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# HYDROGEN TO MEET THE STORAGE DEMAND FOR A FUTURE CLIMATE COMPATIBLE ELECTRICITY SUPPLY IN GERMANY

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**Abstract:** A possible structure of a future electricity supply in Germany that maintains the carbon dioxide reduction limits until the year 2050 is presented. Potentials for the installation of renewable power plants and the development of the future electricity demand are investigated. A simulation of the hourly power generation of numerous distributed wind, hydroelectric, biomass and photovoltaic power plants over one year shows the impact on the operation of conventional power plants as well as the arising storage demand. The extension of the storage demand is estimated and opportunities of hydrogen to meet this demand are discussed.

## 1. Introduction

New climate records show the risks of the greenhouse effect for our future. One of the most significant greenhouse gases is carbon dioxide. 38 % of carbon dioxide emissions in Germany are caused by power plants and district power heating stations. The commission of inquiry „Protection of the earth's atmosphere" of the German Bundestag has formulated strong limits for carbon dioxide reduction to keep the consequences of the global warming under control [1]. The commission has recommended a reduction of the German carbon dioxide emissions by about 50 % until the year 2020 and by about 80 % until the year 2050 related to the year 1987. In this paper, these limits are also applied to the German electric power supply. Only a power supply with a high amount of renewable electricity generation can meet these targets. If the amount of renewable power generation exceeds 30 % an excess generation and a storage demand will occur. Hydrogen is one of the most promising technologies to cover the demand.

## 2. Potential of Renewable Electricity in Germany

In an extensive survey, the capacity of hydroelectric power stations, wind turbines, photovoltaic systems and biomass block heating and generation plants to be installed in Germany have been estimated [2]. These potentials take into account restrictions arising due to the protection of the countryside and noise protection.

Today, the contribution of photovoltaics to the electricity supply is far below one percent. Nevertheless, photovoltaics has the highest potential in Germany. Assuming an annual increase of the production of about 30 %, it will be possible to install photovoltaic systems with a total performance of 18 $GW_p$ until the year 2020. To avoid negative impacts on the landscape when setting up a high number of new photovoltaic systems, 64 % of them are to be installed on roofs and 15 % on building fronts. The total potential of 203 $GW_p$ can be installed until the year 2050.

In German offshore regions, there are about 8,000 potential locations for wind power plants with an installable electrical power of 23.6 GW. At the coasts and the interior of Germany there are about

20,000 locations with an installable power of 53.5 GW. Until the year 2020, one third of the locations can be developed and the total potential will be usable until the year 2050.
The potential for the electricity generation using organic substances in block heating and generation plants in Germany is about 50 TWh/a. By this, the power plants have an electrical power of 19 GW. About 50 % of the potential can be used until the year 2050. The use of water-power is well developed in Germany and it can only be increased up to 25 TWh/a in the year 2050.
Table 1 shows the present output of renewable energy power plants in Germany and the generation of electricity in the years 2020 and 2050 using the potentials described. It is only possible to achieve the recommended carbon dioxide reduction in Germany if these potentials are developed or if we import a high amount of renewable electricity or hydrogen for example from solar thermal power plants in Spain or Northern-Africa.

**Table 1. Annual electricity generation and potentials of renewable power plants in Germany.**

| annual generation in TWh | generation in 2000 | potential until 2020 | potential until 2050 |
|---|---|---|---|
| photovoltaics | 0.05 | 15.5 | 175 |
| wind power (on land) | 9.2 | 24.2 | 85 |
| wind power (offshore) | none | 29.9 | 79 |
| water-power | 20.5 | 20.5 | 25 |
| organic waste | 1.3 | 20.0 | 33 |
| energy plants | none | 5.0 | 17 |
| total generation | 31.1 | 115.1 | 414 |

## 3. Development of the electricity demand und simulation

Two different scenarios, named trend scenario and energy-saving scenario, describe the possible development of the future electricity supply in Germany. The renewable generation supplies 18.6 % of the electricity demand of the trend scenario and 27.5 % of the energy-saving scenario in the year 2020. In the year 2050, the contribution of renewable power stations increases up to 67 % in the trend scenario and up to 99 % in the energy-saving scenario.
Because of the fluctuations of the renewable electricity generation in some periods, demand and generation do not match very well so that there is a high storage demand in the year 2050. To improve this correspondence, some measures are necessary such as

- optimized demand management
- improved operation of pumped-storage power plants
- use of 50 % of the biomass energy in demand controlled block heating and generation plants.

Especially, an optimized demand management, that is the adaptation of the demand to the renewable electricity generation, can reduce the storage demand drastically. 16 % of the demand in the energy-saving scenario and 18 % in the trend scenario is moved temporal. Furthermore, a modified operation of the existing pumped-storage power plants has been considered.
Biomass used in block heating and generation plants is perfectly suitable to allow for the fluctuations of the other types of renewable energy. By this reason, in the simulation half of the available biomass was used in demand-controlled power plants. The number of full-load hours per year was set to 2,000 to achieve a high electrical power level as well as considering the economic aspect.

The hourly power generation of the interconnection of the renewable power systems was calculated with an extensive computer simulation to determine the storage demand for all extension steps and demand scenarios. The hourly output of 42 photovoltaic sites, 24 wind power sites and 68 existing hydropower stations were simulated in hourly steps over one year. The output was projected to the assumed installations in the years 2020 and 2050.
The simulation of the hourly demand of the trend scenario and the energy-saving scenario over a period of one year was subject of a second simulation. In the year 2020, there is no excess generation of the renewable power plants even if the contribution of the renewable energy increases up to 27.5 % in the energy-saving scenario. In the year 2050, the simulation shows that there is a not-covered demand remaining as well as an excess generation within a few days (Fig. 1). The measures proposed above to improve the correspondence of demand and generation were applied to the simulation.

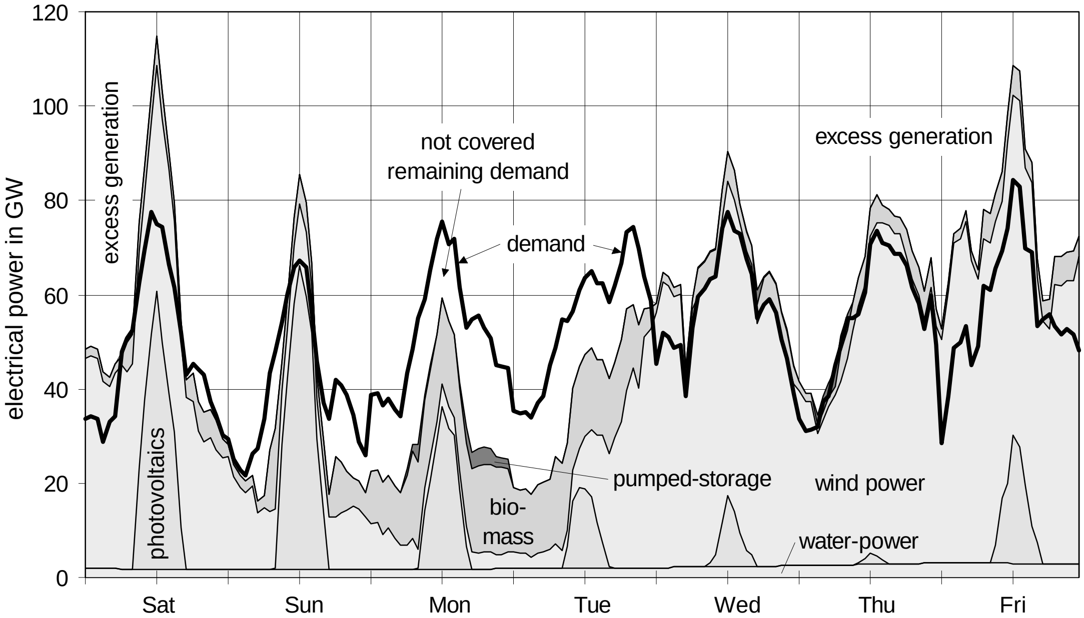


**Fig. 1. Electricity generation over the time of renewable power plants and pumped-storage power stations over seven days in the second half of December in the year 2050 as well as the net demand including transmission losses and pumping work.**

The fluctuations of the power generation decrease significantly due to the wide spatial distribution and the different characteristic of the interconnected photovoltaic, wind power and hydroelectric systems. The mean-of-the-month generation only differs less than 10 % from the mean of the year. If the contribution of the photovoltaic is reduced to 40 % of the above-assumed potentials and replaced by solar electricity import of solar thermal power plants, the correspondence of the demand and the generation will increase even more (Fig. 2). This result corresponds to other studies that include high amounts of solar electricity import [3].

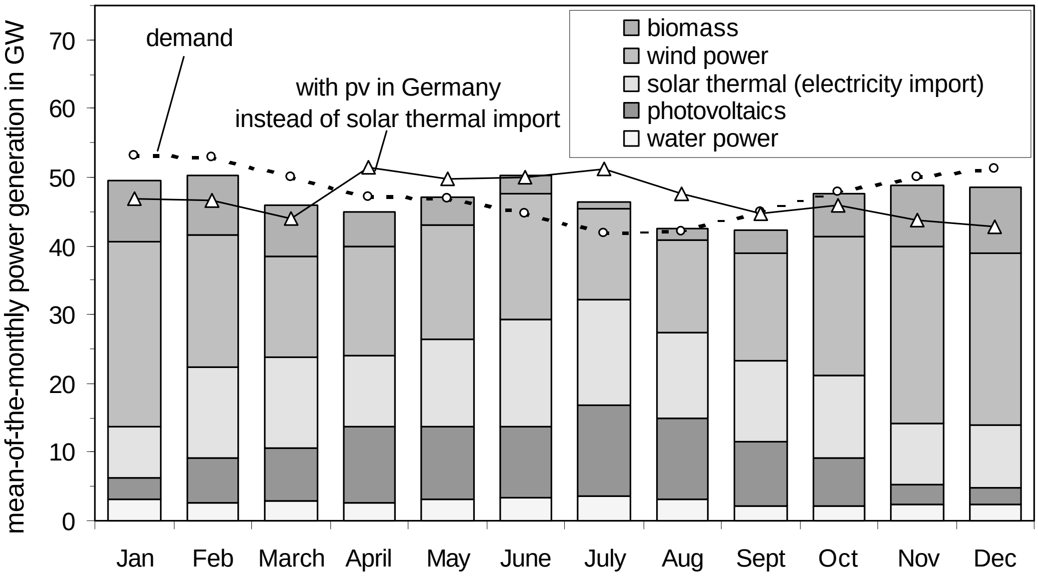


**Fig. 2. Mean of the month generation of the interconnection of renewable power plants in the year 2050.**

## 4. Storage demand

The simulation shows no excess generation in the year 2020 even if the contribution of the renewable power plants increases up to 27.5 % in the energy-saving scenario. The base load of the remaining demand with more than 6,000 full load hours not covered by the renewable power stations increases up to 90 % with the measures proposed above to improve the correspondence of demand and generation. The annual maximum load of the remaining demand decreases in proportion to the contribution of the renewable electricity. Renewable power stations are not additional. They can directly substitute part of the conventional power stations.

The conditions in the year 2050, however, are totally different. The contribution of renewable power plants is 67 % in the trend scenario and 99 % in the energy-saving scenario. The base load drops drastically and in the energy-saving scenario it becomes zero, but the different described measures can improve the conditions.

Not considering solar thermal electricity import in the year 2050, there is an excess generation with a high maximum load due to the high contribution of renewable power plants (Table 2). At the trend scenario the amount of the excess energy over the year is only 5 %. However, considering economic reasons it makes sense to store not the total renewable excess generation. Although, the maximum power of the excess is 83.2 GW at the trend scenario, only 1 % of the excess energy is produced with an electrical power of more than 20 GW.

If the total excess should be stored at the energy-saving scenario in the year 2050, a storage capacity of 13 TWh with an input of 110 GW is needed. The maximum load of the excess is 35 % of the installed renewable peak power, but only 3 % of the renewable energy generation have to be stored within a year. This energy can be stored in form of hydrogen in existing natural gas caverns in Germany. Considering economical aspects, it is not desirable to store the total excess. Table 3 shows that only about 1 % of the excess generation has a peak power of more than 50 GW.

**Table 2. Not covered remaining demand and excess generation in the year 2050.**

| | not-covered remaining demand | | | | excess generation | |
|---|---|---|---|---|---|---|
| | $P_{max}$ in GW | peak load < 2,000 h/a in TWh/a | base load > 6,000 h/a in TWh/a | $E_{total}$ in TWh/a | $P_{max}$ in GW | $E_{total}$ in TWh/a |
| trend scenario | 55.8 | 7.1 | 142.4 | 227.2 | 83.2 | 20.5 |
| energy saving scenario | 31.5 | 3.5 | 0 | 80.6 | 110.0 | 73.2 |

**Table 3. Contribution of the excess generation above a certain peak power related to the renewable annual generation in the year 2050 at the energy-saving scenario.**

| | annual sum of the excess generation above a peak power of | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 GW | 10 GW | 20 GW | 30 GW | 40 GW | 50 GW | 60 GW | 80 GW |
| excess generation in TWh/a | 73.2 | 47.3 | 29.1 | 16.3 | 9.4 | 4.7 | 2.2 | 1.0 |
| part of the renewable generation | 17.8 % | 11.5 % | 7.1 % | 4.0 % | 2.3 % | 1.1 % | 0.5 % | 0.2 % |

## 5. Conclusions

Depending on the two given demand scenarios, named trend scenario and energy-saving scenario, renewable power plants in Germany can cover from 27.5 % of the demand in the year 2020 to nearly 100 % in the year 2050. In the year 2020, there is excess generation in none of the scenarios.

In the trend scenario, the remaining demand has to be covered by conventional power plants, by imported electricity or by electricity of imported hydrogen. Since the base load decreases drastically, conventional base load power plants such as nuclear or coal power plants with high time constants are no more applicable.

High excess with a high peak power occurs in the year 2050 with nearly 100 % renewable energy generation in the energy-saving scenario. To support this, new storage systems are needed. Only 4 % of the renewable generation will be lost if storage systems with a peak power limited to 30 GW are installed for economic reasons. The storage capacity must be only 3 % of the annual renewable electricity generation. Increasing import and export of electricity from and to other European countries can reduce the losses and the storage capacity. However, since pumped-storage power plants cannot cover the storage demand, hydrogen will be a good candidate to satisfy the storage demand in a climate compatible future electricity supply.

## 6. References


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