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The innovative FlexPlan methodology to reap the benefits of including storage and load flexibility in grid planning: methodology and regional study cases

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SUMMARY

In the last years, we are assisting to a high-speed deployment of Renewable Energy Sources (RES) in electric Transmission and Distribution (T&D) grids as well as to an increased penetration of Distributed Energy Sources (DER) in distribution grids. This is making grid planning activities more and more complex and affected by a high level of uncertainty and calls for a deep revision of the consolidated grid planning methodologies applied by the System Operators.
On this pathway, the FlexPlan project (https://flexplan-project.eu/) aims at establishing a new T&D grid planning methodology considering the opportunity to install new storage devices as well as to perform a flexible exercise of some loads located in selected grid nodes as an alternative to building new lines. Local compensation of RES generation spikes could allow to reduce the amount of congestion the grid is exposed to with a less expensive and less environment-impacting intervention.
This paper first analyses which aspects of the present consolidated grid planning methodologies applied by System Operators are becoming critical and then describes the key aspects of the new FlexPlan grid planning methodology aimed to overcome those criticalities. Then, the paper provides details on the reference scenarios adopted by FlexPlan for the three grid years (2030, 2040 and 2050) and provides the first results for the simulations carried out by each of the 6 regional cases. Finally, the paper provides some conclusions that can be drawn from these studies on the role flexibility will play in Europe in the medium-long term and on the benefits that can be reaped by taking it into account in the transmission and distribution grid planning process.

KEYWORDS - Grid Planning, Grid flexibility, Storage, Demand Side Management

INTRODUCTION

In the last years, we are assisting to a high-speed deployment of Renewable Energy Sources (RES) in electric Transmission and Distribution (T&D) grids as well as to an increased penetration of Distributed Energy Sources (DER) in distribution grids. This is making grid planning activities more and more complex and affected by a high level of uncertainty.
Grid investments are capital intensive and infrastructures lifetime spans over several decades. Due to widespread RES and DER deployment, the generation and load scenarios upon which the cost-benefit analyses for new grid infrastructures are based are continuously and rapidly changing. As a consequence, when a new line is commissioned, the techno-economic benefits it was initially supposed to provide could prove significantly lower than expected.
Additionally, building new lines meets more and more hostility from the public opinion, which makes planning activities even longer and affected by uncertainties.
Variable flows from RES are generating a new type of intermittent congestion which can sometimes be better compensated by resorting to system flexibility: in many cases, an investment in a new line/cable would not be economically justified.
On this pathway, the FlexPlan project (https://flexplan-project.eu/) aims at establishing a new T&D grid planning methodology considering the opportunity to install new storage devices as well as to perform a flexible exercise of some loads located in selected grid nodes as an alternative to building new lines. Local compensation of RES generation spikes could allow to reduce the amount of congestion the grid is exposed to with a less expensive and less environment-impacting intervention. This complies with the general terms and intentions of the European Directive on Internal Energy Market (2019/944) [1] and the corresponding Regulation (2019/943) [2], which were a part of "Clean Energy for all Europeans" package [3].
FlexPlan aims at providing the following contributions:

- Development of a new methodology and of a new tool optimizing T&D planning by considering the placement of new storage devices as well as the flexible exercise of some loads in selected grid nodes as an alternative to traditional grid planning. This methodology presents several very innovative aspects, among which: assessment of best planning strategy by analysing in one shot a high number of candidate expansion options provided by a pre-processor tool; simultaneous mid- and long-term planning assessment over three time frames (2030-2040-2050); incorporation of full range of Cost Benefit Analysis criteria into the target function; integrated transmission and distribution planning; embedded environmental analysis (air quality, carbon footprint, landscape constraints); probabilistic contingency methodologies in replacement of the traditional N-1 criterion; application of numerical decomposition techniques to reduce calculation efforts; analysis of variability of yearly RES and load time series through a Monte Carlo process.
- Application of this methodology to perform a grid planning analysis over six European regional cases by considering both the mid- and the long-term (2030, 2040, 2050) in one only optimization process. In addition, pan-European scenarios are run as well, in order to establish consistent border conditions for all 6 regional cases.
- Elaboration of regulatory guidelines aimed at providing National Regulatory Authorities with indications on the opportune regulation to be adopted for maximizing the benefits that can be obtained with the new grid planning methodology. These guidelines will be built by considering the potential role of flexibility and storage as a support of T&D planning, resulting from the outcome of the six regional cases analyses.

This paper first analyzes which aspects of the present consolidated grid planning methodologies applied by System Operators are becoming critical and then describes the key aspects of the new FlexPlan grid planning methodology aimed to overcome those criticalities. Then, the paper provides details on the reference scenarios adopted by FlexPlan for the three grid years (2030, 2040 and 2050) and provides the first results for the simulations carried out by each of the 6 regional cases. Finally, the paper provides some conclusions that can be drawn from these studies on the benefits that can be reaped by taking flexibility into account in the transmission and distribution grid planning process.

CRITICAL ASPECTS OF CURRENT PLANNING METHODOLOGIES

The new context described above should bring grid planners to rethink some foundations of the grid planning methodologies which are applied nowadays.

First of all, distribution networks are now subject to important changes, due to the installation of local generation and storage. Due to that, even the direction of power flows, traditionally from primary substations to the loads, are more and more frequently reversed: distribution networks are becoming able to deliver power to transmission networks. Along with power, distribution networks become able to provide services towards transmission (mainly: balancing and congestion management). Such services are extremely important to provide extra grid flexibility, so as to help integrating an ever increasing amount of Renewable Energy Sources (RES). In this context, distribution grids should abandon the traditional fit-and-forget grid planning methodology based on sizing the grid for a “worst case”. At the same time, transmission and distribution planning should become more and more integrated, in order to realise the best synergies between the two networks and minimize costs. However, taking into account that distribution and transmission planning are carried out by two distinct entities (Transmission System Operators - TSOs - and Distribution System operators - DSOs), it is also important that a certain decision autonomy is maintained between TSOs and DSOs as well as a separation on data management. FlexPlan proposes for the first time a methodology to manage this.

Another important rigidity of present grid planning procedures consists of the fact they don’t co-evaluate a set of reinforcement candidates, so as to determine an economic optimum by considering both operative dispatch costs (OPEX) and capital costs (CAPEX), but they analyse one candidate a time by applying a with-and-without methodology which compares the total costs when the new candidate is present in the grid with the status quo before the investment is carried out (two versions are possible depending if all the other candidates are considered already installed or not, giving raise to the TOOT and PINT methodologies described in ENTSO-E Cost-Benefit Analysis [4]). As each investment influences the economical evaluation of the others, this methodology may bring to sub-optimal decisions.

Another aspect that is completely disregarded by present planning methodologies is that flexibility provided by storage elements and flexible loads can bring congestion management support, especially in the case of short duration congestion caused by RES variability patterns, for which investments in grid reinforcements would not be justified. So, the installation of storage elements in selected nodes as well as a flexible exercise of big loads could prove more efficient than grid reinforcements.

Present grid planning methodologies disregard, or consider in a very qualitative way, environmental externalities (effects on air quality, CO_2 lifecycle or landscape impact), whereas these aspects are more and more important because of growing public sensibility to environmental issues. In order to consider environmental costs in an objective way, it is important to implement a quantitative appraisal methodology allowing to internalize them, so as to put them on the same scale as all other costs.

Nowadays, grid procedures first carry out an optimization of the social welfare and then use the obtained results in a separated cost-benefit analysis. That can be a source of distortions and suboptimalities. A better approach would be implementing a cost-benefit methodology as fully integrated into the target function of the grid planning optimization procedure.

Another important aspect is that grid planning should now look forward till the long term (e.g. 2050 or even beyond) in order to gather a complete overview on the decarbonization path of the European system. So, long-term planning models should be elaborated. Such models should not solve one year a time (e.g. first 2030, then 2040, then 2050) because this approach brings to overestimate the needs for a given target year, conditioning the global optimum and potentially bringing to sub-optimal solutions. The optimisation should be carried out simultaneously for all target years. This enormously complicates the numerical problem, bringing to the necessity to apply decoupling procedures (e.g. Benders’ decomposition) and/or relaxation methodologies.

Finally, contingency analyses based on the traditional N-1 methodology proves more and more fragile and not fit for an objective contingency appraisal (the same fault probability is considered for all branches). Many TSOs already begin to consider replacing N-1 with probability-based methodologies. However, such methodologies are extremely heavy from the computational point of view and their rigorous application to large computational cases (long-term planning, nodal approach for big counties

and hourly time resolution) often results computationally too heavy. Thus, it is important to search for simplified yet efficient methodologies.
As described in the following sections, all the above issues are considered altogether in the innovative approach carried out by the FlexPlan project.

OUTLINE OF FLEXPLAN INNOVATIVE PLANNING APPROACH

The main goal of the FlexPlan approach is to incorporate classical and flexible grid expansion options including their environmental impact in a network expansion optimisation model, capable of determining the optimal network investments under a multitude of future scenarios and operational conditions. The developed model is generic and can be applied to both transmission and distribution networks.

Figure 1 shows the structure of the optimisation model and the input parameters. A set of discrete candidate grid investments, e.g., alternating current (AC) and direct current (DC) transmission assets, AC distribution assets, demand flexibility and storage investments are provided as an input for the tool. These expansion candidates are characterised both technically and economically by the FlexPlan pre-processor. The installed conventional power generation capacity, RES generation and demand time series as well as transmission and distribution system data are used as input.

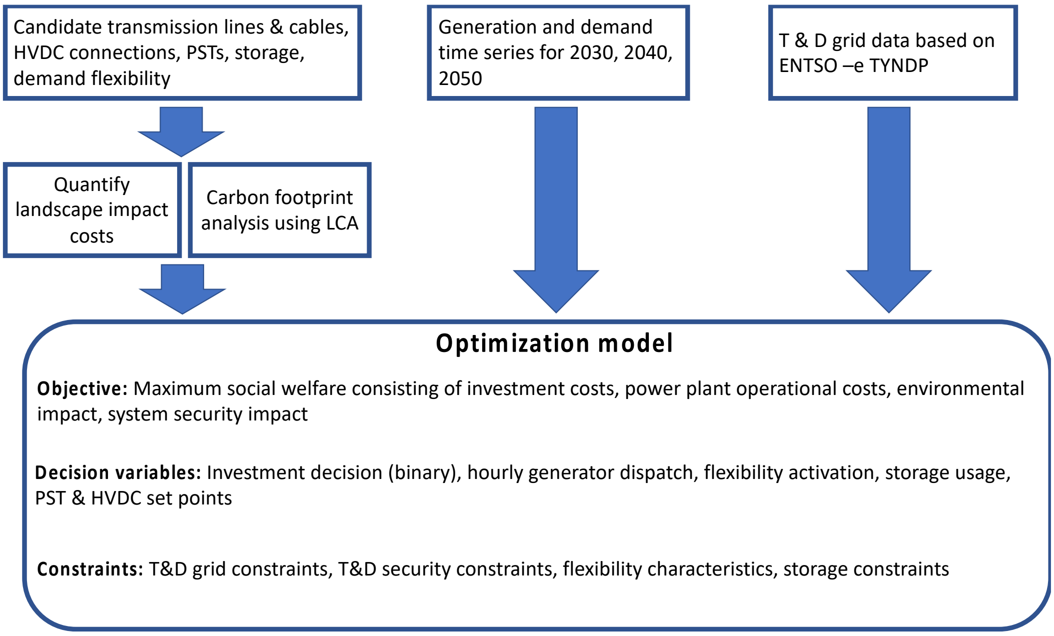

Figure 1 Building blocks, input and output parameters of the planning model

The objective of the optimisation model is to maximise social welfare. This is obtained by minimising the sum of T&D grid investment costs, operational costs bound to generation dispatch and environmental impact costs, while maximising the benefits achieved using the demand flexibility and storage. The resulting optimisation problem has been formulated as a multi-period, stochastic mixed-integer linear problem[5]. Discrete decision variables represent investment decision for AC and DC grid investments, demand flexibility and storage investments. An hourly resolution of the problem is considered over three investment years of the planning horizon, namely 2030, 2040 and 2050. The hourly resolution ensures the accurate modelling of demand flexibility actions, such as demand shifting and charging and discharging of battery energy storage systems. The model is formulated stochastically to account for different future developments with respect to RES penetration as well as climatic conditions. Including different probabilities for each scenario and representing the objective function as a probability weighted sum, a trade-off between all considered scenarios is found. The detailed objective of the optimisation problem is provided under [6].

To limit the computational burden of the optimization problem, a list of network locations and technology candidates for network extension is provided by a SW module. The reduction of investment decision options cuts down the number of binary variables in the formulation.

Flexibility resources, such as storage and loads representing demand response options, are presented as network candidates competing with conventional network assets. Two ways are provided to propose candidates to the planning tool: forced by the user and automatically calculated by the candidate pre-processor module. In the first case, the user, based on its knowledge about the network, can propose network extension candidates. This is specially recommended in two cases:

- Extension of the network between nodes that are not connected through lines in the non-expanded scenario.
- For technologies that require a dedicated study for their installation, e.g., HVDC, phase shifting transformers (PST) and pumped-hydro.

In the second case, the automated proposal of storage, flexible loads and conventional asset candidates is performed in four main steps:

1. Identification network congestions: the results of the non-expanded network Optimal Power Flow (OPF) carried out by the planning tool suite are the inputs that the pre-processor needs to perform this task. Lagrange Multipliers (LM), Locational Marginal Prices (LMP) and Power Transfer Distribution Factors (PTDF) are used, among others. Using this information congestions are identified and ranked based on their severity and occurrence. Considering this ranking, a number of locations is selected for network expansion.
2. Analysis of network congestions: once identified, the selected congestions are analysed more in detail through the identification of power flow directions, number of congestion hours, consecutive congestion hours, etc.
3. Check of locational constraints and characteristics: as part of the grid model definition, the user can provide additional characteristics related to each network node: type of bus (substation and types of load supplied, industrial load, generator), availability of resources, location of bus (rural or urban) and area restrictions (partial or total). It is not mandatory to provide this information, but it helps refining the candidate pre-selection.
4. Proposal of candidates for selected nodes: based on the previous information a set of candidates for network extension is proposed to the planning tool for each selected location. The following technologies are considered as candidate: batteries (Li-ion, NaS and flow), hydrogen, Compressed Air Energy Storage (CAES) and Liquid Air Energy Storage (LAES), demand response (through flexible loads) and conventional network assets (AC lines and cables and transformers). In the case of lines/cables, the influence of updating one network branch is studied, to avoid that increasing the capacity in one segment to solve a congestion causes a new congestion in surrounding lines.

The environmental impact is modelled taking air quality impact, carbon footprint and landscape impact into account. A linearised air quality impact model has been developed which links the impact of CO_2, NO_X and SO_X emissions of conventional power plants to their production. These costs are modelled explicitly within the optimisation objective as the impact is dependent on the dispatch of conventional generation. The carbon footprint of candidate investments has been determined by means of a life-cycle-analysis considering the CO_2 emissions during the manufacturing and installation. The carbon footprint costs are considered as part of the CAPEX of the candidates. Finally, the landscape impact is quantified using an optimal routing algorithm [7] . The optimal routing algorithm uses spatial weights for installing transmission system equipment in certain areas, in particular existing infrastructure corridors, rural and urban areas, mountain regions and protected natural areas both onshore and offshore. These spatial weights are considered as part of the installation costs and using an A-star shortest-path algorithm [7], the optimal right of way for each candidate is determined as a minimum cost path. The developed approach is implemented as an open-source tool calculating optimal routes for both overhead and underground transmission as well as providing partial under-grounding solutions [8].

To keep the optimisation problem tractable, linearised power flow equations have been used for representing transmission and distribution networks. The well-known linearised ‘DC’ power flow approach is used for meshed transmission grids, including linearised formulations representing PST actions, point-to-point and meshed HVDC grids [5]. As opposed to meshed transmission grids, voltage congestion can occur frequently in radial distribution networks. As such, to model the voltage drop and the effect of reactive power on the voltage profile along radial feeders, the linearised DistFlow [9] approach is used to model radial networks.

The optimisation model uses generic storage and demand flexibility models, which can be parametrised based on the characteristics of particular technologies to be analysed. Using a dynamic storage model considering external energy inflow and energy dissipation, the state-of-charge of the storage system is modelled on an hourly basis. Charging and discharging efficiencies are considered in the optimisation. The demand flexibility model (Figure 2) considers voluntary and involuntary demand reduction as well as demand shifting conversing the total energy consumption over a given period. The parameters for the demand flexibility model are obtained through the FlexPlan pre-processor.

$$P^{flex}_{u,t,y} = P^{ref}_{u,t,y} \boxed{- P^{nce}_{u,t,y}} \boxed{- P^{lc}_{u,t,y}} \boxed{+\Delta P^{ds,up}_{u,t,y} - \Delta P^{ds,dn}_{u,t,y}}$$

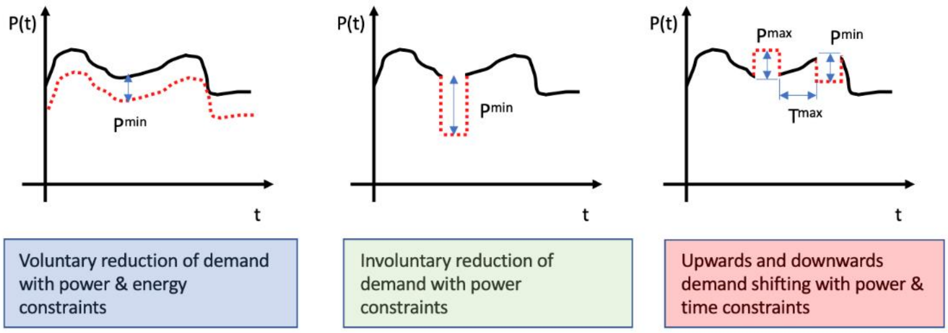

Figure 2 Generic demand flexibility model in FlexPlan

The FlexPlan model has been implemented as an open-source Julia / JuMP library as a proof-of-concept validation [10]. The library is built in a modular way, such that different modelling features, such as modelling of certain expansion options, application of decompositions, or deterministic vs stochastic solution of the optimisation model can be explored individually. The library also allows to interface to a variety of open source or commercial optimisation solvers for convenience.

IMPLEMENTATION OF THE PLANNING TOOL: SIMULATION ENGINE AND GRAPHIC USER INTERFACE

Based on the outcomes of the proof-of-concept using Julia / JuMP, the final version of the new FlexPlan grid planning tool is being developed as a robust cloud-based software. The new grid planning tool is implemented in an agile way using the Python programming language [11], starting from the core building blocks and iteratively increasing the scope with new advanced features.

The flow of the software and interactions between the FlexPlan grid planning tool and the candidate selection pre-processor can be summarized in four main steps:

1. the user inputs the data required to perform the grid planning simulation: the topology of the power system as of today, the asset technical characteristics and the future scenarios (time-dependent data related to loads, renewable generators and storage devices),
2. the planning tool performs a non-expanded optimal power flow in order to identify congested branches (assessed using Lagrange Multipliers associated to the branches’ constraints and power flow directions), as well as the buses with high Locational Marginal Prices, suggesting the nodes which struggle to keep balance between intakes and off-takes, revealing technical opportunities for storage units,

3. based on the results of the previous step, the candidate selection pre-processor computes and provides a list of all promising possible network reinforcement candidates, storage asset candidates and flexible demand candidates,
4. the planning tool solves the grid expansion planning problem and finally outputs the network assets, storage elements and demand response programs selected to solve congestion issues while minimizing global system costs.

The optimization problem is solved using IBM ILOG CPLEX Optimizer [12], one of the leading mathematical programming solvers, modelled with the dedicated DOCplex Python Modelling Library [13]. Note that, in order to verify the accuracy of the implementation, the tool automatically asserts the results obtained with the cloud-based solution against the Julia proof-of-concept. The format used for input and output is JSON [14] with custom models following the standard OpenAPI 3.0 specifications [15], due to its flexibility, object-oriented nature and integration within the chosen implementation language. For future exploitation, handling of CIM/CGMES [16] files is considered. In order to guarantee the privacy of the data being processed by the FlexPlan grid planning tool, several security layers have been implemented. In particular, IP whitelisting and basic authentication are being used. Moreover, all data transfers are done using the HTTPS protocol.

The new FlexPlan grid planning tool is hosted on Amazon Web Servers [17] and can be accessed with two different ways: either through an HTTPS Application Programming Interface (API) which allow an easy interfacing with other tools or through an intuitive Graphical User Interface (GUI). The implementation of the GUI is done following a rigorous methodological process of User Interface (UI) and User eXperience (UX) design in order to build the right product for the future users.

Figure 3 shows some of the mock-ups developed as an outcome of the GUI design phase.

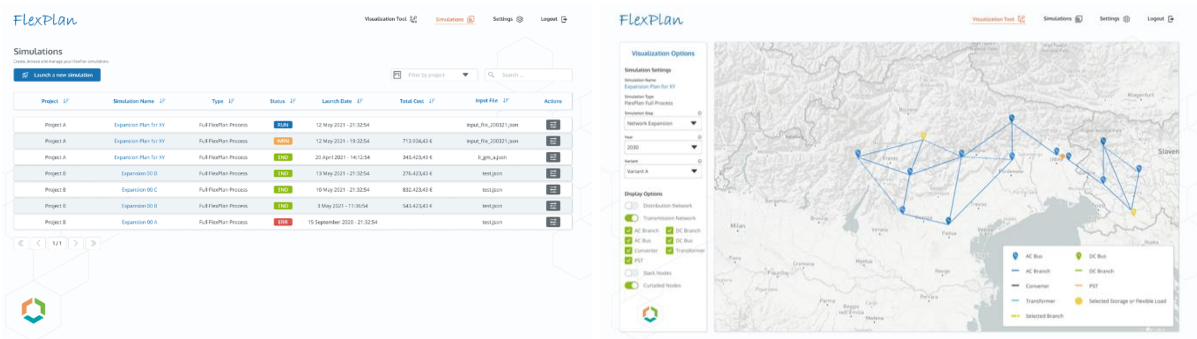

Figure 3: Mock-ups of the FlexPlan planning tool Graphical User Interface

THE SIX REGIONAL CASES: SCENARIOS AND FIRST SIMULATION RESULTS

The innovative grid planning tool developed in FlexPlan is validated within the project scope through its application to six regional cases. These were selected in order to represent realistically the different grid conditions in most of the European continent, as indicated in Figure 4.

The simulation of these regional cases is a highly complex activity from the computational perspective, given the large-scale nature of the considered grids and optimization possibilities (e.g. identification and comparison of grid expansion candidates). Thus, they present a sound way of testing the capabilities of the FlexPlan grid planning tool. Furthermore, by designing such large scale and realistic regional cases, FlexPlan aims as well to contribute to the identification of the role of flexibility solutions and creation of guidelines to cover possible regulatory gaps.

The creation and simulation of FlexPlan regional cases encompasses different activities related to data collection, processing and validation processes, based upon the creation of what can be considered as four main building blocks:

- Full scale transmission network models; [18]
- Synthetic representation of distribution network models

- Energy scenarios for 2030, 2040 and 2050 ensuring that Europe meets the established climate targets
- Full characterization of generation units and flexible loads.

The simulations in FlexPlan regional cases are built upon realistic, large-scale grid models with a one-to-one representation of grid nodes for transmission systems and a representative set of networks for distribution systems. Transmission grid is represented by using the European grid model used for the Ten-Year-Network-Development-Plan (TYNDP) 2018 studies, provided by ENTSO-E, as base dataset. The grid model received from ENTSO-E corresponds to a 2025 operational scenario. In this model, elements connected to 220 kV and above levels are modelled explicitly while branches and substations below this threshold might not be represented in detail, depending on the country analyzed [18]. Load values are represented aggregated by Extra High Voltage (EHV) connection point and embedded generation is connected to the next EHV or High Voltage (HV) node. The grid model was validated by the project team, through its conversion to a format allowing to carry out power flow simulations and was separated into the networks of the different regional cases, considering coherent border conditions for each one of them. This analysis also allowed to identify different data gaps, which had to be solved in order to adapt this model to the FlexPlan needs. These gaps included:

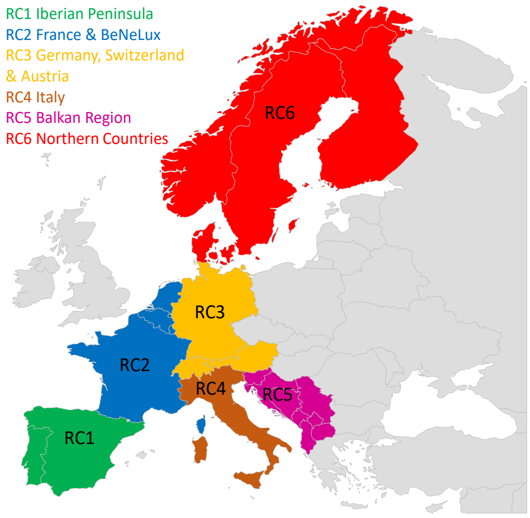

Figure 4: FlexPlan Regional Cases

- Absence of grid models for Nordic countries (Norway, Sweden and Finland), which are required for the Nordic regional case;
- Absence of grid models at 150/110 kV voltage levels in different countries, together with absence of sub-transmission levels;
- Absence of geographic information data for grid nodes, which is a required input in the FlexPlan Tool (all nodes including generation units);
- Incomplete definition of type of generator units (thermal, wind, solar, etc).

These data gaps were solved through a comprehensive data collection process, resorting to data available at TSO/country level and also by using open-source data (e.g. Open Street Maps). The final grid models obtained for each regional case were validated in order to ensure their technical validity. Figure 5 depicts the example of the French transmission system after this process, where the difference between the model obtained from ENTSO-E (after adding geographic location of each grid node) and the final model to be used in the regional case is highlighted.

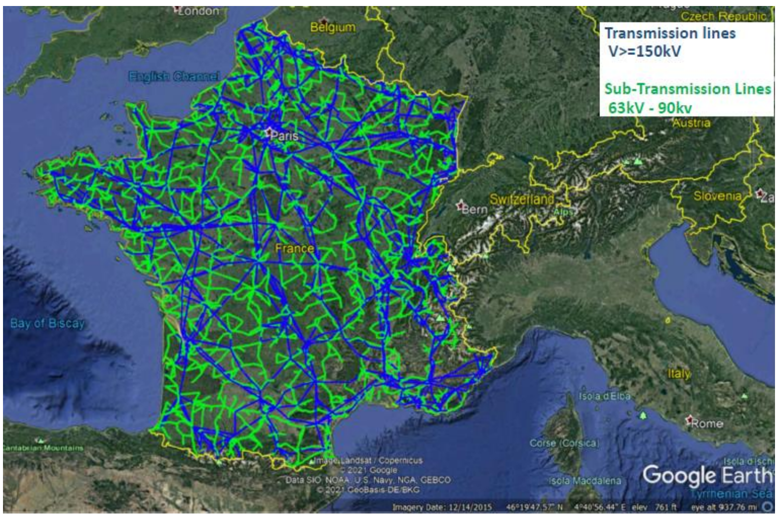

Figure 5 : French Transmission and Sub-Transmission Lines

Due to the lack of a European wide common dataset for distribution systems, and to the impossibility of building such a model, FlexPlan uses a different approach for modelling distribution systems. Here, synthetic networks are generated using an already validated methodology [19]. In order to create these synthetic networks, relevant statistics from representative network models (of real systems) are used, thus resulting in highly reliable distribution network models. These models are then reduced (reducing the number of grid nodes), so as to keep the numerical tractability of the problem to be solved. These statistics are representative of distribution networks existing in the areas covered by FlexPlan. This results in the utilization of synthetic distribution network models, which are representative not only of each regional case, but also covering different geographical conditions (e.g. rural vs urban networks) within each country part of that regional case.

In order to provide a common scenario dataset for the long-term planning horizon for the regional cases, three different scenarios for three different target years are created, resulting in a set of nine different scenarios, which reveal different possibilities to achieve the climate targets defined by the European Commission. National scenario data is generated aligned to ENTSO-Es TYNDP 2020 datasets [20]. As these datasets do not contain data for 2050, data for this year is extrapolated based on a linear approach with further adaptations which take into account the European decarburization trajectory comparing the linearly extrapolated data to scenario data for the year 2050 from 'A Clean Planet for All' report [3], which is a comparable source from the European Commission.

The derived scenarios provide data at a national level, but do not include information on the spatial and temporal availability of RES and usage of loads. However, these data are essential for the following grid studies, hence, national scenario data are spatially distributed to a transmission-nodal level and building on this, time series are generated. For this purpose, a regionalization methodology from the electricity market and transmission grid simulation framework MILES (Model of International Energy Systems) [21] is used and adapted to the context. The regionalization methodology distributes installed capacities taking into consideration statistical parameters based on socio-structural data, the distribution of existing plants, and information on land use. Knowing the installed capacities per node and their geographical location, time series for RES generation and load are calculated. The injection is calculated using historical meteorological data, characteristic models for the different technologies, as well as capacity factors for hydropower plants. Load time series are determined based on historical load profiles. The thereby determined yearly energy quantities are finally scaled to the amount of energy defined by the scenario data for the different types.

The temporal distributions of RES generation as well as load are highly dependent on meteorological conditions, which vary strongly between different climate years. To consider these uncertainties and ensure that networks operate reliably for different possible futures, a scenario generation and reduction approach is used. In a first step, Monte Carlo scenarios are generated by calculating RES injection and load for more than 35 historical climate years based on data from [22], [23]. Secondly, as the consideration of a high number of scenarios is a computational demanding task, the number of variants is reduced in order to determine a representative set of input data for the planning tool, while keeping their temporal and spatial correlation. The scenario reduction methodology clusters the Monte Carlo variants applying feature reduction and k-means clustering. Afterwards, one representative for each cluster is chosen, which is used as input data for the regional cases.

Furthermore, from the starting point of the regionalization results, European market simulations are executed, calculating the optimal dispatch of thermal power plants, storages, and cross-border flows for the considered countries. For this, the market simulation module of MILES [24] is used. The cross-border conditions enable to split the pan-European grid into the regional case studies, while ensuring coherent border conditions for the different regional cases. The overall methodology is briefly depicted in Figure 6.

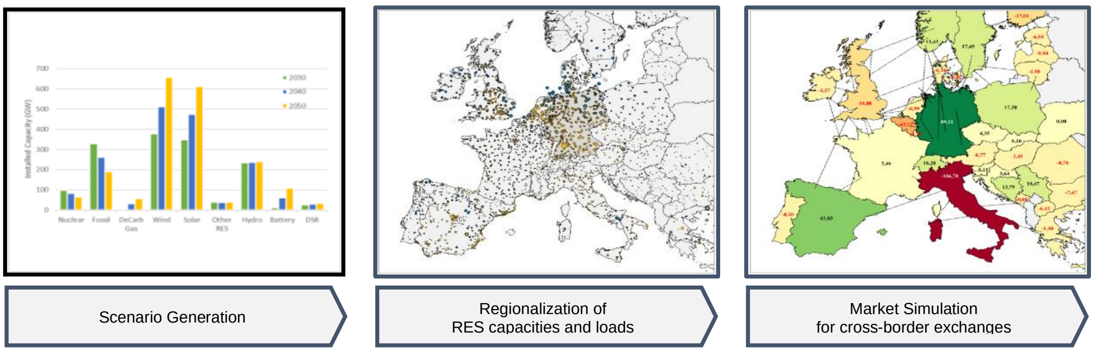

Figure 6: Methodology for modelling approach

In order to realistically represent the operational conditions of existing and forecasted European power system, the third building block of FlexPlan regional cases consists of a full characterization of generation and flexible loads. Most relevant generation units were identified, and a database was built, including relevant parameters as their location, installed capacity and fuel type. This database is built on top of the open-source database for generation units named "*powerplantmatching*". Particularly for thermal power plants, and in order to assess their environmental impact, pollutant emissions data was also obtained, at plant level, and a dedicated emission model is being constructed to take the associated costs into account in the optimization problem [25]. Flexible demand is one of the technologies considered to play a major role in future flexibility needs. In the scope of FlexPlan, major flexible loads are identified and relevant parameters are considered, including their location and main characteristics allowing to characterize their flexibility potential. These include the utilization of Value of Loss Load and demand shift or reduction costs, which are calculated depending on the specificities of each country and taken into account available data at European or national level.

The first step of the simulation toolchain to take place in the FlexPlan regional cases considers the execution of Optimal Power Flows (OPF) to the energy scenarios in 2030, so as to identify grid expansion needs for the first target year. The simulation of a full-year, hourly time-series OPF is a highly complex activity, both from the preparation/validation of the involved data and the computational sides. In order to keep numerical tractability a methodology was implemented, allowing to decouple the yearly data into smaller periods but preserving the seasonality effects particularly relevant for hydro generation modelling. Using this approach, OPFs are solved in sequence for each selected period and the available energy content in hydro reservoirs at the end of each period is considered, in order to account for the typical seasonal effect of hydro. This modelling approach considers average weekly inflows, obtained from market simulation results already performed in the project scope as a proxy or from external data sources (e.g. TSO databases), and reference generation profiles to calculate the available energy content for each period within the year. Then the FlexPlan tool does the optimal dispatch of hydro units within the period timeframe considering the available energy. This approach assumes that flexibility provided by other technologies (e.g. storage units) is compensated throughout the period duration.

Preliminary results already obtained aimed at verifying the optimal period to be selected, allowing to ensure numerical tractability of the problem without reducing excessively the potential for flexibility. Two different periods have been tested: months and weeks. Monthly periods have been selected so as not to excessively limit the benefits of flexibility, as can be seen in Figure 7, where a comparison was performed between monthly (right) and weekly (left) periods. As can be seen, the stored energy in a hydro reservoir (and consequently the generation) is strongly limited to the target value (0.5 pu) if weekly periods are selected, thus reducing its potential to provide flexibility to the system.

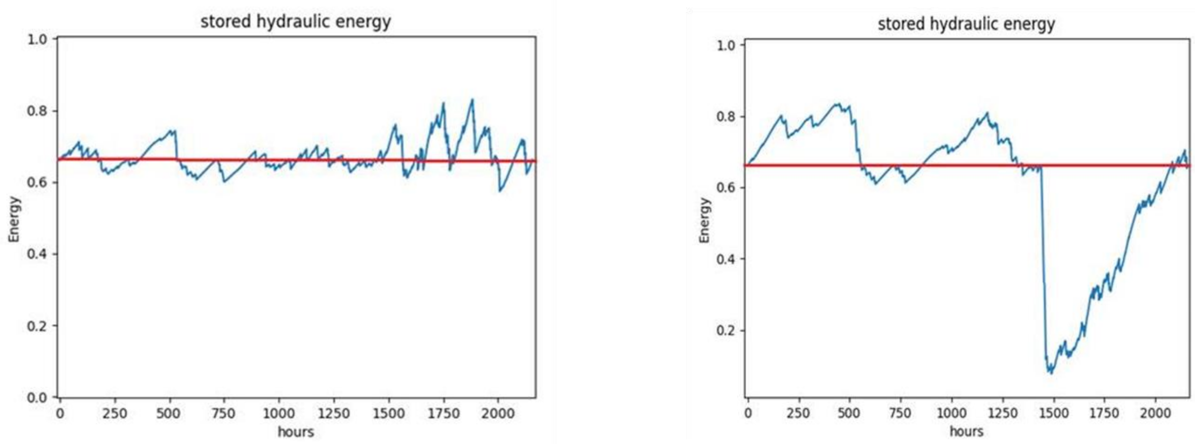

Figure 7 : Comparison between weekly and monthly optimization periods

CONCLUSION

Pursuing the Pan-European environmental goals prompts to bringing significant changes to the conventional power system. This creates new challenges which require to be solved with innovative methodologies. On this pathway, the EC proposes to include flexibility resources as a consistent part of the network expansion planning and to consider demand response and storage with the same priority as generation in dispatching and re-dispatching procedures. This makes FlexPlan project highly relevant and timely both for testing new innovative grid planning methodologies and coping with the present challenges. Furthermore, the application of the FlexPlan methodology to six comprehensive regional case studies is capable to provide important learnings.

Including flexibility into grid planning requires a sound regular interaction between TSOs and DSOs both during the planning and subsequent operation phases. This requires commonly agreed and operative methodologies at least at national, but preferably at Pan-European level. However, a recent common TSO-DSO publication [26] points out that TSOs and DSOs still have radically different points of view on several important issues. One of the initial studies carried out by FlexPlan [27] listed several open issues, which, yet critical, have not been addressed yet, e.g. TSO-DSO priority in sharing of flexible resources or rules for allocation of costs and incomes in new common investment projects.

The common planning challenges for the System Operators call for establishing collectively agreed and universally accepted methods, as, for example, cost-benefit analysis, making possible to acquire shared planning priorities and goals. In addition, these methods should be further elaborated and clarified with regard to the already existing indicators e.g., VOLL or extended with new ones e.g., quantified environmental externalities, as it has been done in the framework of FlexPlan. Common methods should be developed and implemented and a consistent use of them should be enforced by the regulation for all Systems Operators, as it was done by ENTSO-E for the transmission grids. Uncertainty and especially absence of clear regulatory provisions is possibly one of the most significant barriers for establishing new services since this uncertainty could strongly discourage potential investors to develop the necessary infrastructure assets.

Another important learning is that the deployment of common modelling techniques will inevitably have to deal with the difficulties related to the overall complexity of data, especially regarding distribution grids or the opposite i.e., missing or/and erroneous data. Coping with it, the FlexPlan project has successfully tested several techniques as development of synthetic networks, which proved to be viable. In addition, decomposition techniques proved successful to preserve numerical tractability notwithstanding the huge dimension of the problem to solve.

BIBLIOGRAPHY

[1] European Commission, “Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019,” 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944

[2] European Commission, “Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity,” 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0943

[3] European Commission, “A Clean Planet for All—A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy,” Nov. 2018. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN

[4] ENTSO-E, “Revised methodology for assessing electricity infrastructure projects submitted to ACER,” Nov. 2019. [Online]. Available: https://tyndp.entsoe.eu/news/2020/02/revised-methodology-for-assessing-electricity-infrastructure-projects-submitted-to-acer/

[5] H. Ergun *et al.*, “Probabilistic optimization of T&D systems planning with high grid flexibility and its scalability.” 2021. [Online]. Available: $$Uhttps://flexplan-project.eu/wp-content/uploads/2021/03/D1.2_20210325_V1.0.pdf

[6] G. Migliavacca *et al.*, “The Innovative FlexPlan Grid-Planning Methodology: How Storage and Flexible Resources Could Help in De-Bottlenecking the European System,” *Energies*, vol. 14, no. 4, p. 1194, Feb. 2021, doi: 10.3390/en14041194.

[7] H. Ergun, B. Rawn, R. Belmans, and D. Van Hertem, “Technology and Topology Optimization for Multizonal Transmission Systems,” *IEEE Trans. Power Syst.*, vol. 29, no. 5, pp. 2469–2477, Sep. 2014, doi: 10.1109/TPWRS.2014.2305174.
[8] H. Ergun, *OptimalTransmissionRouting.jl - A software package to determine right of way*. Accessed: Oct. 12, 2021. [Online]. Available: https://github.com/Electa-Git/OptimalTransmissionRouting.jl
[9] M. Farivar and S. H. Low, “Branch Flow Model: Relaxations and Convexification—Part I,” *IEEE Trans. Power Syst.*, vol. 28, no. 3, pp. 2554–2564, Aug. 2013, doi: 10.1109/TPWRS.2013.2255317.
[10] H. Ergun *et al.*, *FlexPlan.jl - Flexibility aware network planning model*. Accessed: Oct. 12, 2021. [Online]. Available: https://github.com/Electa-Git/FlexPlan.jl
[11] G. Van Rossum and F. L. Drake, *Python 3 Reference Manual*. Scotts Valley, CA: CreateSpace, 2009.
[12] I. I. Cplex, “V12. 8: User’s Manual for CPLEX,” *International Business Machines Corporation*, p. 596, 2017 1897.
[13] IBM, *DOCplex Python Modelling Library*. [Online]. Available: http://ibmdecisionoptimization.github.io/docplex-doc/
[14] ECMA, *ECMA - 404 The JSON Data Interchange Standard.* [Online]. Available: https://www.json.org/json-en.html
[15] OPENAPI Initiative, *OPENAPI 3.1*. [Online]. Available: https://www.openapis.org
[16] IEC, *Common Grid Model Exchange Standard*. [Online]. Available: https://www.entsoe.eu/digital/cim/cim-for-grid-models-exchange/
[17] Amazon, *Amazon Web Services*. [Online]. Available: https://aws.amazon.com/
[18] ENTSO-E, “Input grid datasets for the preparation of the TYNDP 2018.” [Online]. Available: https://www.entsoe.eu/publications/statistics-and-data/#entso-e-on-line-application-portal-for-network-datasets
[19] G. Vigano, M. Rossi, C. Michelangeli, and D. Moneta, “Creation of the Italian Distribution System Scenario by Using Synthetic Artificial Networks,” in *2020 AEIT International Annual Conference (AEIT)*, Catania, Italy, Sep. 2020, pp. 1–6. doi: 10.23919/AEIT50178.2020.9241109.
[20] ENTSO-E and ENTSO-G, “TYNDP 2020 - Scenarios Data,” Jan. 2020. [Online]. Available: https://2020.entsos-tyndp-scenarios.eu/download-data/
[21] J. Teuwsen, V. Liebenau, and C. Rehtanz, “Comparison of regionalization methods for network development planning,” in *IEEE PES ISGT Europe 2013*, Lyngby, Denmark, Oct. 2013, pp. 1–5. doi: 10.1109/ISGTEurope.2013.6695386.
[22] S. Pfenninger and I. Staffell, “Renewables NInja.” http://www.renewables.ninja
[23] M. De Felice, *ENTSO-E Hydropower modelling data (PECD) in CSV format*. Accessed: Dec. 10, 2021. [Online]. Available: https://zenodo.org/record/3929773#.YbMYXi8w1N0
[24] C. Spieker, “Europäische Strommarkt- und Übertragungs- netzsimulation zur techno-ökonomischen Bewertung der Netzentwicklung,” TU Dortmund, Dortmund, 2019.
[25] F. Gotzens, H. Heinrichs, J. Hörsch, and F. Hofmann, “Performing energy modelling exercises in a transparent way - The issue of data quality in power plant databases,” *Energy Strategy Reviews*, vol. 23, pp. 1–12, Jan. 2019, doi: 10.1016/j.esr.2018.11.004.
[26] CEDEC, EDSO, ENTSO-E, Eurelectric, and GEODE, “TSO – DSO DATA MANAGEMENT REPORT,” 2019. [Online]. Available: https://docstore.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/entsoe_TSO-DSO_DMR_web.pdf
[27] A. Morch, N. Amaro, and D. Siface, “D6.1 Guideline for the compliance of network planning tool with EU overall strategies and regulatory conditions,” 2020. [Online]. Available: https://flexplan-project.eu/wp-content/uploads/2020/04/D6.1_20200429_V2.0.pdf