dena German Energy Agency

dena-REPORT

Transmission Grid Planning in systems with high shares of Renewable Energy

Planning the future energy system in China.

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Imprint

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Date: 06/2019

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

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Executive Summary

Power grid planning is an import task in designing and implementing the transformation of energy systems towards high shares of Renewable Energy (RE). When planning how to integrate RE, it is important to consider **various different aspects and interdependencies** in power grid planning and focus on the **optimisation of the whole energy system**. Energy systems with high shares of RE are increasingly complex, so it is important to consider several technical and economic aspects and policy goals in the planning process.

China's current power planning procedure includes three components: demand, generation and transmission, which correspond to demand forecasting, power source planning, and power grid planning. Over the past decades, power planning has been continuously improved. China's power planning is divided into national (including regional) and provincial power planning. National power planning integrates separate provincial power planning results and is compiled in parallel with provincial planning. The final national power plan is issued by the National Energy Administration (NEA) after being approved by the National Development and Reform Commission (NDRC). The provincial power plan is submitted to NEA and issued by the provincial government after reaching an agreement with the national plan. The National Electric Power Planning and Research Centre and other qualified research institutions undertake the planning. After the important planning topics are completed, the energy authority will have consulting agencies and experts review the document. Environment and water resource topics will be addressed by relevant government authorities.

The first step of China's grid planning is the power flow analysis and is carried out simultaneously with power balance simulation. The second step is to conduct economic and technical analyses of proposed transmission lines to optimize the grid layout. The economic analysis aims at evaluating the lowest cost of line construction. The technical analysis evaluates the impact of a new line on the operational stability of the system, considered for different regions and voltage levels. Planners conduct both project-specific and annual static and dynamic measurements of investment needs, aiming to reduce the total annual cost. In addition, detailed environmental and social impact analysis elements are listed in the *Planning Principles*.

The **grid planning approach in Europe** is divided into three steps to develop the European Union (EU)-wide Ten-Year Grid development plan (TYNDP): The first step is the development of scenarios. The potential development of the energy system is analysed in order to identify what Europe needs in terms of electricity transmission infrastructure. The scenarios aim to address uncertainties and are no predictions of the future. Various stakeholders, like Non-governmental organizations (NGOs), scientists, industry associations representing transmission grid users (like generators, distribution grid operators, suppliers and traders), market participants, consumers (including industry), power exchanges and national regulators (where appropriate) are formally invited to participate in the scenario creation during consultations. The second step is called planning studies. The TYNDP usually contains four scenarios describing the potential development of the future power system. There is a scenario with ambitious objectives regarding the utilization of RE, a scenario that focuses on the effects of a more decentralized power system and a scenario with focus on political considerations, like a strong European legal framework. Using common methodologies like market and grid modelling, experts from all EU member states look at how power could flow in Europe in 2030 and 2040 with regard to the different scenarios. This allows them to predict where bottlenecks could occur and how much transmission capacity is needed at borders to manage these flows. As for the scenarios, the list of projects and regional investment plans are open to public consultation before being finalized. In the third step, single projects are assessed. In this phase, planners assess cost and benefits of projects taking into account how projects support the environment, social welfare, the security of supply and other criteria with regard to total societal costs and benefits.

Based on this multi-criteria assessment, the TYNDP report informs about the value of each recommended infrastructure project. The TYNDP is providing decision-makers with a robust and detailed analysis of transmission infrastructure as base for their decisions. The Agency for the Cooperation of Energy Regulators in Europe (ACER) checks whether the draft of the TYNDP by the European Network of Transmission System Operators for Electricity (ENTSO-E) is coherent with the Unions policy goals, regulatory framework and national plans of the Member countries. ACER decides whether the TYNDP is appropriate before it is send to the European Commission. The European Commission uses the final TYNDP to decide which projects are projects of common interests (PCI) and hence eligible to obtain funding support for the implementation.

This paper **demonstrates the benefits of an advanced multi-criteria grid planning approach** based on scenario modelling results. It compares the stated policy scenario of the China Renewable Energy Outlook (CREO) 2018 with an optimally planned and expanded electricity grid with a scenario without grid planning and grid expansion—meaning the grid would remain unchanged from the present grid. The results of the modelling show that a properly planned electricity grid leads to lower overall system cost, lower emissions, better integration of renewables and less curtailment, as the figures below show.

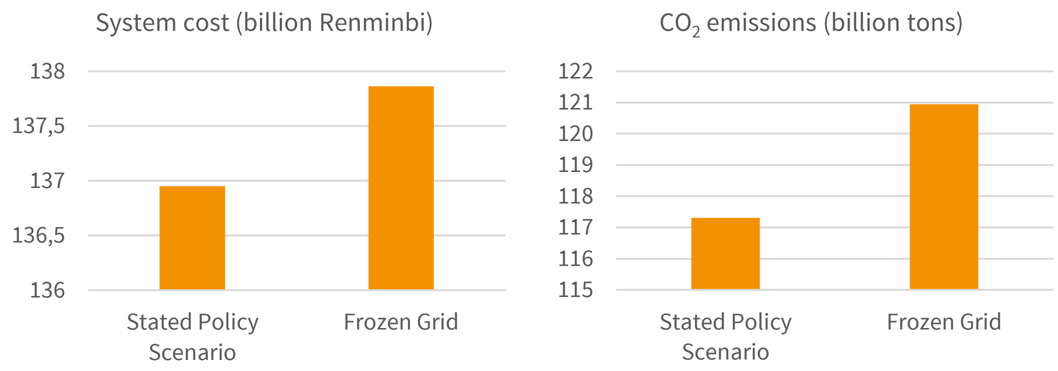

Figure 1: Cumulated system cost in Renminbi (RMB) and CO_2 emissions from 2016 to 2050

Based on the results of the analysis, this report makes the following **suggestions for grid planning processes in China**:

- Grid planning methodologies in China should increasingly consider **uncertainties of grid planning** and analyse the impacts of different policies and developments on the electricity system. Grid planning can be used to illustrate the impacts of different policies and resulting developments of the electricity system, such as new generation capacity, different price levels, and various market designs. Using these uncertainties, different scenarios can be developed and analyses using energy system models to evaluate the need for electricity grid investments in different scenarios.
- For grid planning to achieve its highest value for policymakers, power planning should include two-way interaction between the grid planners, the political stakeholders and the people (citizens, provinces, companies) who are affected by their decisions. The **importance of implementing electricity markets** in the Chinese power planning **is expected to increase significantly**, and more market-based analysis will integrate the effects of electricity markets like inter-provincial transactions.[1]

- Grid planning processes in China should transition **to a system-wide optimization**. System-wide optimization means optimizing overall cost efficiency, electricity flows and system stability in an integrated perspective, rather than only considering how to optimize investment in each new transmission line. This would help to lower overall cost and increase benefits of grid expansion of the electricity system.
- In addition to capital cost and tariffs, China should **include the assessment of social welfare, emission reductions and environment** into the evaluation of the investment in transmission lines.
- For each grid area, it is recommended to **include the secured generation capacity of its respective renewable portfolio** in the grid planning procedures to replace conventional generating capacity. Using portfolio effects in grid planning (i.e. smoothing renewable generation when looking at a large geographical generation area) lowers the need for back-up capacity to ensure security of supply.

1 Transmission Grid Planning in systems with high shares of Renewable Energy (RE)

1.1 Grid planning processes in China: managing highly dynamic demand growth and parallel RE expansion

In the early stage of China's power grid construction, the main purpose of power grid expansion was to ensure the power supply and to expand coverage to areas without power. Since many power generation resources are concentrated in the west and the north, and the electric load centres are concentrated in the most populated central and eastern coastal areas, the expansion of China's transmission lines is based on the West-to-East concept using three main transmission corridors (see **Figure 2**). The northern path transmits coal power from Inner Mongolia and Shanxi and hydropower in the middle and upper reaches of the Yellow River to the Beijing-Tianjin-Hebei region. The middle path connects hydropower bases in Qinghai and in central and western Sichuan to the east. The southern path sends surplus thermal power and hydropower from Yunnan and Guizhou to the southern coastal provinces.[2] By the end of 2017, the total length of China's 220 kilovolt (kV) and above transmission lines reached 688,000 km, four times that of 2000 (164,000 km). Extra-High-Voltage (EHV) and Ultra-High-Voltage (UHV) lines of 500 kV and above reached 205,000 km, which was 7.6 times that of 2000 (27,000 km).[3] The total transfer capacity of West-to-East reached 225 GW, 4.5 times that of 2007 (49.8 GW).[4] Currently, there are eight 1,000 kV UHV alternating current (AC) lines and 13 ± 800kV UHV direct current (DC) lines in operation.[5] The nation's power supply and demand situation overall is adequate, and most areas have excess to generation capacity. Some areas may face generation shortages in summer.[6] In 2015 China has achieved a nationwide electricity access rate of 100%.[7]

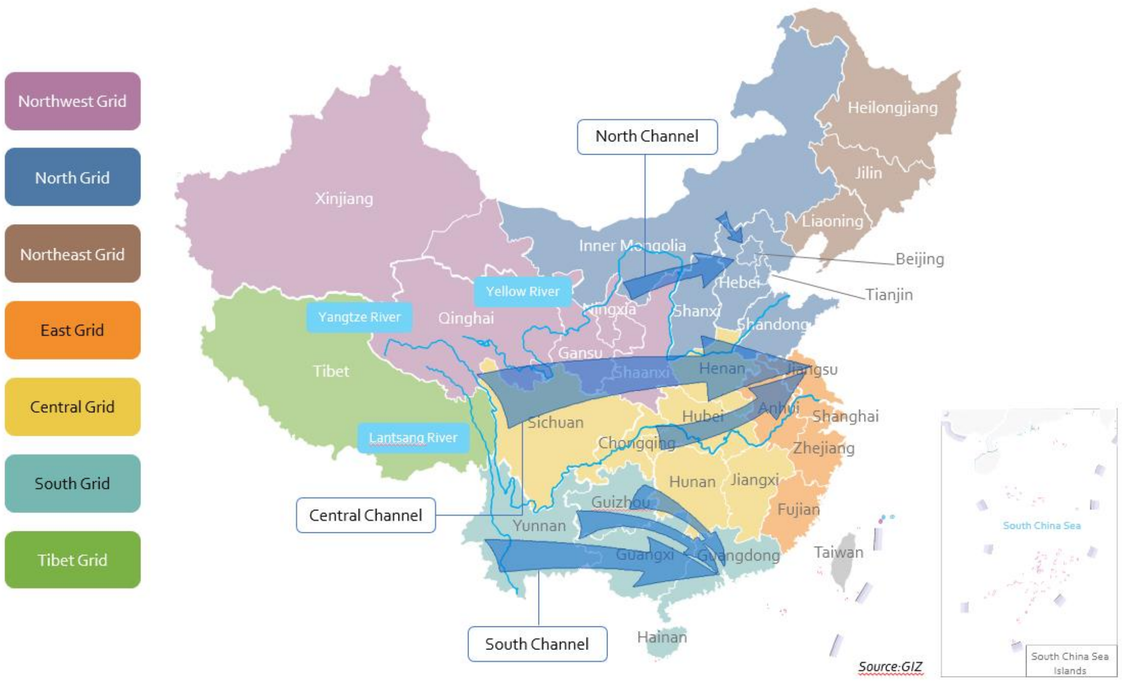

Figure 2: China's power grid regional division and "West-to-East" power flow

In the past ten years, China has expanded the proportion of renewable energy in the power mix. Central government policy is pushing to shift system operations from planned dispatch to market-based power transactions. While China continues to build long-distance transmission lines, it also requires a stronger regional and inter-provincial interconnection capability. At present, China has six regional power grids: Northeast China, North China, Northwest China, Central China, East China and South China.[8]

The three regions of Southwest, Northwest, and Central China have the largest power exports, accounting for more than three-quarters of the total. In 2017, out of 34 provinces and regions in China, 20 provinces' net electricity export exceeded 10 terawatt hour (TWh) (see **Figure 4**), and 13 provinces' net electricity imports exceeded 10 TWh. The Southwest is rich in hydropower: Yunnan and Sichuan provinces have the largest proportion of inter-provincial power export in China, with more than 40% in 2017. Beijing and Shanghai—the most densely populated cities (except Hong Kong and Macau)—source 63.1% and 43.3% of annual electricity consumption from external supplies.[9] Inter-regional and inter-provincial power transmission is increasing (see **Figure 3**).

China's power grid faces several challenges. For example, many regions have generation overcapacity but still the peak load regulation is difficult to fulfil due to high shares of inflexible coal power plants and the resulting lack of supply side flexibility. The construction of transmission lines that should help to integrate renewables has lagged, leading to serious curtailment of wind and solar energy. Overall China's power grid has grown rapidly and the current power planning system supported that growth quite efficiently. But China is in the process of transitioning to a low-carbon energy system, and it will likely have to adjust power planning approaches to meet the challenges of new developments, policies and technologies.

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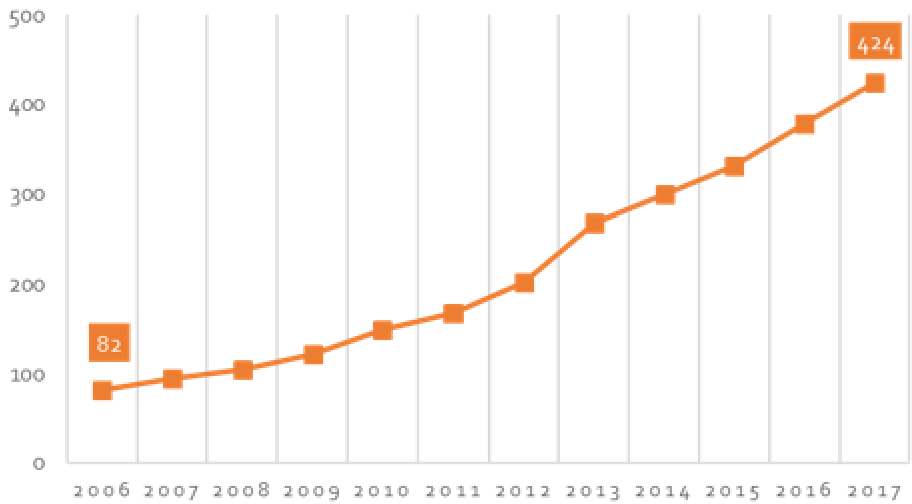

Figure 3: Interregional power transmission from 2006 to 2017 (TWh) [10]

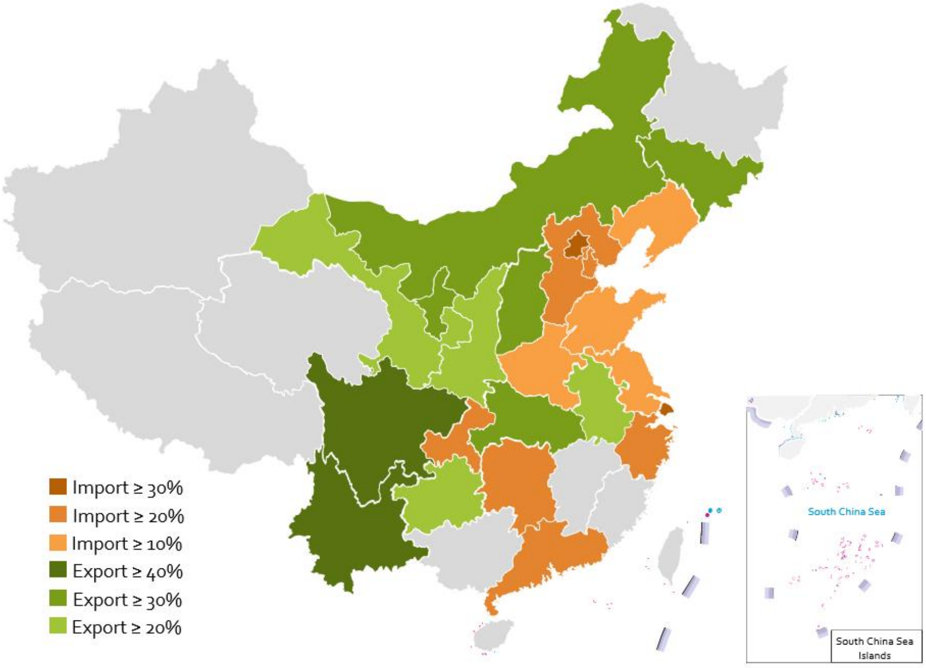

Figure 4: Provincial percentage of electricity import/export of total consumption/generation in 2017[11] (*Note: only includes provinces whose net import/export electricity exceeded 10 TWh in 2017).*

1.1.1 The current grid planning process

Responsible parties and planning processes

China's power planning is divided into national and provincial power planning. In 2016, the National Energy Administration (NEA) issued the *Measures for the Management of Electric Power Planning*, which clarified the participants and related responsibilities of the two types of power planning.[12] The national power plan is led by NEA, and the provincial power plan is led by the provincial energy authorities. National power planning integrates provincial power planning, and is conducted in parallel. NEA issues the final national power plan after its approval by the National Development and Reform Commission (NDRC). The provincial power plan is submitted to NEA and issued by provincial governments after harmonization with the national plan.

China's grid and generation planning (see **Figure 5**) is carried out with a lead-time of two years. The responsible National Energy Administration (NEA) delegates detailed planning tasks to the National Electric Power Planning and Research Centre (also known as the Planning Centre), State Grid Beijing Institute of Economics and Technology and other qualified research institutions.[13] The China Electricity Council (CEC), industry associations, research institutes, universities, and power companies assist. Energy policy-makers integrate their opinions and suggestions through special visits, studies, and seminars. Power generation companies are responsible for providing basic data for planning. After completing important planning tasks, NEA orders consulting agencies and experts to conduct a review. NEA consults with the relevant government departments on questions related to the environment and water resources.[14]

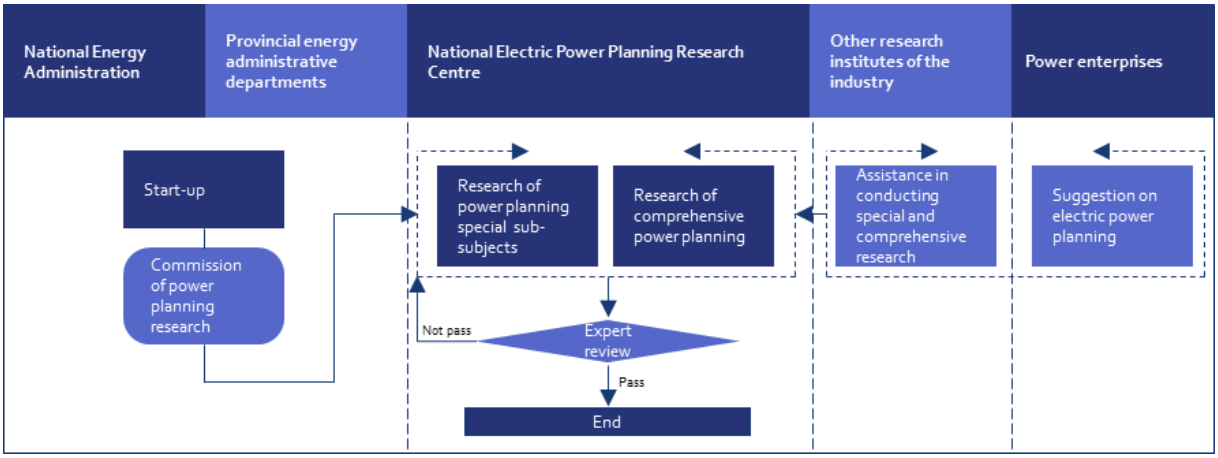

Figure 5: Power planning research and preparation workflow [15]

Types of planning

China's power planning is a three-level plan under the national economic development plan and energy sector plan. The goal of power planning is to invest economically in the power sector and provide an optimized power development program to ensure safe and stable power supply for the entire society at the lowest total social cost. At the same time, planning should also keep in accordance to national policies and the technological development trend.[16] Especially after the adoption of the Paris Agreement, the goal of energy conservation and emission reduction in power planning is clearer and more ambitious. For example, the government has proposed specific targets for coal power phase out and carbon intensity cap of coal-fired power plants.[17]

As early as 1997, China adopted the *Principles of Power Development Planning* (hereinafter referred to as *Planning Principles*). The *Planning Principles* clarify that the schedule of power planning is consistent with the national economic development plan, and is divided into short-term planning (5 years), medium-term planning (10-15 years), and long-term (15 years or more) planning. Both the short-term planning and the long-term planning are revised every five years, and the medium-term planning is revised every three years.[18]

- The **short-term plan** focuses on solving the existing problems of the power grid, and proposes annual power grid retrofit and grid expansion plans to meet load growth as well as to improve power supply quality and reliability.
- The **medium-term plan** is linked to the short-term plan. Feasibility studies are carried out on proposed power generation projects, transmission channels and substations in the medium-term time horizon.
- The **long-term plan** focuses on the overall strategic deployment of the power system, and proposes the basic principles and directions for sustainable power development, including the overall power supply scale and basic layout, as well as the backbone grid framework.[19]

Power planning includes three parts: demand and load forecasting, power source planning and power grid planning. At the same time, the government will organize a number of special research topics. In addition to power topics, it also involves new energy, electricity markets and environmental issues. For example, during the 13th Five-Year power planning period, the Planning Centre organized the *Study on the Joint Transmission of Wind and Coal Power, Research on Wind Power Participation in Power Balance, Research on Business Model and Consumption Issue of Photovoltaic Power Generation, the Research on The Development Planning of Electric Vehicle Charging Facilities and the Research on Environmental Impact Assessment of Planning Schemes*.[20]

Demand and load forecasting

Load forecasting is the first step in power planning. China adopts a bottom-up approach, from the provincial to regional to national level, focusing on long-term electricity demand, peak load, load distribution, and load structure.[21] The load forecast will propose three scenarios: high, medium and low. The high scenario mainly reflects strong economic growth and the load in continuous high temperature weather in summer. The medium-term scenario represents the steady operation of the economy and the slow temperature rise in summer. The low scenario considers the economic growth slowdown and the summer temperature lower than the normal level.[22] Ultimately, only one load scenario will be recommended as the basis for subsequent power source planning and grid planning. Although marketization and new energy factors are gradually being incorporated, the current development of electricity prices, electric vehicles and energy storage has little effect on the overall load forecast.[23]

Power source planning

Power source planning will determine the scale and layout of each power source. The plan will provide multiple power source construction plans to determine the newly installed capacity required and their investment needs.[24] Based on the goal of non-fossil energy accounting for more than 15% of primary energy consumption by 2020, power source planning will first develop scenarios for non-fossil power sources.[25] In each scenario, according to the regional power balance and local renewable power consumption capability, the scale of each fossil power source and each peak shaving power source in the region is proposed. Finally, according to the economic and technical analysis, the regional total installed capacity and power structure will be determined.[26] The scenarios will consider different resource conditions and policies to plan for different power sources. The power balance analysis is based on regional characteristics, using annual, monthly, or typical weekly and daily load curves.[27]

Coal, Oil, Gas, Nuclear	Renewable Energy	Others
• Production capacity, reserves, import dependence • Coal, oil and gas fuel prices • Natural gas storage and transportation infrastructure • Coal phase out and fuel switching from coal to gas targets • Nuclear safety consideration	• Available hydropower capacity to develop, economic and technological prospects of development • Wind, solar resources potential and regional consumption restrictions • Biomass collection, storage and transportation capability	• Power grid construction process • Power system reform • Electricity replacing to fuel targets • Improved level of smart power consumption • Energy saving and environmental protection requirements

Table 1: Factors considered in power source planning [28]

Considerations for the optimization of the planning process include constraints and optimization measures (see **Table 1**). Constraints are e. g. initial, operational and maintenance cost of the project, supporting grid construction costs, fuel consumption and waste disposal. The optimization measures consider effects of policies on power supply, power grid and load, such as coal power flexibility, peak-valley power price mechanisms and electric vehicles participating in peak shaving efforts. Specific policies regarding support and integration of RE are also key elements of system optimization. [29]

Power grid planning

The power grid planning is carried out in parallel with the power source planning. The purpose is to maintain the stability of the power grid operation and meet the power demand. Power grid planning must also be linked to other energy infrastructure construction plans, such as natural gas pipelines, rail transit corridors, telecommunication networks, electric vehicle infrastructure and key resource protection areas. **Power flow analysis is the first step** in grid planning and is carried out simultaneously with power balance simulation.[30]

The **second step** is to **conduct economic and technical analysis** of the transmission line projects to get the optimal grid layout. Economic analysis aims at lowest possible total cost including both the initial investment and cost of operation and maintenance. Technical analyses check if the line construction plan can meet the requirements of stable operation of the system, which is considered in different regions and voltage levels. Grid planning includes transmission line planning and distribution grid planning. Transmission grid refers to transmission lines of 220kV (110kV in few regions) and above within the province and across regions and provinces (see **Table 2**). Inter-regional grid interconnections are a very important part of maintaining system stability, and is analysed during grid planning. Safety requirements include power distribution ratio, the N-1 fault test and secure provision of load peaks.[31]

	Voltage Level	AC	DC
Transmission Grid	Ultra-high	1000kV	±800kV, ±1100kV
	Extra-high	330kV, 500kV, 750kV	±500kV, ±660kV
	High	110kV, 220kV	±50kV, ±100kV
Distribution Grid	High	35kV, 66kV, 110kV	N/A
	Medium	10kV, 20kV	N/A
	Low	380/220V	N/A

Table 2: Transmission and distribution grid levels in China[32]

Cost Benefit Analyses (CBA)

In the planning process, project-specific and annual static analyses of the investment and financing needs are carried out. The goal is to reduce the annual cost and ensure funding.[33] For example, investment estimates for grid projects will be based on the cost for equipment, construction and taxes over the past two years.[34] In addition, detailed environmental and social impact analysis (see Table 3) are conducted according to the **Planning Principles**. However, a standardized quantitative evaluation system has not been established yet.[35]

Environmental Impact factors	Social Impact factors
• Sulfur dioxide emission, smoke emission, waste water discharge, solid waste production, average dust removal efficiency of coal-fired power plants, comprehensive utilization efficiency of fly ash, coal consumption, water consumption, floor space, lines and corridors, flooded area of hydropower station reservoirs, ecological environment, spent fuel production of nuclear power plant, clean coal (including desulfurization) installed capacity, environmental protection investment and share in total investment	• Immigration, inundation area, household income, consumption level, agricultural investment, output value of township enterprises, culture and education, health, religion, ecological environment, etc., to avoid major negative impacts on social development

Table 3: Environmental and social impact factors that need to be considered [36]

1.1.2 Elements of Chinese grid planning that enable RE integration

Policy objectives are considered during planning. They are the primary macro factors to consider in power planning in China. Apart from renewable energy goals, targets of energy storage and electric vehicles development are also gradually involved.

- The **11th Five-Year Plan for Power Development** has set goals for 2020, that non-fossil energy accounts for 15% of primary energy consumption and 39% of total installed power capacity. Among them, wind and solar photovoltaic (PV) reaches 210 GW and 110 GW respectively.[37]
- The **Clean Energy Consumption Action Plan (2018-2020)** aims at the national wind curtailment rate to be below 12%, 10% and 5% in 2018, 2019 and 2020 respectively. For these three consecutive years, the solar curtailment rate should be controlled below 5%.[38]
- The **Guidelines regarding the Establishment of an Orientation Mechanism for the Development and Utilization of Renewable Energy** by the NEA set a minimum indicator for the non-hydropower renewable consumption in each province's electricity consumption by 2020.[39]
- The **13th Five-Year Plan for Renewable Energy Development** specifies that energy storage technology application pilot projects shall be carried out, which combine new energy micro grids and other projects with distributed energy generation. The goal is to improve the economics of energy storage technology in the field of renewable energy and promote the realization of commercial applications.[40]

These policy goals need to be considered during planning and be realised with the help of planning. However, there are still some elements of grid planning that hinder integration of RE.

Policy objectives are the primary considerations in planning. In recent years, China's energy policy mechanism has been continuously improved, and more and more renewable energy development targets have been incorporated into power planning. For example, renewable energy installed targets, abandoned wind and light control targets, and non-hydro renewable energy consumption targets. At the same time, with the development of new energy technologies on the demand side, planning for the application of energy storage and electric vehicle technology has also been considered.

1.1.3 Elements of Chinese grid planning that hinder integration of RE

Power planning in China have become quite complex in the overall system. The planning incorporates a large number of socio-economic and technical evaluation indicators, conducts scenario analysis, and provides support through various special topics. In the process of energy and industry transformation, China's electricity use behaviour is quietly changing - the growth rate of high energy consumption is decreasing, and the service industry is rising.[41]

In order to encourage the development of new energy sources and accelerate the progress of the electricity market introduction, China has introduced a series of new policies. This has increased the uncertainty of the energy and power sector. The current power planning approach considers uncertainties of future development to a low extent, therefore it has had an impact on the implementation of power planning. For example, the government issued new policies in the past few years requiring to slow down the expansion of thermal coal power plants, so the operating hours of UHV lines now is lower than planned. Ultimately, the actual annual power capacity utilisation of some UHV lines is less than one quarter of the designed capacity.[42]

Although the provincial power planning and the national power planning are interlinked, the provincial power grid planning is prepared by the provincial power grid companies and approved by the provincial energy authority. This may result in unsynchronized or uncoordinated construction of provincial and major inter-provincial grid lines or between grids in different provinces. Therefore, it is necessary to strengthen the coordination of power grid planning on national and regional levels.

China's power planning also lacks two-way interaction. First, the role of spot power market will be more important in the near-term power system, and a more market-based analysis could help to activate inter-provincial transaction-based power flows and thereby facilitate better capacity utilisation and integration of RE.[43] Second, the government has issued a clear guiding direction on involving distributed power sources into the system, e. g. electric vehicles and off-grid energy storage facilities, while the planning process has not considered the impacts of such measures specifically.

The Chinese grid planning focuses on specific projects like a certain transmission line or transmission corridor and how these can be used efficiently by balancing power supply at the sending end and demand at the receiving end. This approach neglects RE since they have low operating hours, but can supply electricity with low additional cost. It is needed to optimize the overall energy system instead of specific lines, considering cost efficiency, electricity flows and system stability in an integrated perspective.

China evaluates the investment of transmission lines only with capital cost and tariffs, but makes very rough assessment to social welfare, emission reductions and environment qualitatively. The capacity factors of RE like wind and photovoltaic in the Chinese grid and peak load supply planning is quite low, which leads to a higher assumed need of coal power plants. However, the capacity factors of renewables should be considered for a certain area not one single power plant, since fluctuating generation of RE are smoothened over larger balancing areas.

1.2 Grid planning processes in the EU: Integrating national plans into one conjoint EU-wide plan

In the following chapter the processes and actors of grid planning in Europe and Germany are described. Grid development is a vital instrument in achieving European energy policy objectives, which are security of electricity supply across Europe, sustainable development of the energy system with RE integration and affordable energy for European consumers through transnational market integration.

1.2.1 The Ten-Year Grid development plan (TYNDP) process

ENTSO-E was formed according to a European Commission Regulation (EC 714/2009). It consists of 41 transmission system operators (TSOs) from 34 countries. The objective of ENTSO-E is to ensure optimal management of the electricity transmission grid which enables trading and supplying electricity across borders in Europe.

One of the main tasks of ENTSO-E is to elaborate regularly the EU-wide **Ten Year Network Development Plan** (TYNDP), which provides the central reference point for European electricity grid development. The TYNDP 2018 for example explores the possibility of a European power system where 75% of the emissions in the EU will be cut by 2030 and up to 58% of the demand will be covered by RE. The plan deals among others with target capacities, transmission adequacy[1] and cost benefit analysis of new transmission lines. The YNDP is carried out on a regular basis every two years by 41 TSOs from 34 countries (see **Figure 6**). The process is managed by ENTSO-E, the European association of transmission system operators. These TSOs serve 525 million citizens with electricity, are responsible for around 310.000 km of transmission lines, ensure the delivery of 3.300 TWh / year of electricity and supply 400 TWh/year of transnational electricity exchange. The TYNDP considers challenges in building the necessary infrastructure, security of supply, cost benefit analysis of new transmission lines, drivers for grid investment, electricity market prices and electricity grid bottlenecks. The plan identifies the need for optimisation, strengthening or extension of electricity grid infrastructure for the next ten-years.

Inputs for the TYNDP are the previous version of the TYNDP, the regional and/or national grid development and investment plans, four scenarios of the development of power generation, supply, consumption, import and exports and legal national and EU-wide requirements.

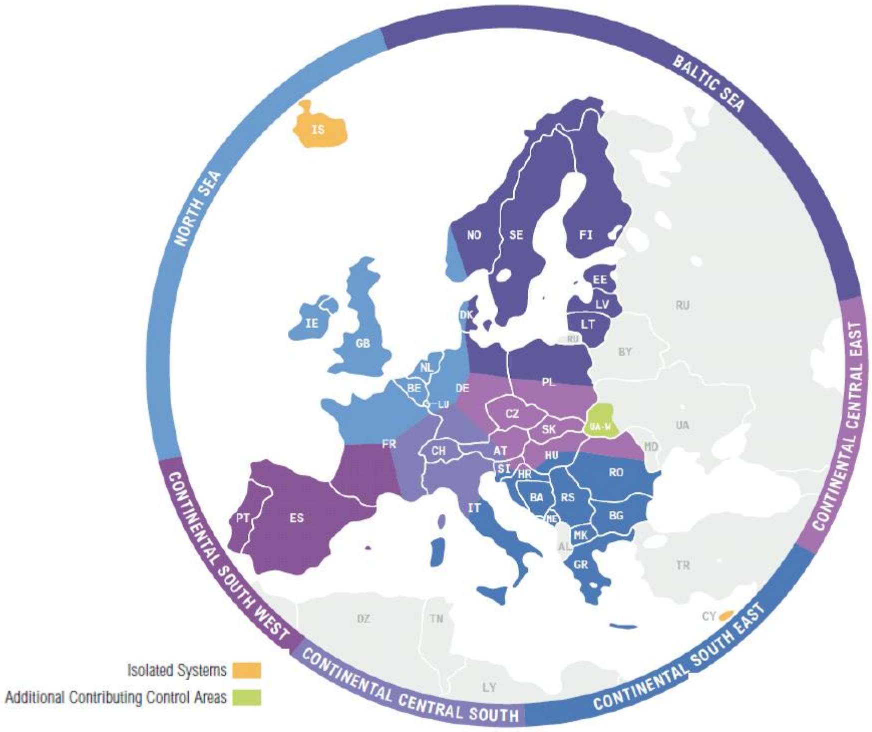

Figure 6: ENTSO-E member countries and regions (source: ENTSO-E (2011) Scenario Outlook and System Adequacy Forecast 2011 – 2025)

[1] The TYNDP defines so-called target capacities. This correspond to the capacity above which additional capacity development would not be profitable, i.e. the economic value derived from additional capacity cannot outweigh the corresponding costs.
Transmission Adequacy on the other hand shows how much transmission capacity would be needed in the future electricity system, to reduce bottlenecks considerably and ensure security of supply.

The elaboration process of the TYNDP is divided into three steps:

Step 1 – Development of scenarios

The potential development of the energy system is analysed in order to identify what Europe needs in terms of electricity transmission infrastructure. Some political objectives are set until 2030/2040 on EU and on national level of the EU Member States, but a lot of uncertainties exist e.g. about generation investments, demand evolution and market developments. The TYNDP scenarios aim to address these uncertainties and their influence on the future system and are no predictions of the future.

Various stakeholders, like NGOs, scientists, industry associations representing transmission grid users (like generators, distribution grid operators, suppliers and traders), market participants, consumers (including industry), power exchanges and national regulators are formally invited to participate in the scenario creation during consultations.

Step 2 – Planning Studies

The TYNDP usually contains four scenarios analysing the development of the future power system. Some have ambitious objectives regarding the utilization of RE, some focus on the effects of a more decentralized power system and some consider the political influences, like a strong European legal framework. Using common methodologies like market and grid modelling, the experts look at how power could flow in Europe in 2030/2040, taking into account the different scenarios. This allows them to identify where bottlenecks could occur and how much transmission capacity is needed at borders to manage these flows.

The results of the planning studies are a series of infrastructure project proposals. These are only one part of the whole set of TYNDP projects. The other part is constituted of projects that are coming from third party investors (non-ENTSO-E members) and that meet the criteria for inclusion in the TYNDP set by the European Commission.

The projects resulting from the planning studies take into account constraints identified in six Regional Investment Plans. The countries belonging to each regional group are shown in **Figure 6**. In these regional plans, national electricity grid development plans are considered. The six regional investment plans cover all of Europe and are focusing at electricity system development issues from a regional perspective. As for the scenarios, the list of projects and regional investment plans are open to public consultation before being finalized.

ENTSO-E usually operates three months of consultation period during which industry stakeholders and the public can hand in opinions and statements about the respective documents. During this time, ENTSO-E usually organizes stakeholder workshops to offer the opportunity to interact and discuss directly with the creators of the TYNDP. After the consultation period, ENTSO-E will issue the final version of the TYNDP which contains, upon judgement of ENTSO-E, adjustments and changes according to the feedback of the stakeholders.[44]

Step 3 – Projects assessments

The last phase of TYNDP creation is the assessment of projects. This is done using a specific pre-determined methodology to assess the cost and benefits of projects[45]. This assessment is not a purely economic assessment. It takes into account how projects support the environment, the welfare in Europe, the security of supply and other criteria with regard to the common welfare. The results of this assessment of projects form the core part of the TYNDP report.

The TYNDP report informs about the value of each recommended infrastructure project. The TYNDP is providing decision-makers with a robust and detailed analysis of transmission infrastructure projects on which to base their decisions. The Agency for the Cooperation of Energy Regulators in Europe (ACER)[46] checks whether the draft of the TYNDP by ENTSO-E is coherent with the EU's policy goals, regulatory framework and national plans of the Member countries. ACER decides whether the TYNDP is appropriate and can be send to the European commission. The final TYNDP is used by the European Commission to decide which projects are projects of common interest and are to be handled with special legal priority.

Especially **Projects of Common Interests (PCIs)** need positive results of the CBA. Projects of common interest are important European infrastructure projects, especially cross-border projects to link energy systems of EU countries. The aim of identifying PCIs is to support achieving the EU energy policy objectives: affordable (by boosting competition and markets integration), secure and sustainable (by integrating RE) energy and decarbonisation of the economy. PCIs benefit from accelerated planning and permit granting, lower administrative costs due to a more streamlined environmental assessment process, increased public participation via consultations, and increased visibility to investors. PCIs have the possibility to apply for funding from the Connecting Europe Facility (CEF).[47]

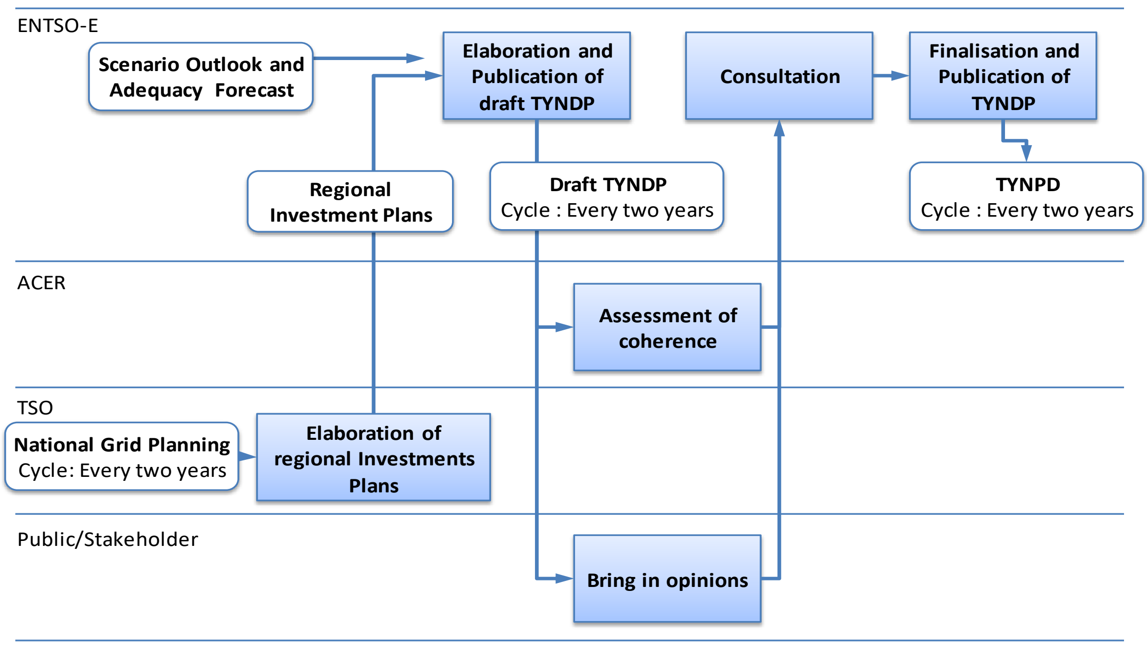

Figure 7: Process to elaborate the TYNDP

Cost Benefit Analysis (CBA): validating cost and benefits of each project

All new transmission project proposals in the TYNDP planning process are assessed according to the same system wide cost-benefit methodology developed according to the **ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects** [48]. The elements analysed in the CBA are [49]:

- Grid Transfer Capacity (GTC) in MW
- Security of supply in EENS (Expected energy not served) or LOLE (Loss of load expectancy)

- Socio economic welfare (SEW), defined as the sum of producer surplus, consumer surplus and congestion rents. SEW includes implicitly monetized values for CO_2 and renewable energy sources (RES) integration (e.g. improved value of RES generation by reducing curtailment of wind)
- Transmission losses (change in losses for the whole system)
- Project cost and changes in other cost incurred by the project (except for losses)
- Technical resilience/system safety (ability of the system to withstand extreme system conditions)
- Flexibility/robustness (the ability of the proposed reinforcement to be adequate in different possible future development paths or scenarios)

How this approach fits together with national grid planning approaches and how the national grid planning approaches work is examined in more detail in the next chapter by way of the example of Germany.

1.2.2 Example of a national grid planning methodology: Germany

Every two years, the four German TSOs create a national grid development plan (Netzentwicklungsplan (NEP)). The objective of the NEP is to identify appropriate measures for needed optimization, reinforcement and expansion of the transmission grid in Germany, which will be required over the next ten years to ensure a secure and reliable grid operation. The procedure is defined by German law (Energiewirtschaftsgesetz) and concerns in particular the four TSOs and the regulatory authority, the Federal Grid Agency (Bundesnetzagentur (BnetzA)). The procedure for the preparation of the national grid development plan is divided into two steps: **1. the creation and approval of a scenario framework and 2. the actual development of the grid development plan**. These steps are described in more detail in the following paragraphs.

Step 1: Creation and approval of a scenario framework

The scenario framework has to contain at least three scenarios on the possible range of probable developments of the German electricity system for the next ten years and correspond to the medium and long-term energy policy objectives of the Federal Government. One additional scenario has the timeframe of fifteen years instead of ten years which has the goal to examine the probable further system evolution and possible consequences for short- and mid-term measures.

The TSOs will send the draft of the scenario framework to BNetzA who publishes the draft and conducts a public consultation. The public and stakeholders like grid users, distribution system operators (DSOs), NGOs, associations, academia and public authorities can comment the draft and propose changes. After evaluating the comments and, if necessary, adjusting the scenario framework, BNetzA approves the scenario framework as the basis for the further development of the national grid development plan by the TSOs.

Step 2: Development of the National Grid Development Plan

On the basis of the scenario framework approved by the BNetzA, the TSOs are gradually analysing the future grid expansion requirements. The generation capacity assumptions included in the scenario framework are regionalized, meaning the capacities are attributed to specific regions, and RE feed-in is simulated for every hour of the year. A Europe-wide market simulation for all three scenarios will be carried out in order to determine the optimum power generation per power plant at any time of the year. The market simulation is carried out with a close view on European electricity trading activities and corresponding transnationally traded and transported volumes of electricity. It takes into account the interconnector capacities available between the European countries. RE electricity production and electricity production by conventional power plants according to the results of the simulations of electricity trading are assigned to each grid node in the European grid for each hour of a simulated year (three years are simulated: five, ten and fifteen years ahead) as a preparation for the grid analysis. The load flows in the grid infrastructure adopted as the starting point need to be determined and are based on the timing and regional distribution of the demand. In this way, frequent transmission bottlenecks can be identified. Further calculations also determine requirements for the system stability of the power grids and electricity system. To cover the calculated future transmission needs, alternative approaches (technological, topological) are developed and evaluated in the model in terms of cost and environmental impact. If a need of optimization or extension is derived, the NOVA–principle is used:

- **Netzoptimierung/grid optimization (NO)**: As first step, optimization possibilities of the existing grid have to be used (e.g. use of electricity temperature monitoring).
- **Verstärkung/grid enforcement (V)**: In the second step, existing grids have to be strengthened in case the possibilities for optimizations are exhausted or insufficient (e.g. adding another line on an existing rack).
- **Ausbau/grid extension (A)**: Thirdly, if neither optimization nor strengthening measures are appropriate to meet future needs, expansion measures of the grid have to be planned.

The national grid development plan is derived as a list of necessary grid expansion projects based on the results of the process above. The TSOs then publish the draft grid development plan and again execute a public consultation process. After evaluating the inputs from the consultation process, the TSOs finalize the grid development plan and send it to BNetzA for approval. BNetzA examines the draft regarding consistency with the TYNDP, the German offshore grid plan and if needed with distribution grid plans. If required, ACER may also be involved in the consistency check by BNetzA. Based on the draft grid development plan, BNetzA creates an environmental impact assessment report that must comply with the requirements of German law[2], publishes the environmental impact assessment report and the draft grid development plan and conducts another consultation process. After evaluation and consideration of the statements of the public and the affected state authorities, the grid development plan is confirmed by the Federal Grid Agency.

[2] §14g of the Environmental Impact Assessment Act

2 Integrated grid planning as base for an efficient power market in China

In this chapter scenarios and modelling approaches are used to analyse the benefits of grid planning and a more intermeshed electricity grid layout in China.

A detailed, bottom-up scenario for the development of the Chinese energy system towards 2050 was used: The stated policies scenario of the Chinese Renewable Energy Outlook 2018. The scenario is represented in CNREC's energy system modelling tool, consisting of three interlinked models: EDO, END-USE, and CGE. The EDO (Electricity and District-heating Optimisation) model is a fundamental model of power and district heating systems on a provincial level. The END-USE model, based on LEAP (Long-range Energy Alternatives Planning system), represents bottom-up modelling of end-use demand and how this demand is satisfied. Please find a detailed description of the scenarios and modelling set up in the CREO 2018, Chapter 2[50].

2.1 Scenario comparison: demonstrating the advantages of an integrated grid planning approach

To demonstrate the benefits of system-wide grid planning in China and a more intermeshed electricity grid, two modelling approaches have been conducted.

- The first approach compares the **stated policy scenario of CREO 2018** (with an optimally planned and expanded electricity grid) with a scenario without grid planning and grid expansion after 2020. This scenario is called **frozen grid scenario**. In the following sections, the stated policy scenario is the reference case and the figures illustrate the relative difference (mostly: decreased efficiency) of various factors in the frozen grid scenario: total system cost, market efficiency and participation, RE curtailment, emission reduction and security of supply.
- The second approach compares two different electricity grid layouts in China: The current electricity grid layout with long distance direct current lines based on the **stated policy scenario** with a much more intermeshed electricity grid, which takes the situation in Europe as reference. This scenario is called the **highly-meshed scenario.**

In all scenarios, the model forecasts the development of levelized cost of electricity (**Figure 8**). The figure shows that due to development of the technologies, photovoltaic and wind are cheaper than coal from 2022 onwards. The model assumes in all approaches that the energy system in China will be increasingly adopting power market mechanisms until 2050. It also assumes that by 2035, the power market can fully promote efficient utilisation of the system and incentivise the use of RE with low marginal cost. Generation quotas and inflexible long-term physical contracts are replaced with flexible spot-indexed contracting and/or market trading hedging products. Spot and balancing markets across the country are interconnected in real-time, or completely integrated.

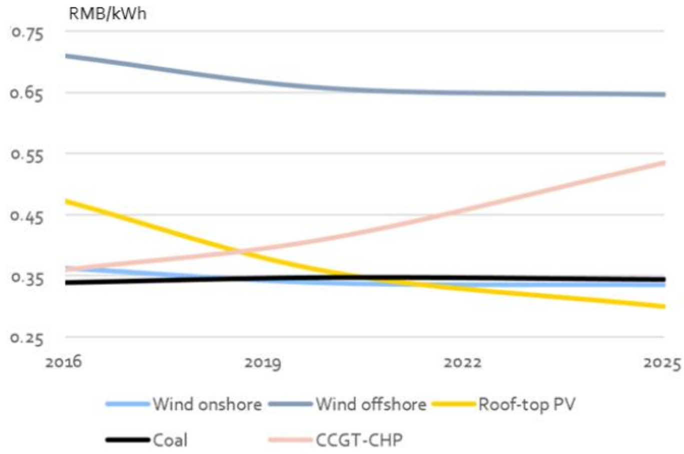

Figure 8: Modelled levelized cost (RMB/kWh) of electricity of various sources in both scenarios

2.1.1 Lower total system cost

The EDO-model was used to compare the **stated policy scenario of CREO 2018** with the **frozen grid scenario**. Already planned transmission lines that will be constructed until 2020 are included in the frozen grid scenario. However, after 2020 no new transmission lines are constructed per definition[51]. In the stated policy scenario, implementation of system-wide grid planning and further expansions of the electricity grid are implemented when the overall system cost are lowered due to new transmission lines. In the stated policy scenario, the EDO-model takes cost (e.g. construction cost) and benefits (e.g. lower curtailment from RE, cost reduction due to electricity trading and a more flexible electricity system) of new transmission lines into account. The figures below show the results of the two scenarios. **Figure 10** shows the transmission grid investments in the Chinese provinces of the stated policy scenario. Especially in Western Inner Mongolia and Shanxi, grid investments have been realised. According to set limits, no grid investments have been conducted in the frozen grid scenario.

The results of the scenario modelling show that system wide grid planning and grid expansion leads to lower overall system cost, lower emissions (see **Figure 9**), better integration of renewables and less curtailment (see **Figure 13**). Generation cost and annualized cost of capital of new connection are included in the total system cost.

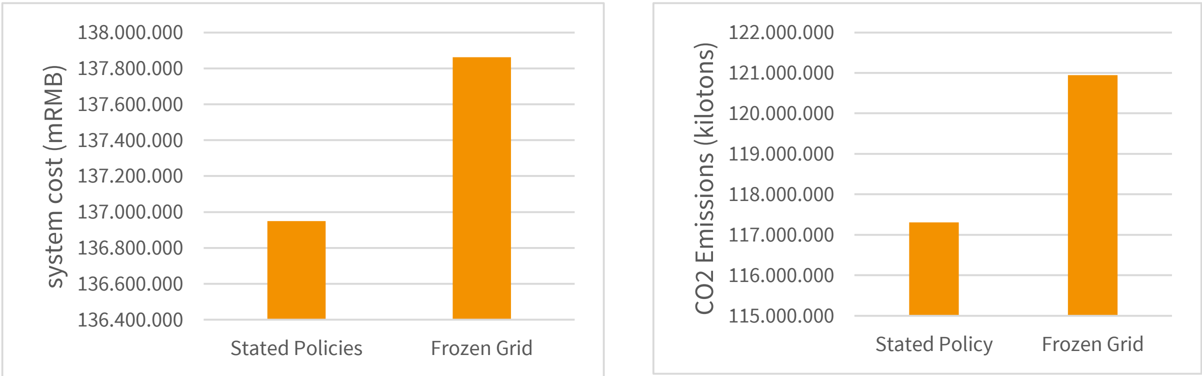

Figure 9: Comparison of total system cost of the scenarios (cumulated from 2016 to 2050) and total emissions (cumulated from 2016 to 2050)

2.1.2 Higher market efficiency and market participation

A well-expanded and meshed electricity grid is needed to enable an efficient electricity market and trading. This is why grid investments are conducted in the stated policy scenario in order to allow more electricity trading between provinces. **Figure 10** shows the grid investments in interprovincial transmission capacity in the stated policy scenario.

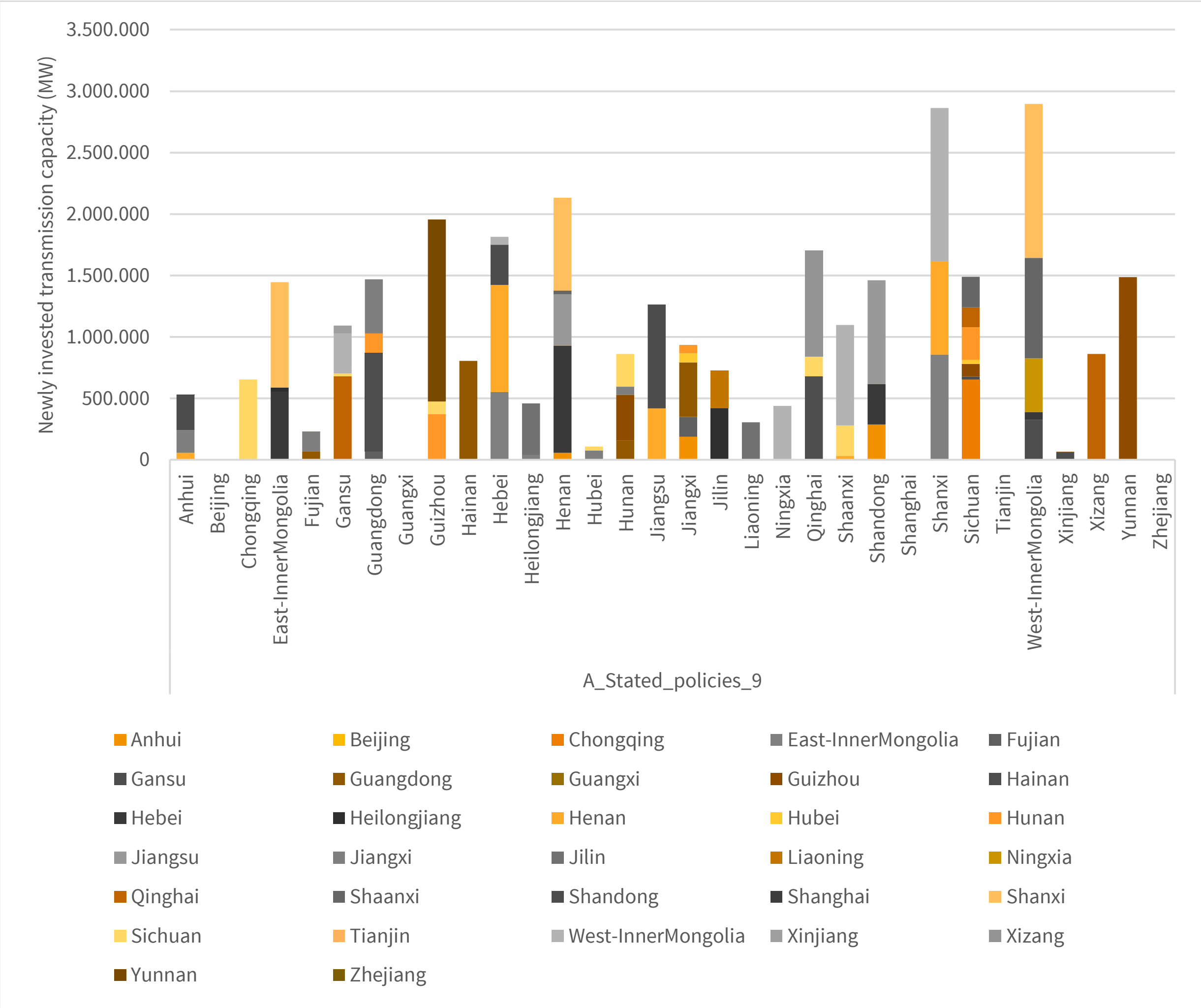

Figure 10: Transmission grid investments in inter-provincial interconnections per province in the stated policy scenario

Especially the electricity grid between Shanxi and Inner Mongolia has been expanded in the stated policy scenario due to the calculated high benefits of trading electricity between these two regions. Inner Mongolia is exporting a high amount of electricity due to its high energy potential to other provinces in 2050.

Figure 11 shows electricity trading and resulting electricity transport volumes between Chinese provinces in both scenarios.

Stated policy scenario: It is demonstrated that the stated policy scenario enables electricity trading to a higher extent compared to the frozen grid scenario. From 2030 to 2050, the interprovincial trade of electricity increases constantly in the stated policy scenario. Inner Mongolia for example is exporting high amounts of electricity since it uses its large RE potential to a high extent. Due to the export of electricity, Inner Mongolia has the opportunity to increase earnings of electricity trading and support economic growth. On the other hand, Jiangsu imports high amounts of electricity in 2050. This enables Jiangsu to consume electricity with lower prices compared to own generation of electricity. Electricity trading leads to lower overall system cost and lower emissions (see **Figure 9** and **2.1.4**). Furthermore, electricity trading leads to less needed electricity generation capacity to ensure security of supply.

Frozen grid scenario: In the frozen grid scenario 3,9% more electricity generation capacity is needed (see **Figure 16**).

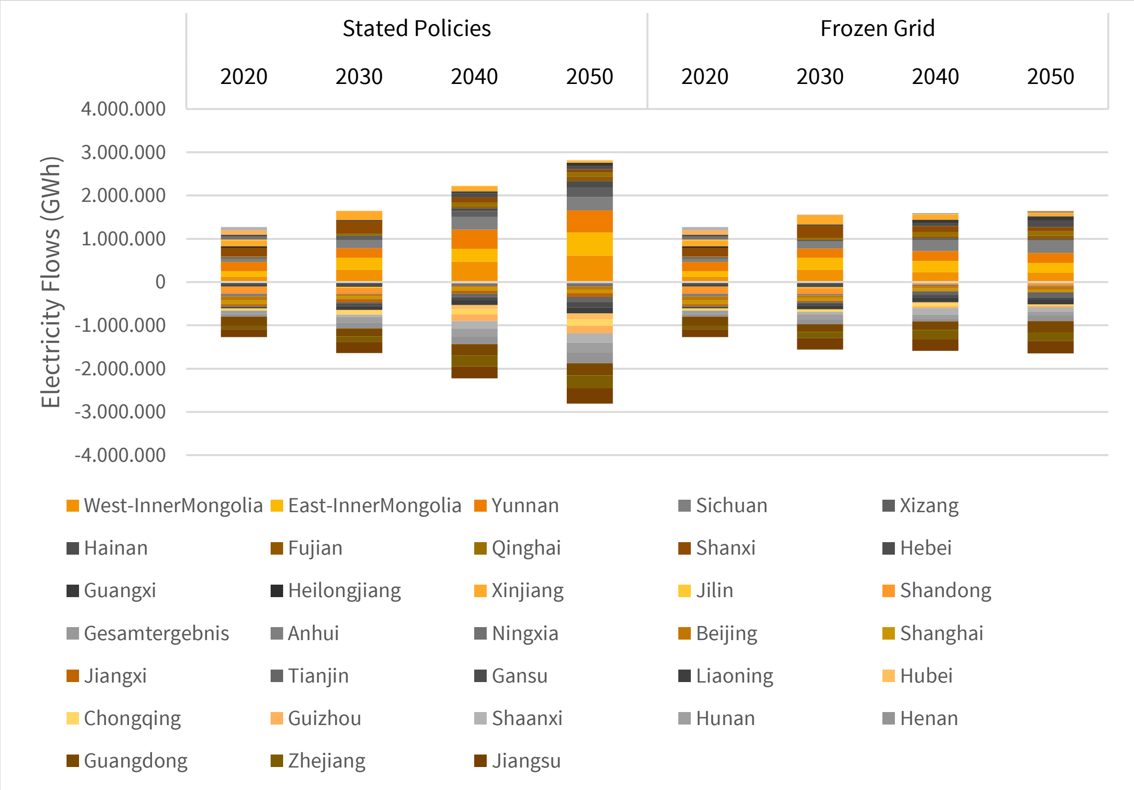

Figure 11: Trading deficits and surpluses in the stated policy and frozen grid scenarios (Provinces in the legend are ordered according to electricity surpluses or deficits in the stated policy scenario in 2050).

2.1.3 Higher cost efficiency by reducing curtailment of RE power generation

In this section, the results of the two scenarios are compared, to evaluate the overall cost efficiency and RE curtailment with and without grid extension and system wide grid planning.

Frozen grid scenario: The generation cost of the frozen grid scenario are significantly higher compared to the stated policy scenario. The additional generation cost outweigh the not conducted grid investments in the frozen grid scenario, so overall system cost are significantly higher (see **Figure 12**). This is due to high curtailments of wind and photovoltaic (see **Figure 13**) which lead to higher generation by fossil technologies like coal power plants (see **Figure 15**), which are becoming more expensive compared to wind and solar (see **Figure 8**). For electricity storage, batteries and pumped storage are used to a higher extent. The results of the analysis show that system-wide electricity grid planning and expansion are important to lower total generation cost and lower overall system cost (see **Figure 12** and **Figure 9**).

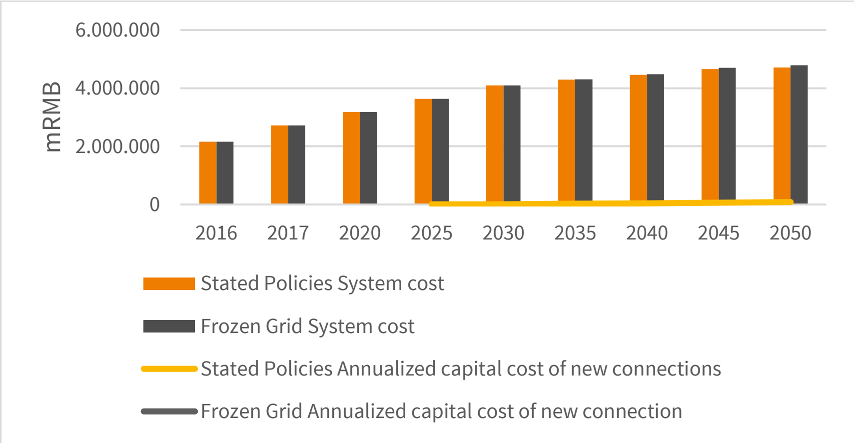

Figure 12: System cost (grid cost and generation cost) of both scenarios

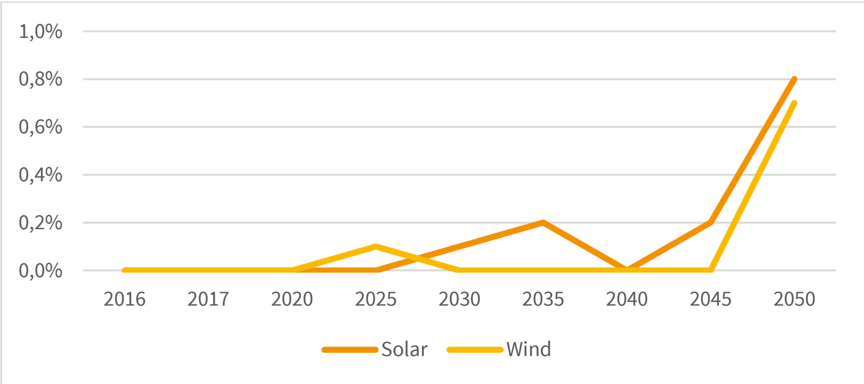

Figure 13: Additional wind and solar curtailment in the frozen grid scenario (compared to the stated policy scenario)

2.1.4 Higher climate efficiency through quicker CO_2 emission reductions

The **frozen grid scenario** is also producing higher CO_2 emissions towards 2050. This is a result of a higher use of coal power plants to compensate the curtailed power of wind and photovoltaic. This means, having no system-wide grid planning and interprovincial power markets also impacts the amount of CO_2 directly.

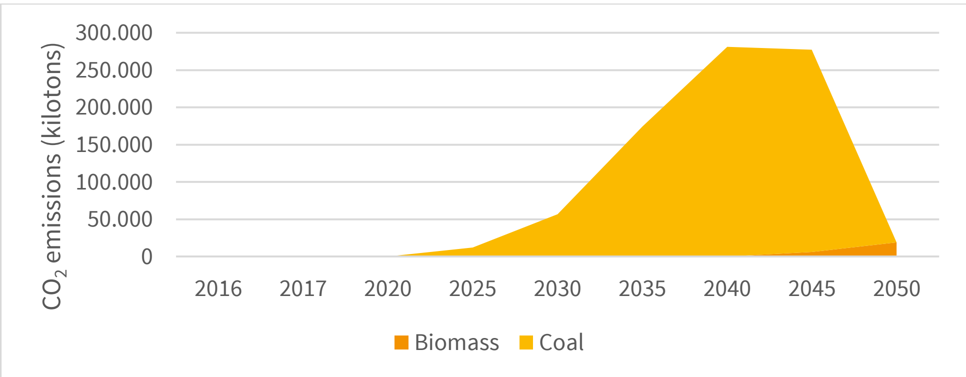

Figure 14: Additional CO_2-emissions of the frozen grid scenario compared to stated policy scenario

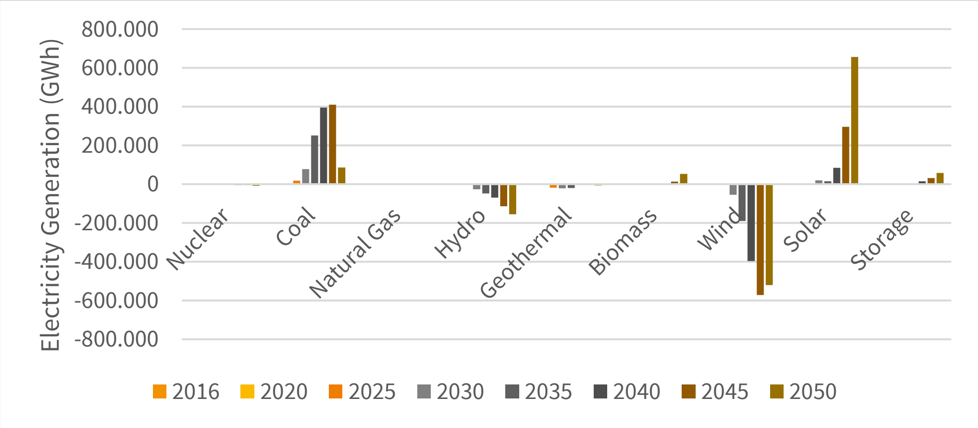

Figure 15: Difference of electricity generation (GWh) in the frozen grid scenario compared to the stated policy scenario

2.1.5 Ensuring security of supply by enabling a robust and cost-efficient system

In both scenarios, **security of supply is fully ensured**. However, they come with different cost and emissions (as shown above) and a different generation capacity mix (see **Figure 16**). The results of the **frozen grid scenario** show (see **Figure 16**) that more coal power capacity is needed if there is no system-wide planned and expanded electricity grid. Furthermore, more solar is installed to compensate for less wind and storage capacity. More solar power potential is available within the area covered by the existing electricity grid compared to wind potentials, whose integration would require a more expanded electricity grid (as modelled in the **stated policy scenario**).

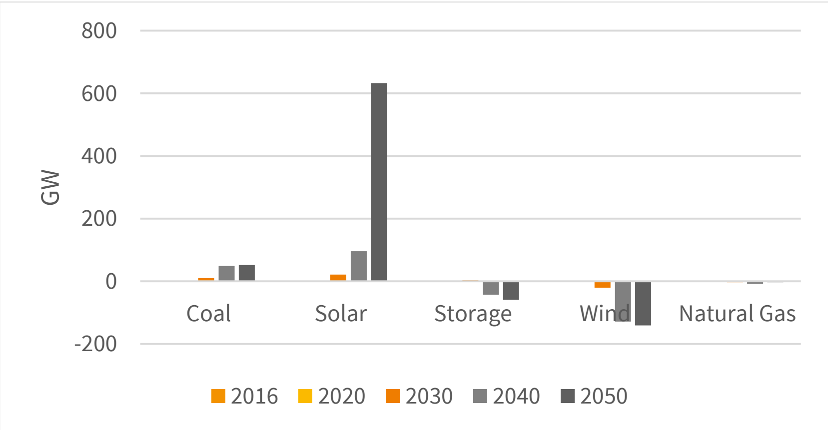

Figure 16: Difference of electricity capacity (GW) in the frozen grid compared to the stated policy scenario

Excursus: How to achieve a more efficient energy system by establishing a more intermeshed grid layout

Another important issue in reference to grid planning is the grid layout. China installed several high capacity and High Voltage Direct Current (HVDC) transmission lines running from west to east. Several of these transmission lines are not intermeshed with transmission lines in those provinces over which the HVDC lines are running (see **Figure 17**). In the **highly-meshed scenario**, a more intermeshed Chinese electricity grid was modelled. An hourly simulation for the year 2020 was **conducted using the assumptions of the stated policy scenario**. It was assumed that all planned transmissions lines will be in operation. This was compared with a scenario using the same assumptions [3], but having a much more intermeshed electricity grid right away in 2020 (**highly-meshed scenario**).

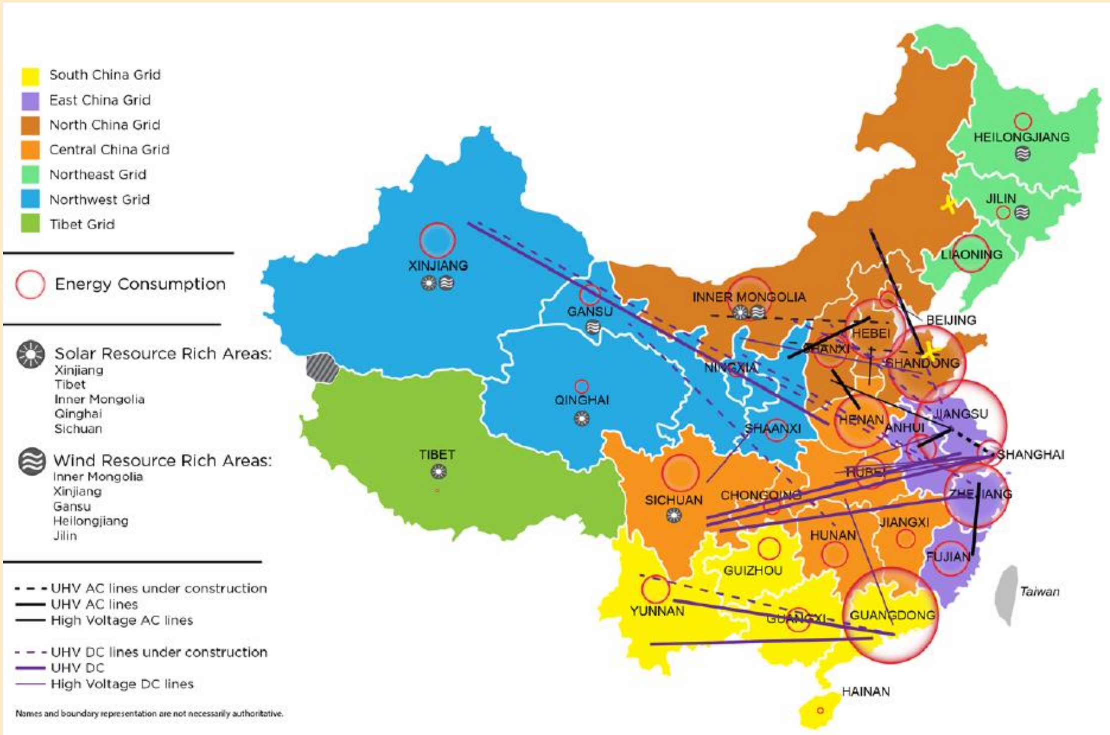

Figure 17: Map of electricity grid zones and high voltage Direct Current transmission lines on mainland China [4]

Below is a list of the HVDC connections which are assumed to be more intermeshed in the **highly-meshed scenario**. When a line is assumed to be more intermeshed, the capacity is subsequently added between the

[3] However, operational distortions (e.g. minimum FLH requirements, excessive unit commitment requirements, limitations on transmission flexibility) are switched off in all calculations. Operational impact of policies (e.g. shadow prices of policy constraints such as North-China Clean Heating Plan) are switched off and therefore have no effect on the dispatch (though capacity expansion is in accordance with the targets as they arise from the CREO simulations).

provinces along the transmission path. For instance, the Yunnan-Guangdong direct transfer capacity is assumed to be 0 GW and capacity of 25 GW is included between Yunnan and Guangxi and between Guangxi and Guangdong.

Connection	Capacity	Path
Yunnan-Guangdong	25 GW	Yunnan-Guangxi-Guangdong
Sichuan-Zhejiang	9 GW	Sichuan-Guizhou-Hunan-Jiangxi-Zhejiang
Ningxia-Zhejiang	9 GW	Ningxia-Shaanxi-Henan-Anhui-Zhejiang
Shanxi-Jiangsu	14 GW	Shanxi-Hebei-Shandong-Jiangsu
Gansu-Hunan	7 GW	Gansu-Shaanxi-Chongqing-Hunan
Inner Mongolia-Shandong	13 GW	Inner Mongolia-Shaanxi-Shanxi-Hebei-Shandong
Inner Mongolia-Jiangsu	10 GW	Inner Mongolia-Hebei-Tianjin-Shandon-Jiangsu
Xinjiang-Anhui	9 GW	Xinjiang-Gansu-Ningxia-Shaanxi-Henan-Anhui
Hubei-Guangdong	4 GW	Hubei-Hunan-Guangdong
Guizhou-Guangdong	7 GW	Guizhou-Guangxi-Guangdong
Ningxia-Guangdong	3 GW	Ningxia-Shaanxi-Shanxi-Hebei-Shandong
Sichuan-Shanghai	8 GW	Sichuan-Hunan-Hubei-Jiangsu-Shanghai
Sichuan-Jiangsu	8 GW	Sichuan-Guizhou-Hunan-Hubei-Jiangsu
Xinjiang-Henan	7 GW	Xinjiang-Gansu-Ningxia-Shaanxi-Shanxi-Henan

Table 4: more intermeshed HVDC connections according to the highly-meshed scenario

One of the benefits of the **highly-meshed scenario** is a reduction in total system cost of 4.7 bn RMB in 2020. This savings result mostly from fuel cost savings due to less coal consumption (see **Figure 18**). Increased flexibility of the electricity system and electricity grid allow for more efficient use of CHP units and more efficient coal power units over less efficient coal power units. This leads to lower CO_2 emissions.

Furthermore, the coal power generation is shifted between provinces, such that more coal-fired power generation takes place in provinces with lower coal prices. **Figure 18** shows the electricity generation of the **highly-meshed scenario** in 2020 compared with the **stated policy scenario**. The figure shows that coal power plants generate less and more efficient coal CHP plants generate more electricity, leading to fuel cost savings and less emissions.

The need to use storage is reduced since other cheaper electricity resources become available due to the more flexible electricity grid. This leads to less conversion losses, for example when transferring electricity to kinetic energy and to electricity again with pumped storage.

Hydro can be used in the **highly-meshed scenario** to **a higher extent.** Since the grid is more flexible, this leads to lower fuel cost of the overall system. Less biomass for electricity generation is needed, so the pressure on natural resources and land-use conflicts are reduced.

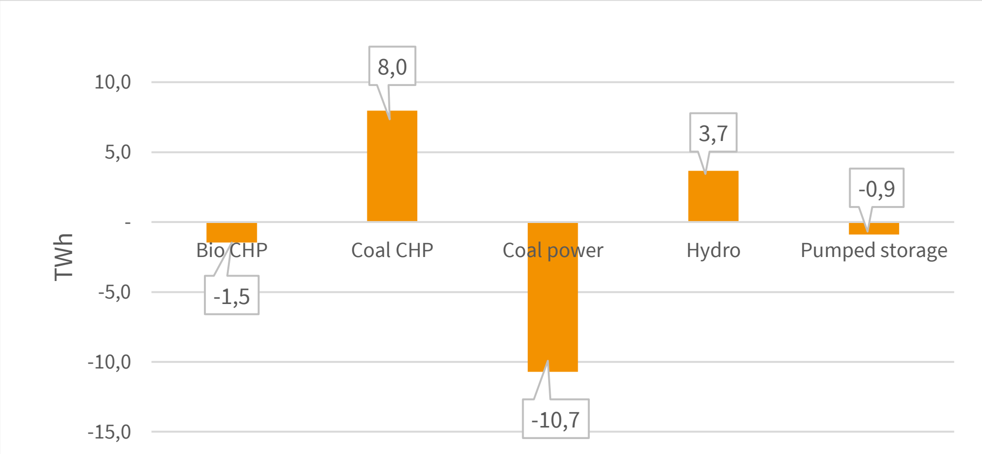

Figure 18: Electricity generation in the intermeshed grid layout scenario (compared to the Stated Policy scenario) (TWh)

The **highly-meshed scenario** allows for a higher usage of electricity trading, allowing provinces to reduce electricity cost when importing electricity from provinces with lower electricity prices or to earn profit, when exporting electricity to other provinces with higher electricity prices. **Figure 19** shows the trading deficits and surpluses in the **highly-meshed scenario** compared to **the stated policy scenario**. Jiangxi for example is able to import 90.101 GWh more electricity in the **highly-meshed scenario**, since other provinces are able to produce electricity at lower cost. This leads to lower overall electricity cost of Jiangxi. Fujian on the other hand is able to become a net exporter instead of a net importer it has been before. So it is able to produce 43.051 GWh more electricity and export part of it to other provinces and generate profits.

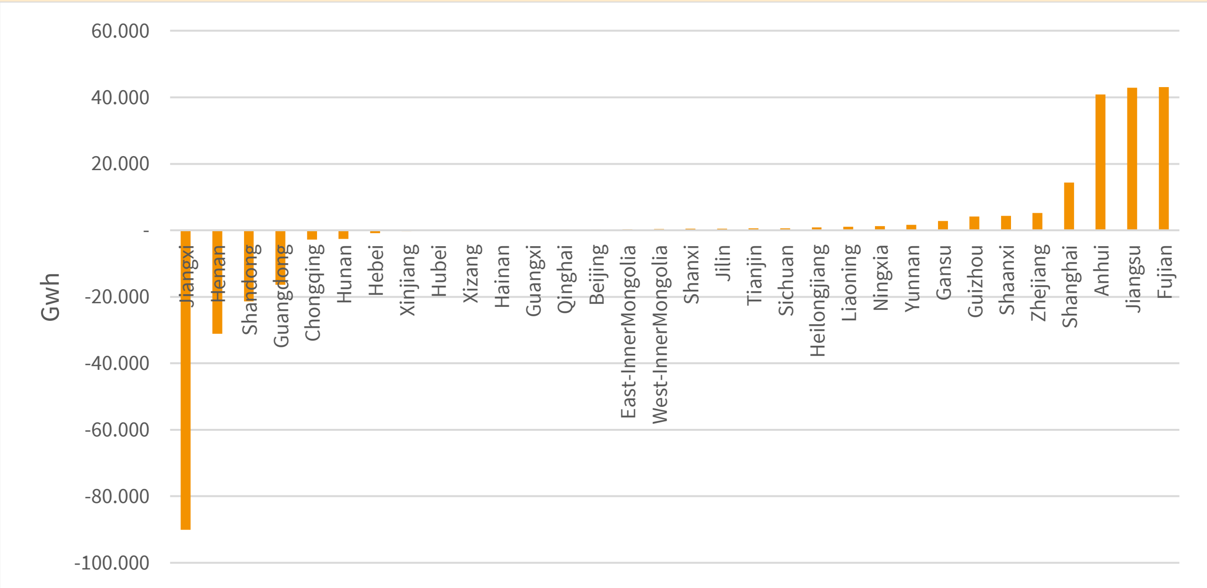

Figure 19: Trading deficits and surpluses in the highly-meshed scenario compared to the stated policy scenario (GWh)

Concluding, the benefits of a more intermeshed electricity grid are: lower electricity generation cost and emissions, leading to higher use of electricity trading and a more flexible electricity system. However, the cost of constructing a more intermeshed electricity grid are not yet included which will have an impact on the overall balance of cost.

3 Planning the future energy system in China: Ideas for process developments

The description of electricity grid planning (see Chapter 1) in China and Europe shows that the electricity grid planning process in Europe considers many factors like policy goals, electricity market / trading and focus on a system-wide approach. The European approach considers uncertainties to a higher extent and shows the impact of different policies by **creating and comparing various probable development scenarios**. Although the national implementation of such a process in China including all provinces would require significant effort and strong coordination, there are significant systemic benefits to be expected from it. Experience shows that it **requires a strong and independent government body/institution** to establish and monitor such a change in processes.

Grid planning processes in China should increase consideration of more **uncertainty factors** of grid planning and **analyse the impacts of different policies** and developments of the electricity system (e.g. power capacity development, price and market development). Using these uncertainties, different scenarios can be developed and analysed in energy system models, to evaluate what kind of electricity grid is needed in different scenarios and what the most robust way forward is. It is necessary to deepen the consideration of power planning as a two-way interaction, and the future power system with high shares of renewables.

The importance to **consider the role and impact of electricity markets** in grid planning in China will increase significantly. More market-based analysis should be integrated in grid planning like the effects of increasing inter-provincial transactions.[52] The Chinese Government plans to introduce electricity markets in China. To consider the effects of short-term electricity markets, grid planning processes in Germany use an electricity market model to calculate the probable electricity flows according to expected and probable trading activities (see 1.2.2). In the actual implementation of power markets, the **market design should contain clear transmission and distribution price mechanisms** which are important to enable the development of inter-provincial and inter-regional free trade of electricity. In a **step-wise implementation**, the proportion of planned power generation in the dispatching mechanism should be gradually abolished and the flexible dispatching capacity of the power grid has to get gradually increased to accommodate high shares of RE.

By **establishing a system-wide optimization approach**, also cost efficiency gets significantly optimized and electricity flows and system stability get integrated into a full national picture. A system-wide optimization approach may lead to lower emissions and total system cost (see **Figure 9**).

Grid planning processes in China evaluate the investment of transmission lines only with capital cost and tariffs, but so far only make rough qualitative assessments of social welfare, emission reductions and environmental effects. A **higher focus on cost efficiency** in the Chinese grid planning by using a standardized methodology for cost-benefit analysis could help to lower the overall cost and increase the benefits of grid expansion. To be able to conduct such a CBA, a **common database for all provinces** is necessary. As a first step, processes to collect these needed data should be implemented.

It is recommended to analyse the **contribution of a RE portfolio to the annual peak load situation**. The capacity factor of a RE portfolio (and the contribution to security of supply) should be analysed for each grid area separately and be used in grid planning procedures to replace conventional generation capacities**. Using portfolio effects of RE** in grid planning (like smoothing of RE generation when looking on a large geographical area instead of a single renewable plant) lowers the need for back-up capacity to ensure security of supply. The current energy planning in China assumes a very low contribution factor of renewables like wind and solar, since they aim at one certain renewable unit. However, the combined effects of renewable generation of a certain portfolio should be the focus, when talking about capacity factors. If China sticks to this method, **more back-up capacity than needed will be build**. This will likely lead to **excessively high investments in thermal power capacity** and eventually to more electricity production from coal and less from RE, resulting in hi**gher emissions and higher cost**.

The report also shows the **benefit of a more intermeshed electricity grid**, like lower cost of the electricity system, lower emissions, higher use of electricity trading and a more flexible electricity system. However, the cost of building a more intermeshed electricity grid are not included, so further research is needed.

Important research questions that will need to be answered in the course of the development:

- Should the power source adequacy analysis method in China be adjusted?
- What energy system structure (central vs decentral) leads to lower overall system cost? Is it more economic to transmit renewable electricity over long distances using DC lines (using geographical areas with great RE potentials) or is an energy system with decentral generation by RE (and less long distance transmission lines) more economic?
- Is there a need to adjust the three-level failure defence and the power transmission adequacy assessment methods in China?
- What cost concept (marginal cost or full cost) should be used in measuring the influence of power market on the direction of power investment?
- Should accuracy of load forecasting methods and models be adjusted in China?
- What are the investment cost of a more intermeshed electricity grid?

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