LCE-04-2017

Innovation Action

flexitranstore

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 774407

D2.2 Flexibility assessment for balancing variability and system planning

Report Identifier:	D2.2		
Work-package, Task:	WP2	**Status – Version:**	1.0
Distribution Security:	Public Version	**Deliverable Type:**	R
Editor:	UCY		
Contributors:	ICCS, TUS, IPTO, SC, CTSO, ESO, WING		
Reviewers:			

Quality Reviewer:			
Keywords:	Flexibility assessment, Adequacy studies, South East Europe Challenges, Flexibility services, Net Load Variability, Flexibility indices		
Project website: www.FLEXITRANSTORE.eu			

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1.1 Scope of deliverable

This deliverable will present the FLEXITRANSTORE project approach with methods and tools to evaluate the flexibility needs and resources in the balancing time frame of minutes–days (up to 36 hours), focusing in the case studies of SEE countries Greece, Cyprus and Bulgaria. These activities are included in Task 2.3 of WP2, as these are orchestrated by the Task 2.1, which is overviewing the latest trends and challenges in the SEE electricity sector and stressing on the gaps and needs for flexibility assessment.

The Deliverable 2.2 proceeds with a 'second-level' analysis to produce a methodology, use-cases and respective custom simulation tools for the upgrade of system adequacy studies, by incorporating the calculation of relevant flexibility indices, alongside the capacity and reliability of supply indices. In this way, conventional transmission system planning studies are revisited: reliability, adequacy and production costs studies are enriched with flexibility requirements, resources and metrics calculation. The Insufficient Ramping Resource Expectation (IRRE) index is calculated through the FLEXITRANSTORE tools, alongside with other flexibility indices providing a comprehensive picture of the current and future challenges of the transmission systems. These activities are included in the activities of Task 2.4 of WP2 as they are orchestrated by the Task 2.1. This simulation method is aiming to express the impact of the innovation technologies of WPs 5-12 and model their effects on the transmission systems, providing a test-bed for the 'third level' analysis that will conduct the what-if studies for strategic decision making on employing innovations in the grid. This approach is further elaborated in the Deliverable 2.3 (i.e. addressing the activities of Task 2.5) describing the cost-benefit approach for strategic decision making by employing the FLEXITRANSTORE smart grid innovations.

In the full deliverable document, the aforementioned studies are grouped by country (Greece, Bulgaria, Cyprus) in order to provide a stepwise insight into the national characteristics, flexibility needs and resources starting from 'rough' FAST based estimation, to hourly simulations and future prospects with respective conclusions. More details for the methodologies and results are provided in related Appendices A, B, C. Closer insights into the perspectives of the SEE region power systems, refinement of modelling and simulation framework and relative power system studies in the SEE will be provided in the final Deliverable 2.4, reflecting the activities of Task 2.6.

1.2 Concept and methodology

During the latest years, there has been an ongoing discussion on introducing systematic flexibility assessment studies in the TSOs system planning process, basically alongside the system adequacy and balancing reserves portfolio evaluation [7, 5, 21, 20, 2, 19]. The provision of market incentives for flexibility services has been a major concern of stakeholders, as this been expressed in the FLEXITRANSTORE questionnaire presented in deliverable 2.1. This need has been driven by:

(a) the augmenting penetration of volatile clean energy generation,

(b) the phase out of old conventional generation plants, disrupting significantly the generation mix and characteristics in many countries,

(c) the capital-intensive nature of transmission investments, long implementation time, public dissent and uncertainty of investment reimbursement schemes for both: fast conventional generation and new transmission infrastructure.

Thus, National Regulatory Authorities (NRAs) and TSOs worldwide are evaluating thoroughly their future needs on managing the huge portion of non-dispatchable generation in the total energy mix, introducing high volatility in net-load profiles, which may be expressed as 'flexibility adequacy' studies. In this context, smart grid ICT technologies, battery storage and market products can provide significant solutions to overcome future challenges and will play a vital role due to their low cost compared to the conventional solutions, their short implementation time and potential for improving overall system observability.

In this context, FLEXITRANSTORE has started in 2017 and is contributing with the demonstration of innovative technology solutions for the flexibility improvement, installed for the first time in the SEE consortium countries.

The added value of WP2 activities is really versatile. The aim is to provide a testbed for (i) assessing the current and forecasting the future flexibility needs and resources of transmission systems (ii) evaluate the effects of innovation technology (i.e. batteries, controllers, PFCs, sensors) into the transmission systems through a systematic way with specific KPIs, to provide an alternative strategic decision-making method for integrating new technology into the grid. The deliverable 2.2 presents the flexibility evaluation methodology and the results of implementation in the SEE countries. It provides a toolbox to build upon and assesses the benefits of technology innovation through the Task 2.5 activities, as these will be presented in Deliverable 2.3. These multi-level SEE studies will be further elaborated in Task 2.6 providing more detailed system models, what-if scenarios of the flexibility indices evolution, innovation integration and market/regulation reforms. In this way, D2.2 provides an assessment framework that links any inflexibility identified through the flexibility indices, resulting from the variation in demand and assets portfolio through the years, with solutions stemming from new market design (i.e. battery integration for different ancillary services, demand response through aggregators) and technology innovations (i.e. fast controllers for demand side response, DLRs and PFCs). This issue is also extended in Deliverable 2.3 with specific use cases and will be further elaborated in Deliverable 2.4, presenting a more in-depth flexibility analysis of the SEE region.

In order to assess the adequacy of a power system, various methodologies are utilized in TSOs' studies. Reliability indices are calculated either via analytical approach, based on the convolution of forced outage probabilities of individual generators, or via Monte Carlo simulations. In the methodology developed for the Hellenic power system study, a Monte Carlo simulation approach was adopted, which allows for more detailed modelling of the power system and market operation, allowing to incorporate stochastic uncertainty in both the supply and demand side. Similar approach is followed in [2-3], where deterministic forecasts are combined with stochastic uncertainty. The main sources of uncertainty that affect adequacy and system flexibility are:

- Climatic conditions, mainly temperature
- Expected demand growth
- VRE penetration levels and generation
- Forced outages of generators
- Hydraulic conditions
- Interconnections' availability

A number of variables above are modelled as distinct scenarios, which are then combined. Specifically, first the climatic conditions are selected based on historical data (10 scenarios available). Afterwards, three scenarios are considered for demand growth (high, low and base case), two scenarios for VRE penetration (high and mild) and three for hydraulic conditions (wet, dry and normal conditions). Overall, this results in:

10 climatic years * 3 demand scenarios * 2 VRE scenarios * 3 Hydro scenarios = 180 scenarios

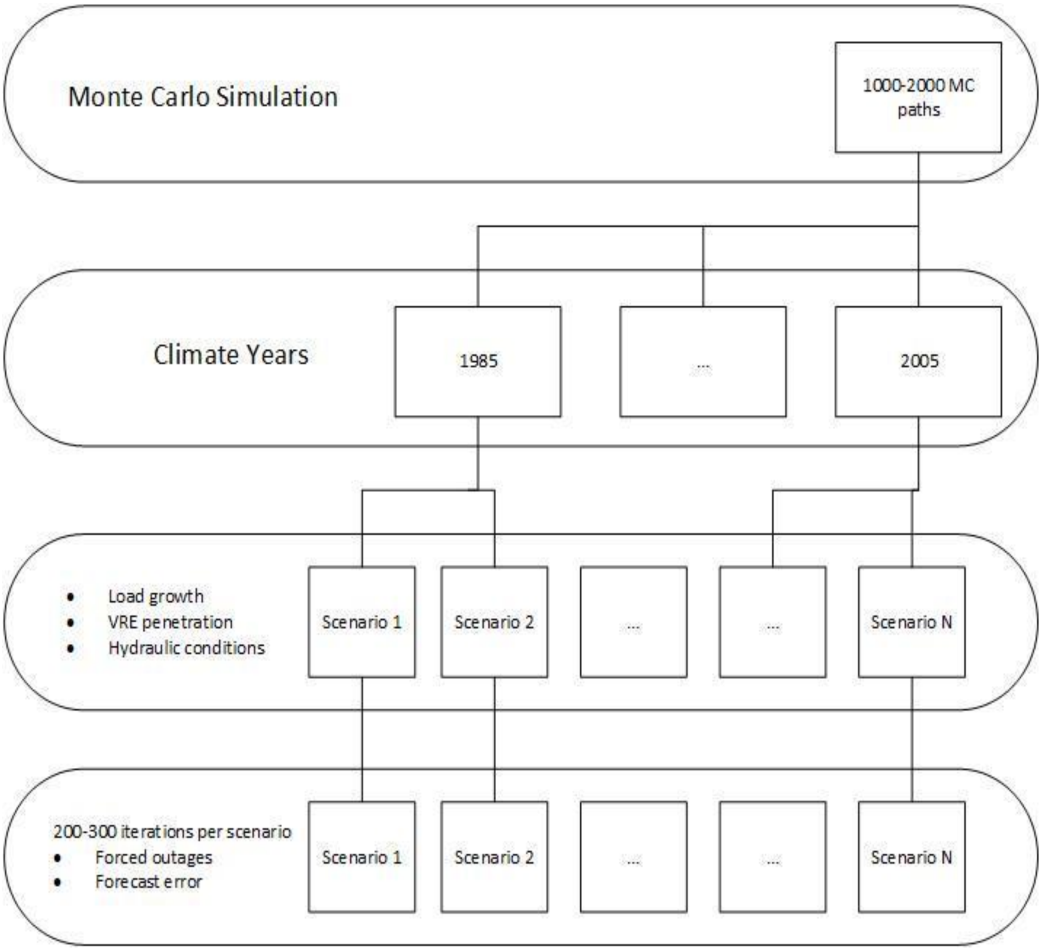
These 180 deterministic scenarios are considered in the adequacy studies of IPTO, for which the Net Load time series is assumed to be perfectly forecasted [1-3]. Subsequently for each distinct scenario we consider different paths, as resulted from Monte Carlo simulations used to model unplanned outages and the availability of the interconnections. Furthermore, we expand on the previous works by considering additional noise on the Net Load time series as it naturally occurs due to forecast errors. In this case the day-ahead optimization process is formulated as a Two-Stage Stochastic Unit Commitment problem (detailed description is provided in the Appendix).

For each scenario the following steps are followed:

1. For each climate year the demand is forecasted based on projections of the normalized load for each hour of the year and rescaled according the temperature conditions
2. The hydro generation is optimized for peak shaving based on the respective hydraulic scenario
3. VRE generation is subtracted from demand based on historical capacity factors
4. Maintenance schedule is determined beforehand (Steps 1-4 are implemented in the PROSIM software)
5. Perfect market competition is assumed when modelling the market operation (each bid represent the plant's marginal cost)
6. The day-ahead unit commitment problem is solved for each day, minimizing the total generation cost
7. Uncertainty is introduced by sampling 200-300 different Monte Carlo paths for each scenario in order to include unplanned outages of power plants and forecast error. The problem is formulated as a Two-Stage Stochastic Unit Commitment Problem (detailed description can be found in the Appendix A of PROSIM software detailed presentation)
8. The selected reliability indices are calculated as the expectation of the distinct scenarios, alongside with the 5th and 95th quantile in order to evaluate more extreme results.

To summarize, our approach provides added value in various aspects compared to traditional adequacy studies. Specifically:

- Market operation is modelled explicitly, instead of assuming priority listing of generator units
- Higher granularity in the optimization algorithm.
- Bridging adequacy and flexibility studies i.e. adequacy and flexibility indices on the same study
- Modelling of reserves based on historical data
- Implementation of Monte Carlo simulation instead of analytical approach (which require simplifications when complex systems have to be modeled)
- Demand side management is included, to the extent that this exists in the Hellenic regulation
- Forecasted errors are included by adding noise to the forecasted Net Load series, based on distribution of historical errors.

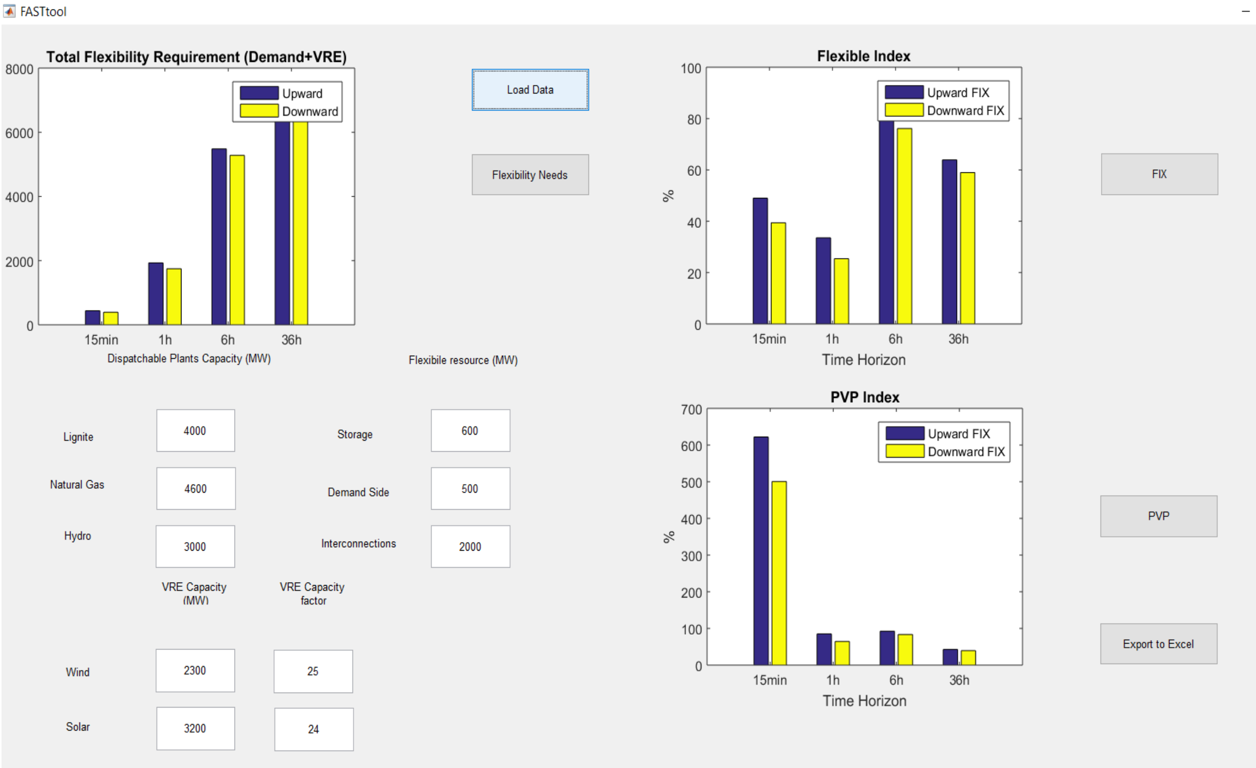


Structure of considered scenarios

In the following paragraphs, the flexibility assessment studies for the SEE countries of Greece, Bulgaria and Cyprus are presented. The studies have been conducted by three 'national' teams comprised mainly of Universities and National TSOs, being aligned with the local practices in system studies and sharing of system operational data.

In the following paragraphs the results of the studies are being presented for each country, with a stepwise approach. IEA FAST methodology guidelines have been followed to provide an introductory picture of the flexibility needs and resources for the three SEE countries Greece, Cyprus and Bulgaria. The data used are derived directly for the National TSOs all being full members of the FLEXITRANSTORE consortium. This provides higher accuracy than the IEA FAST studies [23], where some variables have been approximated with generic values. This is further discussed throughout the country analyses. Furthermore, a user-friendly hands-on tool has been developed in Matlab that allows the user to enter the input data and perform the calculations for the FAST study.

Further on, the 'national' teams have worked closely together to refresh the adequacy studies being carried out by TSOs on an annual basis with flexibility indices that will reflect the future flexibility challenges of the transmission systems in Greece, Cyprus and Bulgaria. The approach for each country is aligned with national practices and the on-going efforts in each TSO to improve their studies with flexibility assessments. Therefore, the flexibility adequacy studies are not absolutely uniform, but involve the strong support of each TSO to provide data and share the 'pros' and 'cons' of their practices and system operation.

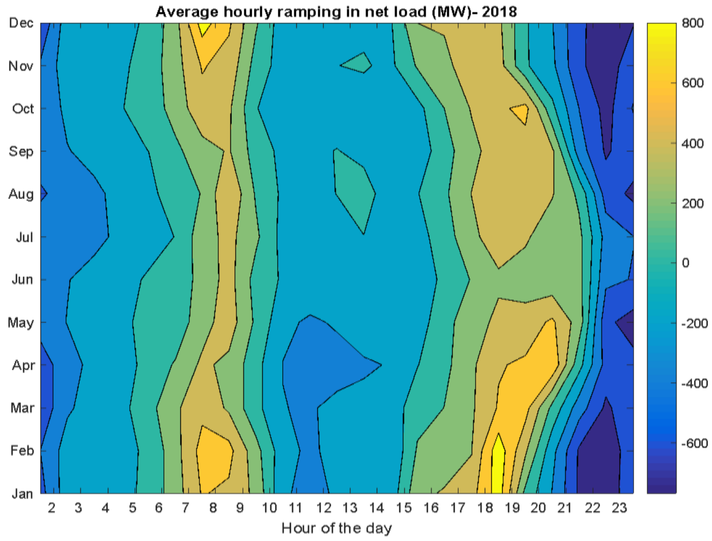


FAST -based flexibility indices calculation tool developed in FLEXITRANSTORE

The strong point of the hereby studies is not accuracy or uniformity but the introduction of flexibility assessment in the context of the TSOs' regular business studies, in order to evaluate the flexibility needs of the following years to address the size and variability of demand and RES generation. Further on, it will provide the basis to evaluate the costs and benefits of FLEXITRANSTORE innovation technologies on the transmission network operation, and provide a strategic decision making method for TSOs to adopt innovations for meeting flexibility challenges. These activities are related with Task 2.5, and Deliverable 2.3.

1.3 Key results/Main findings

In the first step, the flexibility requirements of the net load are determined for four time-horizons, namely fifteen minutes, one hour, six hours and thirty six hours. The calculations are based on actual hourly values from the ex-post data of the Greek power system.

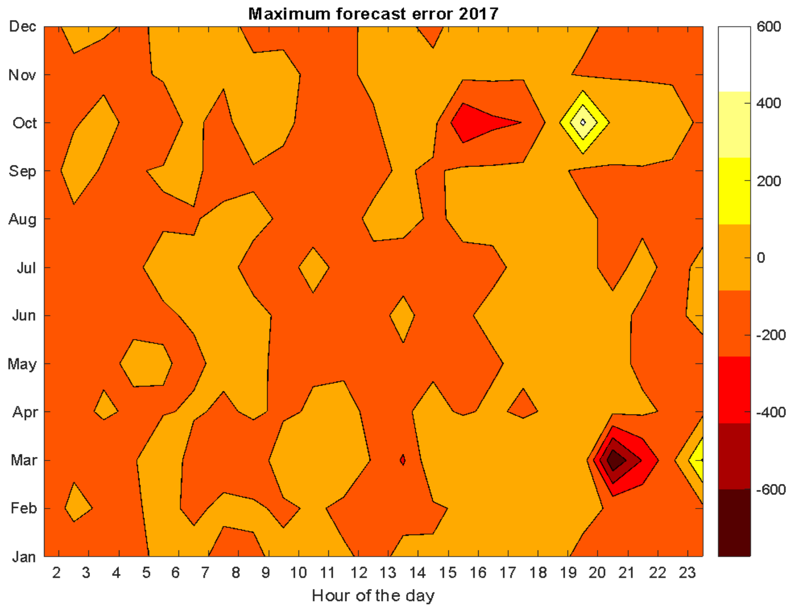


Average hourly ramping up in net load for 24 h (2018).

Both years showcase a similar distribution of ramps, both intraday and monthly. For **2017**, it can be observed that the highest upward ramps occurred during morning (8-9 am) and afternoon hours (6-7pm), while the largest downward ramps took place during the night (10-11pm). Similarly, for **2018** the highest average ramping is observed in afternoon (6-7pm) of January and February. The aforementioned observation holds true for both the average and maximum hourly net load ramps. January and February show the highest morning upward ramps, while February, March and September the highest evening ramps. This slight shift in the maximum ramp is probably an indication of how the weather affected load patterns.

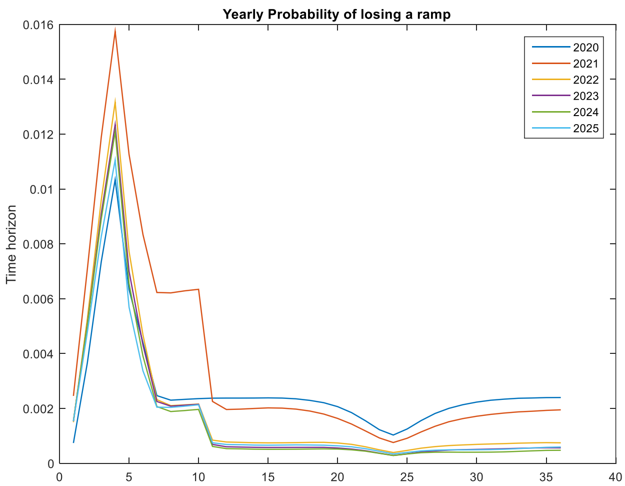
The needs for flexibility, called existing flexibility requirement, are calculated based on the sum of the demand fluctuations and the VRE variability and uncertainty. This is a conservative approach because it regards changes in demand and VRE generation to be negative correlated at all times. Net load data offers a more realistic approach, because it incorporates the time that ramps occurring in demand coincide with changes in VRE output. Most prominent example is the morning ramp in demand which starts at around 7:00 am, which is the time that the PV generation starts to ramp up. Since the historical net load data were available by IPTO, we calculate flexibility needs based on this information.

The maximum forecast error is observed during the hours from early afternoon until late afternoon, when PV generation is ramping down and demand is simultaneously ramping up to its peak. In particular, at early afternoon hours (3-5 pm) in October 2017 we have an absolute value of forecast error around 400MW, while at late afternoon hours (8-9 am) in March 2017 an absolute value of forecast error around 600MW is observed.

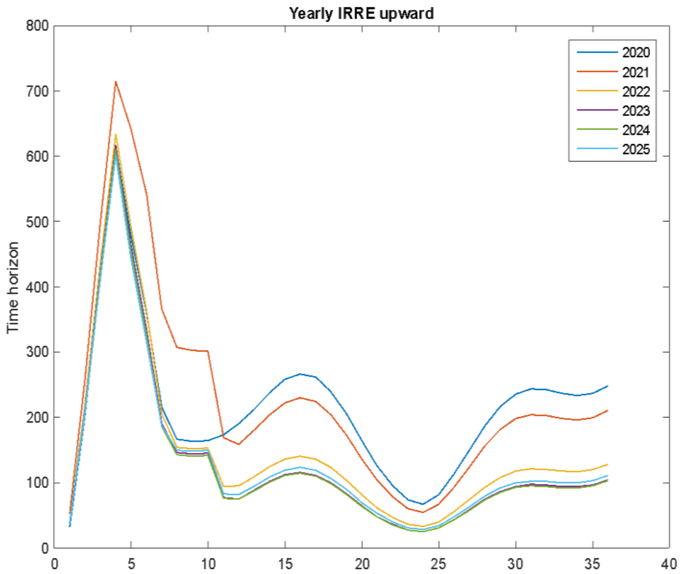


Box plot of day-ahead forecast errors omitting extreme outliers

Regarding flexibility adequacy calculations, the IRRE and the probability of losing ramp indices (more details in the Appendix A of full deliverable) have been calculated for the study period 2020–2025 for different ramping intervals, namely 1 hour ramp to 36 hours ramp. In the following figures the probability of losing a ramp or different ramping intervals and the expected value of the IRRE are illustrated taking into account all the scenarios, along with two extreme values of the confidence interval.



Probability of losing a ramp for the years 2020-2025

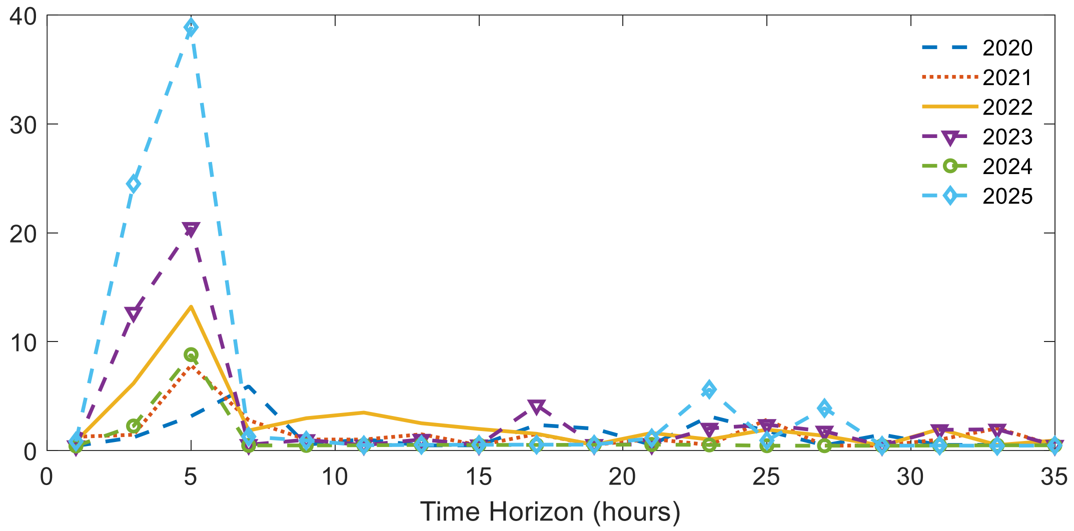


The IRRE index for the years 2020-2025 for the Greek power system

For the Cyprus power system similarly, the **Insufficient Ramp Resource Expectation** (IRRE) measures the flexibility of a power system and is used for long-term system planning. IRRE shows the number of times that a power system may have insufficient flexibility to meet changes in the net load. It should be noted that IRRE has many similarities with the FR metric. In particular, both in the IRRE and the FR, the net load ramp and the system flexibility should be calculated following a similar process as mentioned above for the case of FR. In the case of IRRE, after calculating the system flexibility, the **A**vailable **F**lexibility **D**istribution (AFD) should be formulated based on the available flexibility in each time horizon *i*. Based on the AFD the **I**nsufficient **R**amp **R**esource **P**robability (IRRP) is first calculated while the IRRE is obtained by summing the IRRP for each time horizon. Given the unit commitment results for a certain time interval (in this study for a whole year) the IRRE can be defined by:

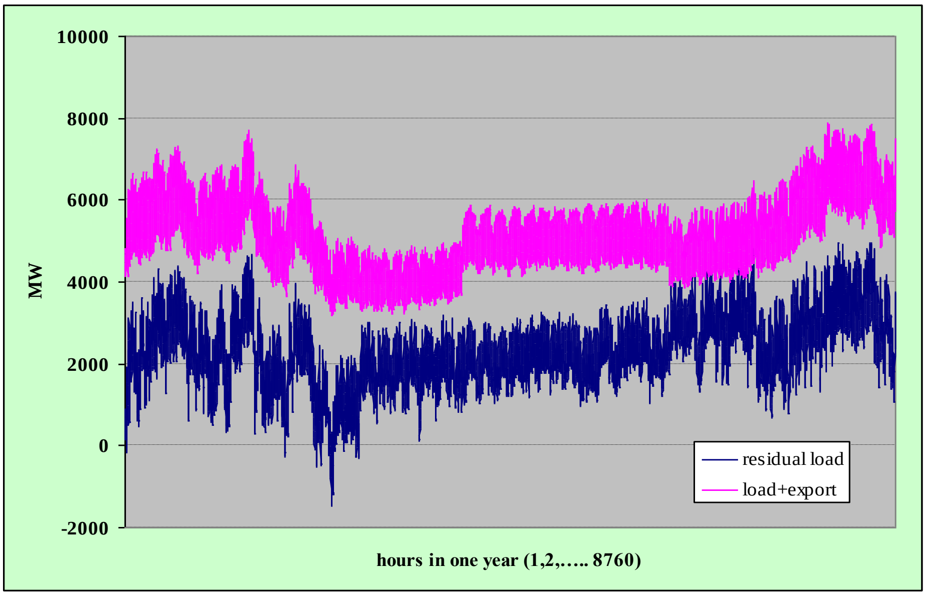
(1) Calculate the net load ramp,
(2) Calculate the system flexibility,
(3) Calculate the available flexibility distribution,
(4) Calculate the IRRP and

(5) Calculate the IRRE for each time horizon i.



IRRE-Cyprus power system for years 2020-2025

Similar studies have been conducted for the Bulgarian power system as well, evaluating the residual load, hourly ramps and flexibility indices indicatively for the year 2018. Respective conclusions of the all aforementioned studies are presented in the following paragraph.



Hourly values of gross load and resulting hourly values of residual load

1.4 Conclusions

The most important results of this deliverable are:

- As pointed out by the FAST-based analyses, downward flexibility of the Greek system is extremely lower than upward flexibility, while the system is yet heavily dependent on lignite generation and lacks storage resources that may support load levelling. Thus, the net-load forecast accuracy and resulting operation planning play a critical role for meeting the flexibility challenges, posing the question whether to invest on improving forecasting or flexibility resources.

- A deeper study of the forecast errors show that these are more evident during the afternoon and evening hours, since in that hour the demand peak coincides with the ramping down in the PV generation and demand is simultaneously ramping up to its peak.
- In all cases of Greek studies, the 5-hour ramp constitutes the highest risk of losing a ramp
- In Cyprus, the FAST study showed there is a lack of flexibility resources in the 15-minute time frame, as the PVP for the 15 minutes is the smallest comparing to the PVPs of the other time frames.
- In Bulgaria, coal fired plants, comprise a significant portion of the generation mix in Bulgaria. During peak hours, most of them operate at maximum output or mid-merit, and the system has fairly good ability to meet upward net load variations in short term.
- In Bulgaria, during hours of minimum demand though, a significant portion of coal power plants are offline and their technical characteristics (namely start-up time) do not allow them to offer flexibility in the 6-hour time horizon. This result illustrates the importance of planning and forecasting, showing that while the system can respond well to short-time horizons, even when we impose upward ramps in states of peak demand, response in longer time horizons is not equally good, due to large start up times of the existing portfolio of power plants.
- In Bulgaria, when PV generation is higher due to climatic conditions and at the same time the demand is relatively low - this being the comfort period regarding daily average temperatures when neither heating nor cooling demand is needed, curtailment of wind and PV may be needed in order to balance the system and this is identified as a downward regulation problem. Storage (i.e. PV-BESS) would provide a solution to this flexibility need while at the same time omitting clean energy spillage.
- Most of the VRE spread in BG is far from load and in areas with remote access. Photovoltaics are main part of VRE but the forecast of their generation is still not sufficient.
- The main flexible resources are provided from coal and hydro power stations.
- Coal fired plants comprise a significant portion of the generation mix in Bulgaria. During peak hours, most of them operate at maximum output or mid-merit, and the system has fairly good ability to meet upward net load variations in short term. During times of minimum demand though, a significant portion of coal power plants are offline and their technical characteristics (namely start-up time) do not allow them to offer flexibility in the 6 hour time horizon.
- Examining two estimated scenarios in BG for 2020 electricity mix show that, with a difference in RES penetration of 10%, difference in demand of 25% and decrease in net exports by 50% (related with RES penetration increase in the adjacent countries), (i) the number of hours of in the year in which the residual load is lower than the absolute minimum annual gross total load will increase approximately 8 times and (ii) number of hours in the year in which the residual load is lower than the corresponding minimum admissible generation will increase approximately 4 times.

- The aforementioned results together with the coal units' phase out program even before 2022 and the lack of big industrial loads, lead the TSO of Bulgaria to the estimation that further future integration of RES in the years beyond 2020 will result in balancing problems
- This is also reflected in the respected increased values of IRRE for the various levels of RES penetration.

- Hydro pump storage and grid infrastructure projects are planned, such as the renovation of the existing big hydro electrical power plants, the new hydro project Yadenitsa, development of 110kV network and 5 new 400kV lines.
- Investigation of wind – storage configurations for ancillary services provision and smoothing of variability would be very beneficial to limit the effects of RES penetration in the next decade.
- IRRE and FR results indicate that, for the period 2020-2023, the Cyprus power system is more prone to lack flexibility, especially in the time horizon between 1h – 7h. Again, the flexibility of this time horizon can be enhanced through fast flexible resources.
- The Loss of Load Expectation (LOLE) for the upcoming years (2020-2025) is continuously increased for the Cyprus power system due to the increase of the load while the generation potential is kept the same for all the years. However, as indicated through the different case studies, the other metrics such as the IRRE and FR can provide more useful information for the planning activities of the CTSO. In particular, through the IRRE and FR the time horizons where the power system needs enhancement (more generation resources) are more obvious than in the case of LOLE.
- The Cyprus power system needs supportive flexible resources such as the interconnection with other countries. An interconnection project through a submarine cable with Greece and Israel is currently under study, the so called "EuroAsia Interconnector Project", which is promoted as a Project of Common Interest (PCI).
- The studies of the FLEXITRANSTORE consortium are following the evolution of the electricity markets in the three SEE countries and will improve the flexibility studies platform being developed in WP2 for flexibility indices assessment and strategic decision making method for innovation integration during the work in the final task 2.6. The results of this work will be presented in the final deliverable 2.4 evaluating in detail the flexibility needs and indices of the SEE power system for the following years, evaluating any local congestion limitations and proposing related relief measures, in relation with the scheduled PCI projects interconnecting the Cyprus, Crete and Greece mainland as well as reinforcing the Greece Bulgaria interconnection.

Furthermore, an in-depth analysis of the ancillary services needs and resources will be provided, improving the functionalities of the WP2 flexibility assessment platform, as designated by the JRC in [4]. This will widen the time horizon of flexibility studies and will reflect the realistic demonstrated scenarios in the WPs 5-12. Furthermore, the grid behavior in case of large RES penetration will be modeled in the flexibility assessment platform providing contingency analysis functionalities.

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