# Simulation of electricity supply and demand

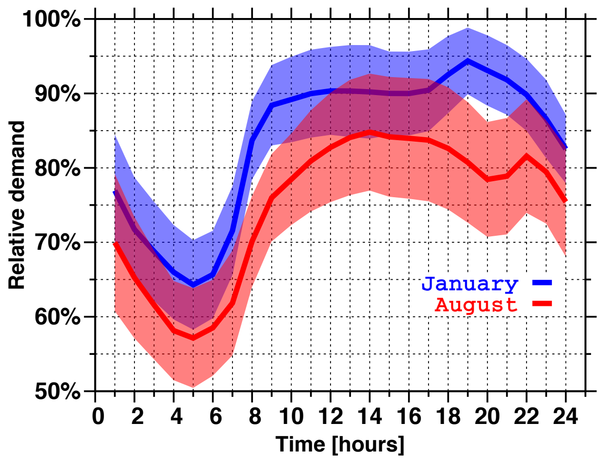
The great challenge of operating the electric grid of a country is to *always exactly* match the demand with appropriate supply, while also being cost effective. For following the principle of sustainable development the minimization of $CO_2$ emission should also be taken into consideration.

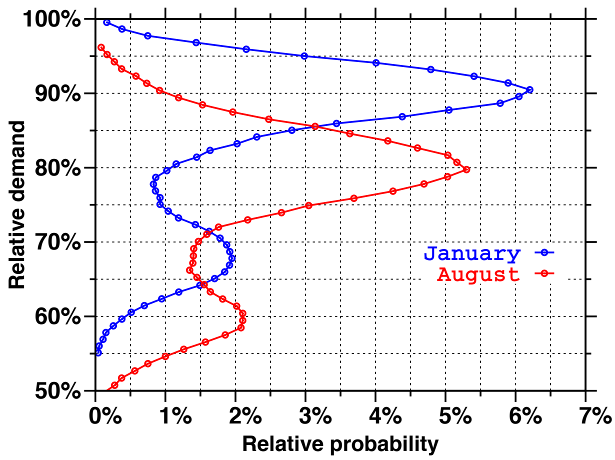
Most countries of the world have based their electricity supply on fossile fuels. Reasons include history, their relative simplicity, low cost, and ease of operation & control. Renewables have a great advantage in terms of $CO_2$ production (or rather, lack thereof). However, their output depends heavily on weather as well as the time and date. Nuclear energy has a large capital cost, while hydro power may have limited availability because of the geological/hydrological properties of a country.

In this simulation we study the case of an imaginary, self-sufficient state; whose climate, geongraphy, and electric demand are reminiscent of that of Hungary. Our task is to design a system, which is able to always meet the demand, while optimizing for cost and $CO_2$ emission. (Self-sufficient means that there is no possibility of importing/exporting electrical power.)

## Electricity demand

The demand varies throughout a day, as well as according to the season of the year and whether it is a working day or not. For simplicity the program only contains demand data for typical working days in summer and winter conditions. **The maximum demand (100%) is 6.5 GW, while the minimum is 47% of the maximum.** The distribution of the expected demand is presented in the figures below (left: as a function of time during a day, right: distribution during a month). The shaded regions indicate where the demand is expected to be in 95% of the time (95% confidence interval). The figure on the right is rotated by 90 degrees for easier comparison.



## Electricity production

We have 7 different types of units available to assemble the system: coal, gas, nuclear, wind, solar, hydro and pump storage. A summary of the main parameters is provided in the table below.

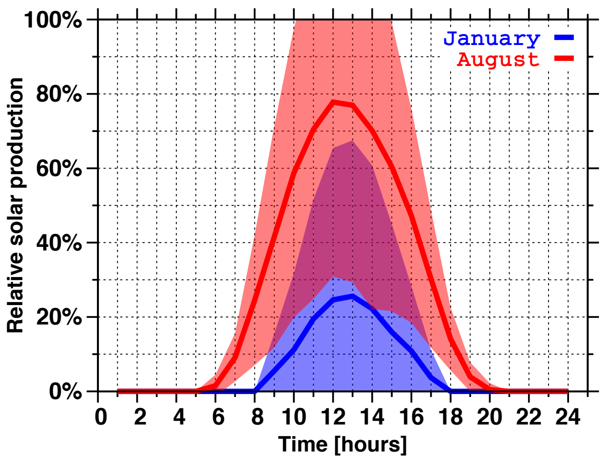
| Type | $N_{max}$ | $P_{max}$ [GW] | $P_{min}$ [GW] | Flex. [GW/h] | Fix. cost [M$/GWd] | Var. cost [M$/GWd] | $CO_2$ [t/GWh] |
|---|---|---|---|---|---|---|---|
| Coal | 10 | 0.6 | 0.3 | 0.3 | 0.6 | 1.2 | 900 |
| Gas | 10 | 0.5 | 0 | 0.5 | 0.3 | 2.2 | 500 |
| Nuclear | 4 | 1 | 1 | 0 | 1.6 | 0.25 | 10 |
| Wind | 15 | 0.3 | - | - | 1 | - | 10 |
| Solar | 20 | 0.2 | - | - | 0.6 | - | 40 |
| Hydro | 3 | 0.6 | 0.2 | 0.6 | 1.3 | - | 20 |
| Pump storage | 4 | 0.5 | -0.5 | 1 | 1.3 | - | 20 |

- **$N_{max}$** Maximum number of possible units.
- **$P_{max}$** Maximum power output of 1 unit.
- **$P_{min}$** Minimum power output of 1 unit.
- **Flexibility** Flexibility of 1 unit, i.e. 1 unit can change its output by these many GWs in 1 hour.
- **Fix. cost** (investment, operation, maintenance) - M$/day cost of sustaining 1 GW capacity.
- **Var. cost** Variable costs (fuel, etc) - The cost of producing 1 GW-day (24 GWh) electricity. The total cost is the sum of fixed + variable costs.
- **$CO_2$** The amount of $CO_2$ emitted (in tons) per GWh electricity produced.

All of these parameters are scaled linearly with the number of units used of each type.

**The power produced in wind- and solar power plants is solely determined by the date, time and weather. Due to subsidies provided to renewables the power produced by solar and wind power plants always has to be accepted by the grid!**

The distribution of power produced by **solar power plants** is shown in the figure below (average and 95% confidence interval). Due to the day-night cycles we receive no solar power production 42% of the time in summer, and 62% in winter (→ nights).




The power output of **wind power plants** is a nonlinear function of the random wind speed. If the wind speed is too low or too high, the wind turbines cannot generate electricity. Furthermore, power production saturates above a certain wind speed. For these reasons the wind turbines implemented in the simulation produce no electricity 31.6% of the time, produce at max output 16.7% of the time, and produce inbetween 51.7% of the time. The power output can vary between the two extremes every hour. The average power output of wind power plants is $30.55\% \pm 38.2\%$, while the median power output is 9.2% (i.e. half the time the power production is above 9.2%, and for the other half it is below 9.2%). Our subject country lacks seasides, and due to its small size the production of wind power plants is correlated.

We can also utilize **pump storage plants** to help balance supply and demand. The storage capacity of a single unit is 6 GWh. We start the simulation at 50% charge, and we should aim to bring the storage between 20-80% by the end of the day, to have headroom for the next day. The efficiency factor of the storage is $\eta = 90\%$ (both at charging and discharging, i.e. the total efficiency is 81%). We can charge the storage unit at a maximum power of 0.5 GW - in this case its net power to the grid is negative.

## User's (simplified) manual

1) At the start of the simulation please select the language (currently English or Hungarian). This will bring you to the main screen.
2) In the leftmost column we find the different power plant types. The program displays the number of units, maximum power, and the actual power during the simulation. In „manual mode" we can adjust the power in 0.1 GW increments for the particular type of plant, if flexibility allows (see 5)).
3) By clicking on the power plant icons we can display detailed information about each plant. We can adjust the number of units, and whether the plants are controlled automatically or manually. The maximum number of units is shown in the table in the manual, and the tooltip when howering the cursor over the input field. When adjusting the next power plant we can directly click on its icon, it is not necessary to close the active window.
4) In the 2nd column from the left we see the average $CO_2$ emission (t/GWh) and price ($/MWh) values. Underneath we can select between winter and summer configurations, and we will be shown the particular date which is taken randomly from the database as reference for demand and solar output.
5) In the center on the 3rd panel we can start / step / stop the simulation. We can simulate an entire day or just 1 hours in manual mode. When the simulation is paused, we can adjust the power output of plants manually.
6) In the center bottom we can adjust the priorities for automatic control. If the production is unsatisfactory, the automatic „grid controller" will increase the power production of plants in this order. When overproduction occurs then the unit on the top will be decreased first. E.g. if we'd like to prioritize hydro over coal, then we should put hydro on top in the demand section, while put coal on top in the overproduction section.
7) On the top right we find the total maximum power capacity (max 20 GW!) and the available storage capacity.
8) The upper graph displays the power produced by each type of plant (MW) as a function of time during the day. Colors correspond to the different types.
9) The lower graph displays the sum of production and demand, and the normalized charge in the storage units.
10) The „Statistics" option in the menu gives detailed statistical information about the system performance.
11) We have the possibility to save and reload complete configurations. A save also produces a screenshot.

# Simulation exercise

This page contains the tasks given to the participants of the 2019 National Szilárd Leó Competition, and the tentative distribution of points awarded by the jury.

We expect the users to use logic instead of trial and error while designing the system, and to optimize it based on the experience gathered by using the simulation. **The points are awarded based on the quality of the thought process and the documentation of the work, while the actual optimum achieved has a relatively lower weight.**

Points displayed in [**x**] rectangular brackets indicate the maximum points awarded per sub-task *as a reference*. The remaining [**2**] points are awarded for the overall quality and readability of the report. The program committee reserves the right to alter the distribution of points after evaluating all the reports received (i.e. in case there are sub-tasks nobody managed to finish).

1) [**0**] Carefully read through this guide!

**A) Getting started: building a system & meeting demand (Σ5)**

2) [**1**] What is the expected maximum and minimum demand [GW]?
3) [**1**] Get acquainted with the UI! Assemble a simple power system using only coal and gas, and run the simulation for a few full days.
4) [**1**] Assemble a system, which can always meet the demand on an average **summer** day. Try to achieve a normalized deviation below 0.5% (statistics page).
5) [**1**] Document the thought process and lessons learned.
6) [**1**] What is the average cost of electricity ($/MWh) and relative $CO_2$ emission (t/GWh) in a purely fossile system?

**B) Optimalization (Σ13)**

7) [**5**] Once we have managed to build a system that can meet the demand, attempt to optimize it. Target a low cost ($/MWh) but greenhouse gas efficent (low $CO_2$ t/GWh) system. Be mindful about the storage capacity.
8) [**2**] For each 1 GW of solar or wind power, how much reserve storage is necessary?
9) [**3**] Can we optimize for cost and $CO_2$ emission at the same time? What is the price of reduced $CO_2$ emission?
10) [**3**] Document the thought process for the optimalization, observations, and lessons learned.

**C) Summer / winter (Σ5)**

11) [**2**] What are the key differences between winter and summer? When is it more challenging to meet the demand and why?
12) [**3**] Using the system optimized for summer, attempt to simulate for winter conditions. What is the experience? What changes would be necessary to make the system viable in winter as well?

## Suggestions for competitors

- Points are awarded for a clear thought process and documentation. Attempt to work logically instead of random trial & error. Document what has been done and why.
- Keep in mind that not every type of power unit has the same flexibility.
- Certain power plants have to have a minimum load. Once they are built in, they will not provide less than this minimum!
- Pay attention to the reservoir in the hydro pump storage units at the end of the days.
- The report can be submitted on paper, electronically, or as a mix. Make sure that your code is part of every filename, and make clear references to the electronic files in the written report.