Future Agorameter Documentation

Version 1

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Introduction

This documentation describes the methodology behind Agora Energiewende's Future Agorameter tool, which was developed with the support of Prognos AG. The regular Agorameter, which serves as the basis, has existed for many years. The data behind the Future Agorameter are the same historical and live data on electricity generation used in the Agorameter. That data is explained in the documentation of the Agorameter, which is available on the website www.agora-energiewende.de.

The Agorameter allows users to follow the progress of the energy transition in real time visualizing the current electricity supply for Germany.

The Future Agorameter projects current electricity generation in Germany into the future. The aim is to show what future power generation could look like with the same weather conditions as today but with renewable installed capacity of the future.

The boundary conditions include laws such as the nuclear phaseout and trends assumed in *Climate-Neutral Germany 2045*, in particular for the newly added renewable capacity. In addition, assumptions are made about trends in additional electricity demand, such as electromobility, and the resulting consumption patterns. In combination with the available live data behind the Agorameter, a future is visualized with similar conditions to the current ones: the pattern of wind, solar, and power demand.

The underlying technical assumptions are based on modeling carried out as part of the Climate-Neutral Germany project. It showed an economically optimized way to achieve climate neutrality across all sectors by 2050 and, in a continuous project, by 2045. Thus, these assumptions are explicitly not a forecast, nor do they necessarily reflect the growth of renewables envisaged in Germany's Renewable Energy Sources Act, which lacks ambition. Rather, the assumptions result from an economic optimization, in which the faster growth renewables than in current law is a cornerstone for climate neutrality.

The future electricity system will be more flexible than today to accommodate fluctuating renewable electricity. Electricity producers and consumers will optimize their behavior to maximize profits. The optimization period in the Future Agorameter replicates the time frame chosen for the Agorameter but can be adopted by the user. The methodology of the optimization, the constraints of the optimization methodology, the constraints of flexible consumers, and the definition of individual parameters are explained in this document.

The timeframe can be shifted, so any week of the past years up to and including the current week can be used as a basis to display the week in the future.

The Future Agorameter can be used for free; it is available on the Agora Energiewende website. The charts can be used free of charge with an indication of the source.

Agora Energiewende strives to continuously improve the Future Agorameter. All data sources and calculations are documented below. Suggestions on how data quality and assumptions can be improved are welcome.

1 Methodology

The Future Agorameter is based on the same historical and live data for German electricity generation as used in the Agorameter. Agora Energiewende does not collect any data itself; the primary source is the European Energy Exchange EEX for data before 2018 or the transmission platforms of the European transmission system operators ENTSO-E for data from 2018 onwards. As these data do not fully represent the German power system, they are adjusted in the Agorameter before they go online. A detailed description of the Agorameter methodology can be found on the Agora Energiewende website.

In the Future Agorameter, the data from the Agorameter are again adjusted. In both, the generation quantities shown are net; i.e., without the power plants' own consumption.

The data are adjusted to reflect the changed conditions for the future as realistically as possible. Mainly:

- conventional power plant capacities will retire,
- renewables will grow,
- there will be more power demand for the production of hydrogen,
- industrial electricity consumption will be more flexible,
- a larger number of heat pumps will be used, and
- the transport sector will further electrify.

Boundary conditions set limits for flexibility. The module used for this purpose was custom-made by Prognos AG.

The calculation steps performed in this process are documented below.

The tool does not calculate CO_2 emissions from electricity generation, wholesale electricity prices, or exact import and export quantities.

In the following, trends in the assumptions of the German power plant fleet's development are explained first, followed by an explanation of how the electricity quantities of individual consumers and the electricity demand are determined. Then, the functionality of the "flexibility module," which determines flexible loads and the use of biomass, is explained. Finally, the determination of the residual load is discussed.

2 Power plant capacity

The calculation of power plant capacity in the future is based on laws such as the nuclear phaseout and on the results of the study entitled *Climate-Neutral Germany 2045*. That study concludes that renewables should be expanded more rapidly than is currently provided for in Germany's Renewable Energy Sources Act; the phase-out of coal would also be moved forward to 2030, compared to the current deadline of 2035/2038. Current capacities are based on data from the Federal Network Agency and the Renewable Energy Statistics Agency. In the following, trends for each energy carrier are presented.

a. Renewable energy

Renewable energy grows in line with the assumptions behind Climate-Neutral Germany, which can be downloaded free of charge from the Agora Energiewende website. According to this study, renewables will be the cornerstone of future electricity generation. The installed capacity in the future year under consideration is decisive for calculating the amount of electricity generated. Additions during the year are not considered separately.

The capacity of bioenergy for electricity generation remains essentially unchanged up to 2030, after which it declines until 2045, as biomass is primarily used in other sectors.

The potential for hydropower has been largely tapped in Germany. For this reason, installed capacity remains constant.

The generation capacity of wind energy increases significantly. In 2030, an installed capacity of 80 gigawatts onshore and 25 gigawatts offshore is assumed. By 2045, the capacity of onshore turbines will increase to 145 gigawatts; offshore, to 70 gigawatts.

Photovoltaics grows the fastest, reaching 150 gigawatts of capacity in 2030 and 385 gigawatts in 2045.

b. Conventional power plants

The electricity generation from all conventional power plants together with the net import balance is collectively shown as the residual load in the Future Agorameter. There is no limitation to the size of the residual load considered in the Future-Agorameter.

3 Calculation parameters

Below, the methodology used to calculate electricity generation from renewables, electricity demand and the Flexibility Module is documented.

a. Renewables

Electricity generation from photovoltaics and wind turbines is calculated on an hourly basis for each energy source for the installed capacity in the reference year and in the future year. The ratio of electricity generation to installed capacity remains unchanged: windy hours in the initial year are shown as windy hours in the future, while dark hours today are also dark in the future. The goal is to visualize the generation patterns of renewable energy based on the weather. How might these fluctuations affect power supply in Germany with a higher share of renewables in the future?

Hydropower is plants with natural inflow and hence explicitly not pumped storage. Thus, generation is not flexible. Since the capacity hardly changes - assuming constant water volumes - the generation volume in the future also remains almost unchanged compared to the current level.

Electricity generation from biomass is limited in terms of maximum capacity according to the same calculation methodology; thus, no more electricity can be generated than there is installed capacity. However, electricity generation from biomass is controllable and can (at least partially) be used flexibly. The current representation of electricity generation from biomass plants does not adequately represent the flexible operation that is possible. Generation from biomass could therefore be more demand-driven than at present. However, limiting factors today are the use in combined power and heat (CHP) plants and market-independent compensation payments, which do not reward flexible operation. The Future-Agorameter does not display this potential for flexibility of biomass plants.

b. Demand

The electricity demand in Germany is first determined congruent to the calculation of renewable power. For this purpose, the current electricity demand is calculated based on the ratio of the total electricity demand between the current year and the future year.

In a second step, however, the potential of flexibilization is determined. For this purpose, the Flexibility Module was developed by Prognos AG for Agora Energiewende (see below).

The demand made more flexible by this calculation step is mapped in the Future Agorameter.

c. Flexibility Module

In an electricity system with a high proportion of variable generation from renewables, flexible electricity consumers help tailor electricity demand to electricity generation, thereby reducing the curtailment of renewable electricity and demand for electricity from fossil fuels.

To represent this flexibility, the Flex Module determines the potential of existing flexibility on the demand side in the power system and aims at a realistic optimization of the power consumers.

Electric cars, heat pumps and also some industrial processes have temporal flexibility for their electricity requirements. Electric cars already have batteries with a range of 300 kilometers and more, and the trend is rising; however, the average distance driven in Germany is less than 50 kilometers per day. Due to the thermal inertia of buildings, heat pumps can also shift their power consumption over time. If a heat storage tank is also available, flexibility increases even further.

For use in the Future Agorameter, flexible consumers are divided into three categories:

- → electric cars,
- → heat pumps, and
- → industrial consumers.

Each of these categories consists of cohorts, which represent the heterogeneity within the category. Within the category "electric cars," for example, a distinction is made between different usage profiles and charging options. The use of batteries in electric cars in the sense of a storage device that can be charged and discharged (bidirectional charging) is explicitly omitted in the current version of the Future Agorameter.

The following cohorts are used:

- Electric cars

  - → Battery-electric passenger cars as plug-in hybrids, fast chargers.
  - → Battery-electric passenger cars with low flexibility of charging timing.
  - → Battery-electric passenger cars with high flexibility of charging timing.
  - → Battery-electric inflexible light-duty vehicles.
  - → Battery-electric flexible light commercial vehicles
  - → Electric two-wheelers
  - → Battery electric trucks

- Heat pumps
  - → Single-family homes with storage tank
  - → Single-family homes without storage tank
  - → Multi-family buildings
  - → Buildings from the commercial, trade and service sector (tertiary sector)

- Industrial consumers
  - → The flexibility of industrial consumers is combined in a virtual storage facility

Each cohort within a category has the following characteristics that specify its use and limit its flexibilty:

- → the maximum hourly *charging capacity per consumer*.
- → hourly *charging availability profile* per cohort, which limits the maximum percentage of individual cars that can simultaneously charge their battery in that hour.
- → an hourly *consumption profile* for the complete year; for cars, defined by a given driving profile; for heat pumps, by the primarily temperature-dependent hourly heat demand.
- → the *size* of the storage (battery and thermal storage; for industrial consumers, an abstract storage that represents the temporal flexibility that arises, for example, in batch processes or through material storage).
- → the *instantaneous charge level* in each hour, which must never fall below a certain level.

Under these conditions, the charging behavior of the flexible consumers is intelligently controlled so that, as far as possible, electricity is always drawn from the grid when the residual load is low or even negative. Assuming that flexible electricity tariffs react to the wholesale price, this behavior also pays for itself for consumers, since hours with a high share of renewable energy correlate very strongly with low prices. The applied algorithm therefore uses a heuristic to approximately minimize the sum of the squares of the hourly residual load.

d. Conventional power generation

The difference between flexibilized demand and the total generation from renewables is shown cumulatively as residual load, which is not further broken down into specific generation technologies. Thus, the amount of residual load in one hour does not indicate which share of it is provided with conventional power generation in Germany and which share is imported or exported. This share is not constant and depends on available generator capacity, cross-country capacities as well as the power price in neighboring countries.

A positive residual load means there is insufficient generation from renewable power. The remaining power is provided with either imports or conventional power generation. A negative residual load means generation from renewable sources is higher than the demand. The overshoot can either be exported or curtailed.

Sources

AG Energiebilanzen (2020): *Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern*:: http://www.ag-energiebilanzen.de/

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Bundesnetzagentur (2021): *Kraftwerksliste*: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Versorgungssicherheit/Erzeugungskapazitaeten/Kraftwerksliste/kraftwerksliste-node.html

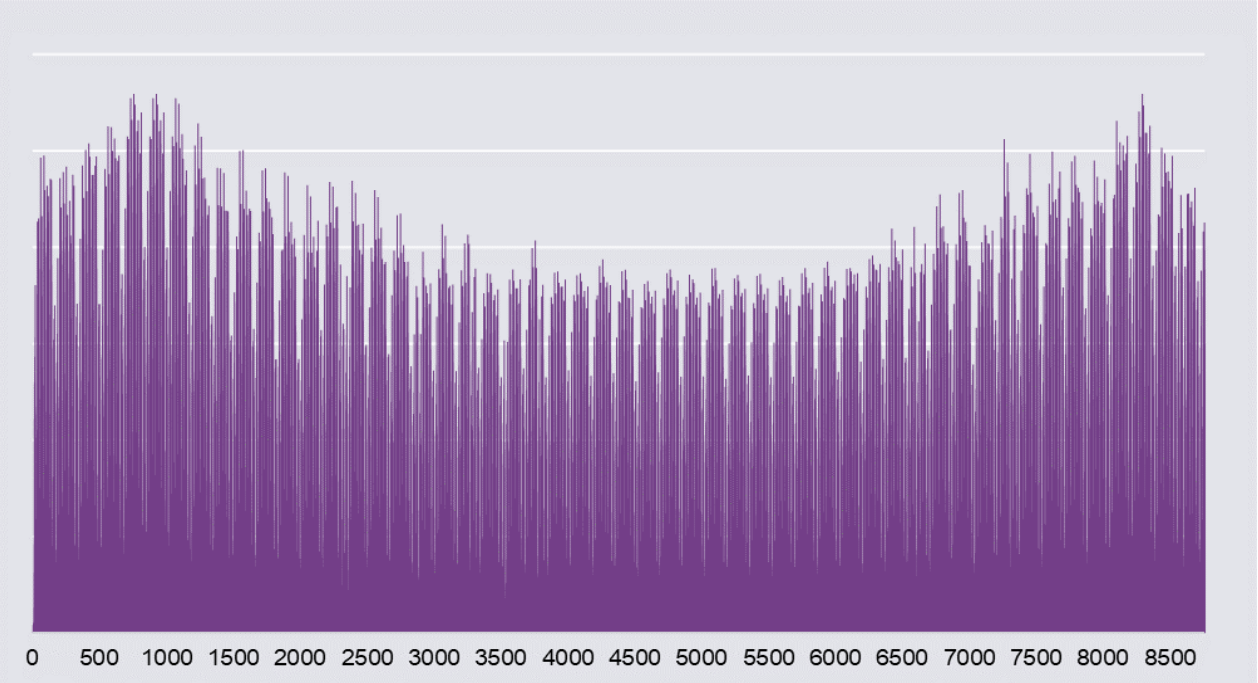
EEX (2012-2017): Market data on power generation; (for processing in the Agorameter, the data are obtained directly from EEX via a server, for which a fee is charged; however, all data on power generation of the plants reporting to EEX are also published on the EEX transparency page at: http://www.eex-transparency.com/)

ENTSO-E (2021): Market data on electricity generation: https://transparency.entsoe.eu/dashboard/show

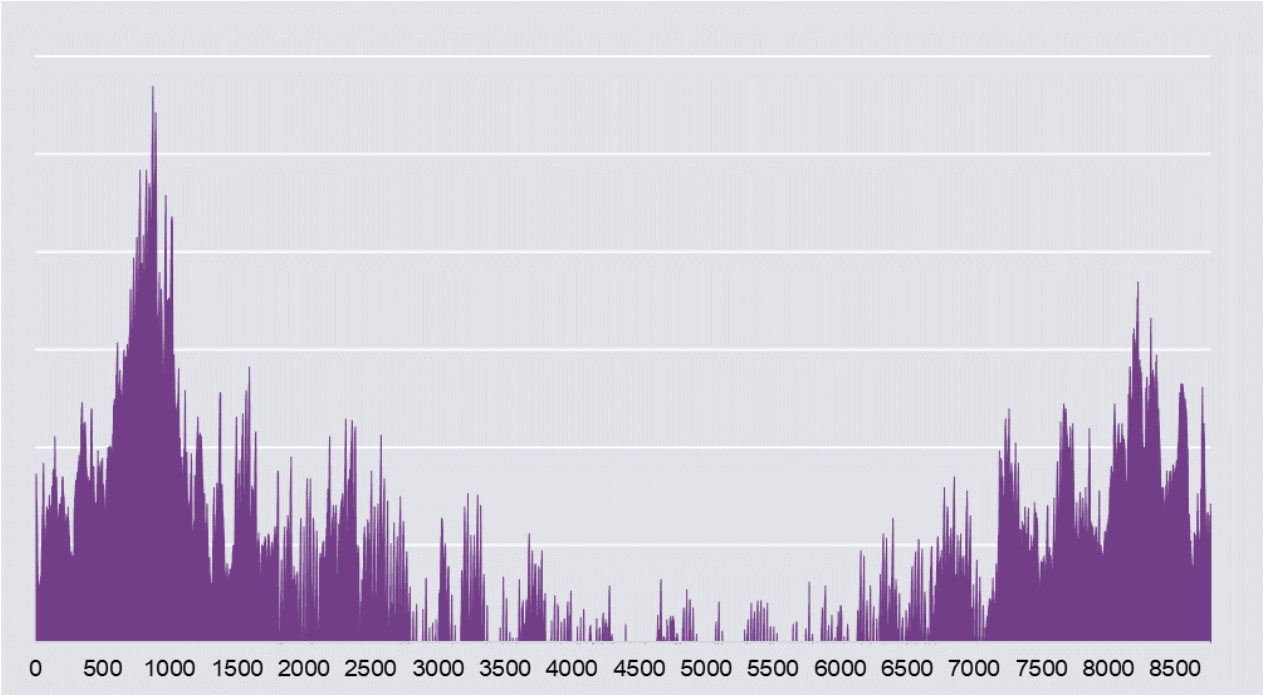
Attachment

The following consumption profiles are based on temperatures from 2012. Further data showing annual renewable energy capacities, electricity consumption and flexible consumers' parameter are listed in the data attachment.

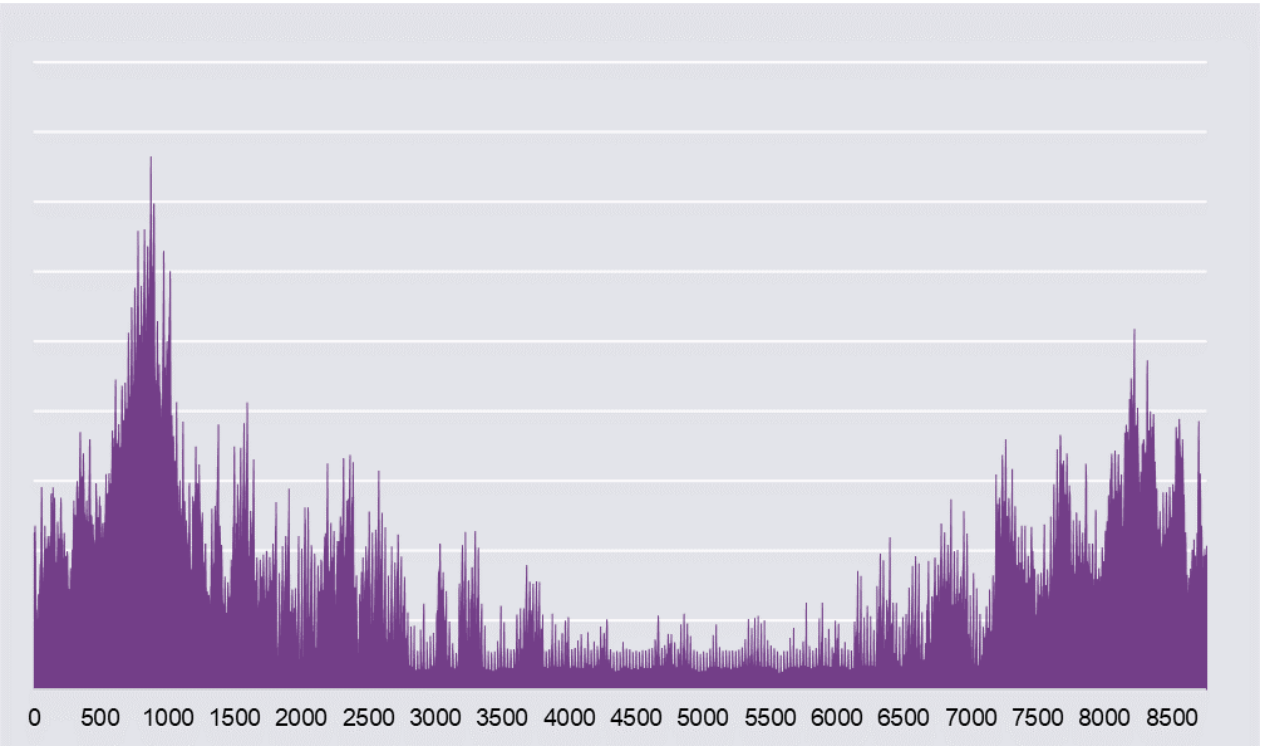
Electric Vehicles: Electricity demand throughout the year



Single-family houses: hourly heat demand throughout the year



Apartment building: Hourly electricity demand throughout the year



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