintain the stability of the system.
- As it is shown from the results, the employment of Energy Storage Systems (ESS) like batteries could be an effective means to make the power systems greener and increase the level of RES penetration in Cyprus. The demonstration in WP5 of FLEXITRANSTORE is already a very good start to familiarize with battery technology for balancing services in the Cypriot electricity network.
- Furthermore, an HVDC submarine interconnection of Cyprus with Greece is planned to be commissioned by 2025 (Euroasia interconnector). The impact of this project on the flexibility has been evaluated in scenarios of co-optimization of operation scheduling among the two countries, reflecting market coupling and high cross border interconnection targets.
- The aforementioned joint study of Greece – Cyprus interconnected co-optimized system operation with 2 scenarios of interconnection capacity (0MW, 500MW, 1000MW) showed significant improvement of LOLE, IRRE and operation cost when moving from 0 to 500MW interconnection, while the improvement from 500MW to 1000MW is significantly less.
- A second Greece and Bulgaria 400kV OHL interconnection is planned to be commissioned by 2025 (Nea Santa – Maritsa 1, PCI project), increasing the electricity exchanges between these two countries. Similarly, the impact of this project on the flexibility has been evaluated in scenarios of co-optimization of operation scheduling.
- Three interconnection scenarios have been studied, i.e 400,800, 1000 MWs of interconnection capacity. Generally, there have been slight improvements in the adequacy, flexibility and

operation costs indices, mainly following the trend of exports from Bulgaria to Greece. Since Greece and Bulgaria are interconnected with other bordering countries as well, a more detailed overall analysis with the rest of SEE would be needed to provide a better insight of the future situation.

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