Synergistic approach of multi-energy models for a European optimal energy system management tool

Click here for Authors

Operating the electricity system with the 2050 targeted shares of renewable energy sources (RESs) will only be possible and affordable if both networks and generation assets evolve towards a system designed to maximise its capacity to host large amounts of RES. This requires optimising existing assets and new investments while making the best use of all sources of flexibility, considering the geographical location and the services provided to the system. Hence, an integrated representation of the system is mandatory, which requires overcoming significant technical hurdles. In this context, the plan4res project has designed a set of highly interconnected models, working synergistically while retaining their modularity, which is necessary for tailoring the tool to the different needs of various stakeholders.

The plan4res modelling suite

Figure 1 shows the set of optimisation models which have been implemented. These include models related to investment planning, seasonal storage valuation, transmission grid expansion for electricity and gas, and a European unit commitment model, which optimises the operation of flexible assets, including multi-energy assets as well as distributed control.

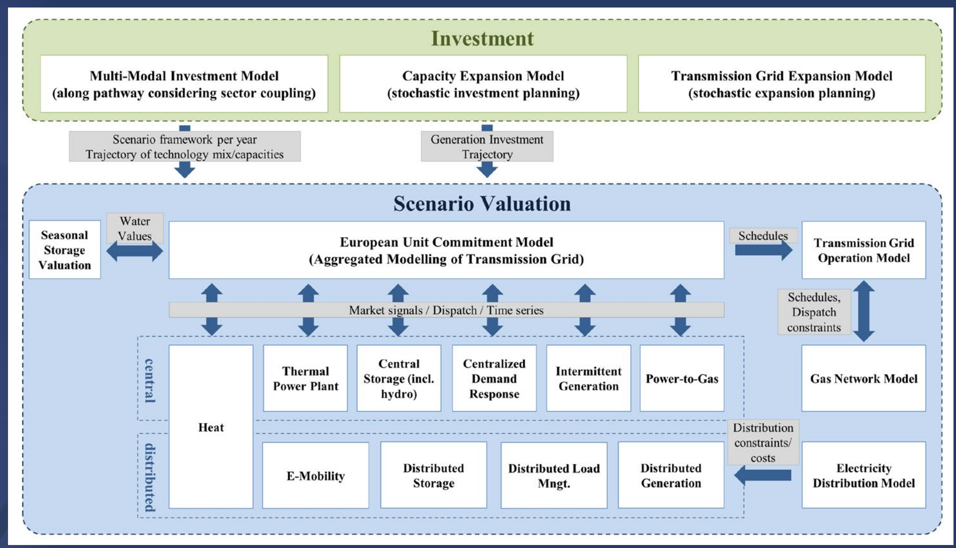

Figure 1: A set of integrated tools.

The main models developed in plan4res are presented below:

The multi-modal investment model (MIM) (Müller *et al.*, 2019) optimises the future energy mix and the national investment plans along a pathway towards 2050, considering hourly operational schedules, costs, revenue streams and security-of-supply. A meshed implementation of the integrated European energy system is created in the form of a linear problem, modelling the coupled energy sectors including electricity, heating and cooling, mobility and gas/fuel, and the competing technologies along with their interactions, also considering technological trends (costs, efficiencies etc.), and a variety of data such as demand levels and installed capacities. Then this linear problem is optimised with perfect foresight, annually and along the pathway, seeking a macro-economic optimum with a side-constraint CO_2 target.

The grid expansion model (GEM) (Giannelos, Konstantelos and Strbac, 2019) constitutes a multi-stage stochastic optimisation model that yields the optimal investment and operational decisions, across a multi-year horizon. Specifically, the horizon covers the period from 2020 until 2060, and the focus is placed on the electricity system across the entire European continent. The results of the model include the amount as well as the location and timing of investments and also the option value—the value that a smart technology possesses from enabling the network planner to deal with uncertainty.

The disaggregated multi-energy model (DMEM) (Schmitt *et al.*, 2021) evaluates the scenarios computed by the MIM model. A multi-modal European market and grid simulation determine electricity and heat supply as well as the resulting grid utilisation and gas demand with a focus on local dispatch of distributed flexible technologies. Based on the resulting local electrical demand and supply schedules, power flow and congestion management in the European transmission grid is simulated.

The gas network optimisation model (GNO) (Koch *et al.*, 2015) evaluates the feasibility of the gas demand/supply results from the DMEM and MIM, including infeed of H_2 from power-to-gas. A physical flow-based stationary GNO is used to solve a "validation of nomination (amount of gas flowing into/out from the gas network) problem (NoVa)". As the detail of readily available grid data on pan-European level from public resources is insufficient to be used with such a model, we also employ two network flow-based models for generating nominations for a restricted region.

The seasonal storage valuation model (SSV) (Ackooij *et al.*, 2019) solves a mid-term (usually annual) problem, which consists of evaluating the expected operation cost and computing strategies for mid-term storages, for a given electricity mix (generation, transmission, storage), while dealing with uncertainties related to demand, inflows, renewable generation potentials, and power plant shortages.

The European unit commitment problem (EUC) (Beulertz *et al.*, 2020) solves the short-term horizon problem (usually daily or weekly), thus computing schedules for all assets while taking into account the "value" that seasonal storage units can bring to the system. Various kinds of flexibilities involving both generation, storage and consumption are dealt with, e.g. the dynamic operation of power plants, storages, curtailment or shifting of consumers loads etc.

SMS++: A modelling suite for structured problems

To solve the aforementioned highly complex problems, a wide variety of modelling methodologies are required, typically based on decomposition, since the off-the-shelf and general-purpose solvers may not yield results at reasonable solution times. The SMS++ modelling and optimisation suite is composed of a set of C++ classes providing the plumbing of the modelling system as well as the general and dedicated solver engine. These capabilities set SMS++ apart from current modelling systems and have allowed the development of a set of solution algorithms that can tackle very-large-scale optimisation problems under uncertainty with innovative nested combinations of algorithms, among which Stochastic Dual Dynamic Programming using Lagrangian Decomposition in each stage, in turn using specialised solution methods for specific subproblems corresponding to individual elements. SMS++ is now open-source and available at https://gitlab.com/smspp/smspp-project.

The p4r-env: A toolbox for portable and scalable deployment of the tool

To cover the entire lifecycle and all user contact points appearing during the project, we built a software container environment. This provides developers with a synchronised build and deployment environment from laptops to high-performance computing. A plugin architecture allows us to include some components only upon user demand (e.g. software requiring specific licences). Among the core components, the container includes a connector to the data store used by all project members. Therefore, deploying a case study run on a different computational environment is seamless for the user, and—subject to access control on the data—running the same computation as a different user is straightforward. This enables reproducible science. We have been using the same container on laptops, small clusters, cloud systems and Cray XC supercomputer systems (with MPI and swift/t for distributed parallelisation) without changes.

Proof-of-concept (POC): Example of uses of the plan4res tools

Three case studies (Most *et al.*, 2018) showing the tool's functionalities and relevance regarding the aforementioned uses (especially key advances included in plan4res) are being conducted, dealing with multi-energy integration, investment planning under uncertainties and flexibility cost integration within a pan-European approach. Some insights about those case studies follow.

All case studies are based on the use of a workflow composed of a sequence of plan4res models, such as described in Figure 2.

POC1
Achieving COP 21 goals considering sector coupling of electricity, gas, heat and transport

Over 100 energy-relevant technologies of five different sectors have assembled in a huge multi-modal linear problem, which was solved by the MIM model for the pathway towards 2050.

The main results

- A business-as-usual scenario already enables a CO_2 emission reduction of roughly -60 per cent, simply by considering economic feasible refurbishments and development of technologies and cost. Carbon Neutrality can be reached within CO_2 penalties below 90€/t_{CO2} but result in average abatement costs of ~57 €/t_{CO2} over the pathway.
- Steady expansion of RESs until a 'socially acceptable' cap is 'hit' in 2050 (PV x 4.25, Wind On x 7.25; Wind Off ~200 GW). This ramp-up induces **economic pressure on the existing base** resulting in an early coal phase-out accompanied by successive reduction of gas turbines and NPPs to ~1/3 till 2040.
- Power2Heat becomes the dominant technology (adds +50 per cent to el. demand). Some Power2Gas becomes noticeable only from 2050, where H_2 and synthetic CH_4 is extensively fed into the gas grid replacing natural gas.
- eMobility gets dominant, but a H_2Mobility sensitivity shows that a promoted road-side H_2Mobility share of >30 per cent in 2040 can trigger a disruption in transportation.

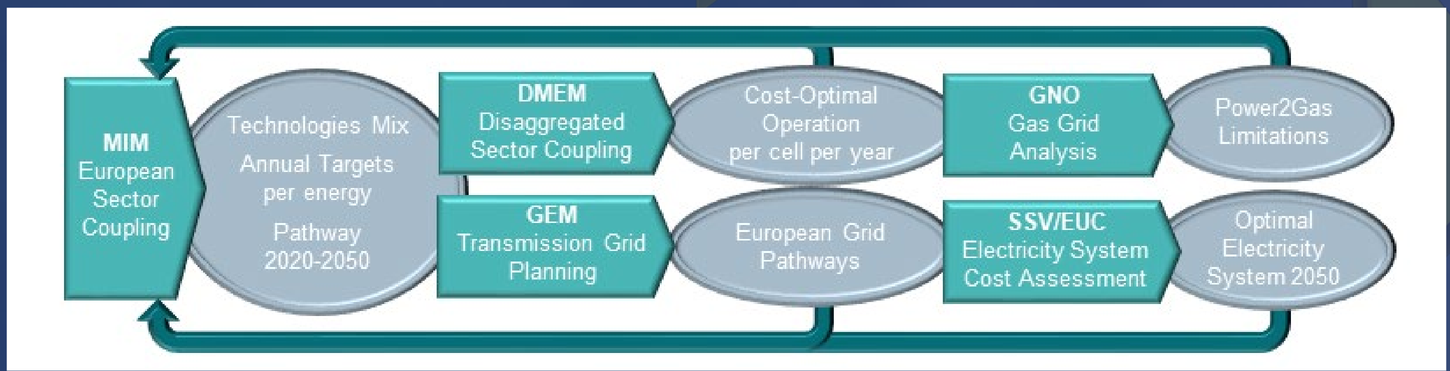

Figure 2: Plan4res models workflow.

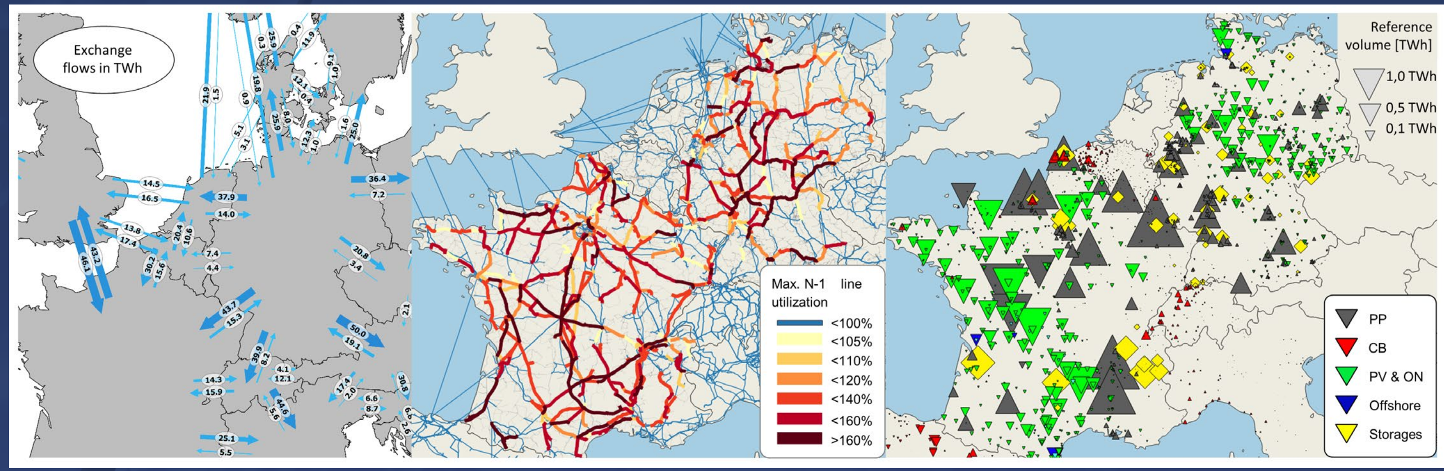

Figure 3: Exchange flows and redispatch volumes in the simulation.

The DMEM enables a precise analysis of the generation dispatch and the impact on the electricity grid with respect to (N-1) safety. The high share of renewables in the energy system and the flexibility of distributed technologies lead to a strong electricity exchange. This exchange and the resulting (N-1) line utilisation and redispatch volumes in the transmission grid are illustrated in Figure 3 for an exemplary scenario.

Finally, we generate gas nominations for Germany, using available European data, for selected days representing European-level supply and demand forecasts. The GNO model is used to evaluate the generated nominations and further analyse infeasible nominations, which will serve as retroaction inputs to the MIM and DMEM.

POC 2
Multi-stage stochastic network planning

The GEM was used to identify the optimal investment decisions that a network planner needs to make on the European electricity transmission system. The study covers the period from 1 January 2020 until 31 December 2059. The objective is to achieve the safe accommodation of the power flows at every point in time, under high demand growth as well as high integration of renewables, which have uncertain deployment patterns in terms of magnitude, timing, and location. As per Figure 4, the results show that a significant amount of energy storage investment is needed to assist with the secure system operation over the coming decades. Energy storage is shown to possess significant option value, which is a metric that quantifies the flexibility that energy storage technology possesses to deal with large scale uncertainty.

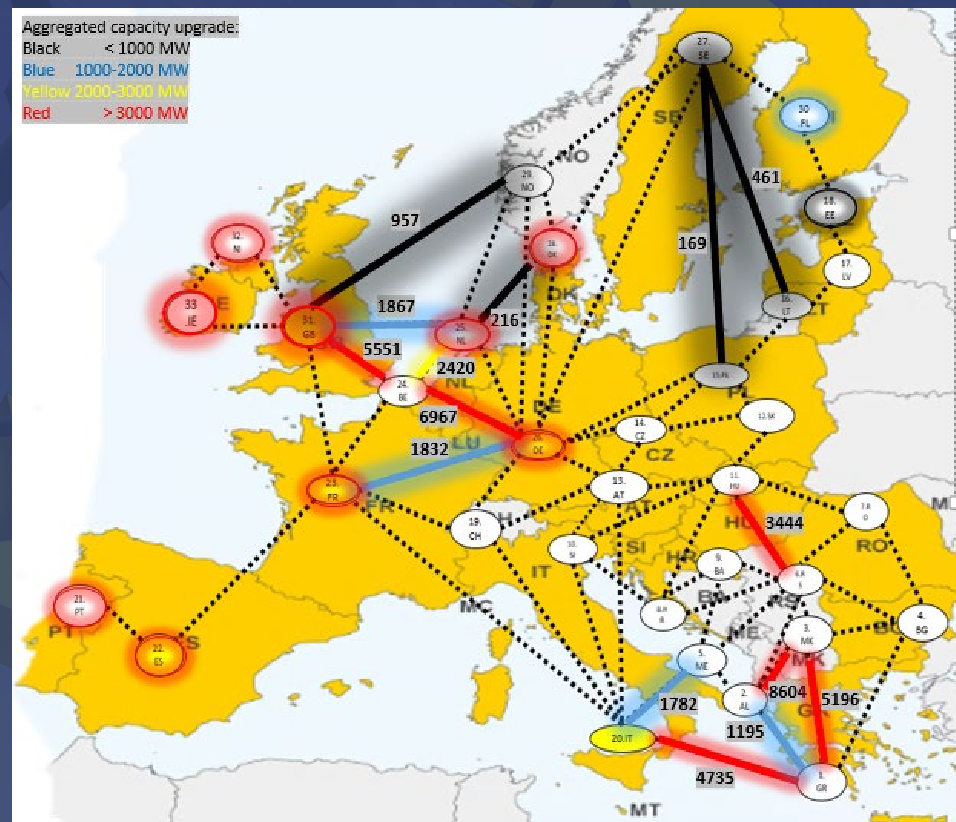

Figure 4: Illustrative map showing cumulative investments (MW) up to 2060.

POC3

Assessing the technical feasibility of a long-term scenario for the electricity system

The seasonal storage valuation and European unit commitment models are used to assess the feasibility and cost of the electricity mix of any long-term multi-commodity scenario. SSV/EUC is also used to evaluate the added-value and potential of any kind of flexibility (such as dynamic flexibilities of power plants, but also load curtailment or load shifting). The example below shows results achieved while assessing the scenario "Techno Friendly 1.0" produced by the openENTRANCE project (Auer *et al.*, 2020). SSV/EUC are accounting for detailed dynamics of each asset, as well as frequency regulation needs of the system, demand and generation seasonality. Besides, uncertainties are also represented both on the demand and generation side with a particular ambition to assess the potentially large impact of the variability of variable renewable generation in future mixes with high shares of renewable. Thanks to this detailed modelling, the suite of models is able to highlight local (both in time and space) infeasibilities and cost peaks and thus derive an adapted feasible electricity mix scenario.

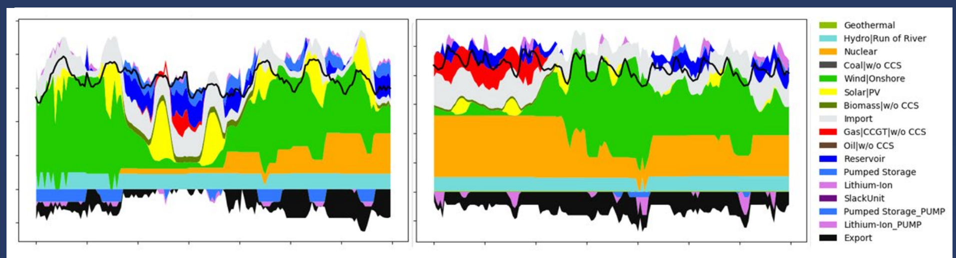

Figure 5: Hourly electricity generation on Winter/Summer weeks, for one country.

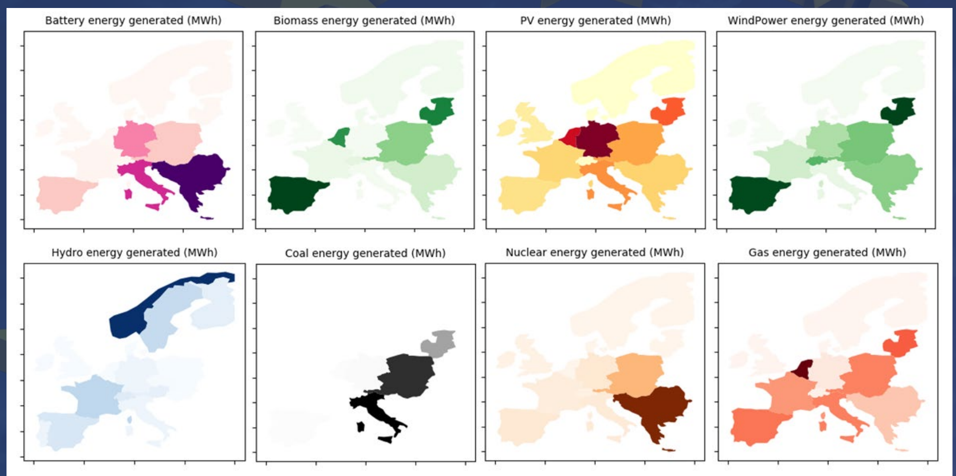

Figure 6: Choromaps

PROJECT SUMMARY

Plan4res is a collaborative research and innovation project aiming to develop an end-to-end planning tool to successfully increase the share of renewable energy into the European energy system without compromising system reliability. The targeted platform will account for the pan-European interconnected electricity system, potential synergies with other energy systems, emerging technologies and flexibility of resources, providing a fully-integrated modelling environment.

PROJECT LEAD

Sandrine CHAROUSSET (EDF) holds an engineering degree from Ecole Centrale Paris. She is the director of the Gaspard Monge Program for Optimisation and Operational Research and a project coordinator for H2020 projects within the low carbon energy field at EDF. She has also been leading research teams on statistics for renewable generation and energy prices, and mathematical optimisation.

PROJECT PARTNERS

Electricité de France (Project Coordinator)
Siemens AG Technology (Germany)
Hewlett Packard Enterprise (Switzerland)
RWTH Aachen University (Germany)
Imperial College London (UK)
Zuse Institute Berlin (Germany)
Interuniversity Consortium for Optimization and Operation Research (Italy).

CONTACT DETAILS

Sandrine Charousset (Project Coordinator)
EDF Lab Paris-Saclay, 7 boulevard Gaspard Monge, 91120 Palaiseau, France
sandrine.charousset@edf.fr
www.plan4res.eu
Data and Publications repository:
zenodo.org/communities/plan4res
@plan4res
/plan4res

FUNDING

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.773897.