TU GRAZ SCIENCE FOR FUTURE

TU Graz

2022: DIGITAL VISIONS

The LEGO Model: A Digital Twin of the Power System

Challenge – Transition to Low-Carbon Power Systems

The **large-scale transformation of Europe's power system** is driven by climate change and accelerated even further by recent energy security issues. As part of the European Green Deal, the European Union (EU) aims to achieve climate neutrality by 2050[1]. The "Fit for 55 package" of the EU is an inter-mediate step to align the current laws with the goals for 2050 by cutting greenhouse gas emissions by 55% by 2030[2]. The transition to a net-zero economy gives energy a central role, as it is currently responsible for more than 75% of the EU's greenhouse gas emissions[3]. The necessary **paradigm shift in the energy sector** will also have a massive impact on the power system: Electrification of other sectors, e.g. e-mobility or replacing traditional heating systems with heat-pumps, will increase electricity consumption. Large-scale deployment of non-dispatchable and variable wind and solar generation makes grid operation more challenging.

Solution – A Digital Twin with the LEGO Model

The **Low-carbon Expansion Generation Optimization** (LEGO)[4] model is a multi-purpose open-source tool to carry out numerous techno-economic analysis of the energy sector. It is the basis of the digital twin of the power system. LEGO's basic structure with its temporal framework and thematic blocks is shown in Fig. 1.

The LEGO model

The LEGO model combines a **flexible temporal framework**, which can work with chronological time steps, time slices/blocks and representative periods, with blocks that can be turned on or off as needed.
Current blocks include:

- **Unit commitment** decisions via Mixed Integer Programming (MIP or rMIP)
- Enabling operating and/or investment decisions
- Considering a single-node problem or an **electricity network** (either via a DC-OPF or approximation of the full AC-OPF)
- Degradation for battery energy storage systems (BESS)
- RoCoF system inertia constraints
- Demand-side-management (DSM) via load shifting and load shedding
- Considering the **hydrogen sector**
- Incorporated policy constraints

Each element of the power system with all its properties is meticulously entered into the Input-Excel of LEGO. For example, the power grid is represented by nodes (with their exact locations, voltage levels and demand) as well as lines. The line data includes the resistance, the reactance, the capacitance and the maximum transmission power. Thermal generator data includes the minimum and maximum power, ramp-up and ramp-down rates, fuel costs, start-up costs and more. Variable renewable energy sources (RES) also include their generation profiles or for hydro power plants their natural inflows. Candidate power plants and lines (for generation and transmission expansion planning) have their associated costs attached.

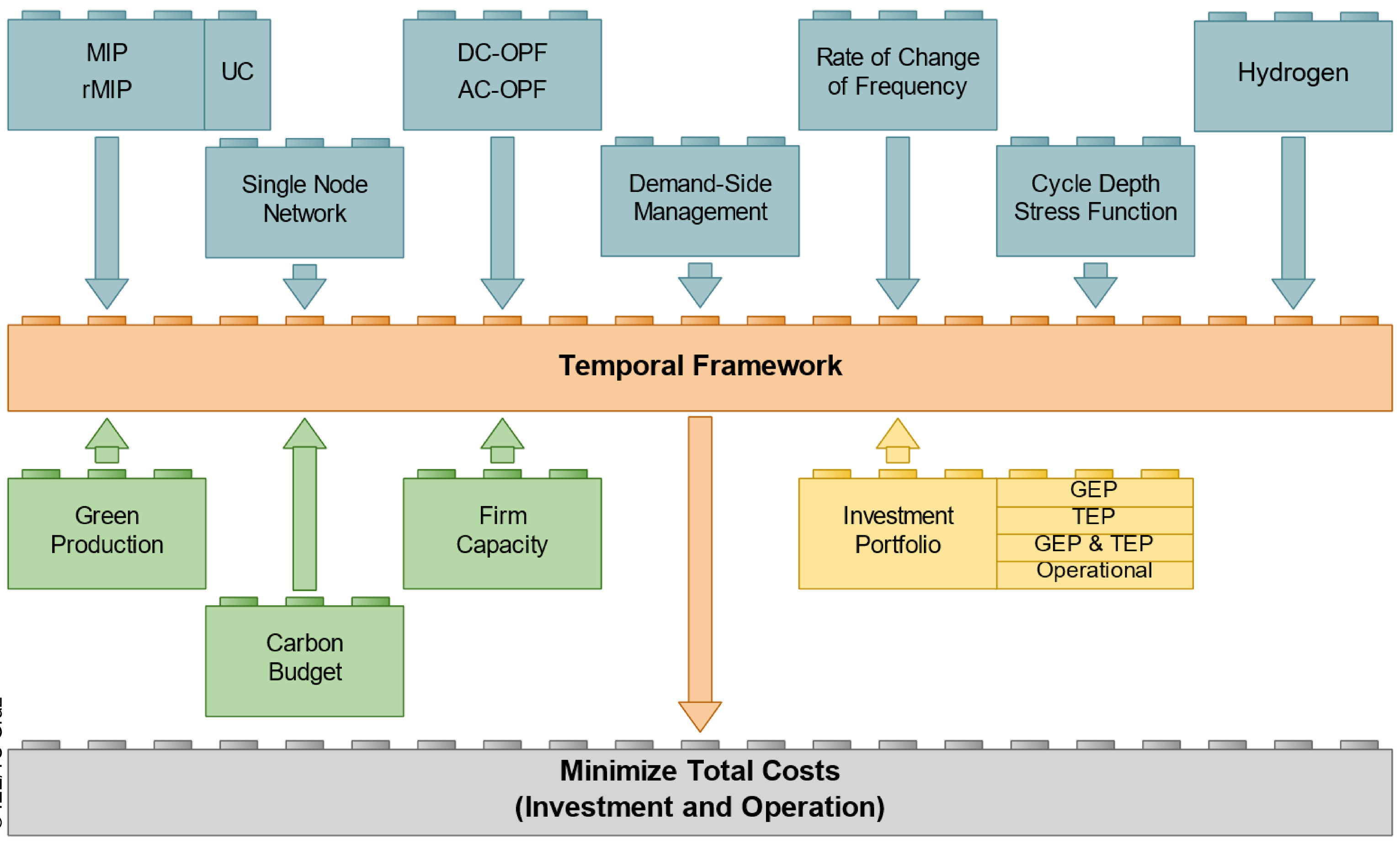

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Fig. 1: LEGO's thematic blocks: Model options that can be turned on or off (blue), political constraints (green) and expansion planning options (yellow).

Application – Digital Twin of the Austrian Power System

To investigate the effects of the **Renewable-Expansion-Act** (EAG) or to study the **consequences of a sudden gas-supply cut** on Austria's electricity sector, a digital twin of the Austrian power system is build, as pictured in Fig. 2. The 380 kV and 220 kV grid is based on publicly available data.[5,6] The power plant data is thoroughly researched and based on data from the power plant owners and operators.

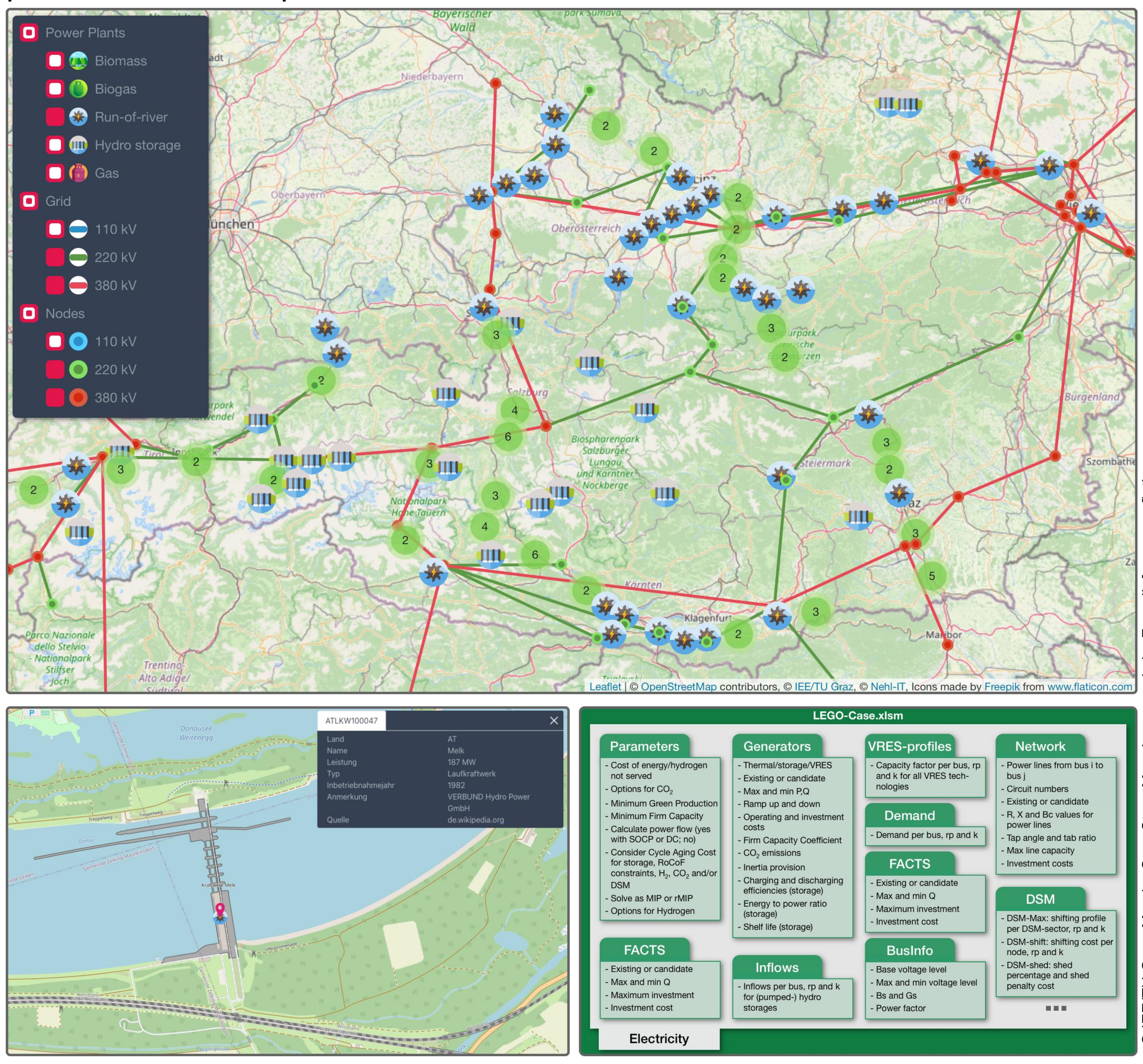

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Fig. 2: A digital twin of the Austrian power system with GPS-accurate mapping of the substations and power plants. The element-specific properties are saved in Excel spreadsheets.

With the aim of covering **100% of Austria's demand with RES** (national balance) by 2030, grid development has to go hand-in-hand with the expansion of RES. In order to fully leverage the RES potential in eastern Austria and using the pump-storage hydro power plants in the western states to store excessive energy, a load-flow analysis of the current power system made with Austria's digital twin[7] shows that grid reinforcement is necessary (see Fig. 3).

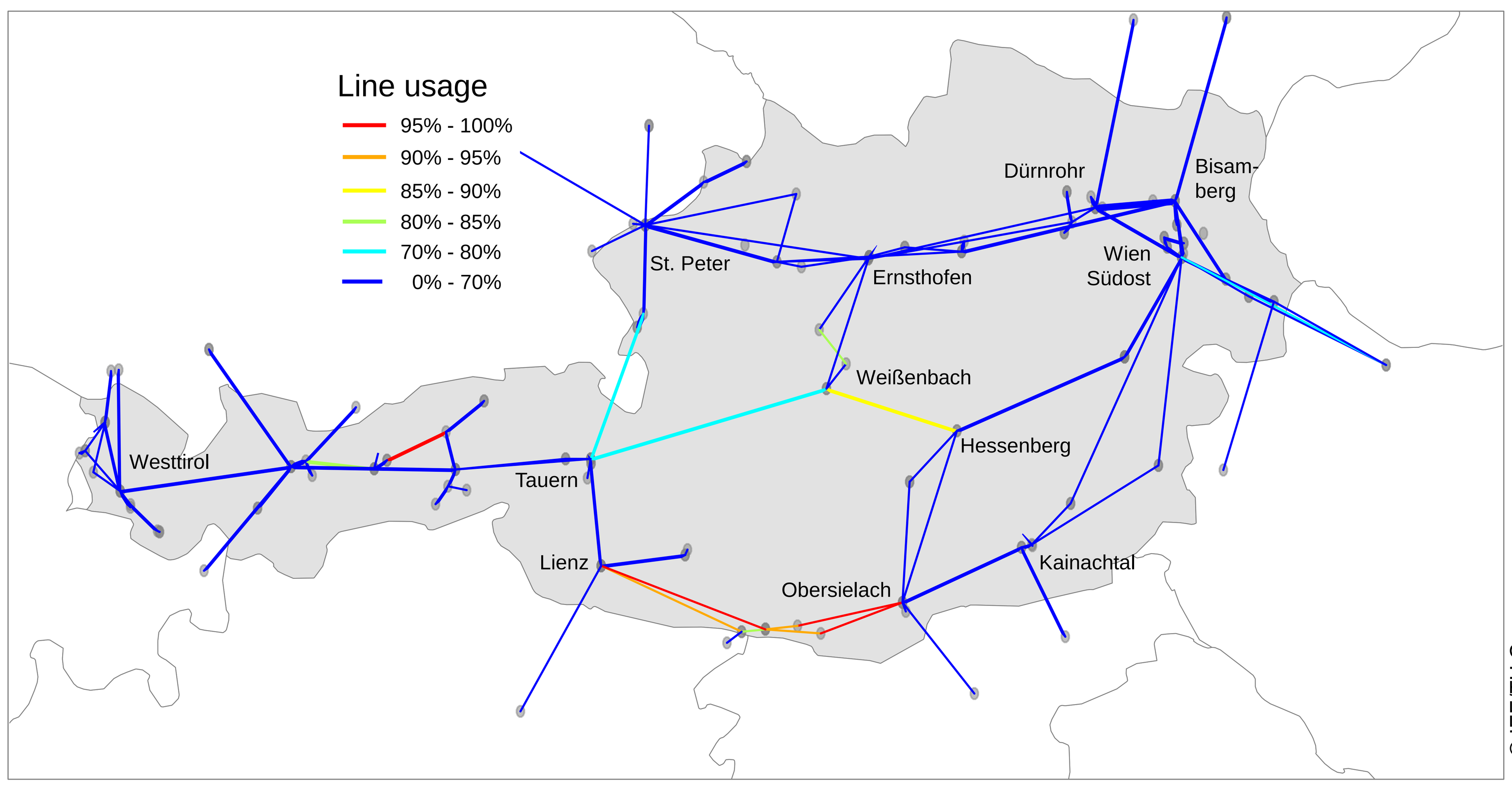

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Fig. 3: Combination of the highest load-flows of every line for 2022 showing the urgency for grid reinforcement between the eastern and western parts of Austria.

Literatur / Zitat

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Sonja Wogrin, Robert Gaugl, Thomas Klatzer, Alexander Konrad
Institute of Electricity Economics and Energy Innovation / Graz University of Technology
iee.tugraz.at

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