MODEL-BASED ANALYSIS OF A DECARBONISED CHINESE ENERGY SYSTEM

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Motivation

The Chinese electric consumption reached 6,490 billion kWh in 2017 [1]. This is a share of 22 % of global energy consumption [2]. Coal power plants covered more than 69 % of the Chinese energy demand in 2017 [3]. In 2005, China takes the lead as the country which has the highest CO_2-emissions in the world [4]. Therefore, in the 11th five year plan from 2006, the Chinese Government has determined to promote the development of renewable energies [5]. The integration of fluctuating renewable energies, in a coal-based electricity system, leads to new challenges in China. The areas with high wind energy potentials are located in the West and North whereas the electricity load centres are located in the South and East [6]. As a consequence, the generated electricity needs to be transported, which leads to further problems like curtailments due to delays in grid connection [7] and inter-regional bottlenecks [8]. Here, we analyse the impact of electricity grids and high hydrogen demands on a fully decarbonized electricity system in China.

Methods

To analyse the Chinese energy system in 2060, scenarios are designed and calculated with the optimisation model Enertile. Enertile is an energy system model which focuses on the electricity sector, developed at the Fraunhofer Institute of Systems and Innovation Research [9–11]. It is a techno-economic optimization model, which minimizes the costs of generation, transmission and storage of electricity also taking into consideration investment costs. The objective function includes the costs of conventional power plants, renewable energies, combined heat and power, cross-border transmission capacities, storage technologies, heat supply of heat grids and the cost of hydrogen production. The exogenously given demand has to be covered at all times in all regions. The hourly temporal resolution of Enertile is important with regard to the fluctuating electricity generation of renewable energies such as wind and solar power. An important part of the model is the calculation of the generation potential with a high spatial resolution. Based on a grid with a length of 6.5 km, extensive meteorological and spatial data is used to derive renewable generation potential for wind and solar technologies. For the problem at hand, China is divided into 10 regions according to [12] to account for potential bottlenecks in the electricity grid (see Figure 1). Between the defined regions, electricity and hydrogen trading and the expansion of the cross-border transmission capacities is possible and part of the optimisation problem. The results of the Enertile model consists of the capacity and hourly generation of the technologies under consideration as well as CO_2-emissions and costs.

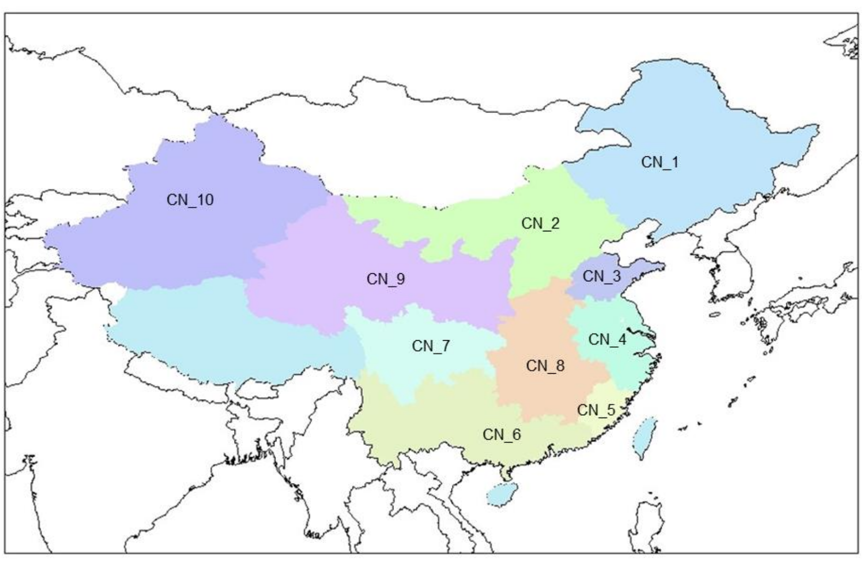


Figure 1: Assumed regions

Results

This subchapter shows the scenario design and the results of our calculation. In Table 1, the different scenario designs are listed. The *HighEL* scenario represents a fully decarbonized electricity system, where the electricity grid can be utilized without any restrictions. The scenario *LimGrid* represents an electricity system, where extension of the electricity grid is limited. Here, the expansion of the existing grid is limited to 15 %. In the *HighH2* scenario, the hydrogen demand is higher than in the other scenarios.

Table 1: Scenario Design ("--" lower; "++" higher)

Scenario	Electricity grid	Hydrogen demand
HighEL	+	-
LimGrid	-	-
HighH2	+	+

The exogenously given electricity demand is set to 15,000 TWh [13] in the *HighEL* and *LimGrid* scenarios. Here, the hydrogen demand reaches 2,699 TWh [14]. In the *HighH2* scenario, the hydrogen demand is set to 7,920 TWh[1].The electricity demand in this scenario is 10,105 TWh [15].

Figure 2 shows the installed capacity of different technologies in the calculated scenarios. In the *HighEL* scenario, the overall installed capacity reaches 14,000 GW. The share of renewables in a decarbonised Chinese energy system reaches over 90 % for each calculated scenario. Ground-mounted PV dominates the energy system in all scenarios with a share of over 60 %. In the *HighEL* scenario, the share of renewables is 94.7 %. In the *LimGrid* scenario, the amount of installed ground-mounted PV increases from 9 TW in the *HighEL* scenario to 10 TW. Furthermore, the installed capacity of wind offshore power plants increases from 18 GW in the *HighEL* scenario to 913 GW. Therefore, the amount of renewables increases in this scenario and has a share of 97.3 %. The installed capacities in the *HighH2* scenario vary slightly compared to the *HighEL* scenario. Here, the share of renewables is 94.4 % and ground-mounted PV reach a share of 64.8 %. The installed capacity of electrolysers varies in the calculated scenarios. The lowest installed capacity is reached in the *HighH2* scenario with almost 800 GW. In the *HighEL* scenario, the capacity of electrolysers is 916 GW and in the scenario with a limited grid, the installed capacity is 870 GW.

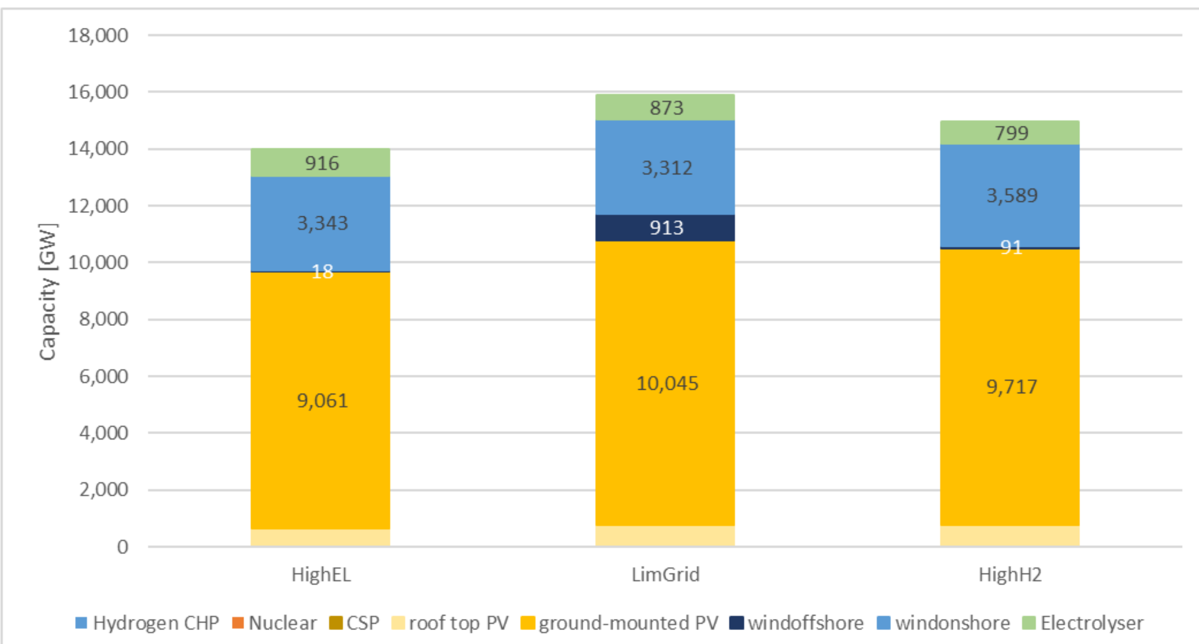
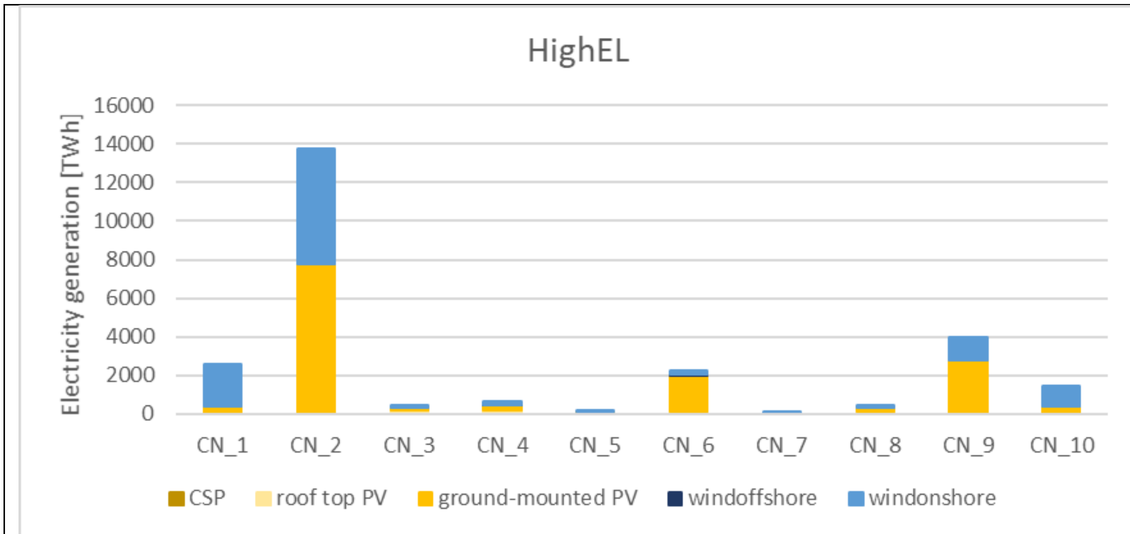


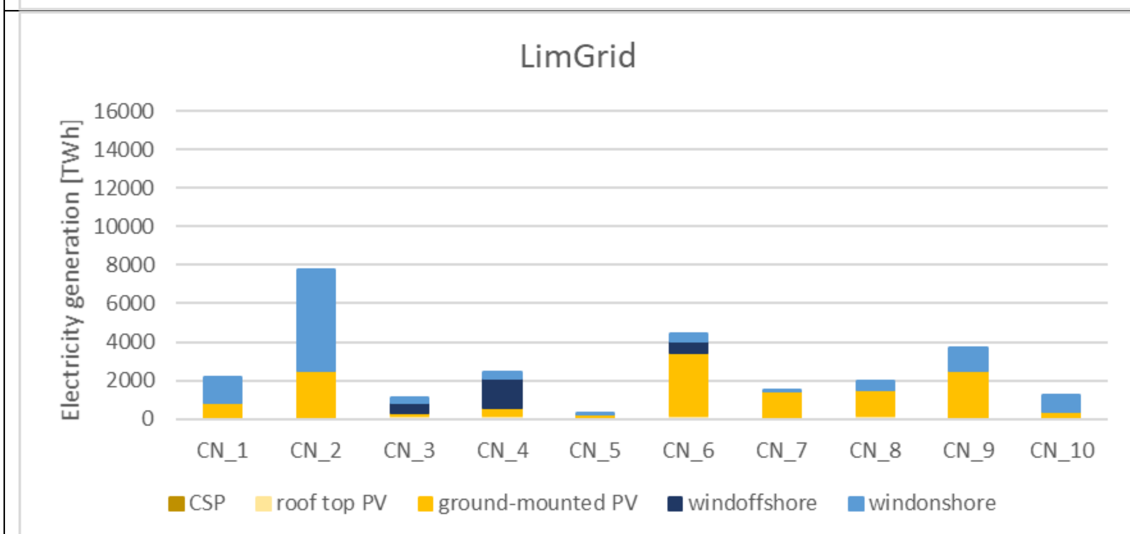
Figure 2: Installed capacity of technologies in the considered scenarios for electricity generation

The distribution of renewable potentials and the electricity generation by renewables varies highly among the considered regions and scenarios. The highest potentials for wind and solar energies lie in CN_10, CN_2, CN_1 and CN_9. As CN_10 and CN_1 lie far away from the load centres in the south and east of China, the potentials in these regions are not fully exploited. Figure 3 shows the distribution of electricity generation from renewable energies in the considered regions. In the *HighEL* scenario, the electricity generation from ground-mounted PV and wind reaches almost 14,000 TWh in CN_2. This region combines high renewable potentials with high electricity demand and a

[1] own assumption

good electricity and hydrogen grid connection. The potentials of wind and solar are lower and more expensive in the southern and eastern regions like CN_3, CN_4, CN_5, CN_7, and CN_8. The electricity demand in these regions is mainly covered by the import of electricity from the north and north-west. The electricity generation in the *LimGrid* scenario in CN_2 decreases from 14,000 TWh to 8,000 TWh. In the *HighEL* scenario, ground-mounted PV reaches a share of 56 % in CN_2 and wind onshore has a share of 44 %. In the *LimGrid* scenario, these shares change. Ground-mounted PV has a share of 31 % and wind onshore is the dominant technology in CN_2 with a share of 68 %. With a limited expansion of the electricity grid, the number of installed capacities of renewables increases in the southern and eastern regions. In CN_3 and CN_4 the wind offshore potentials are exploited. In CN_6 the amount of ground-mounted PV increases from 2,000 TWh to over 3,000 TWh. In the *HighH2* scenario, the distribution of renewable energies is almost similar to the *HighEL* scenario.





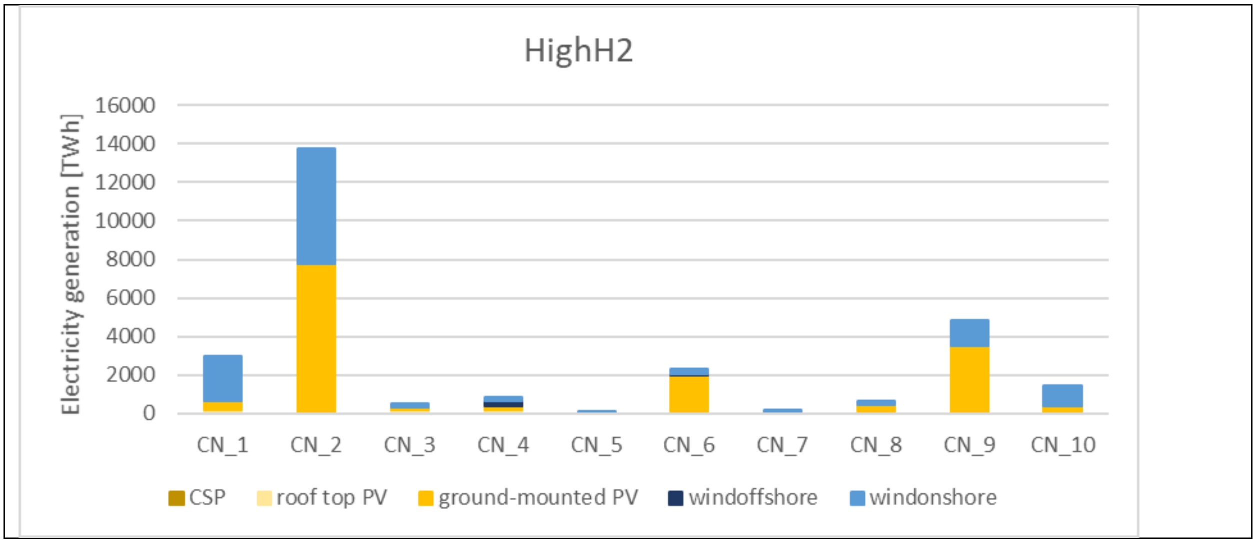


Figure 3: Distribution of the electricity generation by renewable energies in the calculated scenarios

Conclusions

We calculated three climate neutral scenarios for the Chinese energy system in 2060 with our cost-optimisation model Enertile. We excluded the expansion of nuclear technologies [16] and the usage of carbon capture and storage [17] due to uncertainties in cost development and risks. The electricity supply is dominated by ground mounted PV and wind onshore which are mainly produced at the best production sites. If restrictions on the electricity grid are imposed production is shifted closer to the demand centres and wind offshore is also utilised.

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