Sonja Wogrin

Energy System Modeling and Optimization for Climate Neutrality

In Europe, we have embarked on the journey towards net-zero power systems and want to reach full decarbonization by 2050 (European Commission "A clean planet for all"). Austria wants to reach carbon neutrality in the power system by 2030 (Erneuerbaren Ausbau Gesetz – EAG) and full decarbonization of the entire energy system by 2040. Achieving these goals, however, confronts us as a society with unprecedented technical, social and economic challenges.

At the Institute of Electricity Economics and Energy Innovation (IEE), we apply mathematical optimization, game theory, machine learning and analytics in energy system modeling to address these challenges and help climate neutrality become a reality.

In our research, we have essentially built a digital twin of the Austrian [1] (and also European) power sector including existing generators and transmission lines (Figures 3 and 4), which allows us to simulate the impact of climate policies, such as the EAG, or shortages of gas imports in light of recent political events in the Ukraine, on power system operations, electricity prices and security of supply. We do this by merging the Low-carbon Expansion Generation Optimization (LEGO) [2] and the ATLANTIS [3] model. LEGO is a mixed-integer quadratically constrained optimization problem and has been designed to be a multi-purpose tool, like a Swiss army knife, that can be employed to study many different techno-economic aspects of the energy sector. Ranging from short-term unit commitment, optimal power flow or inertia assessments to long-term generation and transmission expansion planning. LEGO is also composed of thematic modules that can be added or removed from the model easily via data options depending on the scope of the study. It is an easy-to-use open-source mathematical optimization software tool freely available on GitHub (https://github.com/IEE-TUGraz/LEGO). >

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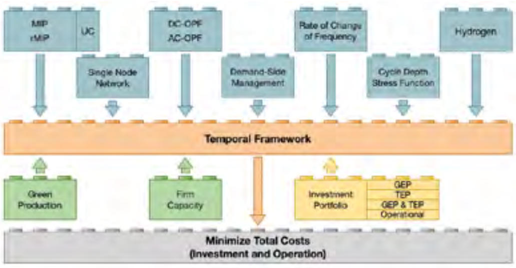
obtained a Dipl.-Ing. in Technical Mathematics at TU Graz and a Master of Science in Computation for Design and Optimization at the Massachusetts Institute of Technology. She obtained her PhD at Comillas Pontifical University in Spain, where she was also working as researcher and associate professor in the Industrial Organization Department until 2021. Since August 2021 Sonja has been the head of the Institute of Electricity Economics and Energy Innovation at TU Graz. Her research interests lie within the area of energy system modeling and optimization.

Source: Lunghammer – TU Graz

a)



b)

Figure 1: Low-carbon Expansion Generation Optimization (LEGO) model: code (a) and software architecture (b).

Source: IEE

eco-friendly buildings) or sector coupling, which means allowing for fluent interactions between the power, heat, gas and transport sector. As of today, it is unclear what these interactions will look like, how they will be regulated, which services will be offered and whether or not they will be profitable in a liberalized market. These "burning questions" have also been discussed intensively by more than 220 speakers and over 630 participants (of academia and industry) at the Symposium Energy Innovation (https://www.en-innov.tugraz.at) – one of the major energy economics conferences in the DACH region and organized by the IEE (Figure 2).

Figure 2: Evening event of the Symposium Energy Innovation organized by the IEE.

Source: IEE

Why is it so important to have a reliable and realistic digital twin of Austria's power system on the path towards decarbonization? First of all, because the power system is at the heart of decarbonization, and the solution to decarbonize, transport for example, is to electrify it, leading to a continuously increasing demand for electric energy. At the same time, this demand should no longer be supplied by traditional dispatchable (and CO_2-emitting) thermal generators, such as gas-fired power plants, but by variable renewable energy sources (VRES). But here's the catch: VRES cannot be scheduled and operated like thermal plants. I cannot ask the sun to shine more, or the wind to blow faster just because I have an increase in power demand. It just doesn't work that way. In order to counterbalance this uncertainty introduced by VRES and to avoid curtailing load (e.g. switching the lights off) when no VRES are available, the power system requires another source of flexibility, which could be provided by energy storage technologies, demand-side-management (e.g. energy communities [4], smart

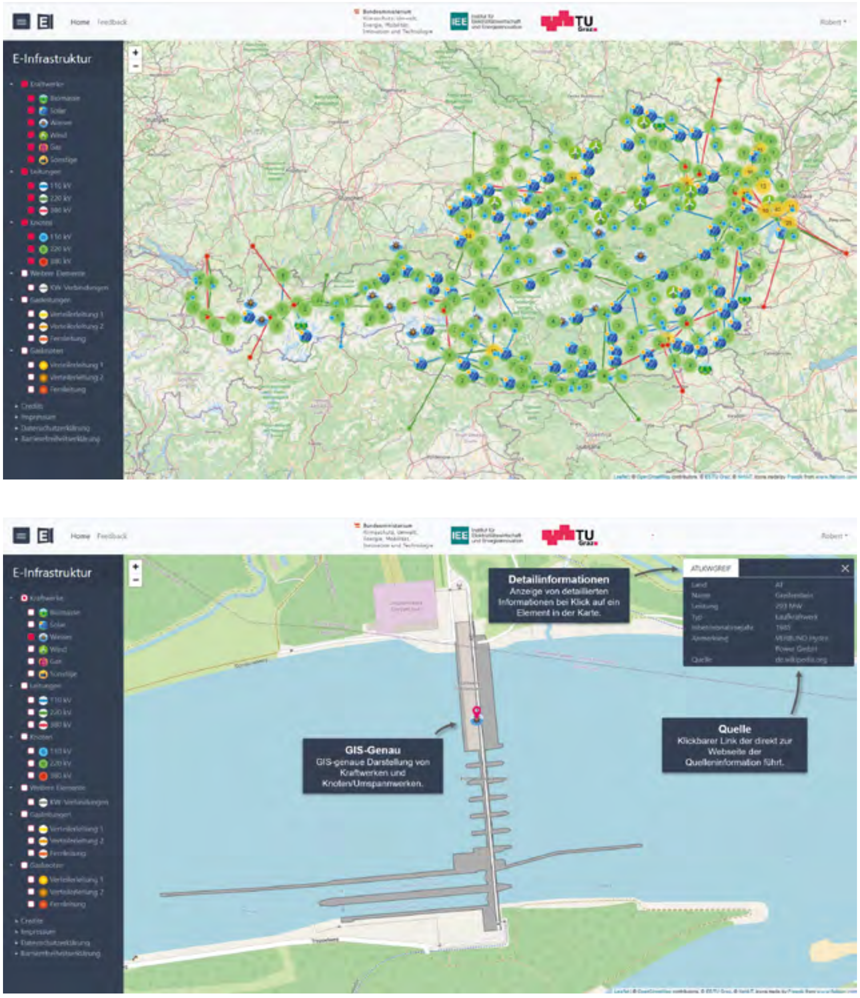


Figure 3: Visualization of Austrian energy infrastructure.

Source: IEE

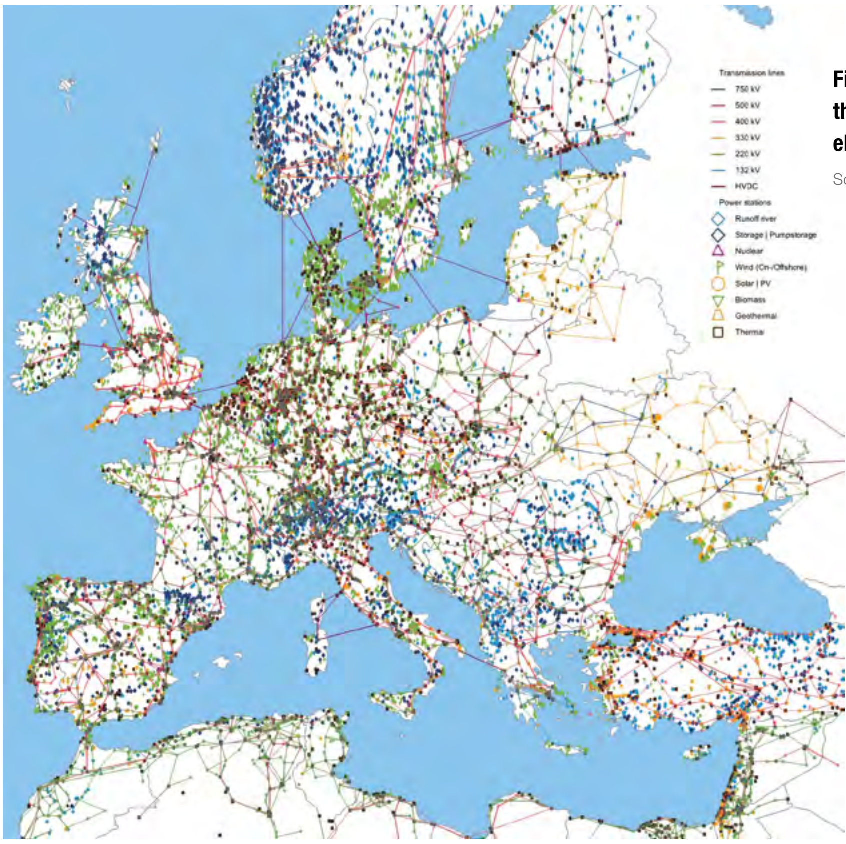


Figure 4: GIS-exact database of the European and North African electricity system.

Source: IEE

Regarding the scientific and technical challenges of energy system models, we are talking about complex physical systems that are governed by nonlinear, nonconvex equations, as for example the Kirchhoff Laws that describe how electric energy flows through a network. Another complicating factor is the sheer amount of BIG data that has to be handled. Representing every hour of a year (i.e. 8760) for every generator in the Austrian power system (approx. 800) yields over 7 million production variables. For binary decision variables that would be 2^7million possible combinations – in conclusion, energy system models become computationally intractable quickly. As a remedy, we frequently employ machine learning techniques such as clustering algorithms [5] to circumvent the problem of tractability. Another alternative is coming up with innovative aggregated optimization models [6] to reduce the computational burden.

Our research at the IEE (Figure 5) lies at the intersection of optimization, data science, economics and energy system modeling to solve real-world problems and support decision makers on the path towards climate neutrality.

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Figure 5: IEE Team (from left to right): Klatzer, Gaugl, Cardona Vasquez, Ljubijankic, Bachhiesl, Wogrin and Gruber.

Source: IEE

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