Generation of Coherent Pan- European Scenario Data for Grid Expansion Studies

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Abstract:

The integration of renewable energy sources requires grid expansion throughout Europe. Due to the highly interconnected system, line expansions influence the overall power flow, so the system must be considered entirely to ensure optimal decisions. As a full pan-European grid simulation is too complex, the system is split into regional cases, considering coherent cross-border conditions between them. These cross-border conditions are obtained, by running a pan-European simulation, including the spatial distribution of renewable energy sources as well as loads, the subsequent time series generation, and the market simulation. The spatial distribution takes into account the geographies of the different countries.

Keywords: Cross-Border Exchanges, Scenario Data, Regionalization, Geo-spatial Analysis

1 Introduction

The European (EU) Union aims at being climate neutral by 2050, leading to an energy system transformation with many changes in the power system. For this, electrical energy will no longer be generated only by large thermal power plants but also by numerous renewable energy sources (RES). As opposed to conventional power plants, RES depend on the availability of primary energy, which mostly does not correspond with the distribution of loads. That leads to a geographical separation between generation and load, which can create extensive congestion in the system, requiring grid expansions in several parts of Europe. As the pan-European system is interconnected, line expansions influence the overall power flow and therefore the system has to be considered entirely to ensure optimal decisions. However, due to the size of the pan-EU grid and the meshed system, a full pan-EU grid simulation is too complex, and broad simplifications would be needed to overcome computational restrictions. These simplifications would not lead to detailed results, hence within the project FlexPlan, another approach is used, namely splitting the system into six regional cases, shown in Figure 1, which include the most relevant parts of the EU grid. To consider coherent cross-border conditions between the regional cases and provide a common ground for the following simulation, a multi-step modeling approach is applied. Common scenario datasets for different future scenarios are generated first. Based on these, the spatial distribution and time series

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for RES injection, as well as loads, are calculated. Using the resulting time series as input, finally, cross-border conditions are determined by simulating the market.

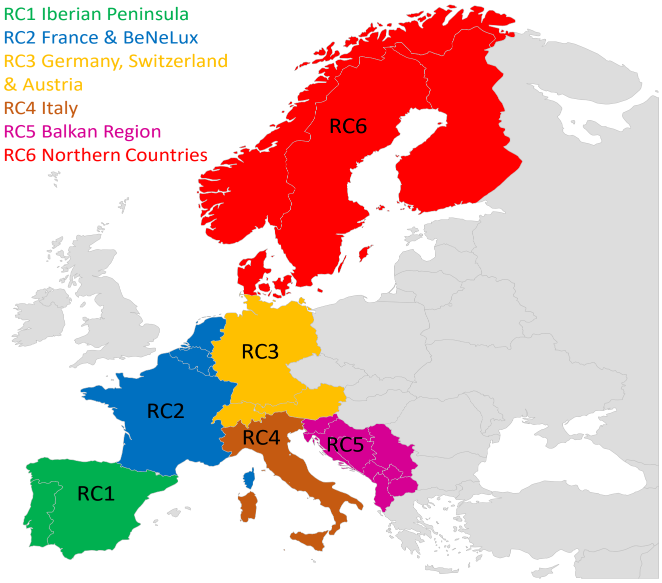


Figure 1: Scope of the regional cases

This methodology was developed and applied within the FlexPlan project, which aim is to establish a new grid planning tool, taking into account the creation and usage of storage systems and flexible loads in electricity grids in synergy with conventional grid expansion. The results of the pan-EU scenario are used as a common ground for the following six regional cases simulations, considering scenarios for three different target years (2030, 2040, and 2050).

The structure of the paper is as following. The second paragraph gives information on the scenario data. In the third paragraph, the simulation framework and the methodology are described. The last paragraph summarizes the paper and provides an outlook on how the results will be used in the FlexPlan project.

2 Scenario Data Generation

The creation of the six regional cases mentioned above includes complex data collection and processing activities, such as the development of energy scenarios for three target years (2030, 2040, and 2050), as they describe the evolution of the power system up to 2050, which is the time horizon for reduction of EU-28 emissions to net-zero following the United Nations Climate Change Conference 2050 (COP 21) goals. Various limitations on the use of primary energy resources, including coal, oil, gas, and nuclear fuel must be addressed in these scenarios. Also socio-political and economic aspects need to be taken into account along with environmental aspects. The scenarios include data that is collected at the national level (installed capacities, load, commodity prices, net transfer capacities), which is then cascaded down to the regional level and finally to the nodal level to correspond to grid node details. Utilizing a well-known and already verified data source allows the FlexPlan project to generate these scenarios and minimize the effort required to validate the collected data or avoid the need for multiple sources that would provide heterogeneous data.

The three scenarios studied in the FlexPlan project are derived from major political factors in coherence with European Network of Transmission System Operators of Electricity (ENTSO-e) Ten-Year Network Development Plan (TYNDP) 2020 [1], providing a common dataset to be used in all regional cases. To achieve the climate objectives established by the EU Commission, these three scenarios provide different future possibilities for the energy system. All scenarios head towards a decarbonized future and have been designed to reduce greenhouse gas emissions in line with EU 2030 targets or COP21 Paris Agreement objective of keeping temperature rise below 1.5° C. For simplicity, the FlexPlan project reuses the original names specified by ENTSO-e in TYNDP 2020 for the following scenarios: National Trends (NT), Global Ambition (GA), and Distributed Energy (DE). NT scenario reflects the most recent EU member state National Energy and Climate Plans, submitted to the EU Commission in line with the requirement to achieve current EU 2030 energy strategy goals. On the other hand, DE and GA scenarios are more ambitious and are fully in line with the COP21 targets, providing different pathways to reduce EU-28 emissions to net zero by 2050. The two scenarios differ only in the focused technologies to achieve the same climate goals. It is also important to note that TYNDP 2020 does not contain all data required for the FlexPlan project, so other sources such as TYNDP 2018 [2] or Mid-term Adequacy Forecast (MAF) 2018 [3] had to be used to fill in the data gaps. The steps of collecting data for the scenarios and the sources of the data are shown in Figure 2.

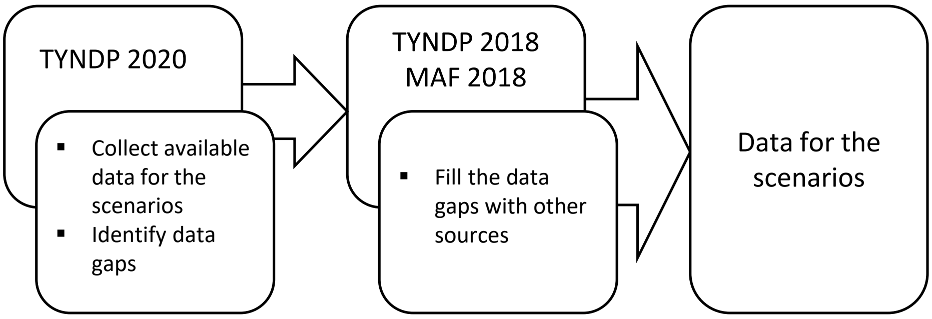


Figure 2: Steps for data collection

However, these reports only provide data at the national level for 2030 and 2040. Since 2050 is also the target year of FlexPlan project activities, an additional methodology has been created to build 2050 scenarios. This methodology consists of two main steps: 1) use the trends demonstrated in TYNDP 2020 – using a linear approximation to obtain 2050 data by utilizing the values from 2030 and 2040 and 2) validate the results for the target years using another well-known and accepted data source. For this, the EU Commission’s long-term climate strategy – A Clean Planet for All [4] – was selected.

3 Simulation

The scenario data includes information on planned installed capacities of RES and the amount of generated energy for future years. The information is given on a national level however, it neither includes information on the location of newly built RES nor on the chronological sequence of RES infeed or load. As these data are required to calculate the market and determine cross-border conditions, a methodology for the spatial distribution and the generation of injection time series is required. For this, the simulation framework MILES (Model of International Energy Systems) [5] is used, which was developed at the Technical University of Dortmund and is continuously refined. As MILES was mainly dedicated to system studies with a strong focus on Germany, it is adapted to the needs of the other EU countries. MILES consists of several modules, including regionalization, time series generation, and market simulation, which are employed in the FlexPlan project. The regionalization module determines the spatial distribution of RES as well as loads. In the time series generation module, demand and injection time series are calculated. The market simulation runs an economic dispatch model and determines power plant and storage schedules as well as cross border exchanges between the different countries. Figure 3 depicts the used modules of MILES. The modules are described more in detail below.

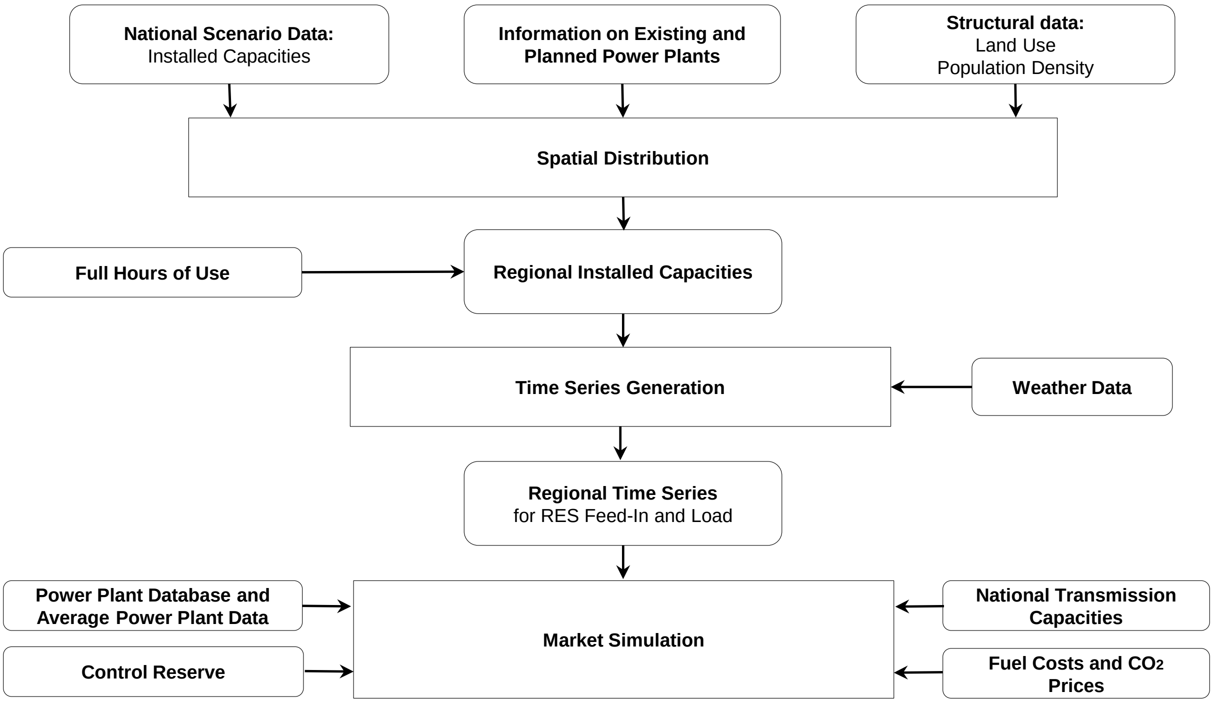


Figure 3: Conceptual block diagram of the simulation framework

3.1 Regionalization

As opposed to the location of existing plants, the locations of future plants are unknown and have to be determined. To spatially distribute the overall future installed capacity, information on the distribution of existing power plants as well as structural data, such as land cover and population density, are considered. CORINE (Coordination of Information on the Environment) Land Cover [6] data is used as the source for information on land use and land cover. Information on the population density is taken from [7]. These data are applied to form statistical parameters, representing proportionalities between land use and installed capacities. For this purpose, regionalization factors ($F_{Regionalization}$) are used, describing the percentage of the total installed capacity, which is installed in the considered region (F_{Region}^{n}). Regionalization factors can be differentiated between one-dimensional ($n = 1$) and multi-dimensional ($n > 1$) factors. One-dimensional factors employ one set of input data. Multi-dimensional regionalization factors require a main parameter and a weighting factor [8].

$$F_{Regionalization} = \frac{\prod F_{Region}^{n}}{\sum_{Region} \prod F_{Region}^{n}}$$

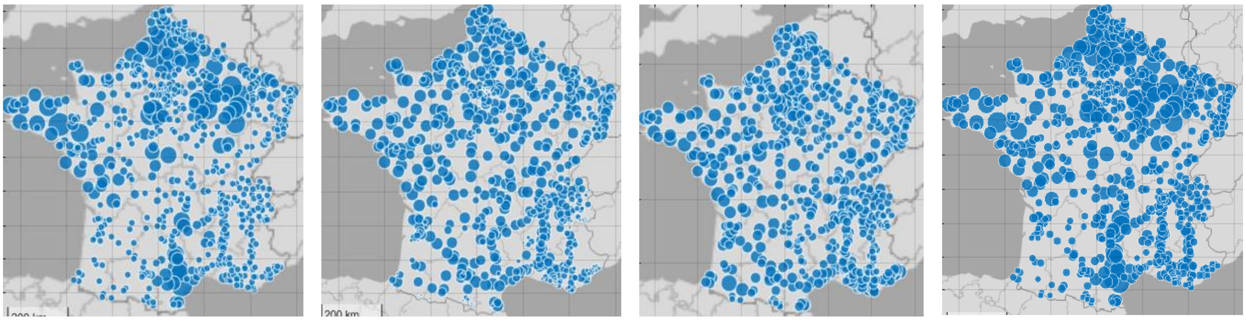
Geographical requirements of different RES depend on several factors, thus regionalization factors are determined individually for each technology. The regionalization for the individual technologies is described in the following.

3.1.1 Wind Turbine Generators

There is a limited number of commonly excepted locations with good wind conditions. Thus, the oldest and hence least efficient Wind Turbine Generators [WTGs] are located at widely excepted places with optimal wind conditions. As they have a limited lifetime and due to the decrease of efficiency at locations with poorer wind conditions, repowering is very common for WTGs [9]. Hence, it is assumed that the distribution of new WTGs will be similar to the distribution of existing ones. The share of existing plants in the prospective overall installed capacity, set by the scenario

$$share_{ex} = \frac{P_{existing}}{P_{scenario}}$$

varies considering different years and countries. If the $share_{ex}$ is low, significant expansion is required and vice versa. With low expansion needed, it is likely that the trend is followed and most prospective plants will be build or repowered similar to the existing infrastructure. To take this into account, an individual threshold for $share_{ex}$ is defined. If $share_{ex}$ exceeds the defined threshold, a larger proportion of the installed capacity of future plants is extrapolated from existing plants. If $share_{ex}$ is smaller than the threshold, the distribution is carried out mainly based on structural data. Since the installed capacity increases during the time horizon, different thresholds are defined for the varying target years. Analyzing the spatial distribution of existing WTGs, reveals the correlation between the distribution of WTGs and two factors: the population density and the agricultural use of the area. Assuming that WTGs are mainly installed in sparsely populated agricultural areas, a two-dimensional regionalization factor is used. Agricultural land data is weighted reciprocal to the population density. Figure 4 demonstrates the exemplary methodology for the spatial distribution of WTGs in France. Part a) shows the distribution of the existing plants, which are scaled up. The second part, b) visualizes the number of agricultural areas in each region. The population density is depicted in part c). Part d) ultimately presents the resulting WTGs distribution, combining the aforementioned parameters.



a) Existing plants b) Agricultural areas c) Population density d) WTGs distribution

Figure 4: Spatial distribution of wind power plants in France for scenario year 2030

3.1.2 Photovoltaic

Photovoltaic (PV) systems can be distinguished between mounted on rooftops or ground-mounted systems. In countries with lower solar irradiation, plants are mainly private and usually placed close to consumers, i.e., on rooftops, in contrast to countries with high solar irradiation, where larger PV systems are predominantly ground-mounted. To consider this in the regionalization, an average solar irradiation comparison is performed based on data from [10]. For countries with low solar irradiation, it is assumed that PV plants are mainly located in urban areas. In countries with higher solar irradiation, it is assumed, that PV systems are mainly installed on non-irrigated arable land [11]. In both cases, a one-dimensional regionalization factor is applied. As there are few limitations on the construction of PV plants, the regionalization of existing plants is not considered.

3.1.3 Hydro Power Plants

Hydro power plants can be distinguished between Run of River (RoR), reservoir and Pumped Storage Power plants (PSPs). As the energy generation of PSPs does not depend significantly on meteorological circumstances but on the decision of pumping, they are not considered during the regionalization but only in the market simulation, which does not require their spatial distribution. The location of ROR and reservoir power plants depends on particular environmental conditions. There are several factors influencing, whether a location is suitable for a new plant, which can’t be considered by a simple analysis of the land usage. Since, the number of these locations is quite limited, a simplistic approach is used, assuming that existing plants will be expanded or new plants will be build close to existing ones. Hence, existing plants are scaled up to the required installed capacity. In order to prevent this procedure from leading to very large plants, which might be unrealistic, it is assumed that the extrapolated plants are not only connected to the closest node but also to the surrounding nodes of the grid, which are up to a distance of 30 km from the plant.

3.1.4 Load

As load is mainly related to the presence of civilizations, a proportionality between the population density and the distribution of loads is assumed. Hence, a one-dimensional regionalization factor is used.

3.2 Time Series Generation

The standardized injection of WTGs and PV plants is calculated based on characteristic curves, distributed installed capacities, and regional weather time series [8]. For this, the weather year 2012 from the Cosmo-EU model [12] is used. To guarantee constituency with the scenario data, the obtained time series are scaled to the generated energy defined by the scenario. In order to ensure that the installed capacity is not exceeded, a correction factor is applied lastly.

RoR plants depend on the amount of water being available in rivers and due to a seasonal variability of rivers they follow a seasonal trend. Thus, their generated energy E_{RoR} is determined by means of historical national capacity factors CF from [13] and the installed capacity P_{RoR}.

$$E_{RoR} = P_{RoR} * CF$$

Reservoir power plants are controllable and less weather dependent. As it is assumed that they are used to cover the load, their generation time series are formed proportional to the national load. Load time series are obtained using historic national load profiles. In Figure 5 hydro power plants injection time series are compared to load for the example of Italy.

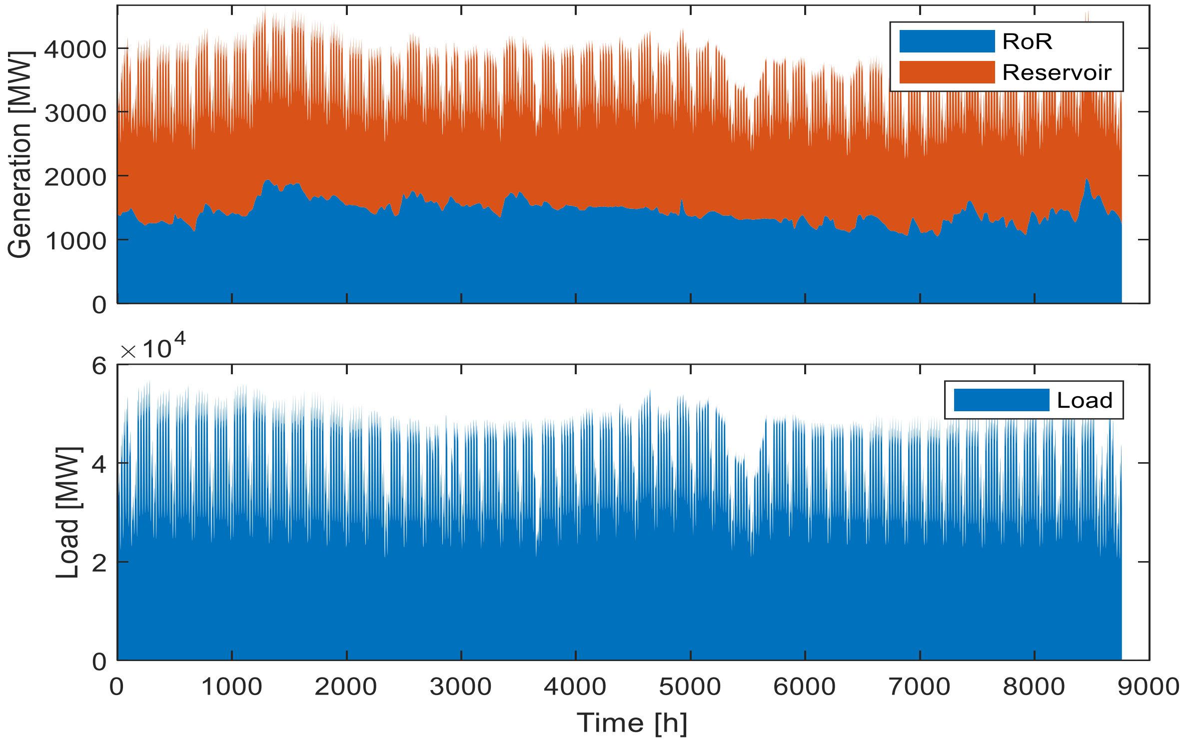


Figure 5: Exemplary results for hydro generation compared to load for regional case 4 for scenario year 2030

3.3 Market Simulation

To ensure a balance between load and generation in each country while minimizing the overall costs, the commitment of thermal power plants and PSPs as well as the cross border flows are adjusted according to the gap between RES injection and load, running a market simulation. The market simulation is based on a fundamental market model. In order to minimize the overall generation costs, the power plant deployment is optimized using a security constrained unit commitment model, which is formulated as a linear problem. The optimization takes into account available transmission capacities between the neighboring countries, time-coupling restrictions of the units, and the control reserve power, which has to be maintained. In order to limit the computational effort and keep the problem solvable, a rolling approach is used. For this, the year is divided into overlapping intervals of equal duration of ten days, representing the planning horizon of the market participants. These intervals are solved successively using the last state of the preceding interval as the initial state of the next interval. Besides, a pre-simulation is carried out in order to generate a steady state, which is used as the first state at the beginning of the year [5]. The results of the optimization include schedules for conventional power plants and storage facilities on a national level as well as trade flows between different countries. Figure 6 shows renewable generation and cross border flows as exemplary results for the scenario year 2030 for regional case 3.

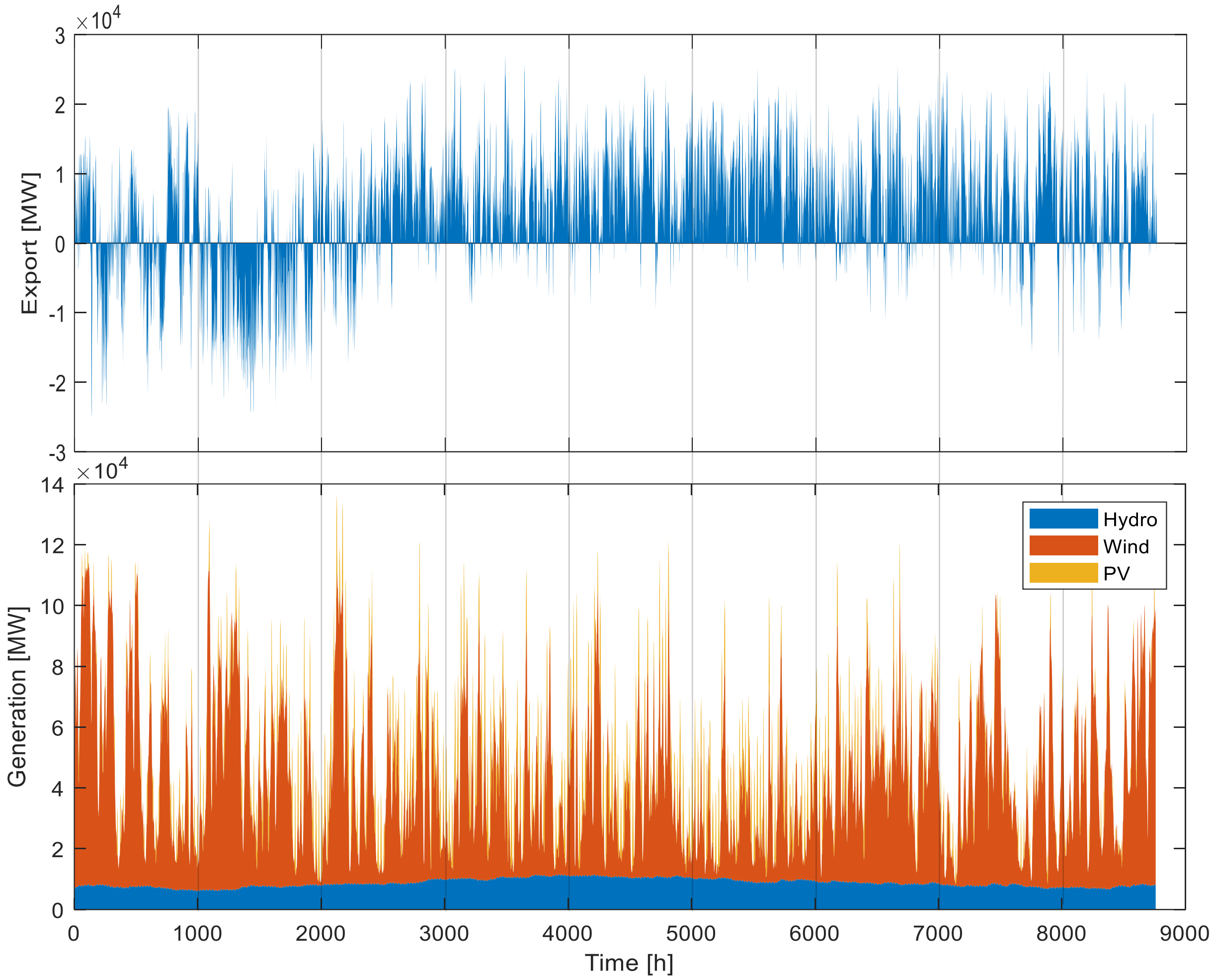


Figure 6: Exemplary renewable injection and cross border exchanges for regional case 3 for scenario year 2030

4 Summary and Outlook

In a nutshell, the existing MILES framework was adapted to the pan-EU needs. The methodology determines the spatial distribution of RES as well as loads considering the surrounding conditions and generates injection time series based on weather data. Besides, the economic dispatch and cross border conditions are determined.

The results provide a common ground for the regional cases within the FlexPlan project. Nodal time series of RES and loads can be used as input data and coherent border conditions enable to split the pan-EU grid into regional case studies. In the further course of the project, more detailed simulations have been run for the six regional cases and the FlexPlan tool was applied to investigate optimal grid expansion and flexibility usage.

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