AI based prediction of the Merit Order (of the marginal power plant) to substitute CO_2 emissions in the German electricity mix.

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Hypothesis and goals

If it can be predicted which marginal power plant (technology) determines the merit order (supply and demand curve of the national electricity markets), the amount of CO_2 emissions saved by the additional feed-in of a distributed (renewable) generation plant (merit order effect). can be estimated. An AI model learns from historical and forecasted national consumption, generation, weather data as well as cross-border flows which generation technology of which nation provides the marginal power plant under which external conditions and consumption patterns. Which technologies contributed when and in which quantity to the national energy demand can be determined by the so-called "flow tracing" (see subchapter Flow Tracing). Based on a graph based representation of the energy system under consideration, flow tracing can be used to determine which technologies provided which amount of energy at each node at any given time. This data will then be used as target feature for the prediction model of the *Merit Order*. If the load or the feed-in of renewable energy sources was changed artificially, the *Merit Order* also changes and it becomes visible which technology formed the marginal power plant or generally in the optimization of operating strategies.

The objective of this work is to develop an AI based predictive model to determine the substituted amount of CO_2 emissions as an operational decision in power plant management.
Goals:

- Development of a forecast model for the prediction of the cross-market Merit Order of Germany
- Publication of the results/approaches in a joint scientific publication
- Reusable source code (open source?) (non-productive code) without license restrictions

Background

Merit Order

Merit order is the term used by the energy industry to describe the order in which power plants that produce electricity are deployed on an electricity trading platform in order to ensure the economically optimal supply of electricity. The merit order is based on the lowest marginal costs, i.e. the costs incurred by a power plant for the last megawatt hour produced. The merit order is therefore independent of the fixed costs of a power generation technology. According to the merit order, the power plants that continuously produce electricity at very low cost are the first to be connected to the grid. After that, power plants with higher marginal costs are added until demand is met [1].

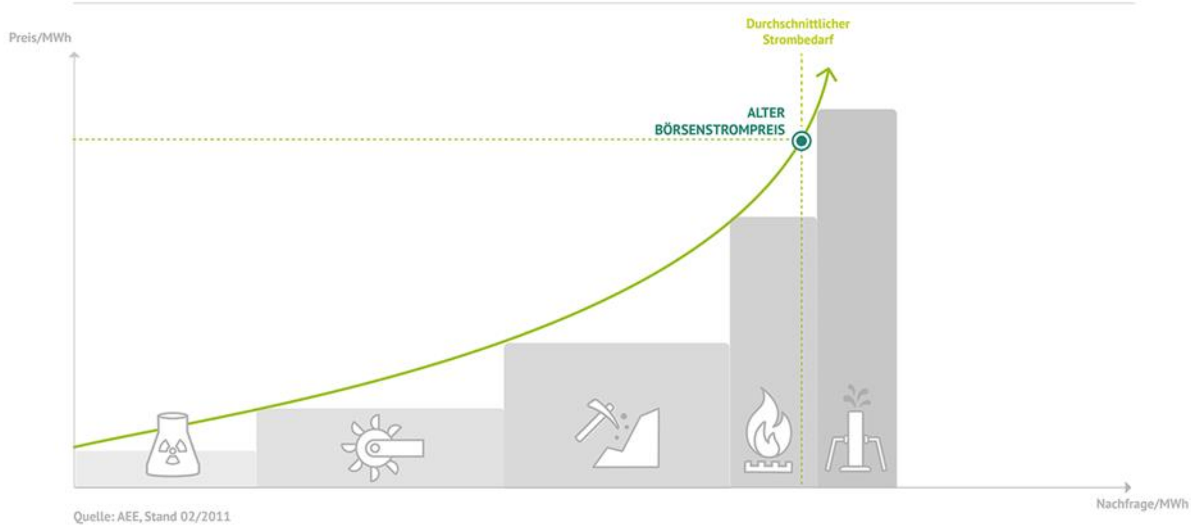


Figure 1 - Conventional merit order [1]

The merit order is a possible description model of a functioning electricity market. The assumption behind this model is that power plant operators always want to cover their costs for the next megawatt hour produced, otherwise they would not produce it. Power plants with low marginal costs can therefore offer a lower price for their electricity and are thus subsidized more often than power plants with higher marginal costs. The merit order thus attempts to explain how pricing works in the electricity market; it is not a "law" that coordinates power plant dispatch. [1] In economic terms, this methodology corresponds to the classical supply and demand curves of microeconomics (cf. [2]).

Merit-Order Effect

Within the merit order, permanently falling electricity production costs shift the conventional order of power plants. Such an effect can currently be observed in particular due to the growing feed-in of renewable energies (photovoltaics, wind energy, biomass). Fluctuating feed-in photovoltaic and wind power plants with marginal costs close to zero are advancing into the market and pushing peak load power plants far down the merit order. The energy industry refers to this phenomenon as the merit order effect (MOE) of renewables. Only the residual load - the remaining electricity demand that renewables cannot cover - still has to be balanced by conventional power plants. [1]

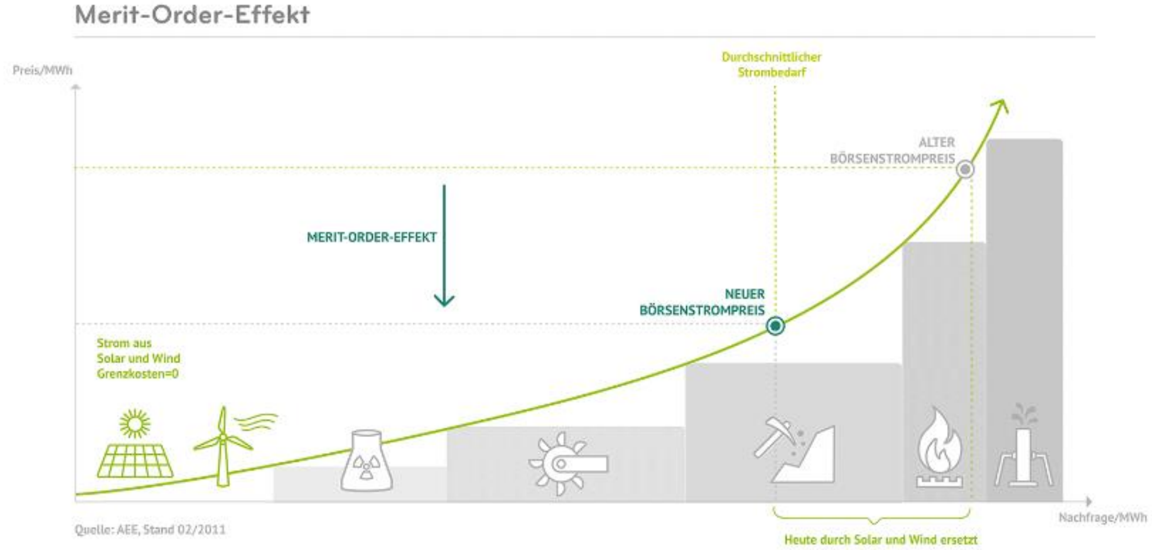


Figure 2 1 - Merrit-Order effect [1]

Flow Tracing

Flow tracing can be used to determine for individual nations how their own supply depends on their technologies, based on imports and exports from neighboring countries and their generation structure, and is therefore important for determining the exact composition of the electricity mix and thus the emissions [3, 4].
The basic idea of flow tracing is based on Kirchhoff's node rule and the representation of the European energy system as a directed graph: flows that flow into a node also flow out again. It is irrelevant whether the flows go to other nodes or to a sink (from the network under consideration). Furthermore, it is assumed that the currents flowing into a node mix uniformly, so that all currents flowing out have the same composition of currents. In other words, the currents mix as one would expect water to mix. If one now assigns a marker or "color" to each stream that is introduced into the network, then after calculating the flows between the nodes, the proportion of the stream with the "color" can be determined. From again, the origin of the current can be inferred.

The following figure shows an example of a node *n* with the flows into and out of the node:

- G_n: Generation at node n
- L_n: Load at node n
- S_n^+ : Flow from storage at node n (discharging)
- S_n^- : Flow to storage at node n (charging)
- $F_{m\rightarrow n}$: Flow from node m to node n
- $F_{n\rightarrow k}$: Flow from nodes n to nodes k
- I_n Import: Flow from outside the network to node n
- X_n Export: Flow of nodes n out of the network

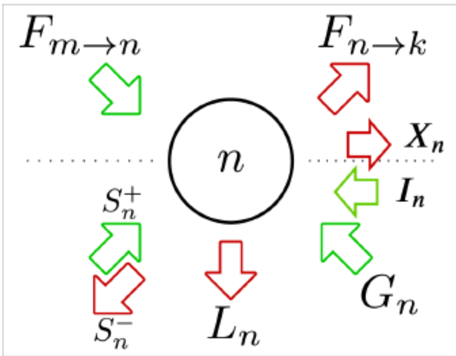
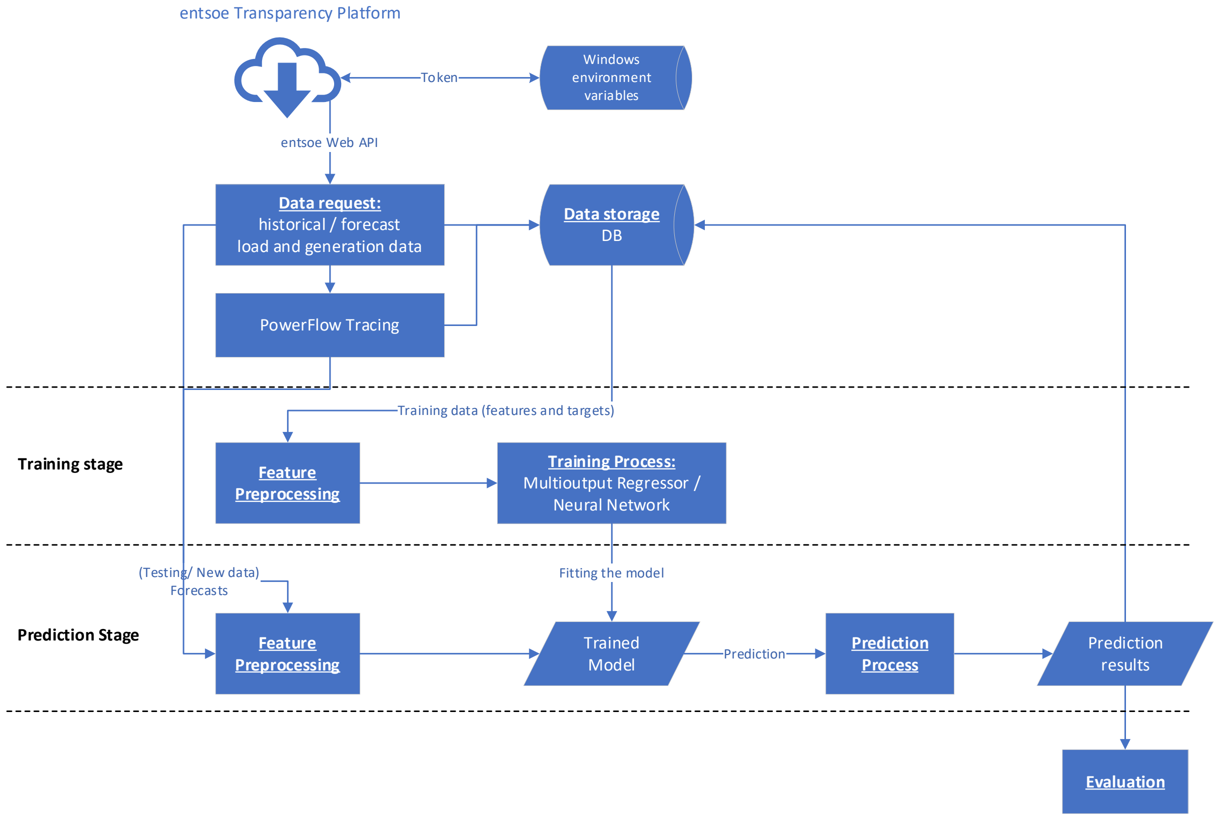


Figure 3 - Flows into and out of an exemplary node

The European interconnected transmission grid then looks as follows for flow tracing:

Figure 4 – Flow Tracing of the European transmission grid

The Prediction Model



Data

Training Features	Actual	Forecast	Reference
Load	Actual Total Load [MW]	Day-ahead Total Load Fore-cast [MW]	[5]
Generation	Actual Generation per Pro-duction Type [MW]	Generation Forecast - Day ahead [MW]	[5]
	Installed Capacity per Pro-duction Type	Generation Forecasts for Wind and Solar	[5]
	Historic Generation per Unit (After Flow Tracing)		Lucas
Transmission	Cross-Border Physical Flow	Cross-Border Physical Flow	[5]
		Day-ahead Prices	[5]
Weather reports	Temperature, Windspeed, Irradiance, Cloudiness …	Temperature, Windspeed, Irradiance, Cloudiness …	[6], DLR-VE
Additional Features	Calendaric (Holidays…), Sin, Cos, …		Self-made

What should be predicted?

➔ Generation by technology (with changed generation or load behavior)

	Target Features	
	Generation	Generation per Technologie/Unit [MW]

Time Schedule

Working Packages	Duration in weeks	Description
WP 1 – Data pre-processing and feature engineering	1 - 4	Data pre-processing and feature selection for further predictions **Goal**: Building an operational data set
WP 2 - Algorithm selection and simple try outs	1 - 8	Search for suitable algorithms. Implementation of short tests for the evaluation of the algorithms. **Goal:** Selection of a suitable algorithm
WP 3 – Prototype structure and test	9 - 14	Creation of a prototype structure for the forecast model and test scenarios. **Goal**: Implemented prototype of the prediction model
WP 4 - Evaluation	14 – 20	Evaluation of the prediction quality and code performance. Uncertainty quantification **Goal**: Implemented metrics on quality and uncertainty
WP 5 - Optimization	16 - 24	Optimize code and run various tests to validate results (hyper parameter optimization). **Goal**: Optimized prediction model and executable code for further application

References

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