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Energy Cooperation Platform

中国 - 欧盟能源合作平台

A4.1.1: ENTSO-E Grid Planning Modelling Showcase for China

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The EU-China Energy Cooperation Platform was launched on 15 May 2019 to strengthen EU-China cooperation on energy policies, and to support the implementation of activities announced in the 'Joint Statement on the Implementation of EU-China Energy Cooperation'. In line with the EU's Green Deal, Energy Union, the Clean Energy for All Europeans Package, the Paris Agreement on Climate Change and the EU's Global Strategy, this enhanced cooperation will help increase mutual trust and understanding between the EU and China and contribute to a global transition towards clean energy on the basis of a common vision of a sustainable, reliable and secure energy system. Phase II of ECECP is implemented by a consortium led by ICF, and with National Development and Reform Commission-Energy Research Institute. Policy steering is by the EU (DG ENER) and the China National Energy Administration.

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FOREWORD

To reach the goals of decarbonisation in China and in Europe, electrification of the energy system is vital. The cost of renewable energy production has decreased substantially, and the direct use of electricity will be the energy solution in most sectors. ‘Hard to abate’ sectors like heavy transport, aviation and industries (e.g. cement, steel, refineries) will need green gases/liquids based on renewable electricity production.

Before the liberalisation of the electricity market in Europe, each country had a national long-term plan for production and grids based on cost optimisation, taxes on borders to prevent exchange, a central dispatch and no markets. The price of electricity was often decided in national parliaments. It often ended up in huge over-capacity both in production and transmission. In such a system the costs for a green transition would be unacceptable to many countries in Europe.

The market reforms in the EU are based on a comprehensive regulatory framework which provides the basis for the energy transition. The transition needs to be affordable for ordinary people, while security of supply - short term and long term - is vital. In this context, grid planning and market development is crucial, and both infrastructure and markets need to succeed.

The EU-China Energy Cooperation Platform (ECECP) is a basis for exchanging best practice on the regulatory set up and on how to set up institutions. The exchange of models for grid planning and market development is key. I have been fortunate to be able to follow this successful project from the start.

This report is titled ENTSO-E Grid Planning Modelling Showcase for China. Can the EU’s Grid Model be of use in China and what are the key learnings?

The project draws on existing scenarios and modelling frameworks for China and Europe, with an emphasis on Cost Benefit Analysis in the grid planning processes. This shows the critical linkage between grid planning and power market reform. A key feature of the methodology is the recognition, from the transmission grid planning perspective, that the market will determine the use of the grid.

Europe’s ENTSO-E methodology uses a coordinated and comprehensive transmission grid planning approach, which includes development of scenarios, screening of potential new transmission assets, and combined CBA. The aim is to ensure system reliability, guarantee power supply and integrate more renewable energy at the lowest possible cost. Comparing current Chinese grid planning approach with the ENTSO-E approach shows potential room for improved efficiency in China’s grid planning.

Model results indicate that a market-based approach, where transmission expansion is market led, could achieve significant CO_2 emission reductions in China’s power system. The reduction can be achieved because transmission expansion will allow higher amounts of renewables to be generated and transported to consumers, thereby displacing coal-fired power generation. Our experience in Europe is that our model works. I hope this project report will inspire others to follow suit!

For its part, Europe has a lot to learn from China's experiences. I am glad to hear that the ECECP will continue to offer the opportunity to exchange best practice. Cooperation is certainly the way forward!!

Bente Hagem

Former chair of the Board of ENTSO-E
and former executive Vice President of Statnett SF
Oct 20, 2021

FOREWORD

Both Europe and China are facing a critical moment in the transition to clean energy. The Chinese government recently issued the 'Working guidance for carbon dioxide peaking and carbon neutrality in full and faithful implementation of the new development philosophy' (hereafter the 'Guidance'), which clearly sets out phased targets for 2025, 2030 and 2060, and puts forward specific requirements for industries, including the energy sector. The EU's recent 'Fit for 55' package, which builds on the 2019 Clean Energy for All Europeans Package, further raises the target for renewable energy's share of the market. Market-oriented reform is an important step in energy transition, and the newly issued 'Guidance' puts forward specific requirements for energy system reform and market-oriented reform in the power sector. In the course of a review of China's and Europe's journey towards power market reform, many similarities between the two parties have been identified. The energy sectors in China and the EU are both working actively and steadily toward their established goals, while constantly optimising their practice and building on their accumulated experience.

In a Joint Statement on the Implementation of EU-China Energy Cooperation, the EU and China resolved to establish the EU-China Energy Cooperation Platform (ECECP) in 2019. Since its establishment in May 2019, ECECP has conducted a series of exchange activities and research projects covering various topics such as energy transition, power market reform, renewable energy development and grid planning methodologies. It is essential for the EU and China to continue and deepen this ongoing relationship.

This report, 'ENTSO-E Grid Planning Modelling Showcase for China', provides a detailed introduction to the European power grid planning modelling and research method. Taking China's power grid conditions at 2020 as the starting point for reference, the report applies the ENTSO-E modelling method based on scenario building, and shows how the inter-provincial power flow and transmission line development can be synthetically optimised. By applying simulated market prices into the method, the transmission scheme with the lowest overall system cost is screened out, and several transmission projects are selected as cases for detailed cost-benefit analysis (CBA).

In 2010, soon after the enactment and implementation of the Third Energy Package of the European Union in 2009, ENTSO-E started to devise a ten year network development plan (TYNDP) for the European power grid, which is updated every two years in order to ensure it always keeps up with the rapid development of renewable energy. The TYNDP caters for the needs of the electricity market and provides detailed guidance for the development of the European power grid.

Prepared by Chinese specialists, Chapter 3 of this report introduces the process and methods of Chinese power sector development planning (including power grid planning). The planning cycle for the development of China's power system is generally five years. It focuses on the next 10 to 15 years for forecast analysis in order to optimise the future arrangement of power supply and the efficiency of inter-provincial power transmission. Through repeated demonstrations, economically viable cross-regional and inter-provincial transmission schemes are thus identified.

Through participating in this project, experts from both Europe and China have gained an in-depth understanding of each other's power grid planning methods. Although the methods are different, the objectives for grid planning are basically the same, only with different focuses in certain steps. Chinese experts have reaped no little benefit from their participation in the research team working on this project.

Looking forward, renewable energy will see rapid development in order to meet energy transition targets. Yet this leaves many issues that require further study and analysis. I genuinely hope that experts from the EU and China will be able to work together to continue this work towards energy cooperation and exchanges..

Yang Kun

Executive President of China Electricity Council
October 29, 2021

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EXECUTIVE SUMMARY

This is the final report for project A4.1.1: ENTSO-E Grid Planning Modelling Showcase for China, which is part of the EU-China Energy Cooperation Platform (ECECP).

The overall objective of the project is to demonstrate how effective grid planning can enable integration of growing shares of renewables and thereby reduce emissions, so accelerating the transition to clean energy and helping in the fight against climate change.

China aims for CO_2 emissions to peak before 2030 and to achieve carbon neutrality before 2060. This is a tremendous task: China today accounts for half of total global coal consumption and its energy related CO_2 emissions represent about 30% of global emissions. Wind power and solar power installations in the power system, combined with electrification of industry, buildings and transport are all foreseen to be of pivotal importance in achieve these ambitious goals.

The project draws on existing scenarios and modelling frameworks for China and Europe, with an emphasis on market modelling and CBA (Cost Benefit Analysis) in grid planning processes. This will showcase the critical linkage between grid planning and power market reform.

In general, the approach ensures that grid planning is optimised for the common good and addresses the different interests at stake. A key feature of the methodology is the recognition, from the transmission grid planning perspective, that the market will determine the use of the grid.

Europe’s ENTSO-E methodology uses a coordinated and comprehensive transmission grid planning approach, which includes development of scenarios, screening of potential new transmission assets, and combined CBA. The aim is to ensure system reliability, guarantee power supply and integrate more renewable energy (RE) at the lowest possible cost. Comparing current Chinese grid planning approach with the ENTSO-E approach shows a potential gap of improvement for grid planning in China.

Model results indicate that a market-based approach, where transmission expansion is market led (as already demonstrated in the ENTSO-E methodology), could achieve significant CO_2 emission reductions in China’s power system. Simulations of the screening process for new transmission assets show that such transmission investment could lead to CO_2 emission reductions in the power system amounting to 150 million tonnes per year of CO_2 in 2030. The reduction can be achieved because transmission expansion will allow higher amounts of renewables to be generated and transported to consumers, thereby displacing coal-fired power generation.

The project participants believe that the objective of the project has been achieved.

The result of the project offers a suggestion that China should include an interlinkage between grid planning, market modelling and market reforms. It is important to emphasise that further market development in China with a well-established provincial spot market prices is a prerequisite for applying the proposed CBA methodology and reaping the benefits of economic efficient planning. The demonstrated market-based approach will be one of more important measures in order to achieve an affordable transition of the energy system in China. The approach will support the integration of future increased large-scale amounts of renewables (wind and solar) by providing additional transmission capacity, contributing to necessary system flexibility and thereby help pave the way for a transition to clean energy in China.

Looking ahead, both China and the EU need to make use of sector coupling. In the battle against the climate change, it is increasingly necessary to reap the benefits of synergy between the different energy sectors and networks (power, natural gas, hydrogen, heat, industrial processes and transport). Interactions take place through the conversion of energy between different energy carriers and their storage facilities in order to provide services and to ensure that each is managed optimally from an overall perspective.

Enhanced modelling capability is needed in order to analyse sector coupling in both China and the EU. An important first step would be to develop an interlinked electricity and gas market and network model that includes both electricity and gas transmission infrastructure. This could e.g.be achieved, for example, by extending an existing power system model using a gas module and by including the ability to represent the various aspects of Power-to-X. (PtX). [PtX is the process where (green) electricity is converted to hydrogen or other hydrogen-based products].

This project addresses transmission planning in a market framework. It is worth noting also that the present Chinese generation planning needs to change with market reform as has been the case in Europe. This topic could be another study area in future cooperation between China and Europe.

The project was carried out by a project team including the following organisations and with ICF as facilitator:

- State Grid Energy Research Institute (SGERI).
- China Electricity Council (CEC).
- Energy Research Institute under the NDRC (ERI/CNREC).
- Ea Energy Analyses (EA), project lead.

The project started in March 2020 and will finish in late summer 2021.

Comprehensive Resume

Introduction

This is the final report for project A4.1.1: ENTSO-E Grid Planning Modelling Showcase for China, which is part of the EU-China Energy Cooperation Platform (ECECP). An additional proposal for a follow up study is outlined in Chapter 10.

National level grid planners in China and ENTSO-E fulfil a similar role in developing coordinated grid planning across a very large system that is made up of sub-systems.

In the context of further developing the electricity market and interlinked grid planning approach in China, it is appropriate to demonstrate the ENTSO-E grid planning methodology in a Chinese context and thereby show the relevance of the ENTSO-E cost-benefit analysis (CBA) for China.

The overall objective of the project is to demonstrate how effective grid planning can enable integration of growing shares of renewables and thereby reduce emissions, so accelerating the transition to clean energy and helping in the fight against climate change.

The project draws on existing scenarios and modelling frameworks for China and Europe, with an emphasis on market modelling and CBA in grid planning processes. This will showcase the critical linkage between grid planning and power market reform. The project aims to offer hands-on experience of ENTSO-E methodology, not to deliver a transmission plan for China. Comparing the current Chinese grid planning approach (described in Chapter 4) with the ENTSO-E approach shows potential room for improvement for grid planning in China.

The project participants believe that the objective of the project has been met. The results of the project will provide a basis for future effective grid planning in China, taking into account the interlinkage between planning, market modelling and market reforms in China. It is important to emphasise that further market development in China, with well-established provincial spot market prices, is a prerequisite for applying the proposed CBA methodology and reaping the benefits of economic efficient planning. The market-based approach showcased here will be one of the more important measures to help achieve an affordable transition of the energy system in China. The approach will support the integration of future increased large-scale amounts of renewables (wind and solar) by providing additional transmission capacity, contributing to necessary system flexibility and thereby helping to pave the way for a transition to clean energy in China.

The project also offers benefits to the EU. EU companies, including technology providers, energy companies and consultancies, will benefit from increased transparency in the planning processes in China's power system. This transparency will make the market easier to access and will reduce risk. Additionally, efficient grid planning that is based on the showcased market-based approach, combined with an emphasis on RE integration and CO_2 emission reduction, will contribute to global CO_2 mitigation.

The project was carried out by a project team including the following organisations and with ICF as facilitator:

- State Grid Energy Research Institute (SGERI)
- China Electricity Council (CEC)
- Energy Research Institute under the NDRC (ERI/CNREC)
- Ea Energy Analyses (EA), project lead

The steering group is made up of DG ENER; Kristian Ruby, secretary general, EURELECTRIC; Kaare Sandholt, Energy Research Institute of the National Reform and Development Commission; Lei Xiaomeng, senior advisor and personal envoy to Mr YANG Kun, executive president, China Electricity Council; Christian Romig, managing consultant for China; AFRY Consulting, Gianluca Fulli, deputy head of the Energy Security, Distribution and Markets Unit, Joint Research Centre of the European Commission and Ms Bente Hagem, former CEO of ENTSO-E and vice president of Statnett.

The project began in March 2020 and will finish in late summer 2021.

European ENTSO-E planning methodology in a nutshell

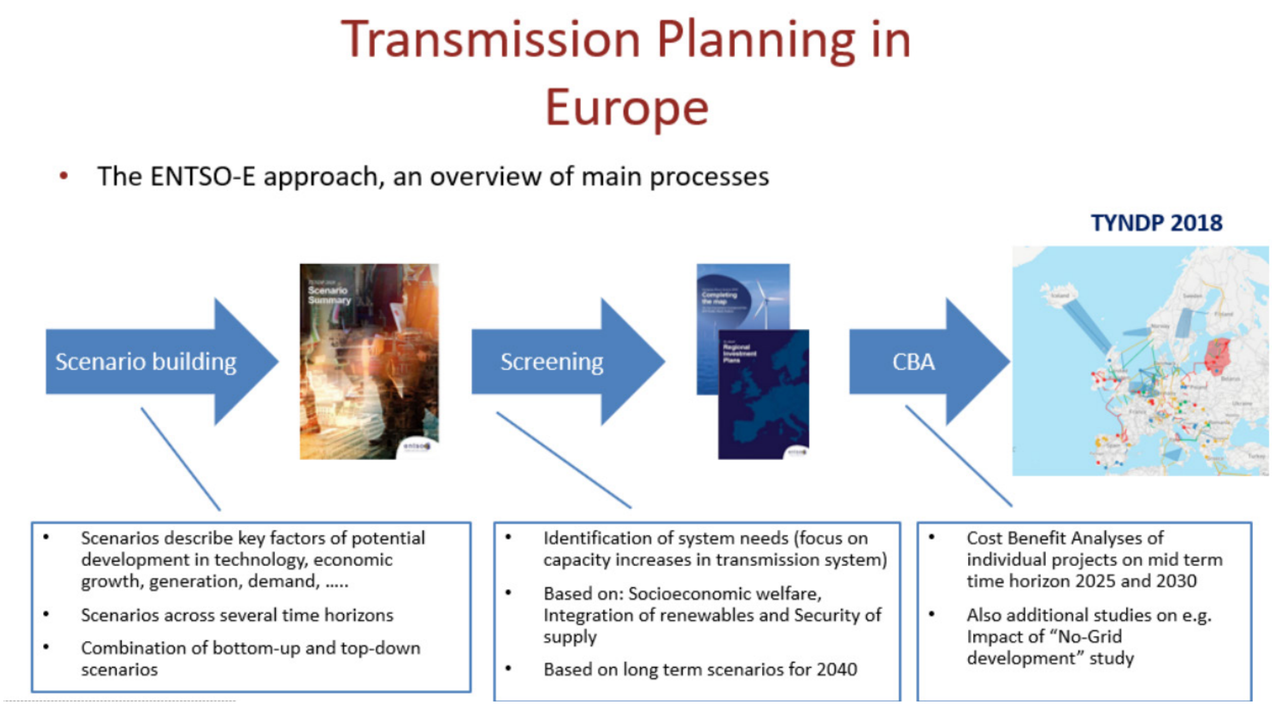
ENTSO-E uses a coordinated and comprehensive transmission grid planning approach, which includes sharing of data, development of scenarios, screening of potential new transmission assets, combined cost benefit analysis (CBA), stakeholder engagement, etc. The aim is to ensure system reliability, guarantee power supply and integrate more renewable energy (RE) at the lowest possible cost.

In general, the ENTSO-E approach ensures that pan-European grid planning is optimised for the common good and addresses the different interests at stake. A key feature of the ENTSO-E methodology is the recognition, from the transmission grid planning perspective, that the market will determine the use of the grid. The main processes in the ENTSO-E approach are scenario building, screening, and CBA.

Scenarios for the Chinese power system

CREO (China Renewable Energy Outlook) 2019 uses scenarios to analyse how renewable energy can be used in the Chinese energy system. The scenarios provide a consistent vision for long-term development as a basis for short-term decisions. Two

Figure 1: ENTSO-E transmission planning process.



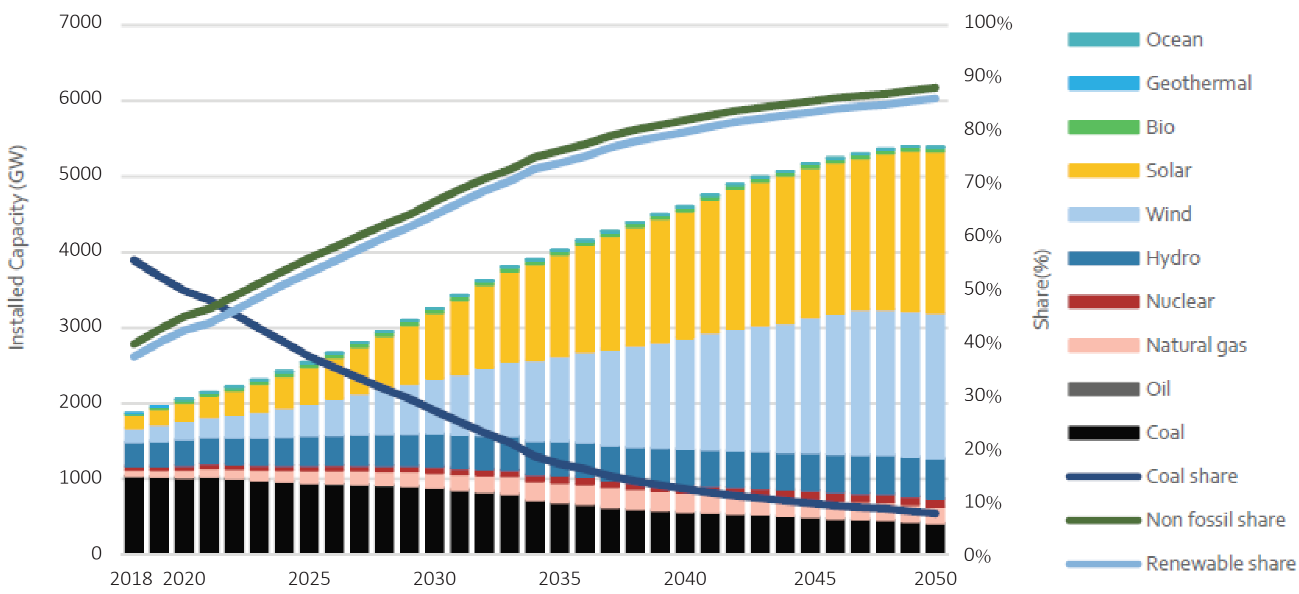
scenarios are used in the project: the Stated Policies Scenario expresses the impact of a firm implementation of announced policies, while the Below 2°C Scenario shows a pathway that China could take in order to fulfil the 2015 Paris Agreement on climate change.

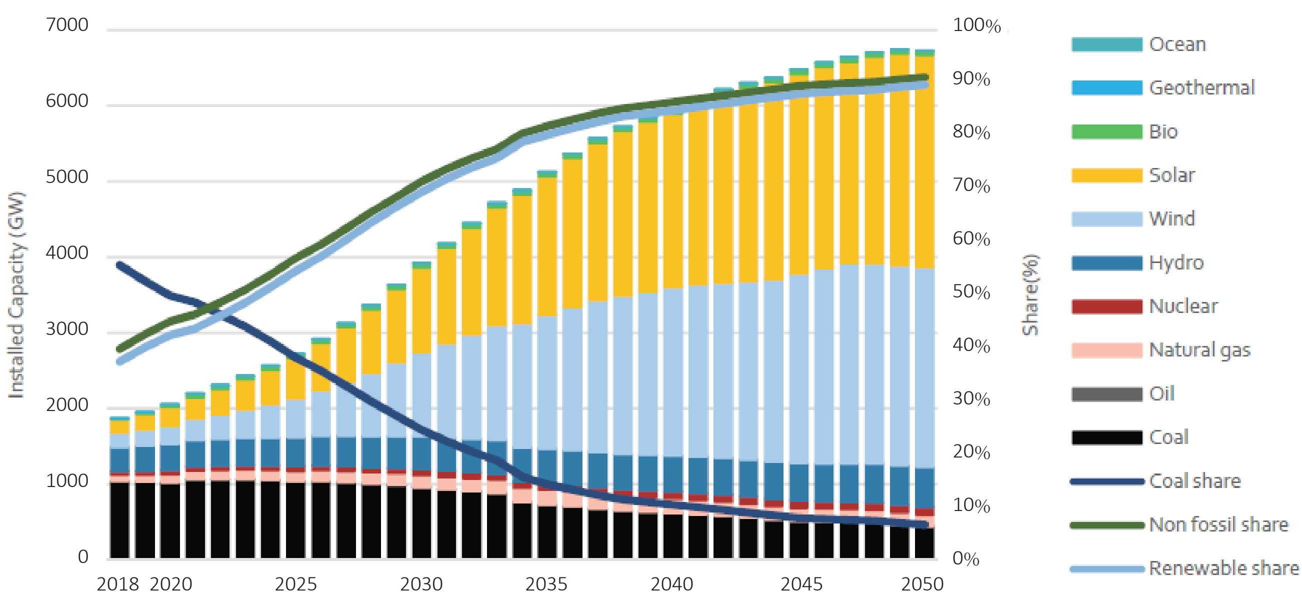
- Stated Policies Scenario. This assumes full and firm implementation of energy sector and related policies expressed in the 13th Five-Year Plan and in the 19th Party Congress announcements. The scenario also includes the NDC climate target for a peak in emissions before 2030, the effects of the Blue-Sky Protection Plan, aspects of the Energy Production and Consumption Revolution Strategy, and the National Emissions Trading Scheme.

- Below 2°C Scenario. This complies with all long-term goals to build a clean, low-carbon, safe and efficient energy system. China's contribution is an essential part of global efforts to comply with the temperature objectives of the Paris Agreement.

Towards 2050 both scenarios show significant increases in power generation from variable renewable energy, which will meet at least 80% of total generation in 2050. By 2030, variable renewable energy meets between 45% and 55% of needs, compared to around 28% in 2020. As wind and solar power generation capacity grows, the distribution of renewable energy resources and demand centres become more relevant, and the importance of the transmission system becomes increasingly clear.

Figure 2: Stated Policy Scenario (top) and Below 2°C Scenario (bottom) for the development of the Chinese power system.





EDO (Electricity and District Heating Optimisation) model

The model used in the project is the ERI/CNREC's EDO model. The model was applied for screening of new transmission lines and CBA assessments of selected potential new transmission investments.

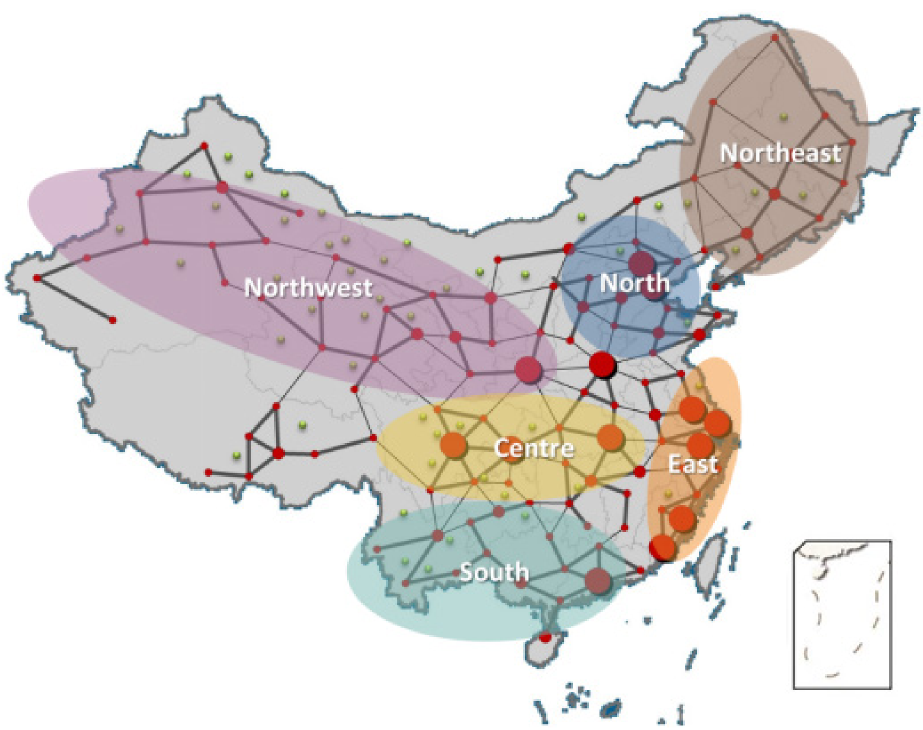
EDO is a combination of a capacity expansion model and an optimal unit commitment and economic dispatch model. Essentially, the model finds the optimum cost solution for the power and district heating sectors by minimising total costs including capital, operation and maintenance, and fuel, subject to constraints such as specific targets or policies that must be met. Policy and scenario assumptions are implemented to guide the model results towards the scenario narrative, rather than allowing the least-cost algorithm solely to determine the capacity mix.

The electricity grid in the EDO model for China is represented at a provincial level. Each province is treated as a node in the network with a particular generation capacity portfolio as well as a predictable electricity demand. It is assumed that there is no congestion within a province.

Demonstration of ENTSO-E screening process for China

The transmission capacities for 2020 and 2025 are based on the existing grid and on firmly planned interconnectors. This is the 'frozen grid' used as a reference for the screening process.

Figure 3: Schematic illustration of EDO model layout - grid 2020.



New transmission projects considered in the screening process are connections between adjacent provinces as well as long distance connections between provinces that are not adjacent, such as the connection between Sichuan and Jiangxi. In the screening process, 76 connections are considered as optional reinforcements of the existing grid towards 2030.

The potential for transmission system buildout is analysed against a background of generation capacity and demand development as defined in the Stated Policies and Below 2°C Scenarios. Both scenarios were originally developed using the EDO model to co-optimise both generation and transmission system investments, using the Normal Annual Investment Calculation (NAIC). However, the aim here is to demonstrate the ENTSO-E methodology of screening in relation to China. The methodology only includes the existing grid and firmly planned grid expansions, leading to a scenario with the same generation capacities, but lower transmission grid capacity. This is referred to as Remove Grid Investment Annual Calculation (RGIAC).

Remove grid investment annual calculation (RGIAC) - 2030
Based on the NAIC result, this case removes projected grid investments but retains the generation investments. It shows the provincial level electricity price differences if no further grid investments are undertaken, while projected generation capacity investments continue.

Screening criteria
'Benefit over cost ratio' is introduced to estimate the value of investing in a new connection against the value of expanding the capacity of an existing connection. It is calculated as MWh price spread over the connection / (MW construction cost of the connection × annuity factor in a particular year. The connections are ranked according to the average 'benefit over cost ratio' under the two scenarios. The ones that have high values have a higher potential to be selected in this screening process. Once the 'benefit over cost ratio' of a connection is equal to or less than a specified reference value, it can be concluded that the connection is no longer a worthwhile investment.

The process starts with a simulation of the EDO model using only the reference grid without the addition of new transmission projects (RGIAC). By iterations (steps) a number of new projects are identified using the screening criteria and are added to the grid. A calculation is then made of the new 'total system costs'. This process is continued until the total system costs after the next step in question is higher than that of the previous step.

Screening process
Through the iterations of the screening process using the criteria explained above, 14 steps have been identified and simulated using the EDO model.

Table 1 shows which projects were selected at each step and the size of the transmission capacity.

Each specific step includes the calculations included in earlier steps, e.g. Step 3 includes the transmission capacity expansions found in Steps 1 and 2.

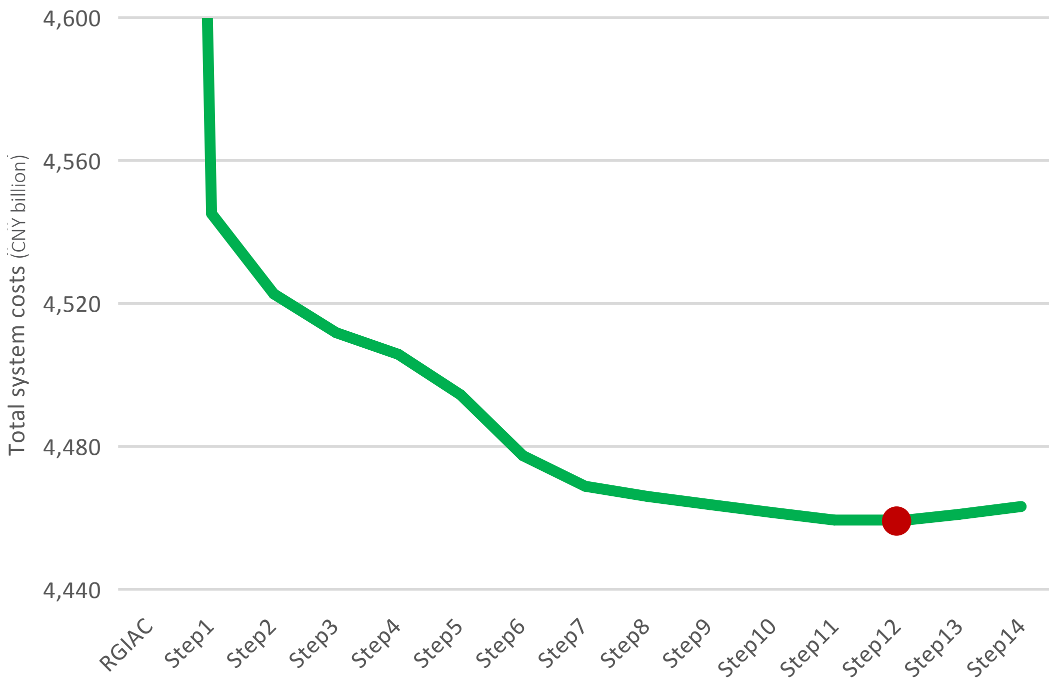
Step 13 and Step 14 show the increasing total system costs (averaged over two scenarios) compared to those in previous steps, thereby indicating that the transmission projects found in the first 12 steps would yield the best solution for the system in terms of social economic welfare.

Table 1: Additional transmission capacity per step in MW.

Transmission capacity (MW)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10	Step 11	Step 12	Total
Hubei - Jiangxi	8 000	2 000	-	-	1 000	2 000	1 000	-	-	-	-	-	14 000
Shanxi - West-Inner Mongolia	4 000	8 000	8 000	4 000	-	2 000	400	400	400	400	2 400	-	30 000
Guangdong - Hainan	100	100	100	100	-	-	-	-	-	-	-	-	400
Qinghai - Tibet	-	4 000	2 000	2 000	-	-	-	-	-	-	-	-	8 000
Hubei - Hunan	-	-	400	-	200	200	400	-	-	-	-	-	1 200
East-Inner Mongolia - Shanxi	-	-	2 000	2 000	400	400	800	400	400	400	1 200	-	8 000
Hunan - Guangdong	-	-	-	400	200	-	200	-	-	-	-	-	800
Henan - Shaanxi	-	-	-	1 000	2 000	400	400	-	-	200	2 000	-	6 000
Ningxia - West-Inner Mongolia	-	-	-	-	400	400	400	400	400	400	1 600	-	4 000
Hebei - West-Inner Mongolia	-	-	-	-	4 000	-	4 000	4 000	4 000	4 000	4 000	4 000	28 000
Chongqing - Xinjiang	-	-	-	-	4 000	-	-	-	-	4 000	-	4 000	12 000
Hunan - Henan	-	-	-	-	-	4 000	-	-	-	-	-	-	4 000
Anhui - Jiangxi	-	-	-	-	-	-	400	-	-	-	-	-	400
Fujian - Jiangxi	-	-	-	-	-	-	400	-	-	-	-	-	400
Guizhou - Hunan	-	-	-	-	-	-	400	-	-	-	-	-	400
East-Inner Mongolia-Hebei	-	-	-	-	-	-	800	400	-	400	2 400	4 000	8 000
Heilongjiang - Jilin	-	-	-	-	-	-	400	400	-	-	400	-	1 200
Chongqing - Sichuan	-	-	-	-	-	-	400	400	-	400	800	-	2 000
Sichuan - Jiangxi	-	-	-	-	-	-	-	4 000	-	-	-	-	4 000
Hunan - Sichuan	-	-	-	-	-	-	-	2 000	-	-	-	-	2 000
Gansu - West-Inner Mongolia	-	-	-	-	-	-	-	400	400	400	800	-	2 000
Henan - Hebei	-	-	-	-	-	-	-	2 000	4 000	400	1 600	4 000	12 000
Hebei - Shandong	-	-	-	-	-	-	-	-	400	400	1 200	6 000	8 000
Anhui - Shandong	-	-	-	-	-	-	-	-	4 000	-	4 000	4 000	12 000
Gansu - Qinghai	-	-	-	-	-	-	-	-	-	2 000	2 000	-	4 000
Henan - Shanxi	-	-	-	-	-	-	-	-	-	4 000	4 000	-	8 000
Hebei - Shanxi	-	-	-	-	-	-	-	-	-	4 000	-	4 000	8 000
Liaoning - Jilin	-	-	-	-	-	-	-	-	-	-	1 200	-	1 200
Hubei - Shaanxi	-	-	-	-	-	-	-	-	-	-	4 000	4 000	8 000
Gansu - Shandong	-	-	-	-	-	-	-	-	-	-	2 000	2 000	4 000
Yunnan - Guizhou	-	-	-	-	-	-	-	-	-	-	-	4 000	4 000

The average total system cost (for the two scenarios) for the power and heat system decreases significantly in the first steps of the screening process. These costs include the total CAPEX for both generation and transmission capacity, as well as the variable costs associated with heat and power generation in the system, which include fuel costs, variable operation and maintenance, start/stop costs on plants, operational reserve payment, emission taxes and value of lost load (lost load decreases in parallel with grid expansion).

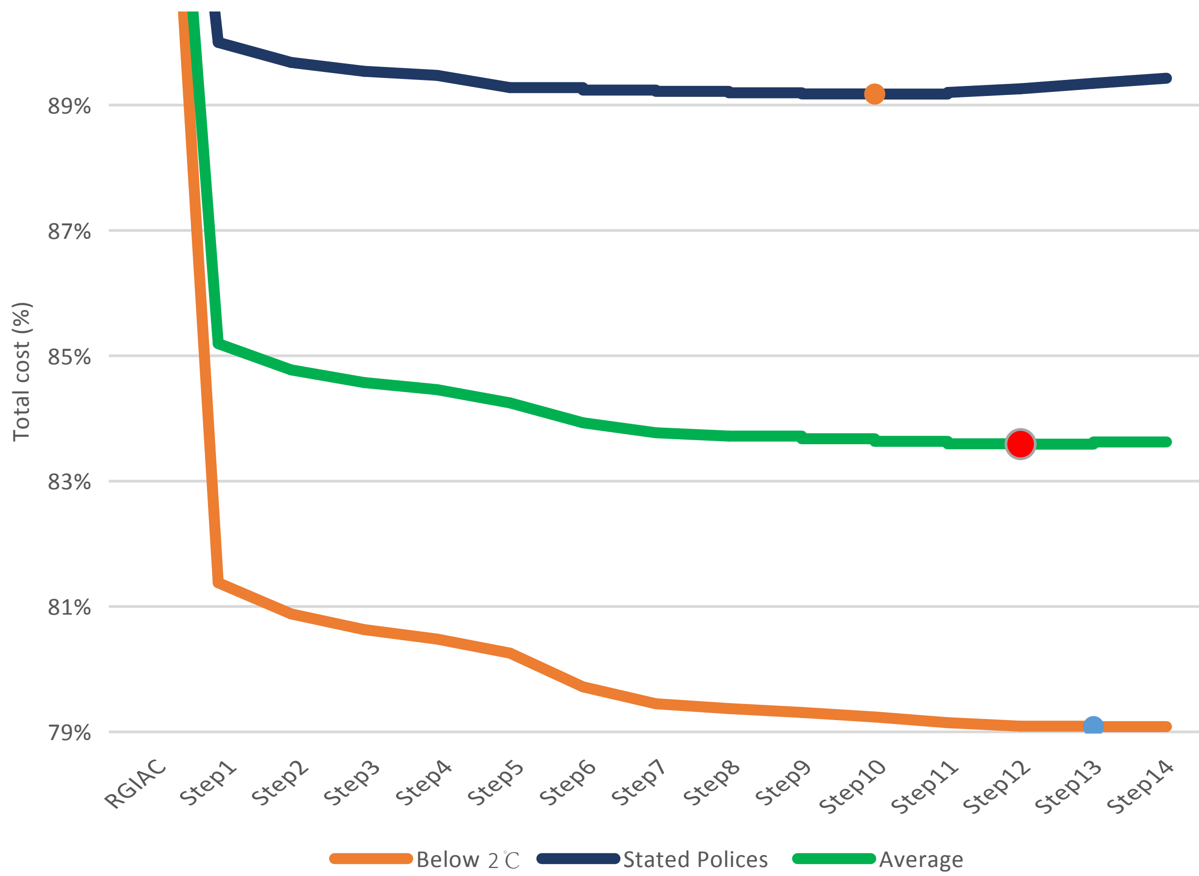
Figure 4: Total system costs at each step of the screening process.



The figure below shows the reductions in total system costs compared to the reference (respective RGIAC power systems) for the two scenarios and their combined average. This demonstrates that the steps of the screening process are sensitive to the system they relate to. In the Below 2°C Scenario the lowest system cost is found in Step 13, while Step 10 shows the lowest cost in the Stated Policies Scenario. On average, the lowest system costs are found in Step 12.

This indicates a need for higher transmission capacity in the Below 2°C Scenario compared to the Stated Policies Scenario, owing to the larger share of renewable energy and thus a greater need for integration through transmission lines. The figure also demonstrates the importance of robust results when determining the viability of transmission projects. The early steps are beneficial in both scenarios, but in subsequent steps the benefit depends on the detailed configuration of the power system in each of the two scenarios.

Figure 5: Total system costs compared to the reference (=100%) in each step of the screening process.



Selection of a portfolio of potential new transmission investments
A selection of lines is chosen for detailed individual cost-benefit analysis. In the ENTSO-E process, projects are evaluated based on their actual projected transmission capacity between two regions.

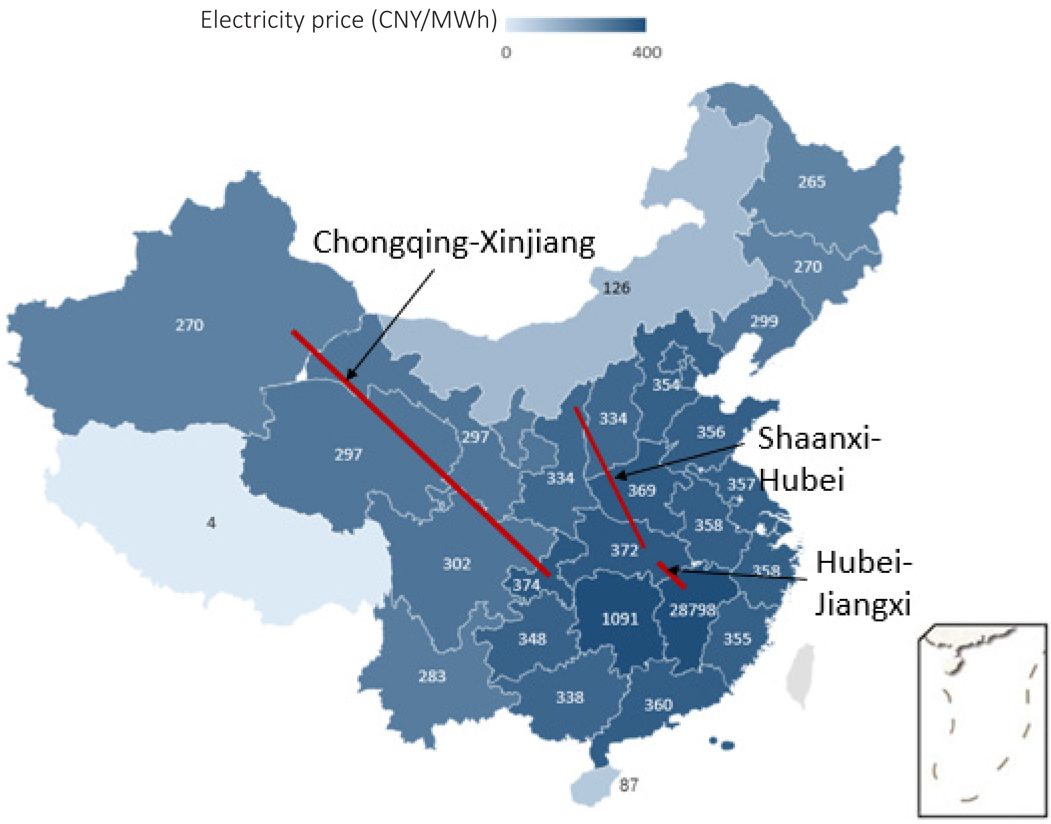
The lines chosen for further individual CBA analysis are 'Hubei-Jiangxi', 'Chongqing-Xinjiang' and 'Hubei-Shaanxi'.

The Hubei-Jiangxi interconnector could be the key to the problem of unmet power demand; the screening process identified a total expansion potential of 14 GW.

Chongqing-Xinjiang is a long-distance project already under consideration and the screening process showed a potential for expansion of 12 GW in total.

The Hubei-Shaanxi project is designed to promote the intensive development of energy supplies in the northern Shaanxi and large-scale power delivery. The connectors are shown in Figure 6.

Figure 6: Proposed lines for further CBA assessment



(Prices are arbitrarily selected as average day-ahead province prices at the start of the screening process)

Table 2: Key parameters of selected transmission lines for CBA analysis

Connection	Capacity	Voltage level	AC/DC	Length
Hubei-Jiangxi	14 000 MW	750 kV	AC	390 km
Chongqing-Xinjiang	12 000 MW	±800 kV	DC	2 300 km
Hubei-Shaanxi	8 000 MW	±800 kV	DC	1 136 km

Demonstrating the ENTSO-E CBA methodology in relation to Chinese transmission investments

General

The result of the screening process for China shows that for a number of potential lines that are scheduled for construction before 2030, the benefits of transmission capacity expansion are higher than they would be for a single project. The value of the first project will be different from the value of the last project (assuming no changes in the surrounding system).

This leaves a number of options for the cost-benefit analysis:

- Value of total transmission expansion of given line.
  This calculation is based on the comparison of a situation without and with the entire transmission expansion in question.

- Value of first project.
  This calculation is based on the comparison of a situation without transmission expansion with a situation where the transmission capacity is increased by one project.

- Value of last project.
  This calculation is based on the comparison of a situation without the final step of transmission expansion with a situation where the final step in the transmission expansion is included.

In the CBA analysis of transmission expansion projects in China, all three approaches are illustrated.

In the CBA analysis, the focus is on CBA parameters generated through market modelling. This choice has been made because markets and market modelling are fairly new concepts in China. Therefore, the greatest value to China from the present study is to demonstrate the application of these new concepts to Chinese conditions.

The selected CBA parameters are:
- SEW (socio-economic welfare)
- Fuel costs (included in SEW)
- CO_2 reduction (included in SEW)
- RES integration: Reduction in curtailment (GWh/yr)
- CAPEX (capital costs) for investment in question
- OPEX (operational and maintenance expenditure) for the investment in question

During the screening process an estimate for the best portfolio of transmission lines was found in Step 12. Therefore, the transmission system corresponding to Step 12 is used as the reference transmission grid for CBA analysis and the resulting cases will be referred to in relation to Step 12.

CBA results – Year 2030
The CBA is demonstrated by the results for the line Chongqing-Xinjiang.

The cost benefit assessment is summarised in Table 3. It follows that all expansions have a positive net benefit.

Table 3: Annual cost benefit in CNY million.

Annual cost-benefit	Chongqing-Xinjiang		
	All 12 GW	First 2 GW	Last 2 GW
Fuel Cost	6 157	1 166	907
Variable O&M	-43	-18	-14
Start-up and ancillary services	197	61	-11
Taxes, quotas, and subsidies	581	156	58
Total dispatch benefit	**6 892**	**1 364**	**939**
Value of lost load	-2	-2	-0
Capital cost transmission	-4 773	-796	-796
Total cost benefit	**2 117**	**566**	**143**

Figures 7, 8 and 9 show the CBA-results for Chongqing-Xinjiang.

They show that all expansions lead to lower CO_2 emissions as coal is replaced with natural gas and wind. The increased wind power in the system is the result of reduced curtailments.

Figure 7: Increase in CO_2 emissions for the full project, the first 2 GW and the last 2 GW of the Chongqing-Xinjiang line in kilotons/yr and the respective CO_2 emission change per MW transmission capacity. Positive values are increase in CO_2 emissions.

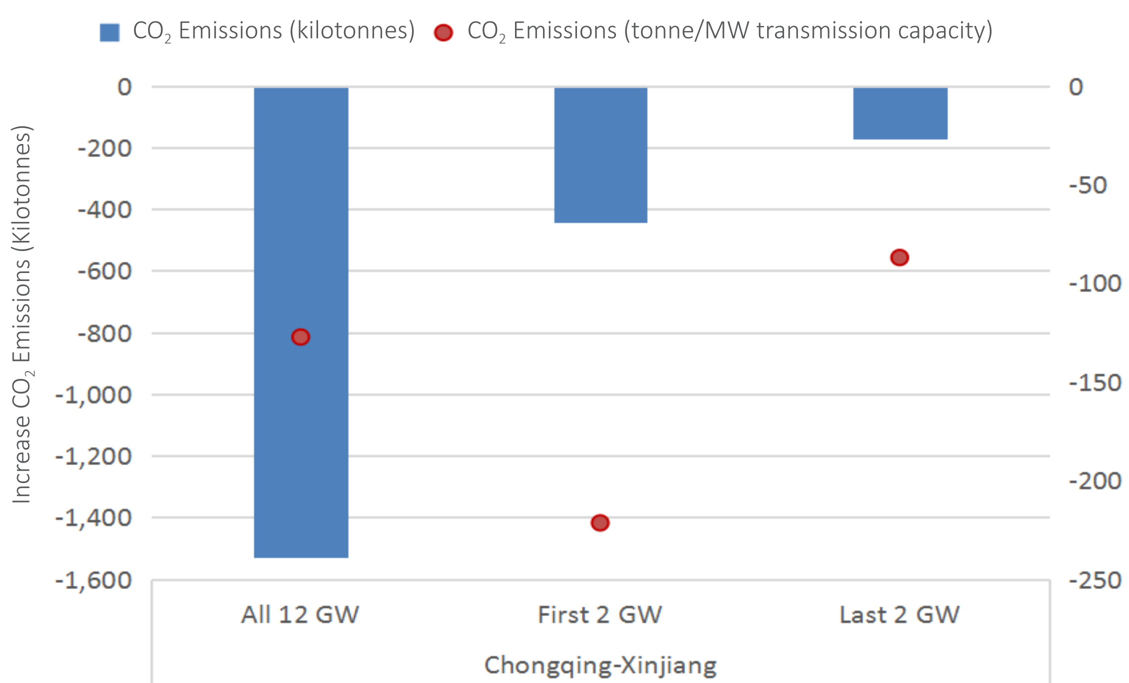


Figure 8: Change in electricity generation for the full project, the first 2 GW and the last 2 GW of the Chongqing-Xinjiang line in TWh/yr. Positive values mean an increase in generation due to transmission expansion.

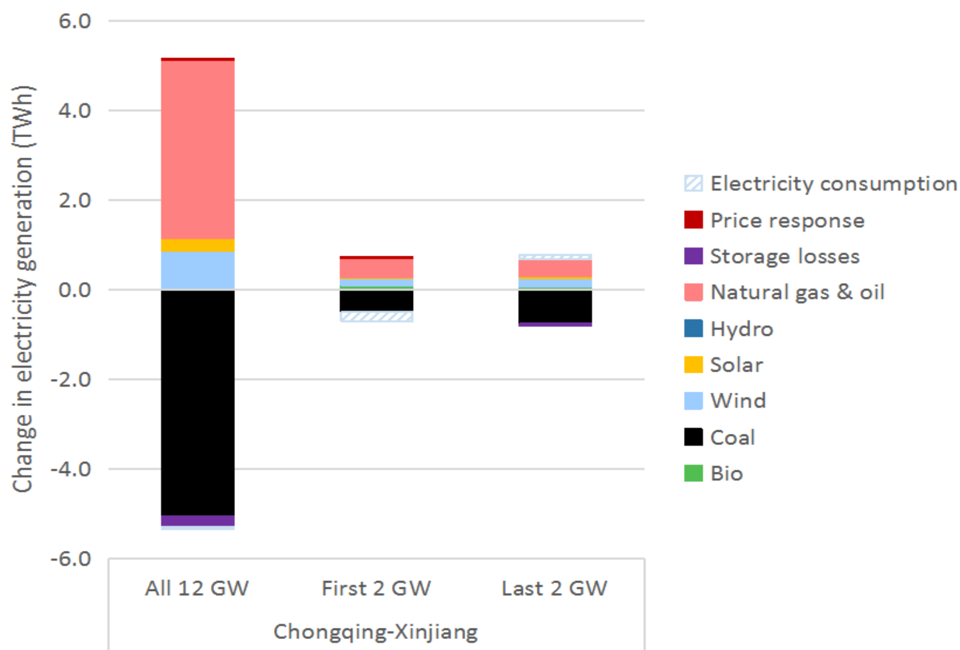
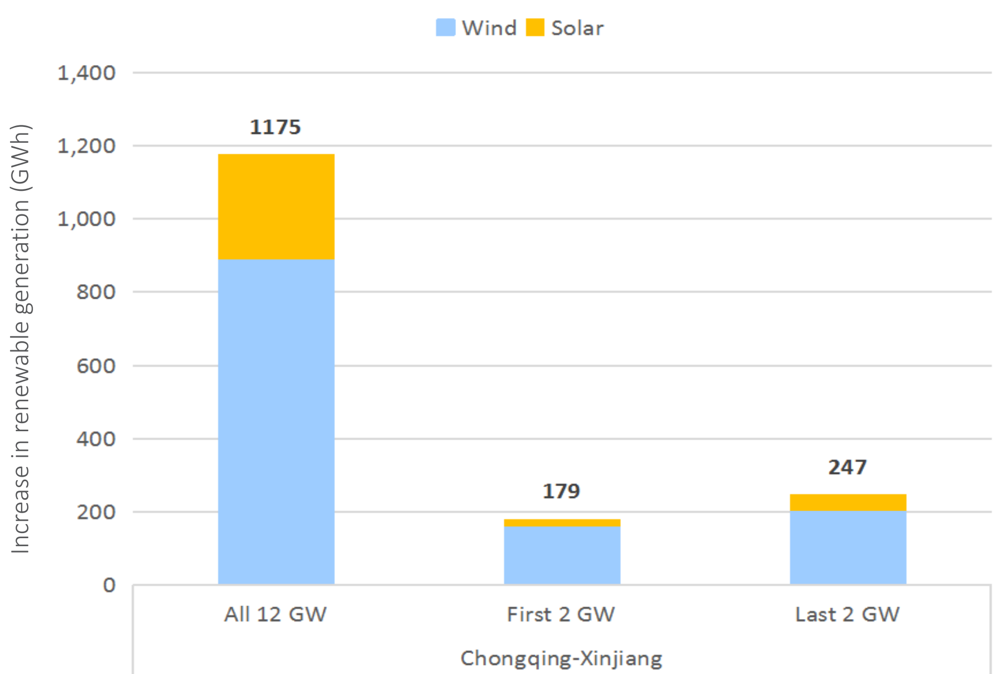


Figure 9: Increase in renewable electricity generation for the full project, the first 2 GW and the last 2 GW of the Chongqing-Xinjiang line in GWh/yr. The increase is due to reduction in curtailment of wind and PV.



The following figures show the duration curves for price difference at transmission endpoints in the two scenarios in alternative development schemes.

The sum of hourly price differences over the year at a given stage of expansion is equal to the marginal value of transmission expansion. The values are presented in the table below.

Figure 10: Duration curves for price difference at transmission endpoints (Chongqing to Xinjiang) after 12 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of expansion. Below 2˚C Scenario, numbers in CNY/MWh.

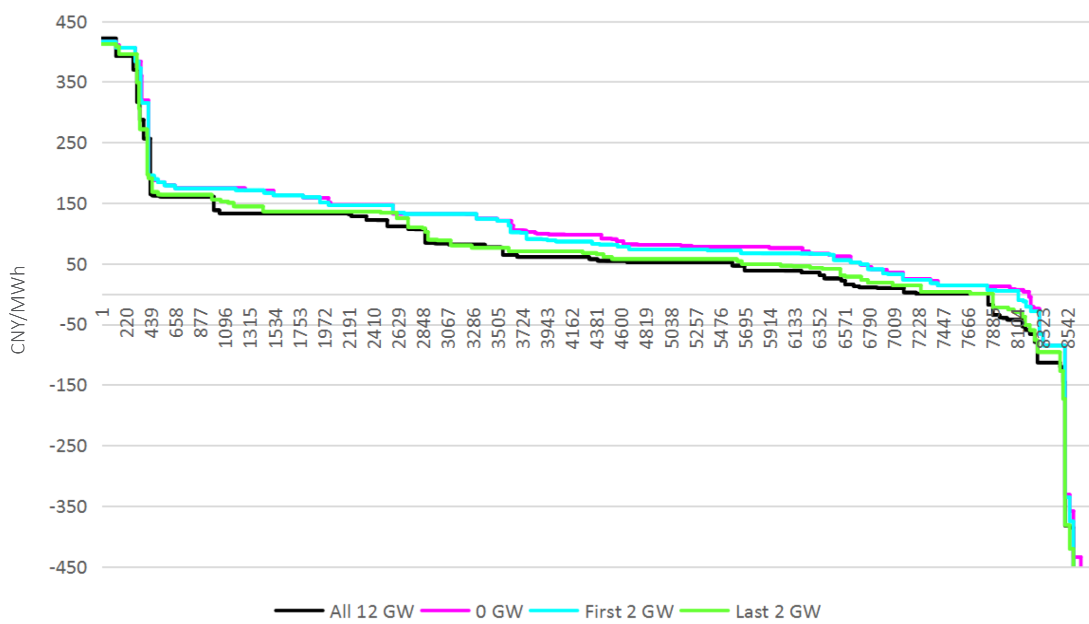


Figure 11: Duration curves for price difference at transmission endpoints (Chongqing to Xinjiang) after 12 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of development. Stated Policies Scenario. Numbers in CNY/MWh.

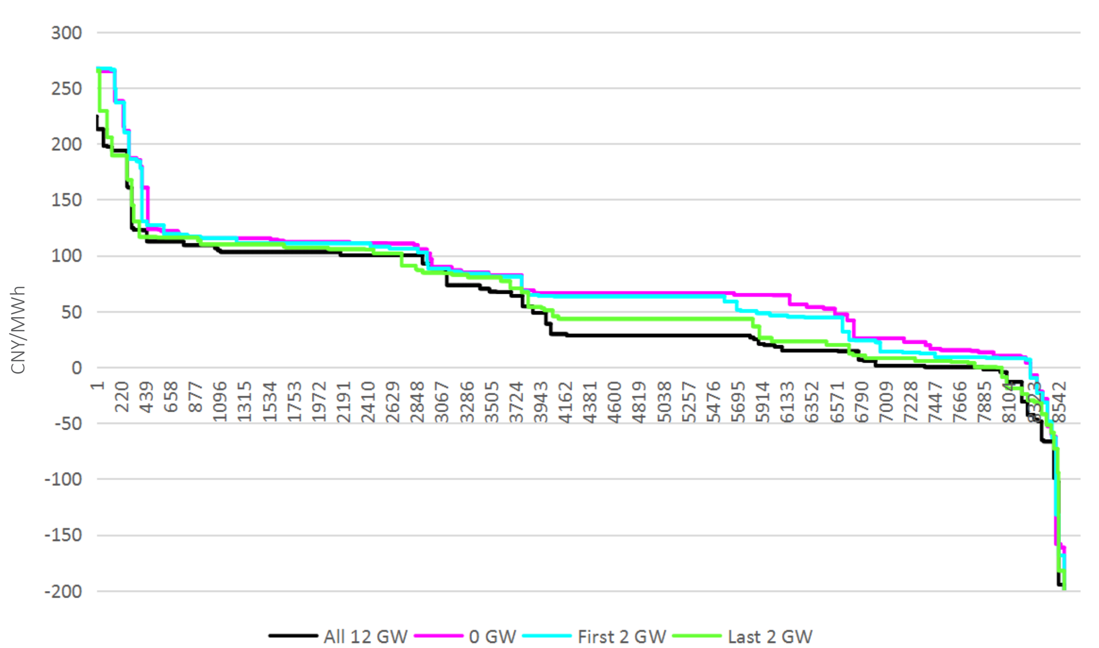


Table 4: Marginal value of expansion. Numbers in CNY million /MW/yr

Marginal value of expansion	Chongqing-Xinjiang			
	0 GW	First 2 GW	Last 2 GW	All 12 GW
Below 2°C	1.05	1.03	0.89	0.84
Stated Policies	0.75	0.72	0.64	0.59

Annual investment cost per MW: CNY 0.40 million.

It follows that the marginal value of expansion is higher than the marginal cost of expansion in all cases. It also follows, as expected, that the marginal value of expansion decreases as line capacity increases.

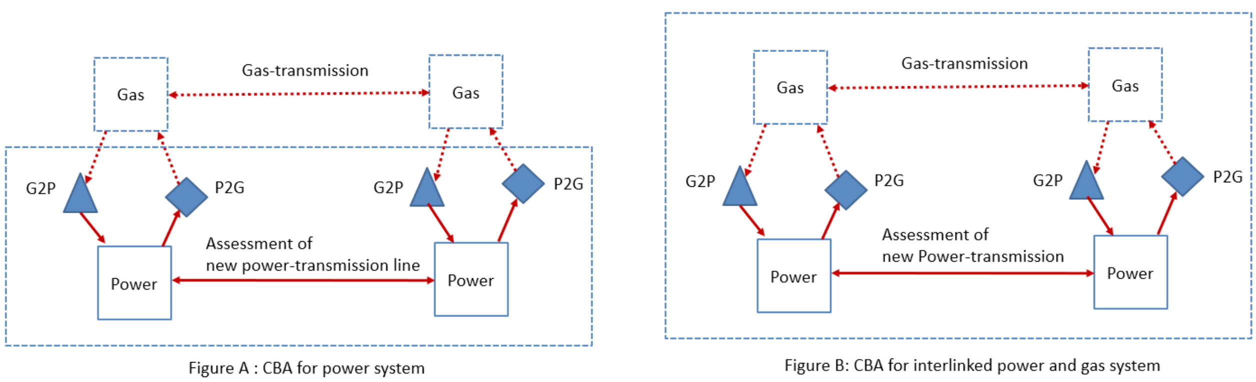
Proposal for 'follow up' study to the A4.1.1 project

In the context of European transmission system operators (TSO), the assessment of the power and gas system has for some time been the subject of discussion between the ENTSOs (ENTSO-E and ENTSO-gas), the European regulator (ACER) and the European Commission.

According to Regulation (EU) No 347/2013, the ENTSOs must develop a 'consistent and interlinked electricity and gas market and network model including both electricity and gas transmission infrastructure'.

The ENTSOs have delivered an interlinked model that focuses on common scenario building, but ACER take the view that a number of additional aspects should be investigated in more detail. This would mean that interlinkage issues could be included in the cost benefit calculations for power and gas projects in the TYNDP for power and gas.

Figure 12: Illustration of interlinkage between power and gas systems. A: separate system approach. B: Interlinked systems



(Source: Ea Energy Analyses)

In the illustration above, the linkages between the gas and power system are illustrated by G2P (gas to power stations) and P2G (power to gas). In reality, there are more linkages between the two systems, but here the linkages are limited to G2P and P2G for the sake of simplicity.

It is clear that an assessment of a new project, e.g. a power line, that is limited to an estimate of the impact on the power system could prove inadequate (see above, Figure A). A new power line may also have a significant impact on the gas system in relation to the quantity of gas supply to power stations, the amount of green gas production (P2G) and the amount of gas flowing into the gas transmission lines (see above, Figure B).

Gas is expected to play an important role in the coming years in China, as coal consumption is reduced. It would therefore be beneficial to enhance power system models in China (e.g. the ERI's EDO model) with a gas module that includes the ability to represent the various aspects of Power-to-X. This adjustment would significantly enhance the energy system modelling capability.

This project addresses transmission planning in a market framework. It is worth noting also that the present Chinese generation planning needs to change with the market reforms as has been the case in Europe. This topic could be another study area in future cooperation between China and Europe.

1. INTRODUCTION

This is the Final Report for project A4.1.1: ENTSO-E Grid Planning Modelling Showcase for China, EU-China Energy Cooperation Platform (ECECP).

The project was launched at a virtual online web-based event on 17-19 March 2020.

The project participants are SGERI, ERI/CNREC, CEC, Ea Energy Analyses and ICF as facilitator.

At the launch, a number of presentations were given by the project partners about current transmission planning in China and EU, markets, market models and scenarios. A discussion took place about the way forward: which tasks were necessary and how the work should be distributed among the project parties.

As an initial task, the project parties agreed to put together an inception report, to include the knowledge collected at the launch with additional relevant elaborations. The inception report was submitted in May 2020.

The inception report included a detailed scoping of the project tasks with a description of the screening process, the selection of potential new transmission investments and cost benefit analysis of selected transmission investments.

In October 2020, the Steering Group held a virtual meeting with the project participants and entered further discussions about the objectives and progress of the project. The meeting saw a presentation of the preliminary screening results under to the ENTSO-E planning process.

The Screening Report was submitted in December 2020. The report demonstrated how the EU/ENTSO-E screening process can be applied to potential new transmission lines/ corridors in China.

Taking 2030 as the cut-off point, a selection of potential new transmission lines were submitted for a detailed CBA analysis.

The CBA Report was submitted in April 2021. It offered a CBA assessment for three selected transmission investments. The assessment was conducted using the European CBA methodology applied to ENTSO-E transmission system planning.

The current report describes the tasks carried out by the project parties and summarises the main contents of the previous reports: Inception Report, Screening Report and CBA Report.

The report is structured as follows:

Chapter 2*: Market development in China in comparison to the EU.

Chapter 3*: The transmission planning process in China today.

Chapter 4: Transmission system planning in Europe.

Chapter 5: The scenarios for China's power system development used in the demonstration of EU/ENTSO-E transmission planning methodology.

Chapter 6: Description of the energy system models applied.

Chapter 7: Grid representation in the models.

Chapter 8: Demonstration of the European screening process in relation to transmission grid investments in China.

Chapter 9: CBA for potential Chinese transmission projects. Demonstration of European methodology.

Chapter 10: Proposal for a follow up study after completion of A4.1.1.

Annex 1 offers a simple alternative method developed by CEC for pre-screening transmission investments in China.

Annex 2 provides SGERI's description of the five projected important long distance transmission lines (in cooperation with CEC) .

Annex 3 consists of minutes of the ENTSO-E China Showcasing Project Steering Group Meeting, 13 October 2020.

***Chapters 2 and 3 together give an overview of the Chinese power market development and planning process, which are also presented in the Energy Modelling in EU and China report. These sections are included in both reports for completeness.**

Glossary

Term	Description
BIPV	Building Integrated Photovoltaic Power
CapEx	Capital Expenditure
CBA	Cost benefit Analysis
CFD	Contract for Difference
CNREC	China National Renewable Energy Centre

Term	Description
CREO	China Renewable Energy Outlook
CSG	China South Power Grid
CSP	Concentrated Solar Power
ECECP	EU-China Energy Cooperation Platform
EDO	Electricity and District Heating Optimisation
EENS	Expected Energy Not Served – the amount of electricity demand that is expected not to be met by generation in a given year
ENTSO-E	European Network of Transmission System Operators for Electricity
ERI	Energy Research Institute (China) of the NDRC
FCA	Forward Capacity Allocation
G2P	Gas to Power
GTC	Grid Transfer Capacity
HVDC	High Voltage Direct Current
ICE	Internal Combustion Engine
KPI	Key Performance Indices
LOLE	Loss of Load Expectancy
NAIC	Normal Annual Investment Calculation
NDRC	National Development and Reform Commission
O&M	Operation and Maintenance
OPEX	Operational and Maintenance Expenditure
P2G	Power to Gas
PINT	Put In one at a Time
Prosumer	An Individual Who both Consumes and Produces Energy
PX	Power Exchange
RAB	Regulatory Asset Base
RE	Renewable Energy
RES	Renewable Energy Systems
RGIAC	Remove Grid Investment Annual Calculation
SERC	State Electricity Regulatory Commission
SEW	Socio-Economic Welfare
SGCC	State Grid Corporation of China
SPCC	State Power Corporation of China
T&D	Transmission and Distribution
tce	Tonnes of Coal Equivalent
TOOT	Take Out One at a Time
TPA	Third Party Access
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan
UHVDC	Ultra High Voltage Direct Current
VIU	Vertically Integrated Utility
VRE	Variable Renewable Energy

2. MARKET DEVELOPMENT IN CHINA AND THE EU

2.1 Power market development in China

China has experienced a long process of market-oriented reform in the power sector since last century, marked by three directives from the national government. The directives have clearly divided the process into three stages. By 2019, the power sector in China had developed from one with a critical shortage of power supply to one with a fully interconnected national power system with a capacity of 2 010 GW, an RES share in total generation (including hydro) of 26.37%, and 14 UHVDC transmission lines. This history of development is central to a review of the process of market-oriented reforms in the power sector to promote sustainable development of power industry, as well as the systematic and gradual implementation of the transition to clean energy.

2.1.1 Stage 1 (1985-2001)

'Directive 1985/72 Resolution for Multi-Channel Funds Raising for Power Development and Multiple Electricity Pricing' issued by the State Council of the People's Republic of China (hereafter Directive 72) guided the process. Before the early 1980s the power sector was owned and vertically operated by both national and local government. For some time, China had experienced serious shortages in power supply and investment which were having a critical impact on the development of the national economy. Directive 72 widened the investment channels and changed the state ownership to some extent.

The main points of Directive 72 are:

- encouraging foreign investors, local governments, enterprises and even individuals to invest in power projects with cost plus pricing.
- using a double track electricity pricing system including cost+ based and electricity rationing.
- withdrawing government control over vertically integrated utilities; setting up a power dispatching hierarchy.

After the implementation of Directive 72, power generating capacity developed rapidly and the provincial power systems were interconnected to form six regional systems. A level pricing system was introduced for each power plant, however this system of 'one price for one plant' distorted the electricity price. The State Power Corporation of China (SPCC), a vertically integrated utility, was founded in 1997, introducing full separation between government and power enterprises.

2.1.2 Stage 2 (2002-2014)

'Directive 2002/5, The Resolution of Power Sector Reform in China' (hereafter Directive 5) guided the process.

The process built on the reforms introduced by Directive 72. The main points of Directive 5 are:

- unbundling generation from the vertically integrated SPCC.
- establishing an independent regulator, State Electricity Regulatory Commission (SERC).
- starting market-oriented competition on generation.
- divestiture of non-T&D regulatory asset base (RAB).
- development of cross regional power transmission.

In the process, SPCC was separated into two TSOs - SGCC (State Grid Corporation of China) and CSG (China South Power Grid) - and five generating groups, comprising 50% of total power generation capacity in China. Since that time, many generating companies have emerged which have broken the monopoly and provided competition. Major adjustments were made to the 'one price, one plant' electricity pricing structure. A benchmark price was implemented for coal-fired power plants based on fuel cost in each province, resulting in a single price for coal fired power plants in each province. These were all interim steps on the way to market competition. In line with the terms of Directive 5, SERC issued a series of rules for tariff reforms, network codes, operation, ancillary services and so on.

A pilot of annual and monthly generation competition in the northeast region extended to 80% of total generation with a single buyer model. It was intended that the findings from this pilot would be used to inform the introduction of further market competition. However, significant issues remained, and the momentum towards a more market-oriented system stalled. SERC became part of the National Energy Administration (NEA) in 2013.

2.1.3 Stage 3 (2015-present)

'Directive 2015/9, The Resolution for Deepening Power Sector Reform' (hereafter Directive 9) formed the basis for further development of the power sector.

Directive 9 was issued in 2015 and draws on the experiences and lessons learned in the previous two stages of development, whilst taking on the additional challenges of the transition to clean energy.

The main points are:

- further deregulation of the generation and consumption tariff and schedule.
- retail business opening.
- full implementation of third party access (TPA) in transmission and distribution.
- establishing independent power exchanges (PX).
- opening new distribution businesses to public investment.
- enhancement of power development planning, regulation, safe operation, security of supply.

The Directive introduced guidelines and rules relating to transmission and distribution tariffs, establishment of power exchanges, market design, market-oriented scheduling for generation and consumption, inter-provincial and inter-regional power trading, retail, and new distribution businesses opening for public investment, embedded generation, renewable energy and so on.

Beijing's PX is responsible for cross-provincial and regional power trading in the SGCC service area; Guangzhou PX deals in cross provincial power trading in the CSG service area, while the provincial PXs oversee power trading in their own provinces.

Transmission and distribution tariffs designed using a cost+ methodology for the provinces have been approved by local governments, but transmission and distribution businesses have not yet become independent entities. Directive 9 has played an important role in promoting market development. Market trading of electricity represented 38.22% of total electricity generation in 2019.

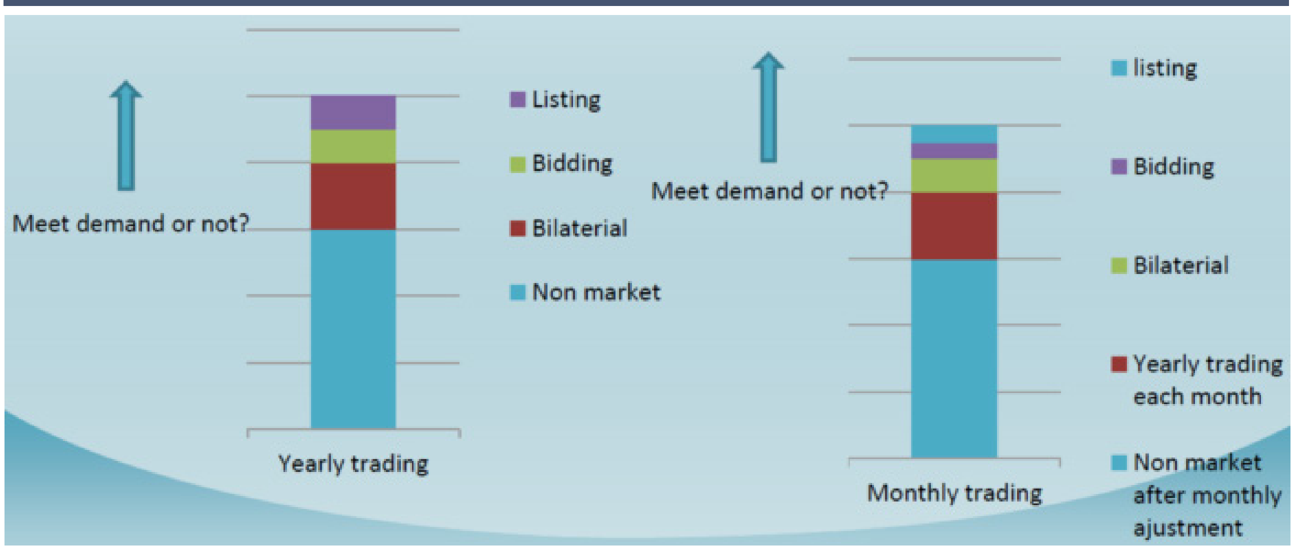
A feed-in tariff was selected for variable RES, with regulated prices, but in some provinces with a high production of variable RES, the regulated price for a set volume of variable RES was reduced. Most coal-fired power generation businesses have been exposed to the market and are subject to a +10% price ceiling and -15% price floor as introduced by the NDRC's Document No. 1658 .

2.1.4 The development of long- and medium-term power trading, inter-provincial and regional power trading and the spot market.

Annual and monthly power trading in the provinces
The annual generation schedules of the non-market part are organised and then allocated to each month, while residual electricity is traded on the market until demand is met.

Monthly power trading follows the same process once the annual power trading has been allocated. Both annual and monthly power contracts are traded once or twice before delivery. It is not a continuous process.

Figure 2.1: Annual and monthly trading.

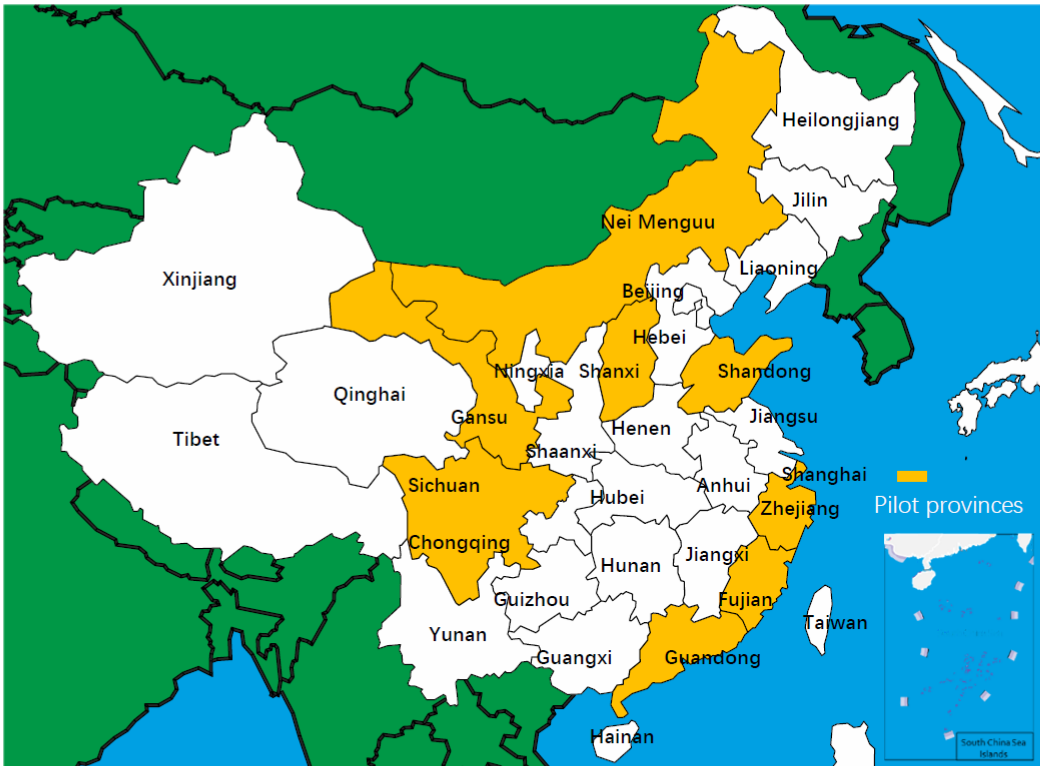


Inter-provincial and regional power trading
In China, demand is concentrated in the east, while the coal mine deposits and RES are predominantly in the west. It is now common to see long distance and high-volume energy transmission being used to optimise allocation of energy resources. Total cross-regional transmission capacity stood at 136.15 GW in 2018. Some basic rules for annual and monthly inter-provincial or inter-regional trading are as follows:

- Contract path principle.
- Wheeling charges with stamp methodology.
  Provincial charges (220 kV and below at most, only if the generators are connected to the provincial grid).
  Regional charges (500 kV and above, with power trading using the regional grids, based on the contract path).
  Charges for the use of inter-regional transmission lines (HVDCs at most).
- A sequence of annual and monthly power trading, coordination with non-market sector.

The spot market
After annual and monthly trading, residual demand is handled in the spot market. The NEA has designated eight provinces as pilot spot markets (Figure 2.2). These eight provincial systems have selected two different models for their local spot markets.

Figure 2.2: The eight provinces with pilot spot markets.



Model 1: Annual and monthly power trades are physical contracts and residual demand after the annual and monthly power trading is handled in the spot market. Suppliers and large consumers may participate in the spot market and trade with generators directly.

Model 2: Annual and monthly power trades are governed by Contract for Difference (CFD) financial contracts. The full volume of generation is traded on the spot market and the annual and monthly trades are settled by CFD contracts in each trading period.

2.1.5 Recent progress in power market development

Power market reform has seen significant progress following the publication of two documents by NDRC and NEA jointly in the first half of 2020:

- 'The basic rules for medium and long-term power trading revised'.
- 'The notification of promoting continuous trial operation with financial settlement for the pilot power spot markets'.

Outlines of 'the notification of promoting continuous trial operation with financial settlement for the pilot power spot markets' and recent progress.

The national government issued this document in March 2020 to guide the financial settlement process.

Its main points are as follows:
The pilot spot markets represent an important step in power sector reform. They will help to build a fair and competitive market environment by: strengthening guidance in the initial stages; improving the connections between spot market and long/medium power trading; reinforcing management of the financial settlement process in the spot power markets; maintaining the neutrality of power market operators; preventing the risks of market distortions and so on.

Recent progress
In accordance with the quarterly monitoring reports of power market reform published by CEC, some of the pilot provincial markets have begun a continuous trial operation with financial settlement. For example, Fujian provincial power market has started a continuous trial operation with financial settlement for two months. Others are preparing to begin the process.

Some difficulties in the pilot spot markets persist. For example, on one occasion there were significant imbalances in day-ahead power trading in Shandong power market because a large amount of VRE was imported from other regional systems but did not enter the spot market. The Shandong market operator revised the market rules to distribute the cost of the imbalance between the generators and suppliers or large users. This incident has shown that coordination between market and non-market trading, long/medium and spot market, provincial and cross-provincial trading needs to be carefully handled.

Outlines of 'the basic rules of medium and long-term power trading revised', and recent progress.

This revised version of the basic rules for medium and long-term power trading summarises the operational experiences of medium and long-term power trading over recent years. Some of the important points are: more trading products relating to years, year, season, month, and week and distinguished as peak and off-peak; additions and improvements to regulations for market participation, trading products, pricing, trade scheduling, non-market and market trading coordination, imbalance treatment, security checks, market supervision, ancillary services, partial VRE participation, continuous trading in the trading period and so on.

Recent progress

Most provinces have drawn up their own provincial rules based on the national rules and the process bears some resemblance to elements of the EU's 2009 Third Energy Package – a legislative package that aimed to further open up the gas and electricity markets in the European Union.

In 2021, 'the rules of medium and long-term cross provincial power trading in East China region' were announced by the regional regulator. This represents an important instance of provincial power markets coupling in one region and will add to an accumulation of experience of market coupling in regional systems at a national level.

2.2 Comparison with development and status in Europe

The development of the power market and transmission systems in China and Europe have some similarities, such as large, interconnected power systems, a step-by-step process of market development, three directives in China and three energy packages in Europe, RES targets and carbon emission reduction targets.

The power sector in Europe has experienced unbundling transmission from VIUs, regulated Third Party Access (TPA), T&D tariff, independent regulators, retail business opening, market coupling, and cross border trading guided by the three energy packages issued by the European Commission between 1996 and 2018.

The power sector in China has taken the similar road map. It has introduced double track electricity pricing, levelised cost plus pricing for generators, benchmark pricing for coal fired generation, unbundling generation from vertically integrated undertakings (VIU), regulated third party access, T&D tariff, independent regulator, retail business opening, and a competitive market, as directed by the three directives between 1978 and 2021.

The key features in Europe and China are explained as follows:

- **Unbundling**
  China: The competitive part, generation, was separated from the monopoly part, transmission and distribution after unbundling.
  Europe: The monopoly part, transmission and distribution, was separated from the competitive part, generation and supply, after unbundling.

- **Independent regulation**
  China: The independent regulator, SERC, was founded in 2003 and became part of the NEA in 2013.
  Europe: The independent regulators were established following the issue of the Third Energy Package by the European Commission.

- **Power exchanges (PX)**
  China: The PXs are relatively independent to a certain extent and TSOs hold shares in the PXs.
  Europe: The PXs for long and medium-term trading (financial trading) are independent and the PXs for the spot market are owned by TSOs.

- **Long and medium-term trading**
  China: Energy-only trading is not separated into peak and off-peak trading. The trading process is not continuous: trades may occur one or more times prior to delivery.
  Europe: Energy trading is separated into peak and off-peak periods and the trading process is continuous. Trading can take place during the trading period with no limit on frequency.

- **Power dispatching**
  China: SGCC and CSG have set up highly hierarchical power dispatching structures and these have played important roles in ensuring the safe and stable operation of the transmission systems.
  Europe: A pan-European power coordinating centre is under consideration. Some regional power coordinating centres already exist, in countries that are already closely interconnected.

- **Transmission capacity allocation**
  China: HVDC transmission lines now transmit a large amount of power from energy resource rich provinces to distant regions with a high concentration of load centres, and interconnect all the regional systems countrywide. All the transmission assets are owned by SGCC and CSG and transmission capacity is efficiently allocated and utilised.
  Europe: The Forward Capacity Allocation guideline (FCA) lays down detailed rules on cross-zonal capacity allocation in the forward markets and on the establishment of a common methodology to determine long-term cross-zonal capacity, as well as the establishment of a single allocation platform at European level offering long-term transmission rights.
  The allocation of transmission capacities between bidding areas in the spot market in Europe is determined implicitly in the European market optimisation algorithm.

Summary
On many issues China and Europe have to some extent exploited parallel paths in market development.

3. TRANSMISSION PLANNING PROCESS IN CHINA TODAY

3.1 Chinese power system planning

3.1.1 Chinese power planning process

Power planning consists mainly of national power planning and provincial power planning. The national power plan is prepared and issued by the NEA after having been approved by the NDRC. The provincial-level power plan is prepared by the provincial energy authority and is reported to the provincial government for approval and publication after being reported to NEA. The national power plan guides the provincial power plan. The provincial power plan complies with the national power plan and the provincial energy development plan.

EPPEI (Electric Power Planning and Engineering Institute) is the main unit responsible for electric power planning research work. It is tasked by the NEA and the provincial energy authority to carry out specialist and comprehensive research on electric power planning.

Electric power enterprises implement and ensure the safety of electric power planning. They are responsible for providing basic planning data, undertaking research topics for electric power planning, making planning recommendations, cooperating with planning, and preparing business cases in accordance with approved national and provincial power plans. Relevant units such as power industry federations and other industry associations, societies, scientific research institutions, and universities are required actively to coordinate power planning work and make research recommendations to the competent energy department.

NEA and provincial energy authorities carry out power planning two years in advance. Power planning in China consists of five steps: research and preparation; compilation and connection; review and release; implementation and adjustment; evaluation and supervision.

(1) Research and Preparation
Power planning research includes planning recommendation, special topic research and comprehensive research. Power planning recommendations are put forward by power companies, power industry associations, research institutions and universities. These recommendations form the basis for power planning. The specialist research is related to power planning and involves power demand, structure and layout, system security, economic evaluation, environmental evaluation, scientific and technological progress, and system reform. The remit of the comprehensive research is to offer extensive and systematic power planning by means of a comprehensive selection and balance.

The comprehensive research report forms the basis of preparations for national and provincial power planning.

(2) Compilation and Connection
Power planning should be incorporated into the comprehensive research results of power planning, fully absorb the power planning recommendations, and put forward the guiding ideology, basic principles, development goals, key tasks and safety measures for power development.

National power planning needs to focus on: large-scale hydropower (including pumped storage); nuclear power scale and project construction arrangements (including commissioning and start-up); wind power; photovoltaic, CSP, and other new energy power generation large-scale construction projects; large-scale coal generation projects; inter-provincial and inter-regional power grid project construction arrangements (including commissioning and start-up); provincial power grid project construction arrangements for projects of 500 kV and above (including commissioning and start-up); and the province's own coal and gas power over the five-year planning period.

Provincial power planning should focus on clarifying the construction arrangements (including commissioning and start-up) of large and medium-sized hydropower (including pumped storage), coal, gas, and nuclear power projects in its region, and further clarifying the scale and layout of new energy generation. It will also include proposals for 110 (66) kV and above power grid project construction arrangements (including commissioning and start-up) and 35 kV and below power grid construction projects.

Provincial power planning is subordinated to national power planning and provincial energy planning, and the national power planning and provincial power planning are connected as follows:

- After the start of planning, the provincial energy authorities study and submit the first draft of the provincial power plan and submit it to the NEA.

- After NEA has organised a summary balance of the first draft of the provincial planning, it initially defines the main objectives of the national plan, the overall framework and the boundary conditions of the provincial plans and submits written feedback to the provincial energy authorities.

- The provincial energy authorities prepare provincial power plans (including an environmental impact assessment) based on feedback and submit them to NEA.

- NEA integrates and balances the provincial power planning and provides written feedback. The provincial energy authorities revise and improve the provincial power planning in line with the feedback.

(3) Review and release
National electric power plans are generally submitted to the NDRC for approval by the NEA before the end of May of the first year of the Five-Year Plan and are publicly released by the NEA. Provincial power planning is generally prepared by the provincial energy authority before the end of June of the first year of the Five-Year Plan, and is published once it has been agreed by the NEA.

(4) Implementation and adjustment
After the approval of the power plan, the energy authorities and power companies at all levels have to implement in full the tasks specified in the plan. Power companies are required to formulate their development plans in accordance with the approved electric power plans. The annual scale of new energy generation approved by the provincial energy authority may not exceed the target for the year in question as determined by the annual development plan. Unapproved power projects cannot enter the power market for trading, cannot be included in the permitted cost of the power grid, and cannot enjoy support policies such as electricity price subsidies and tax reductions.

While the plan is being implemented, it can be adjusted to reflect the actual situation. Two to three years after the release of the power plan, the NEA and the provincial energy authority may adjust the Five-Year Plan based on economic development and implementation of the plan. For power planning adjustments, special research work should be organised in the second year of power plan implementation, and adjustment plans should be prepared in the third year, when the adjustment plan should be reviewed, approved, and issued.

(5) Evaluation and supervision
The NEA and the provincial energy authority should entrust intermediaries to carry out mid-term assessments of national and provincial power planning and draw up a 'Mid-term Assessment Report on the Implementation of Power Planning' two years after the implementation of the plan and a 'Power Planning Implementation Evaluation Report' after the end of the Five-Year Plan. The NEA's agencies have to prepare and publish a 'Supervision Report on the Implementation of the Mid-term Power Plan' and a 'Supervision Report on the Implementation of the Five-Year Power Plan' accordingly. These act as important reference points for future planning preparation and adjustment.

3.1.2 Power planning content

The power plan is synchronised with the national economic and social development plan. The preparation cycle is generally five years. The research and preparation of the power plan should look at power development trends 10-15 years ahead. Considerations should include load forecasting, power generation planning and power grid planning.

(1) Load forecasting
A prediction is made for each region's load demand, taking into account key factors such as economic development, industrial structure adjustment, the urbanisation process, and electric energy substitution. These factors together yield the future

power demand and load curves of various provinces and regions. Usually, three load forecast prediction scenarios are prepared (high, medium and low), of which one is recommended.

(2) Power generation planning
A power balance analysis takes account of the demand level and characteristics of the local electricity market. It makes a reasonable assessment of the scale of renewable energy generation and gives priority to renewable energy, so reaching a decision on the installed capacity, structure and layout of power generation. Combined with load characteristics, a system peak shaving balance analysis is carried out to determine the construction scale and scheme selection of the peak shaving power source. The analysis also formulates a number of alternative construction options, conducts technical and economic comparisons, and proposes a reasonable annual construction scale and investment estimates.

(3) Power grid planning
Power grid planning takes into account factors such as load development, power supply layout, power transmission and receiving scheme, after which the necessary electrical calculation and analysis are carried out to estimate power flow, stability, reactive power, short-circuit current and so on, so that the project can be incorporated into the target grid scheme of 220 kV and above. The planning process also develops a number of alternative construction options, conducts technical and economic comparisons, proposes recommended solutions, power transmission and distribution projects and makes estimates of the investment required. Other factors include consideration of urban and rural economic and social development and the urbanisation process, and preparing distribution network planning and smart grid planning.

3.2 Chinese transmission planning practice

3.2.1 Power grid planning mechanism of SGCC

In 2019, the SGCC established the Power Grid Planning Management Committee and the Power Grid Planning Expert Advisory Committee.

Responsibilities of the Power Grid Planning Management Committee
To study power grid development strategy, development direction and development ideas, examine work plan and priorities of power grid planning; coordinate the safety, quality, and efficiency of power grids, consider major issues of power grid development, the reconstruction of backbone grids and major project construction schemes, and examine the overall planning report of the State Grid.

Responsibilities of the Power Grid Planning Expert Advisory Committee
To provide advice and suggestions on major boundary conditions, technical standards, and basic principles of power grid planning, and provide technical support for the decisions of Management Committee.

SGCC’s transmission grid planning

- **The headquarters** is responsible for the overall planning of the State Grid and oversees regional power grid planning.
- **The regional division** is responsible for regional power grid planning and oversees provincial power grid planning (high voltage grid).
- **The provincial division** is responsible for provincial-level power grid planning and oversees municipal grid planning.
- **The municipal division** is responsible for power grid planning of 110 (66) kV and below.

3.2.2 Basic principles of grid planning

China’s power grid planning follows the basic principles of safe, green, efficient, coordinated and shared development.

Safe development. Grid planners should: encourage bottom-line thinking (where outcomes can be measured more quickly and easily); deepen research on the characteristics of large power grids; improve the structure of the power grid; rationally stratify and partition; solve the problems of ‘strong DC and weak AC’, short-circuit current exceeding the standard, and heavy load of the current; and avoid dense transmission channels as much as possible. Key users and areas should be equipped with certain emergency self-provided power supplies and ‘black start’ power supplies. Key cities should construct important networked channels as ‘security’ lines. Grid planners should encourage continued improvement of the ‘three lines of defence’ to prevent the risk of large-scale blackouts.

Green development. Grid planners should: actively develop non-fossil powered energy; promote the clean and efficient use of coal power and achieve full control over coal consumption; strengthen the regulation capacity of the power system; promote the unified planning of source-grid-charge-reservoir; accelerate the flexible adjustment of power supply construction; and meet the need for large-scale development of new energy. Grid planners should propose a reasonable development scale and layout for new energy, in line with the target for a new energy utilisation rate of not less than 95%. The aim should be to improve the grid-connected performance of new energy grid-connected units and improve the tolerance level and support capacity of new energy.

Efficient development. Grid planners should: make good use of resources, make optimal increments, and actively improve the overall efficiency of the power system. In the planning stages, they should give full consideration to demand response, backup sharing, peak load and valley filling at 5% of the maximum load and put more emphasis on power balance. Plans should prioritise scientific, steady, and precise investment. Plans should implement the central government's deployment of price and fee reductions, tap all potential to increase efficiency, reduce and cut costs, and continuously improve the quality and efficiency of development.

Coordinated development. Grid planners should: optimise the power structure and layout according to the local balance principle; give priority to the power supply in the receiving area and support clean and efficient coal power at the load centre. Gas-fired power stations will be arranged in the Yangtze River Delta and the Beijing-Tianjin-Hebei region where gas sources are guaranteed, and electricity more affordable.

While making effective use of existing channels, the plan is for new cross-regional transmission channels to be built. In accordance with the principle of integration of wind, sunlight, coal storage and transmission, the power supply at the dispatch end, the corridor along the way and the end market will be coordinated. New cross-regional connectors should first adhere to market orientation and agreement, and the governments and relevant companies who are contracting to sell or buy power should sign long-term agreements to clarify transmission and pricing principles.

3.2.3 Chinese transmission planning process

Chinas power grid planning follows the basic principles of safe, green, efficient, coordinated and shared development. It includes four steps: research on major issues, determination of planning boundary conditions, comparison of options, and preparation of planning reports.

(1) Research on major issues
Power demand forecasting and load characteristics research
Tasks: Study and evaluate the medium and long-term economic development trends, consider the development of new kinetic energy, and make projections for the total amount, structure and layout of electricity demand. Consider the impact of distributed power, energy storage, and electricity price policies on load characteristics, analyse the peak and off peak consumption differential and evaluate the demand-side management potential and implementation measures.

Research on power supply structure and development layout
Tasks: Implement the national energy development strategy, analyse the medium and long-term development paths of various power sources, focus on clean development and construction scale and layout of coal power, peak shaving performance, flexibility reform and policies relating to coal power units, and put forward proposals for coal power development. Combine new energy development policies, technological progress, market factors, and so on, to evaluate the scale and timing of distributed and offshore wind power development in central and eastern China. Research and make proposals for new energy development and layout. Analyse peak capacity and peak demand in power grids, and make proposals for pumped storage power stations, energy storage, and gas. The recommendation is to make flexible adjustments to the construction scale and layout of power generation, in order to make the system easier to regulate.

New energy consumption research
Tasks: Calculate the contribution of new energy to the power balance in actual operation. Analyse the impact of new energy output characteristics and unit performance on the safe operation of the power system. Combine the system with peak and frequency modulation performance. Research and propose new energy consumption capacity and development scale recommendations.

Power grid security research
Tasks: Identify and evaluate the weak links that might impact the nation's power grid security. Analyse the profound changes in power grid characteristics brought about by the large-scale connection of new energy sources and multiple DC feeds. Study and make proposals to optimise the power grid structure. Enhance the frequency, voltage support and anti-disturbance capability of the system.

Grid economic research
Tasks: Following the increase in electricity consumption, a rolling analysis of the power grid's capacity will be a boundary condition for new power grid project arrangements. Research will need to focus on two key factors - reducing the cost of social energy consumption and achieving sustainable development of power. This will involve improving efficiency and preventing risks, deepening the research of grid investment strategies, clarifying the investment direction, structure, scale and timing, improving grid efficiency, and enhancing the operating efficiency of grid companies.

(2) Determination of boundary conditions
Major boundary conditions such as power demand forecast, power supply installation scale and layout, and cross-provincial and cross-regional power flow, represent the prerequisites and foundations of grid planning. Reaching a reasonable determination of boundary conditions is key to ensuring the accuracy of power grid planning. Grid companies need to take the initiative to communicate with the government's energy authority in order to clarify the boundary condition plan as a basis for grid planning. On the basis of previous major studies, recommendations for grid planning boundary conditions have been put forward:

- Provinces to research and present recommendations for boundary conditions such as power demand, installed power, and cross-regional power and capacity arrangements.

- Research will include carrying out load characteristic analysis, uniform adoption of production simulation procedures, power supply and demand balance analysis by province and region, and a study of the scale, occurrence period and duration of electricity and power profit and loss.

- The aim will be to coordinate the development of power supply bases, the consumption market, and the construction of delivery channels, optimise the adjustment of existing power flows, and propose new cross-provincial and inter-regional power flows.

- Provincial companies will report the power supply and demand situation and the proposed layout of power sources to provincial energy authorities and clarify the power demand forecast and power construction plan for each province.

- The State Grid Development Department takes the lead and actively participates in the work of the NEA's power planning working group to promote the clarification of major boundary conditions such as national power demand forecasting, power supply scale and layout, and inter-provincial and inter-regional power flows.

(3) Comparison of options
Grid companies need to study solutions and measures based on the needs of grid development, combined with actual operational problems. They should strengthen the calculation and analysis of grid planning simulation and consolidate the planning foundation. The grid plan proposes that the grid company planning unit needs to carry out a comprehensive technical and economic comparison and selection of multiple schemes and propose recommended schemes to improve the scientific level and authority of the planning.

- Through the grid planning simulation calculation platform provided by the State Grid Simulation Centre, unified calculation data for the entire network is available. The current grid uses measured values, and the planning grid uses typical parameters.

- According to the actual development and operation of the power grid, a variety of power grid schemes are constructed, and comprehensive technical and economic comparisons are proposed for individual schemes to ensure that the scheme is technically feasible, economically reasonable, and practicable.

- Suggestions relating to the construction of major projects will be used as the basis for the annual operation mode arrangement.

- Planners need to ensure that the production and operation departments are involved throughout the process and that their opinions are sought on power grid and engineering construction plans.

- Grid planning can include not only projects and investment, but can also include an analysis of investment capacity and electricity prices. It must be linked to operating indicators such as asset-liability ratios and the performance of provincial companies.

(4) Preparation of planning reports
The **grid development planning report** is a guiding document for the company's grid planning at all levels, the basis for scheduling of grid projects, and the ultimate expression of the results of grid planning.

The SGCC draws up a 'three-level' grid planning report for the headquarters, the six regions, and the 27 provincial grids. Planning reports at all levels include a general report, two special reports (a special report on power supply and demand analysis, and one on grid planning simulation calculations), as well as additional special reports as required by the characteristics and issues of the individual province. The planning report should include power grid development assessment, power supply and demand and balance analysis, target grid planning, grid construction focus, investment estimates and benefit evaluation, policy recommendations and safety measures.

3.2.4 Key factors in transmission planning

For high-voltage (especially DC) transmission, the need for resource allocation and the complementary and mutually beneficial functions among different regions are crucial. In such cases, more communication is required between the various stakeholders (power generation and power grids, different provinces, national and local governments). Such plans are likely to be somewhat controversial. The final construction depends on the outcome of discussions between the stakeholders and the attitude of the national government.

For low-voltage transmission, the main issue is to ensure the safety and stability of power system operation and the reliability of power supply. In such cases, the planning scheme is based more on objective laws and actual physical needs, which do not tend to be controversial. The viability of construction mainly depends on local requirements for power supply reliability and the investment situation of grid companies.

3.2.5 Outlook for transmission planning in a market environment in China

Intermediate steps in the planning process
Firstly, greater value needs to be given to the question of whether power generation companies and power grid companies are willing to invest in power plants and power grids. In a market environment, the construction of certain power sources and transmission lines is not determined by national or local government. Therefore, a viable planning scheme needs to consider the attitude of the relevant power companies.

Secondly, incentives are set to play an increasingly important role in grid planning. Currently, transmission planning focuses on specific transmission projects, because the decision on whether to proceed with construction or not is cleared at the top level of government. However, future transmission planning needs to feature proposals to encourage companies to invest in the projects.

Thirdly, a market operation simulation is necessary. The CBA process needs to be changed so that in future, experts and planners in China think about the profitability of certain projects based on a market operation simulation. The operation hours and transmission profit per kWh should form part of the planning stages.

Changes when dispatch of power generation becomes more market based
The long-distance transmission lines that are designed to transmit a certain mix of new energy generation and thermal power generation are set to be planned in a different way.

Currently, a number of long-distance transmission lines are planned that will transmit energy resources from the resource centres in the western part to the load centres in the eastern part in China. New energy resources such as wind and solar are taken into consideration, together with coal power, and this mix offers stability to the power transmission system.

In a market environment, the generation mix may be different from this approach. Planners should be ready for transmission lines that focus on delivering new energy generation.

Additionally, the location of power sources with lower costs will be a crucial factor in transmission planning. More transmission capacity is necessary to meet the requirements of power plants that are likely to be built in future. Therefore, the planning process for transmission projects will need to consider the location of various power plants and rank them accordingly.

Changes when power prices are established in each province based on market principles

A more cautious approach will be taken towards transmission lines that connect different provinces. Since power prices are established in each province based on market principles, power price trends are different in each province. Therefore, an economic evaluation of cross-province transmission lines is both more critical and more challenging. A simulation of market operation in the relevant provinces is necessary, rather than the current practice of calculating the fixed power price difference.

4. TRANSMISSION SYSTEM PLANNING IN EUROPE

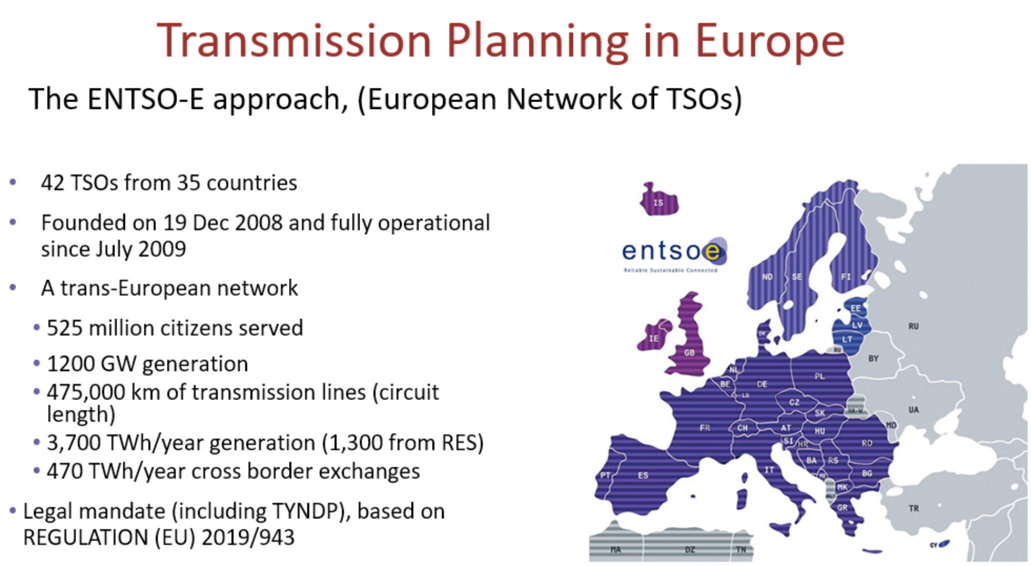
4.1 ENTSO-E overview

ENTSO-E promotes closer cooperation across Europe's TSOs to support the implementation of EU energy policy and achieve Europe's energy and climate policy objectives, which are changing the very nature of the power system. The main objectives of ENTSO-E centre on the integration of renewable energy sources (RES) such as wind and solar power into the power system, and the completion of the internal energy market (IEM), which is central to meeting the European Union's energy policy objectives of affordability, sustainability and security of supply. ENTSO-E aims to be the focal point for all technical, market and policy issues relating to TSOs and the European network, interfacing with power system users, EU institutions, regulators and national governments.

With the establishment of ENTSO-E the European TSOs have been given important tasks and thereby substantial influence on the development of the European power market and transmission system. Key figures for ENTSO-E are shown in Figure 4.1.

One of the main tasks of ENTSO-E is to create a non-binding community-wide TYNDP (Ten Year Network Development Plan) every other year. Grid development is a vital instrument in achieving European energy objectives, such as security of electricity supply across Europe, and sustainable development of the energy system with RES integration and affordable energy for European consumers through market integration. As a community-wide report, the TYNDP contributes to these goals and provides a central reference point for European electricity grid development.

Figure 4.1: ENTSO-E key figures.



Besides proposing an EU-wide TYNDP, ENTSO-E has a mandate to:

- Propose network codes.
- Ensure EU-wide market integration.
- Support research and development.
- Analyse the European Resource Adequacy Assessment (5-15 year horizon).
- Provide an integrated network modelling framework at the European level.

4.2 ENTSO-E TYNDP - overview

As mentioned above, the mainstay for TSO planning is the TYNDP which is carried out under EU regulation 714/2009. While the plan is non-binding; the TYNDP is an important pan-European planning tool which is published every two years. The TYNDP 2018 - consists of a package of documents[1], including the following:

- A scenario report describing future European scenarios that form the basis for the TYNDP. The scenarios have been developed in cooperation with European stakeholders including regulators. For the first time, the same scenarios are used both for power and gas (ENTSO-G is the corresponding cooperation for gas-TSOs, and draws up a parallel TYNDP for European gas transmission). Therefore, TYNDP-Electricity and TYNDP-Gas use the same data describing future energy systems for 2025, 2030 and 2040.

- For the first time a pan-European 'system need' report has been introduced. The report describes future power system needs with a focus on new or reinforced transmission capacity in the main European transport corridors. The results are based on long term pan-European market- and grid-analyses extending to the year 2040.

- The idea is to compare the power system with a 'frozen' transmission grid (corresponding to the 2020 grid) with a system with sufficient grid development for 2040, to illustrate the benefits of a proper grid development.

- Regional investment plans address system and transmission needs at a regional level. For planning purposes, Europe has been divided into six regions.

- The TYNDP 2018 main report makes transmission development its focus, by means of a socio-economic cost benefit analysis of a number of concrete projects. Most projects have been nominated by the TSOs based on national and regional planning and on the work carried out based on 'system need' (see above).

- In addition to the TSOs' project proposals, third-party projects (typically commercial investor projects) are addressed in the TYNDP. Third party

1 https://tyndp.entsoe.eu/tyndp2018/

projects must meet the same criteria for inclusion in the TYNDP as TSOs' projects.

- Alongside the TYNDP main report, a number of insight reports are published that focus specifically on key regional or European subjects that are important for the future development of the power system (e.g. transition of the power system into a green system).

4.3 TYNDP results – overview

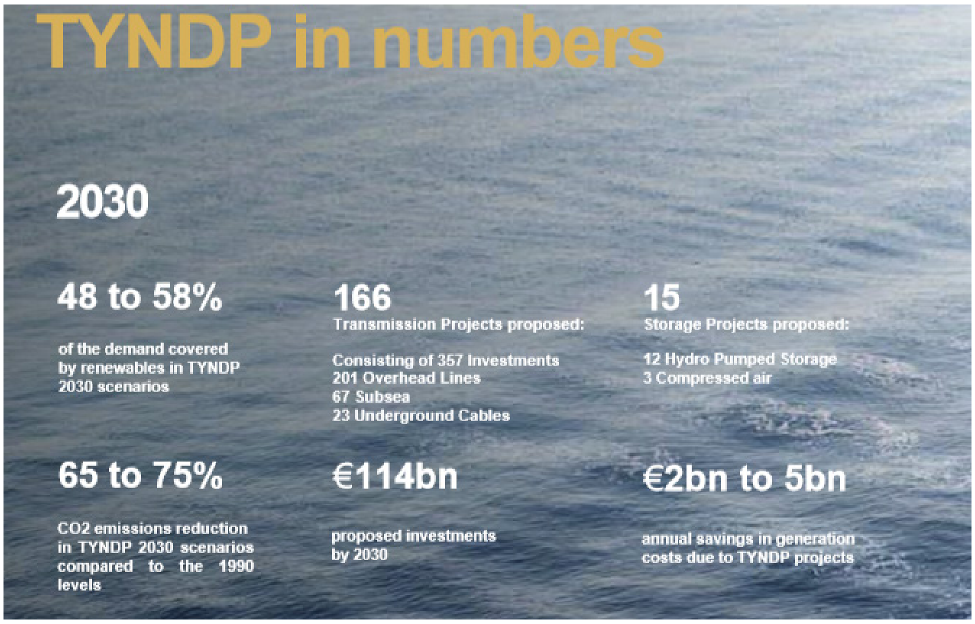
The 2018 TYNDP plan includes a description of 166 transmission projects and 15 storage projects, all scheduled to be commissioned before 2030. For each project, cost-benefit evaluations were conducted in four European scenarios. The total investment in TYNDP 2018 was estimated at EUR 114 billion. The projects will lead to savings of EUR 2.5 billion/yr in generation costs. The plan also illustrates a decline in wholesale prices as the transmission projects allow for the cheapest generation resources to be shared across Europe.

Investment in more grid connections is a precondition for further RE integration (wind and PV). According to the 2030 scenarios, RE will account for between 40% and 58%, while CO_2 emissions will reduce by between 65% and 75 % in the 2030 scenarios.

In addition, the TYNDP projects in general will help to ensure improved security of supply, because they are helping to relieve existing bottlenecks in the system.

Main results from TYNDP 2018 are shown in Figure 4.2.

Figure 4.2: Brief overview of TYNDP 2018 results.



4.4 Project of Common Interest (PCI)

Every second year the European Commission updates a list of projects of high European importance, the so-called PCI list. This list is taken from the most recent TYNDP. The latest list was published in November 2019.

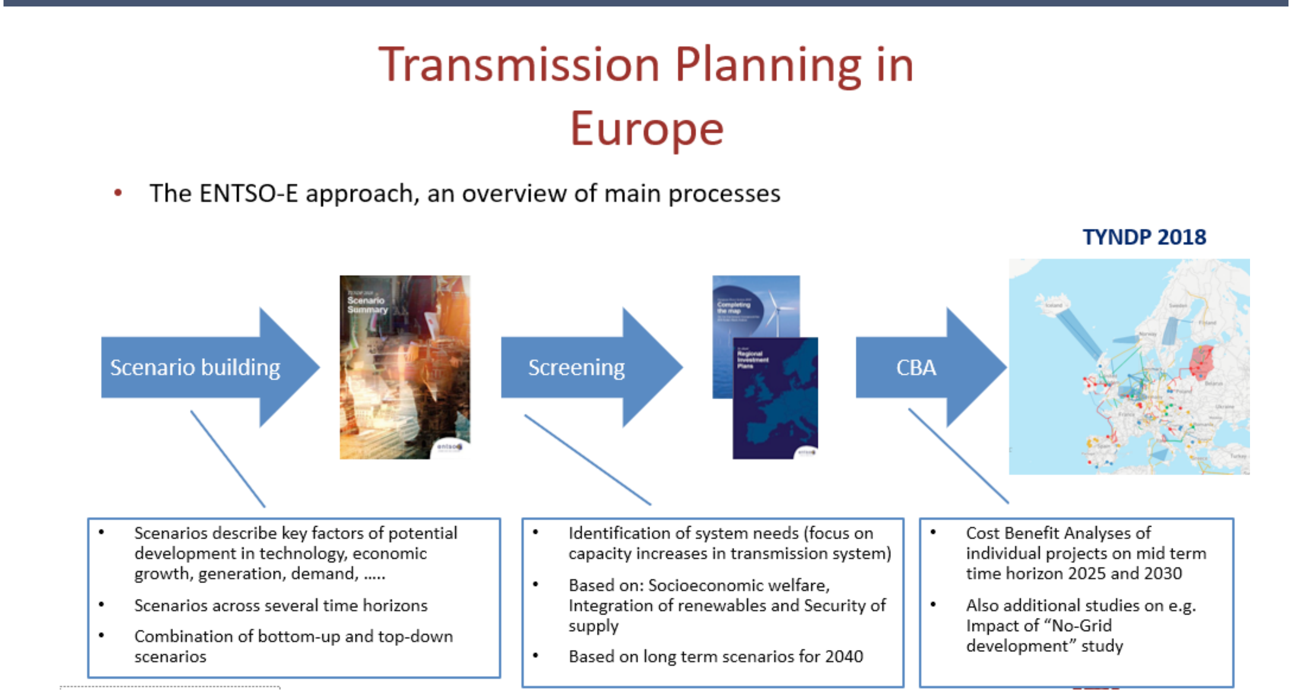
PCI projects have to comply with certain rules with regard to transparency and involvement of stakeholders. However, in return the PCI projects can anticipate more rapid authorisation and financial support from EU.

4.5 ENTSO-E planning process

General
ENTSO-E uses a coordinated and comprehensive transmission grid planning approach, which includes sharing of data, development of scenarios, coordinated market modelling and grid stability modelling, combined cost benefit analysis, stakeholder engagement, and so on. The aim is to ensure system stability, guarantee power supply and integrate more RE at the lowest possible cost.

In general, the ENTSO-E approach ensures that pan-European grid planning is optimised for the common good and addresses the different interests at stake. A key aspect of the ENTSO-E methodology is the recognition from the transmission grid planning perspective that the market will determine the use of the grid. The main processes in the ENTSO-E approach are scenario building, screening, and CBA (see Figure 4.3).

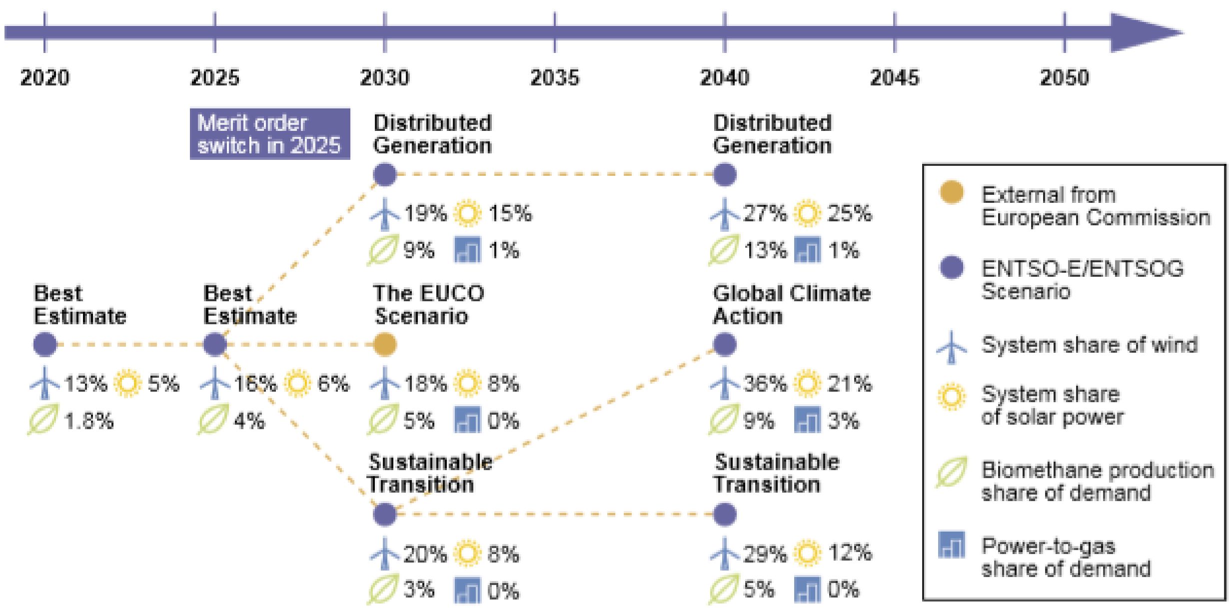
Figure 4.3: ENTSO-E TYNDP planning process.



Step 1– develop scenarios for the future
To identify what Europe needs in terms of electricity transmission infrastructure, it is first necessary to analyse how the energy landscape will evolve. Some political objectives have been set for 2030/2040, but many uncertainties remain regarding generation investments, demand evolution and market developments, to name but a few. The TYNDP scenario development is about framing uncertainties. It is not about predicting the future. Stakeholders are strongly encouraged to participate in the scenario building.

The TYNDP scenarios include a 'best estimate' scenario for the short and medium term (including a merit order sensitivity between coal and gas in 2025), but three narratives regarding the longer term reflect increasing uncertainties. However, they are all on track to meet the 2030 decarbonisation targets set by the EU. The scenario pathways from 2020 to 2040 can be seen in Figure 4.4.

Figure 4.4: TYNDP 2018 scenarios.



To give an idea of the spread in narratives of scenarios, we have listed narratives for three of the scenarios 2030/2040 (ref ENTSO-E TYNDP 2018 scenario report):

- Sustainable Transition (ST) seeks a quick and economically sustainable CO_2 reduction by replacing coal and lignite in the power sector with gas. Gas also displaces some oil usage in heavy transport and shipping. The electrification of heat and transport develops at a slower pace than in other scenarios. In this scenario, reaching the EU goal (80%-95% CO_2 reduction by 2050) requires rapid development during the 2040s by means of increased technological adoption or evolution.

- Distributed Generation (DG) places prosumers at the centre. It represents a more decentralised development with a focus on end user technologies. Smart technology and dual fuel appliances such as hybrid heat pumps allow consumers to switch energy depending on market conditions. Electric vehicles see their highest penetration with PV and batteries widespread in buildings. These developments lead to high levels of demand side response. Biomethane growth is strong as connections to distribution systems grow, utilising local feedstocks

- Global Climate Action (GCA) represents a global effort towards full speed decarbonisation. The emphasis is on large-scale renewables and even nuclear in the power sector. Residential and commercial heat become more electrified, leading to a steady decline in gas demand in this sector. Decarbonisation of transportation is achieved through both electric and gas vehicle growth. Energy efficiency measures affect all sectors. Power-to-gas production sees its strongest development within this scenario.

Step 2 – Screening of needs for infrastructure expansion
The TYNDP normally offers three or four scenarios for the development of the power system. Some set high targets for RE, some envisage a more decentralised power system, and some envisage a strong European framework. Based on these scenarios, experts representing the 41 TSOs in 34 European countries carry out joint planning studies.

Using common methodologies and tools, the experts look at how power will flow in Europe in 2030/2040, taking into account the different scenarios. This allows them to see where bottlenecks will be and how much transmission capacity is needed at borders to manage these flows.

The screening studies result in a series of infrastructure projects. These are only one feature of the entire TYNDP. Other features are made up of projects from third party investors (non-ENTSO-E members) that meet the European Commission's criteria for inclusion in the TYNDP.

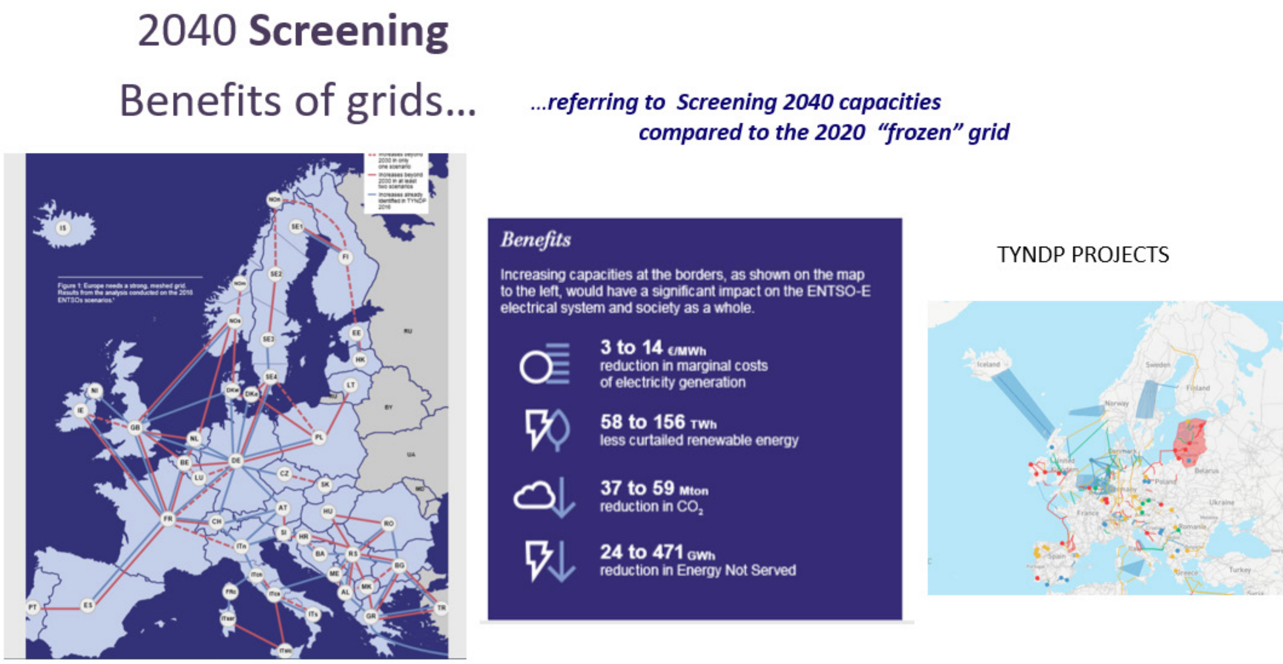
The list of projects is open to public consultation before being finalised.

Figure 4.5 shows an example of the results of these screening studies in the TYNDP 2018 process. The results are based on market modelling for Europe as an integrated system. The market model emulates the European spot market in the future scenarios. In an iterative process, the capacities at the borders between market areas are successively increased, and borders with highest socio-economic benefits compared to investment costs of expansion are selected for further assessment.

Figure 4.5 shows a comparison between the 2020 'frozen' grid and an expanded 2040 grid. It follows that the expansion of the grid as proposed in the screening will cut the marginal costs of generation, limit curtailment of renewables, and reduce CO_2 emissions.

In addition, a reduction of expected energy not served (EENS) is evident.

Figure 4.5: Example of screening results for selecting potential projects for the TYNDP 2018.



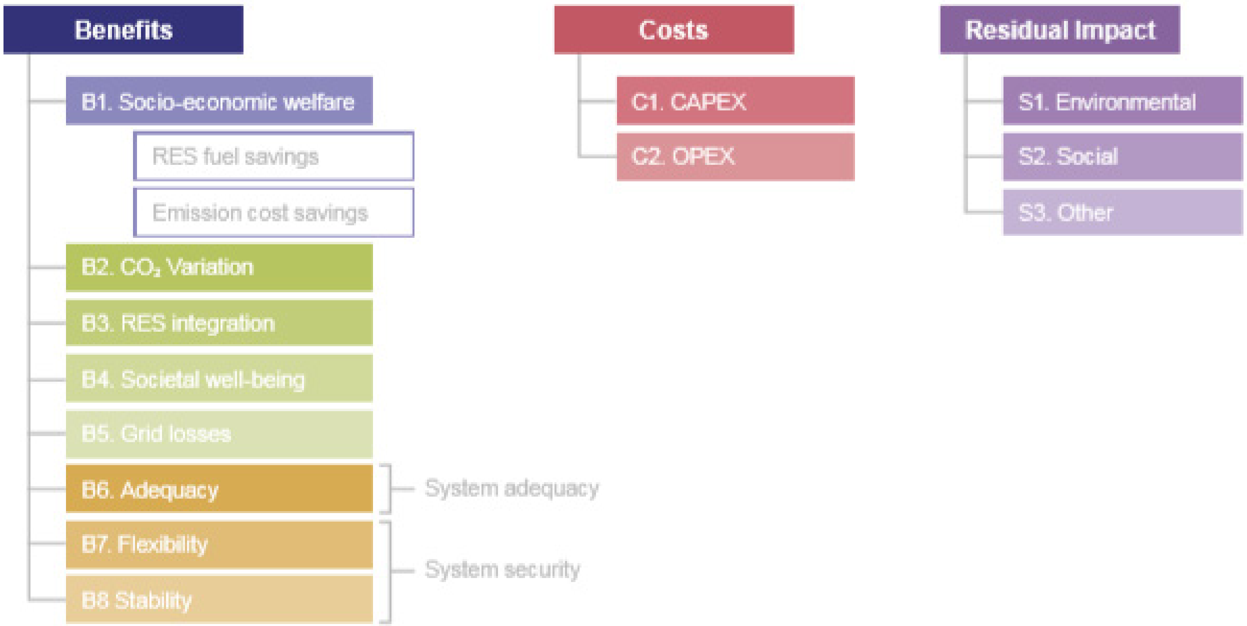
Step 3 – Project assessments
The final phase of the TYNDP planning process is the assessment of projects. This is done using a European approved methodology to assess the costs and benefits of projects. This is not purely an economic assessment. It also takes into account how projects support the environment, welfare in Europe, the security of supply, and other factors. The results of these cost and benefit assessments form the core of the TYNDP report.

The TYNDP report illustrates the value of each infrastructure project. It provides decision-makers with a robust and detailed analysis of transmission infrastructure projects on which to base their decisions. TYNDP projects and the accompanying assessments are used in a European Commission-led process for updating the PCI list of projects.

4.6 ENTSO-E system-wide CBA Analysis - method

General
All new transmission project candidates in the TYNDP planning process are assessed according to the same system-wide cost-benefit methodology developed by ENTSO-E (ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects) and approved by the European Commission. The assessment includes the categories outlined in Figure 4.6.

Figure 4.6: Categories of cost benefit assessment parameters, TYNDP 2018.



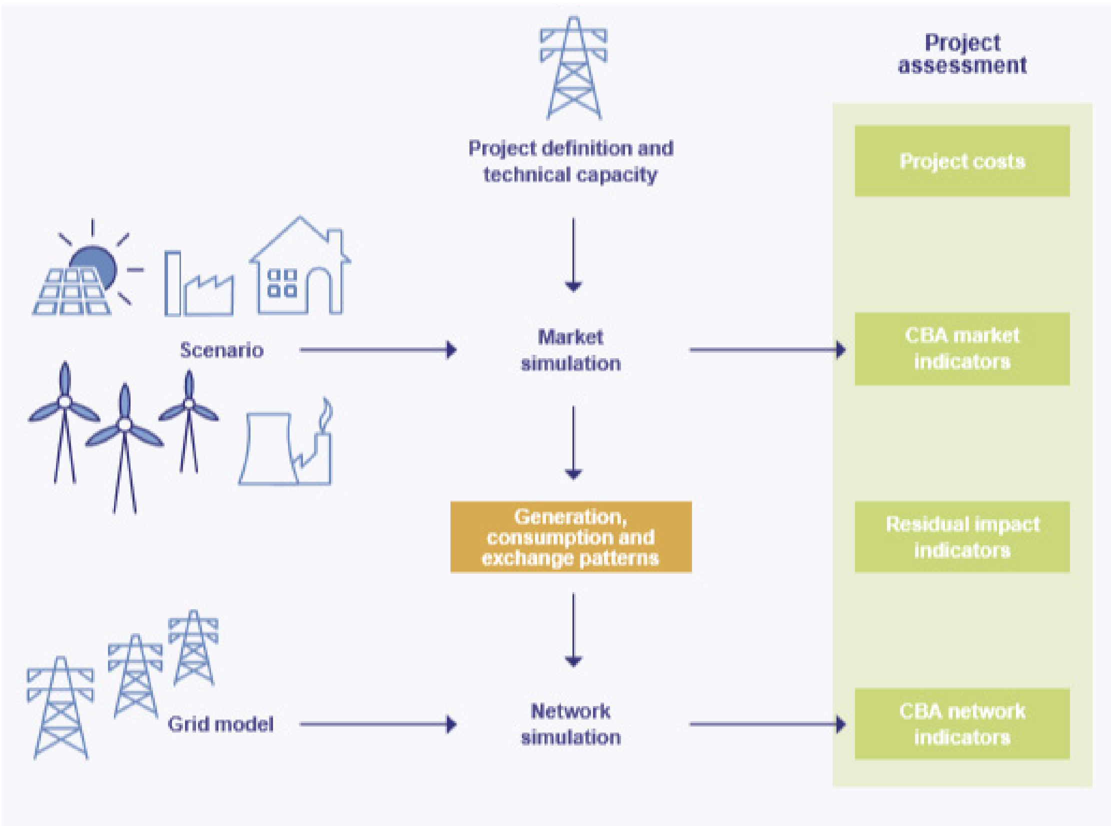
The elements analysed in the CBA are:

- Grid Transfer Capacity (GTC) in MW. This is estimated by grid analysis.
- Security of supply is Expected Energy Not Served (EENS) or Loss of Load Expectancy (LOLE).
- Socio economic welfare (SEW) is defined as the sum of producer surplus, consumer surplus and congestion rents. SEW includes implicitly monetised values for CO_2 and RES integration (e.g. improved value of RES generation by reducing curtailment of wind).
- Monetised values for CO_2 and RES integration (e.g. improved value of RES generation by reducing curtailment of wind).
- Losses are transmission losses (change in losses for the whole system).
- Costs are project costs and changes in other costs incurred by the project (except for losses).
- Technical resilience/system safety is the ability of the system to withstand increasingly extreme system conditions (exceptional contingencies). Semi-quantitative estimate is based on KPI (key performance indices) scores.

- Flexibility/robustness is the ability of the proposed reinforcement project to be adequate in different possible future development paths or scenarios. Semi-quantitative estimate is based on KPI scores.

The assessment framework is shown in Figure 4.7 with market and network indicators resulting from market and network modelling, respectively.

Figure 4.7: 'CBA market' and 'CBA network indicators' are the direct outcome of market and network studies, respectively. 'Project costs' and 'residual impacts' are obtained without the use of simulations.



Reference grid
Project benefits are calculated as the difference between a simulation which does include the project and a simulation which does not include the project. The two proposed methods for project assessment are as follows (see Figure 4.8):

- TOOT (Take Out One at a Time) method, where the reference case reflects a future target grid situation in which all additional network capacity is presumed to be realised (compared to the starting situation) and projects under assessment are removed from the projected network structure (one at a time) to evaluate the changes to the load flow and other indicators.

- PINT (Put IN one at a Time) method, where the reference case reflects an initial state of the grid without the projects under assessment, and projects under assessment are added to this reference case (one at a time) to evaluate the changes to the load flow and other indicators.

Given that the selection of the reference case has a significant impact on the outcome of an individual project assessment, a clear explanation of it must be given. This should include an explanation of the initial state of the grid, in which none of the projects under assessment in the relevant study is included. The reference network is then built up including the most mature projects that are a) in the construction phase or b) in the 'permitting' or 'planned but not yet permitting' phase, where their timely realisation is most likely i.e. when the country-specific legal requirements have been met and the need for these projects has been acknowledged.

Projects in the 'under consideration' phase are seen as non-mature and are therefore generally excluded from the reference grid, leading to an assessment using the PINT approach.

Figure 4.8: Reference grid and definition of TOOT and PINT.

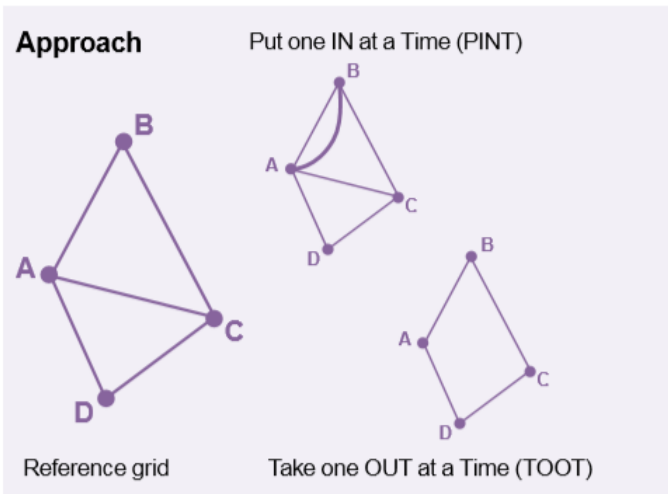
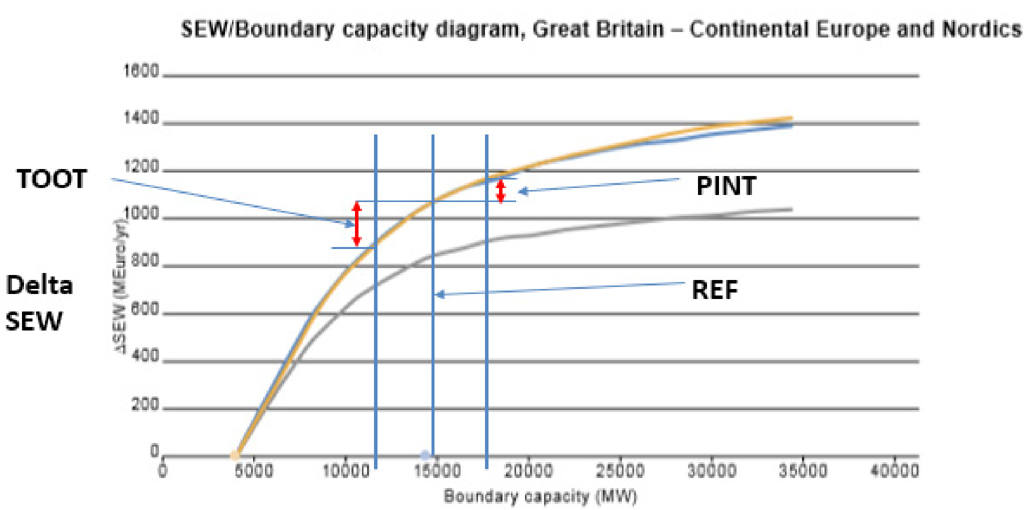


Figure 4.9 illustrates the assessment of a capacity investment at a boundary with decreasing marginal expansion benefit. It follows that TOOT and PINT will result in different results.

Figure 4.9: Assessment of capacity expansion across a border according to TOOT and PINT.



Specific description of CBA parameters, overview
Benefit categories are defined as follows:

B1: Socio-economic welfare

SEW, or market integration, is characterised by the ability of a project to reduce congestion. It thus provides an increase in transmission capacity that makes it possible to increase commercial exchanges, so that electricity markets can trade power in a more economically efficient manner.

BOX 1: Illustration of socio-economic welfare (B1)

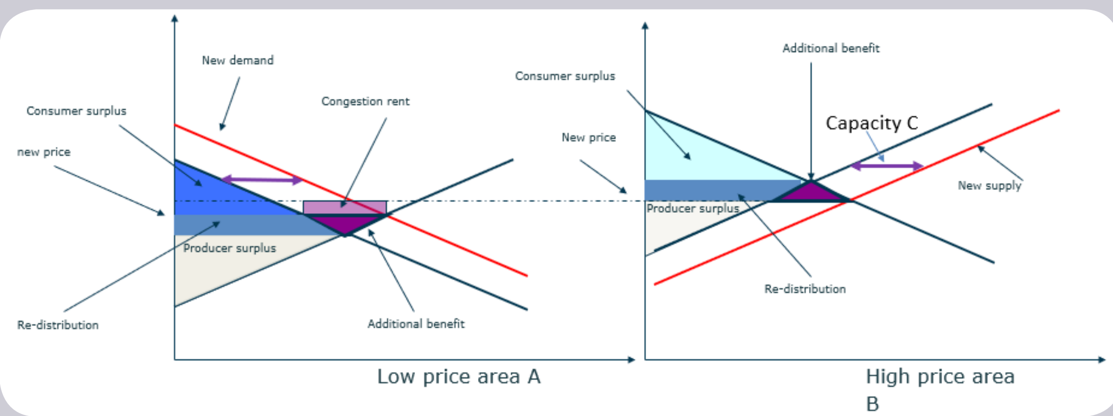
Principles of calculation of SEW

A central parameter in most European projects is SEW (socio-economic welfare) – referred to here as B1. In the European TYNDP this parameter is often the most important source of evidence for a proposed infrastructure expansion. The calculation of B1 is conducted via market modelling of the European system in two cases: with and without the project in question. In the model the European day ahead market is emulated in each hour over the year in each scenario.

The principle is illustrated in Figure 4.10, showing the gain in B1 when connecting two bidding areas (zonal price design) by a transmission line with capacity 'C'. The optimal scheduling is to transport the amount 'C' from the low-price area to the high price area. Thereby the price will increase in the low-price area and decrease in the high price area, as shown in the figure. The prices in the two zones will in this case end up being different due to congestion constraint on the interconnector.

The figure shows the change in consumer and producer surplus in the two price areas. The net increase in surpluses is indicated by the dark purple triangles. The light purple area is the congestion rent.

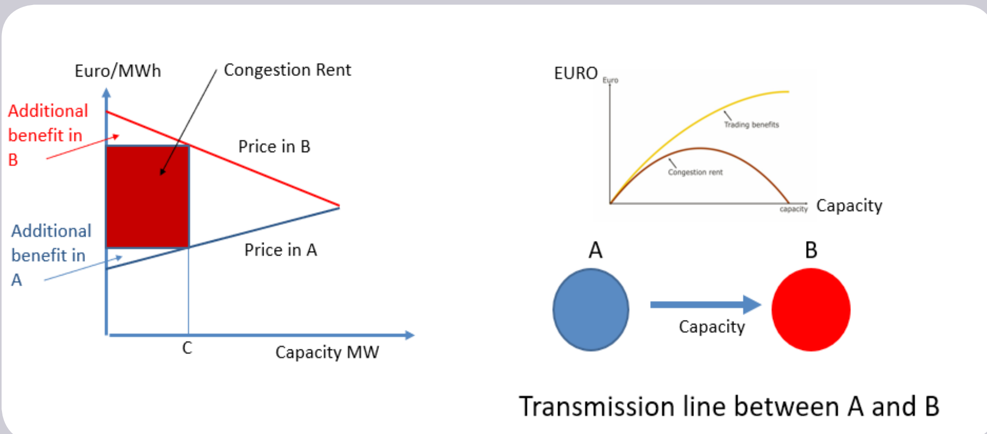
Figure 4.10: Optimal flow between two market zones in the market model.



The situation is further illustrated in Figure 4.11. This shows the prices in area A and area B when the capacity between areas increases, together with congestion rent and gains in B1 in the two areas (on the left hand side of Figure 4.11).

The illustration also shows the variation in congestion rent (lower red curve in right part of the figure) and total trading benefit (=SEW) (the upper yellow curve in right part of the figure).

Figure 4.11: Congestion rent and SEW as a function of transmission capacity

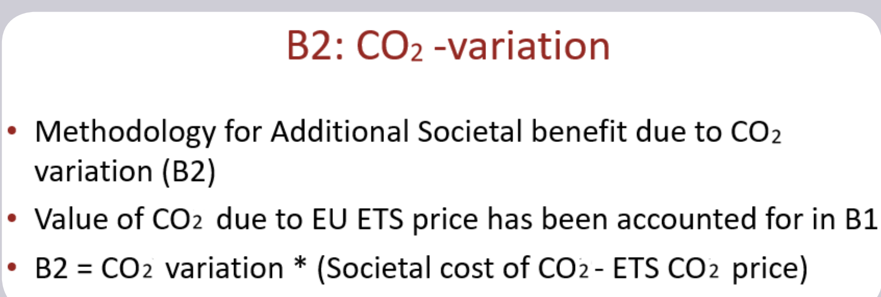


(Source: Ea Energy Analyses).

In the market model the total gains in SEW are calculated for all price areas including total net increase in all congestion rents for the whole European system when adding a given project. This is done for each hour over the year in all scenarios.

In addition to the changes in SEW, the changes in CO_2 and in the curtailment of renewables (wind and solar) are evident in the market modelling.

BOX 2: Illustration of CO_2 variation (B2)



B2: CO_2 variation

The calculation of the additional societal benefit due to CO_2 variation represents the change in CO_2 emissions in the power system due to the project. It is a consequence of changes in generation dispatch and unlocking renewable potential. The EU has defined its climate policy goals by reducing GHG emissions by at least 40% by 2030 compared to 1990 levels. As CO_2 is the main greenhouse gas for which the electricity sector is responsible, it is displayed as a separate indicator. This indicator takes into account the additional societal costs of CO_2 emissions compared to the assumed future EU ETS price, which is already included in B1.

B3: RES integration

Contribution to RES integration is defined as the ability of the system to allow new RES generation to connect to the grid, unlock existing and future renewable generation, and minimise curtailment of electricity produced from RES. RES integration is one of the EU's targets. The monetary value of improved RES integration is included in B1.

B4: Variation in societal well-being

Variation in societal well-being as a result of variation in CO_2 emissions and RES integration is the increase in societal well-being, beyond the economic effects that are captured in B1.

B5: Variation in grid losses

Variation in grid losses in the transmission grid is the cost of compensating for thermal losses in the power system due to the project. It is an indicator of energy efficiency.

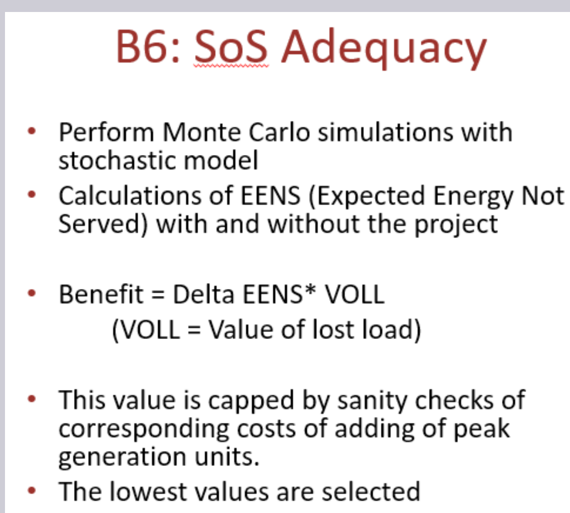
B6: Security of supply (SoS)

Adequacy to meet demand characterises the project's impact on the ability of a power system to provide an adequate supply of electricity to meet demand over an extended period of time. Variability of climatic effects on demand and renewable energy sources production is taken into account.

B7: Security of supply – system flexibility

System flexibility characterises the impact of the project on the capacity of an electric system to accommodate rapid and far-reaching changes in net demand in the context of high penetration levels of non-dispatchable electricity generation.

BOX 3: Illustration of SoS adequacy (B6)



B8: Security of supply – system stability
System stability characterises the project’s impact on the ability of a power system to provide a secure supply of electricity.

Residual impact is defined as follows:
S1. Residual environmental impact characterises the (residual) project impact as assessed through preliminary studies and aims to give a calculation of the environmental sensitivity associated with the project.

S2. Residual social impact characterises the (residual) project impact on the (local) population affected by the project as assessed through preliminary studies and aims to make a calculation of the social sensitivity associated with the project.

S3. Other impacts includes an indicator to capture all other impacts of a project.

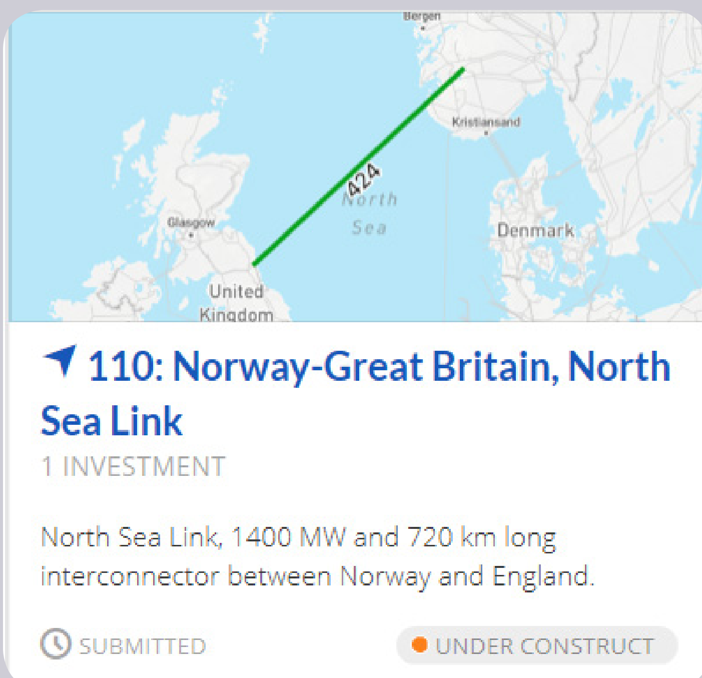
Costs are defined as follows:
C1. Capital expenditure (CAPEX). This indicator reports the capital expenditure of a project, which includes elements such as the cost of obtaining permits, conducting feasibility studies, obtaining rights of way, land, preparatory work, designing, dismantling, equipment purchases and installation. CAPEX is calculated using analogous estimates (based on information from prior projects that are similar to the current project) and parametric estimates (based on public information about the cost of similar projects).

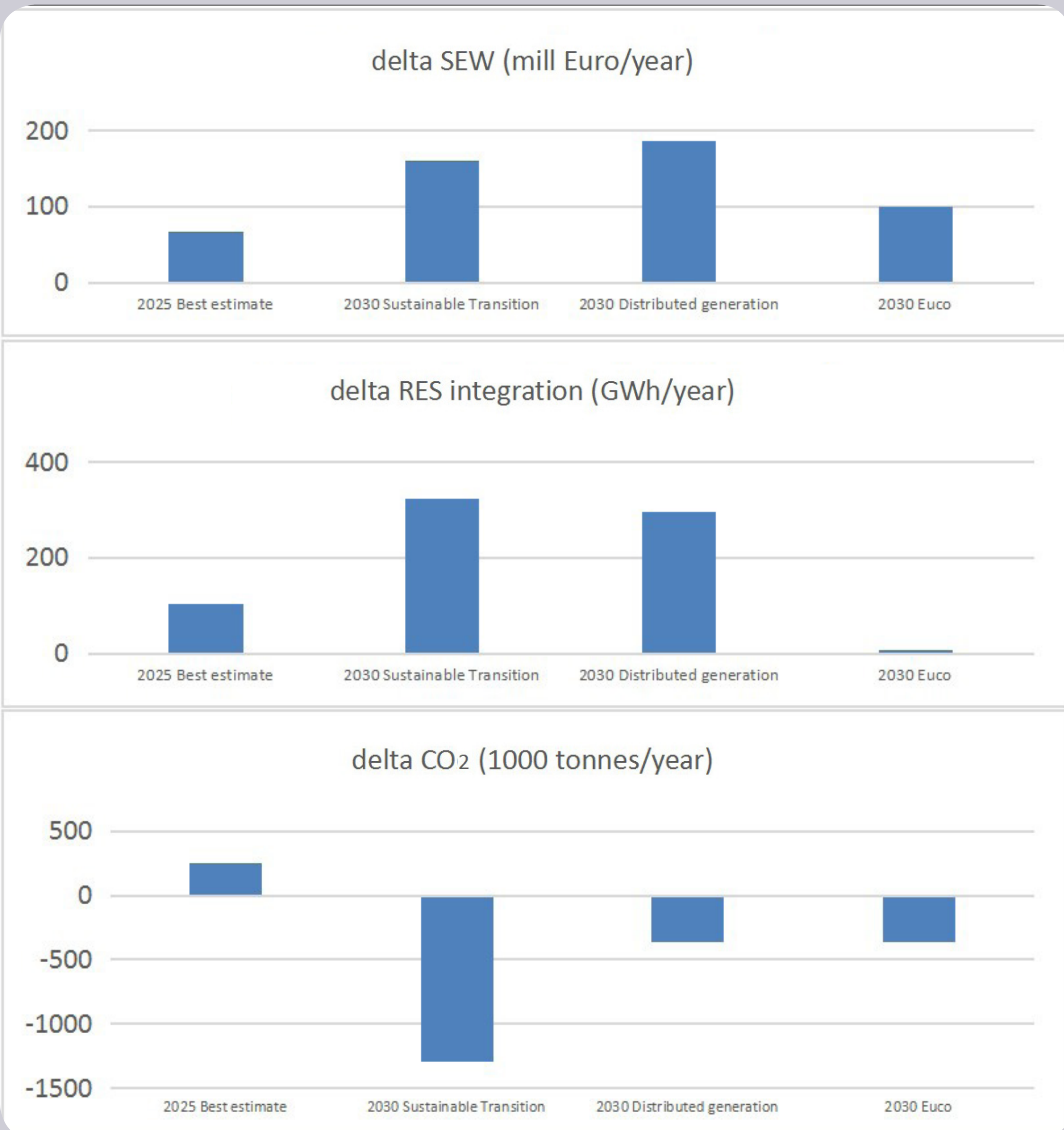
C2. Operating expenditure (OPEX). These expenses relate to project operating and maintenance costs. The calculation of the OPEX for all projects must be based on the costs for the year of study (e.g. for TYNDP 2018 the costs should relate to 2018).

Box 4 is an example from TYNDP 2018, showing results for changes in SEW, RES integration and CO_2 due to a 1 400 MW interconnector between Norway and Great Britain.

BOX 4: Case study from TYNDP 2018

1400 MW interconnector between Norway and Great Britain.





** Euco is a scenario developed by the European Commission.*

5. SCENARIOS

5.1 Introduction

In Section 5.2 and Section 5.3, Chinese scenarios for the future are described. Section 5.2 sets out the SGERI scenarios and Section 5.3 outlines the ERI/CNREC scenarios.

At the initial project meeting on 17-19 March 2020, it was decided that both the SGERI scenarios and the ERI/CNREC scenarios should be used during the present study, where ENTSO-E methodologies are being applied to China's transmission planning. The SGERI scenarios were to be applied to SGERI's model and ERI/CNREC's scenarios were to be applied to ERI/CNREC's model.

However, it was later concluded that the resolution on SGERI's model was too low (simulation is based on regions instead of provinces). Instead, only ERI/CNREC's model has been used for screening scenarios and CBA simulations.

Nevertheless, the SGERI scenarios are also described in this chapter (Section 5.2) for the sake of completeness.

5.2 SGERI scenarios

This section aims to describe the path for China's future energy development by setting up different energy transition scenarios.

Taking into account China's national energy security strategy and global carbon emissions reduction target, China's energy transition involves the exploitation and utilisation of clean energy on a massive scale while also increasing the share of electricity in final energy consumption. A two-pronged approach, involving 'increased electrification' and 'decarbonised power generation', will help to build a modern energy system centred upon electricity and usher in a new phase of development based on 're-electrification'.

Given that 'accelerated electrification + new-generation power systems' will be an important impetus for the energy transition towards a clean and low-carbon future, this description is based on the new trend of high-quality economic growth and the modern model of energy transformation and development. With enhancements in energy efficiency and adjustments to energy structure, the description constructs future development scenarios by focusing on developments in electrification and clean energy as well as describing the role and influence of electricity in China's energy transition process.

This section sets up two representative transition scenarios: The Conventional Transition Scenario and the Accelerated Electrification Scenario. In the Conventional Transition Scenario, the implementation of various transition measures is relatively balanced, while in the case of the Accelerated Electrification Scenario, the level of electrification increases much faster, and the scale of clean energy development is more significant.

Conventional Transition Scenario

Here, the energy efficiency of conventional technology increases at a slowing rate, while electrification increases steadily. Natural gas consumption rises rapidly as coal consumption decreases, whereas petroleum consumption remains relatively stable. Steady improvements can be seen in the final energy consumption structure, alongside improvements to end-use energy efficiency. New-energy makes up an increasing proportion of final energy consumption, while coordinated 'source-grid-load-storage' development gradually takes shape.

Accelerated Electrification Scenario

In this scenario, improvements to the energy efficiency of conventional technology slow down gradually, while newer technologies such as electric boilers, electric kilns, heat pumps, smart homes and electric vehicles will expand their range of application. As a result, the level of electrification across society will progress at a rapid pace, accelerating the replacement of coal and oil in final energy consumption. In addition, there will be rapid improvements to the final energy consumption structure, promoting the continuous and swift advancement of end-use energy efficiency.

Growth in natural gas consumption in the Accelerated Electrification Scenario is lower than that in the Conventional Transition Scenario. New energy develops rapidly, and the smart development and regulation capacity of power grids makes further advances, pushing the power system towards greater, coordinated 'source-grid-load-storage' development.

In both the Conventional Transition and Accelerated Electrification Scenarios, the effective demand for end-use energy, as determined by economic and social development standards, needs to be broadly consistent. Differences in end-use energy demand are reflected mainly in the energy efficiency gap caused by end-use energy-consuming technologies. For example, opinions differ as to whether to choose conventional fuel cars or electric cars for the same commute; whether to choose coal heating, gas heating or heat pumps to meet the same heating demand, or whether to smelt ores or process recycled metals to produce the same amount of steel and aluminium.

In the Accelerated Electrification Scenario, the future disruptive effects of 'transport-sharing' may unleash greater effective demand for end-use energy in the transportation sector after 2030, while somewhat reducing the energy-consuming production of upstream products, such as steel, copper, and aluminium.

Differences in main parameters between the two scenarios are shown in Table 5.1.

Table 5.1: Setting of main scenario parameters.

	Conventional Transition Scenario	Accelerated Electrification Scenario
Economic environment	With respect to the international landscape, there have been setbacks to global trade liberalisation. Sino-US trade frictions have impacted China's economic development to a certain extent. Regarding China's domestic environment, the socio-economic situation remains stable, economic growth has been gradually slowing, economic structures are being optimised and adjusted, and growth momentum is shifting from traditional manufacturing sectors to tertiary and high-end manufacturing industries. Over the 14th and 15th Five Year Plans, GDP is likely to grow at 5.5% and 5.0%, respectively. From 2030 to 2040 and 2040 to 2050, GDP growth rates will respectively be 4.2% and 3.2%. China's population will show a trend of slowing growth. In 2050, total population will be 1.4 billion.[2]	
Electrification levels	Electrification levels in various energy consumption fields will gradually increase. For example, the proportion of electric furnace steel in the iron and steel industry in 2020, 2035 and 2050 will respectively reach 10%, 20% and 32%. EV numbers in 2020, 2035 and 2050 will respectively reach 4 million, 92 million and 240 million. Accordingly, small sections of urban short-distance freight services will become electrified.	Electrification levels in various energy consumption fields will be higher than that in the Conventional Transition Scenario. For example, the proportion of electric furnace steel in the iron and steel industry in 2020, 2035 and 2050 will respectively reach 15%, 35% and 54%. EV numbers in 2020, 2035 and 2050 will respectively reach 5 million, 140 million and 350 million. Accordingly, urban short-distance freight services will become electrified.
End-use energy structure	According to the principle of 'choosing to use electricity, gas or coal in accordance with realities', electricity substitution will be steadily promoted, the use of natural gas will grow at a slightly higher pace, coal and combustion fuels will be gradually replaced, and there will be some scope for hydrogen energy applications.	Considering supply constraints, natural gas substitution will be lower than that in the Conventional Transition Scenario. The substitution of coal and combustion fuels with electricity will be higher than that in the Conventional Transition Scenario. There is reason to be optimistic about the popularisation of hydrogen energy applications.
End-use energy efficiency	The energy efficiency of major industrial products will either reach or be close to internationally advanced levels in 2020, and China will become a global leader in energy efficiency by 2035. Energy consumption per unit of GDP in 2020 will be 15% lower than in 2015 and will reach the global average in 2030. The rate of decline in end-use energy consumption intensity will slow down gradually, with greater energy efficiency brought about by the replacement of coal and combustion fuels by natural gas and electricity.	Based on the Conventional Transition Scenario, the popularisation and application of more efficient technologies for electricity utilisation, such as regenerative metal smelting, heat pump technology and so on, will be higher than that in the Conventional Transition Scenario. The breadth, depth and speed of electricity substitution will be higher than that in the Conventional Transition Scenario, which will significantly increase energy efficiency.

2 Refers to forecast data from the State Information Centre.

New-energy power generation cost[3]	The installation costs of onshore wind power in 2035 and 2050 will respectively decrease to CNY 5 000/KW and CNY 4 700/KW. The installation costs of offshore wind power in 2035 and 2050 will respectively decrease to CNY 10 000/KW and CNY 8 600/KW. The installation costs of PV power in 2035 and 2050 will respectively decrease to CNY 2 800/KW and CNY 2 300/KW. The installation costs of photothermal power in 2035 and 2050 will respectively decrease to CNY 9 700/KW and CNY 4 500/KW.	The installation costs of onshore wind power in 2035 and 2050 will respectively decrease to CNY 4 500/KW and CNY 4 000/KW. The installation costs of offshore wind power in 2035 and 2050 will respectively decrease to CNY 9 000/KW and CNY 7 400/KW. The installation costs of PV power in 2035 and 2050 will respectively decrease to CNY 2 300/KW and CNY 1 900/KW. The installation costs of photothermal power in 2035 and 2050 will respectively decrease to CNY 7 600/KW and CNY 3 200/KW.
Carbon emissions cost	Gradual increase from CNY 20/ton in 2020 to CNY 200/ton by 2050.	Gradual increase from CNY 30/ton in 2020 to CNY 300/ton by 2050.
Change in degree of coal power flexibility	Peak-shaving depth of co-generation units will respectively reach 30% and 40% in 2035 and 2050. Peak-shaving depth of non-cogeneration units will respectively reach 60% and 70% in 2035 and 2050.	Peak-shaving depth of co-generation units will respectively reach 40% and 50% in 2035 and 2050. Peak-shaving depth of non-cogeneration units will respectively reach 70% and 80% in 2035 and 2050.
Participation of cross-regional transmission in peak-shaving	50% of transmission capacity	80% of transmission capacity
Demand response potential	6% to 8% and 10% to 12% of the maximum load in 2035 and 2050, respectively.	7% to 9% and 15% to 18% of the maximum load in 2035 and 2050, respectively.
Energy storage costs[4]	Fixed investment costs in 2035 and 2050 will decrease to CNY 3 000/KW and CNY 2 000/KW, respectively.	Fixed investment costs in 2035 and 2050 will decrease to CNY 2 000/KW and CNY 1 000/KW, respectively.

3 The yearly cost forecast curve is formed according to the forecast of international authority institutions such as International Energy Agency, International Renewable Energy Agency, Bloomberg Finance L.P., etc. Due to space limitations, only the values of key years and the national average are shown, and the differentiated handling of each region is not shown. All prices in the report and model are based on the current price level, monetary value changes are not considered.

4 The yearly cost forecast curve is plotted in accordance with forecasts from authoritative domestic and foreign institutions such as the International Energy Agency, Bloomberg Finance L.P. and the China Energy Storage Alliance. Due to space limitations, only the values of key years are shown.

5.3 ERI/CNREC scenarios

China Renewable Energy Outlook 2019 uses scenarios to analyse how renewable energy can be used in the Chinese energy system. The scenarios provide a clear and consistent vision for long-term development as a basis for short-term decisions. Two scenarios are defined: The Stated Policies Scenario expresses the impact of a firm implementation of announced polices, while the Below 2°C Scenario shows a pathway for China to achieve its ambitious vision for an ecological civilisation to fulfil the Paris agreement.

The scenarios are modelled in detailed bottom-up models for the end-use sectors and for the power sector. Specific assumptions for macroeconomic indicators, demographic indicators and targets or restrictions to the scenarios' energy systems are used as input to the models to guide the development trends in the desired direction and to ensure fulfilment of the goals for energy system development. Within these boundaries, the power sector model is driven by an overall cost-optimisation to ensure cost-efficient energy system transformation.

The scenarios are designed to achieve the following:

- Provide a clear long-term vision. The energy system composition of this vision will be presented as well as the reasoning behind.
- Establish a clear view of the current situation, trends, market and policy direction, and project this into the future.
- The forecasted trends and the long-term visions are forced to converge and form a connected story as a complete energy system scenario.

5.3.1 Two main scenarios

Stated Policies Scenario expresses firm implementation of announced policies
The scenario assumes full and firm implementation of energy sector and related policies expressed in the 13th Five-Year Plan and in the 19th Party Congress announcements. Central priorities are the efforts to build a clean, low-carbon, safe and efficient energy supply. The scenario also includes the NDC climate target to peak in emissions before 2030, the effects of the Blue-Sky Protection Plan, aspects of the Energy Production and Consumption Revolution Strategy, and the National Emissions Trading Scheme.
Policy trends are extrapolated to set the longer-term policy drivers.

Below 2°C Scenario shows how China can build an energy system for the ecological civilisation
The Below 2°C Scenario shows a road for China to achieve its ambitious vision for an ecological civilisation and to fulfil the terms of the Paris Agreement. The main driver is a hard target for energy related CO_2 emissions by means of a strategy that has renewable electricity, electrification, and sectoral transformation at the core. The target is for a total of 200 million tons of energy related CO_2 emissions between 2018 and 2050.

5.3.2 Key assumptions

Macroeconomics and population
In the 16 years between 2021 and 2035, China will be in the middle and later stages of industrialisation and urbanisation. It will have the world's largest manufacturing sector, service industries, urban agglomerations, and middle- and high-income groups. The mode of economic growth is undergoing major changes. After 2035, China will start to build a modern and prosperous country, and its per capita GDP will reach about USD 40 000 by 2050.

Table 5.2: Assumptions related to macroeconomics and population.

	Stated Policies Scenario	Below 2°C Scenario
Population	Population will grow in the next 10 years and then drop. The population will be around 1.38 bn in 2050.	
Economic development	Economic growth from CNY 90 trillion in 2018 to CNY 380 trillion by 2050.	
Urbanisation rate	The process of urbanisation in China will continue to be an important factor. According to the National Bureau of Statistics, urbanisation will increase from 59.6% in 2018 to 70% by 2030. According to ERI assumptions, 78% of citizens will be living in an urban environment by 2050.	

Energy volume and structure
A green, low-carbon, safe, and efficient modern energy system is the future development direction of China's energy system. The medium- and long-term energy development goals adopted by China, and the assumptions made to meet the above goals, are listed below.

Table 5.3: Assumptions related to energy sector.

	Stated Policies Scenario	Below 2°C Scenario
Primary energy consumption limit	Growth in primary energy consumption should be controlled. By 2020, primary energy consumption was set to remain below 5 billion tce based on the 13th Five-Year Plan. By 2030, primary energy consumption should not exceed 6 billion tce, in line with the Energy Production and Consumption Revolution Strategy. The vision for 2050 states that primary energy consumption should stabilise between 2030 and 2050.	
Coal consumption limit	In 2020, coal consumption was set to account for less than 58% of the primary energy consumption, according to the 13th Five-Year Plan. The scenarios restrict coal consumption to 1 billion tons of coal by 2050, according to an ERI assessment of the boundaries for an environmentally sustainable energy system for China.	

<table>
<tr><td>Security of supply</td><td colspan="2">The energy supply should be diverse and dependence on fuel imports should be reduced significantly.</td></tr>
<tr><td>Energy intensity per unit of GDP</td><td colspan="2">The 13th Five-Year Plan set a target for reducing energy consumption intensity by 15% in 2020 relative to 2015. In the scenarios, the energy intensity should be reduced by 85% relative to 2018 (base-year).</td></tr>
<tr><td>Non-fossil proportion of primary energy supply</td><td colspan="2">The 13th Five-Year Plan aimed for non-fossil fuels to make up 15% of primary energy supply in 2020 and 20% in 2030. The Energy Production and Consumption Revolution Strategy further states that by 2050 more than 50% of primary energy supply should come from non-fossil sources. However, in order to achieve emission reduction targets and successfully develop an ecological civilisation, non-fossil energy must account for at least two thirds of primary energy supply by 2050 in both scenarios.</td></tr>
<tr><td rowspan="2">Natural gas targets</td><td colspan="2">The 13th Five-Year Plan established a target to increase the proportion of natural gas in the primary energy supply to 10% by 2020. The Energy Production and Consumption Revolution Strategy aims for natural gas to account for 15% of the energy mix by 2030.

Natural gas will further expand in the short-term but is required to peak in 2040 in both scenarios, and subsequently recede to be replaced by non-fossil sources.

Due to the difference in primary energy consumption in the scenarios, the absolute levels of natural gas consumption differ, and boundaries are set in each scenario.</td></tr>
<tr><td>The peak in 2040 is in the range 630-650 bcm</td><td>The peak in 2040 is in the range 580-600 bcm</td></tr>
<tr><td rowspan="2">Electrification rate</td><td colspan="2">The 13th Five-Year Plan aimed for a 27% electrification rate by 2020. As a core pillar of the energy transition strategy, electrification is set to be increased significantly.</td></tr>
<tr><td>>50%</td><td>>60%</td></tr>
</table>

Environment and resource potential
The energy transition needs to consider both ecological and environmental protection, as well as the energy resource conditions. It also needs to take into account international commitment goals for carbon emissions. China has rich coal resources, but its oil and gas supplies are likely to rely on both domestic and international resources for a long time to come. In the future, renewable energy, such as hydropower, wind power, solar energy, and biomass resources need to be further developed.

Table 5.4: Assumptions relating to environment and resource potential.

	Stated Policies Scenario	Below 2°C Scenario
Carbon emission constraint	China's official target in the NDC and other policy documents is for carbon intensity to decrease by 40%-45% and 60%-65% by 2020 and 2030 respectively, relative to 2005.	Based on the carbon emissions limit set by the simulation results of the Intergovernmental Panel on Climate Change (IPCC) database, a 66% confidence rate can keep the temperature rise below two degrees. Cumulative emissions between 2018-2050 should be limited below 200 billion tons, and 2050 emissions should be less than 2 500 million tons.
Resource potential	In light of safety issues, only coastal sites are considered for nuclear power developments. A total capacity of 100-110 GW is envisaged in the long term (capacity in 2021 stood at 47.5 GW). Hydro power is well developed in China: further resources are planned for the future, mostly concentrated in Sichuan, Yunnan, Tibet, and Qinghai. In total, 530 GW hydro power will be developed in the period to 2050. The technically and economically feasible resource potential for wind power and solar PV is modelled for different provinces. The overall potential for onshore wind is 4 900 GW, of which less than 2 000 GW can be developed in the form of distributed wind. The potential for offshore wind is 217 GW (mainly nearshore). The resource potential for solar PV is 2 537 GW for utility-scale PV plants, and 1 633 GW for different types of distributed PV including Building Integrated PV (BIPV) and roof-top PV.	

End-use sector development

The energy transition begins with transformation in the way energy is used. The key indicators guiding the development of the scenarios' end-use consumption are provided below.

Table 5.5: End use sector guidance.

	Stated Policies Scenario	Below 2°C Scenario
Industry	Phase out excess capacity: by 2050, steel output decreases by 27%; cement output drops 50%.	
	Resource recycling: Share of scrap-based steel reaches 50% by 2050; share of recycled aluminium reaches 45% by 2050.	Share of scrap-based steel reaches 65% by 2050; share of recycled aluminium reaches 58% by 2050.

<table>
<tr><td rowspan="7">Transportation</td><td colspan="2">Per capita ownership of private cars increases by 60% in 2035 and by 120% by 2050.</td></tr>
<tr><td>A ban on internal combustion engines (ICE) for passenger light-duty vehicles will be introduced by 2050.</td><td>An ICE ban for passenger light-duty vehicles will be introduced by 2035.</td></tr>
<tr><td colspan="2">Non-road passenger transport turnover increases by 30% by 2050. Passenger transport by rail and air will rise 200% and 180% respectively by 2050.</td></tr>
<tr><td colspan="2">Freight transport turnover increases by 80 % before 2035, and 115% before 2050, relative to 2018. The proportion of freight transport by road, rail, and sea shifts from the current 48%, 20% and 32% to 32%, 30% and 38% by 2050.</td></tr>
<tr><td>New energy vehicle (NEV) market share of light trucks is set to reach 12% by 2035 and 24% by 2050.</td><td>NEV market share of light trucks is set to reach 67% by 2035 and 100% by 2050.</td></tr>
<tr><td>NEV market share of medium and heavy trucks is set to reach 12% by 2035 and 20% by 2050.</td><td>NEV market share of medium and heavy trucks is set to reach 42% by 2035 and 75% by 2050.</td></tr>
<tr><td rowspan="6">Buildings</td><td colspan="2">The total floor area occupied by buildings increases by 48% before 2035, and 70% before 2050. The proportion of urban residential, rural residential, and commercial buildings shifts from the current 41%, 34% and 25% to 55%, 17% and 28%, respectively.</td></tr>
<tr><td colspan="2">International Data Centre (IDC) floor area increases five-fold by 2035, and nine-fold by 2050.</td></tr>
<tr><td colspan="2">Heating intensity is set to fall between 15% and-35% for urban residential buildings and between 30% and 50% for rural residential buildings by 2035.</td></tr>
<tr><td colspan="2">Heating service saturation for urban residential buildings reaches 100% in 2035 in all areas.</td></tr>
<tr><td colspan="2">Increase of cooling intensity is set to rise between 15% and 35% for urban residential buildings and 28% for rural residential buildings by 2035.</td></tr>
<tr><td colspan="2">Cooling service saturation for urban residential buildings reaches 100% in 2035 in all areas.</td></tr>
</table>

Power sector development
Both scenarios posit that the development of non-fossil fuel and renewable energy must be at the foundation of the energy system transformation. This is implemented primarily through the power sector. The key indicators underpinning this scenario strategy are listed below.

Table 5.6: Power sector assumptions

	Stated Policies Scenario	Below 2°C Scenario
Non-fossil proportion of electricity	In the power generation mix, a minimum target of 50% non-fossil electricity by 2030 is applied in both scenarios, based on the guidance set in the Energy Production and Consumption Revolution Strategy.	
Energy resource potential and long-term targets	In light of safety issues, only coastal sites are considered for nuclear power developments. A total capacity of 100-110 GW is envisaged in the long term (capacity in 2021 stood at 47.5 GW). Hydro power is well developed in China: further resources are planned, mostly concentrated in Sichuan, Yunnan, Tibet, and Qinghai. In total, 530 GW hydro power will be developed in the period to 2050. The technically and economically feasible resource potential for wind power and solar PV is modelled for different provinces. The overall potential for onshore wind is 4 900 GW, of which less than 2 000 GW can be developed in the form of distributed wind. The potential of offshore wind is 217 GW (mainly nearshore). The resource potential for solar PV is 2 537 GW for utility-scale PV plants, and 1 633 GW for different types of distributed PV including BIPV and roof-top PV.	
RE subsidies	By 2020, wind was set to be competitive with coal fired generation and solar was set to be competitive with grid electricity. Additionally, distributed solar was to be competitive with the grid price.	
Carbon pricing	The price of CO_2 in the power sector rises from CNY 50/ton in 2020 to CNY 100/ton in 2030.	By 2030, the CO_2 emission cost to the power industry will increase to between CNY 160/ton and CNY 180/ton, and by 2040 will increase to about CNY 200/ton.
Power generation cost	The energy generation costs from solar and wind rapidly decline, making wind and solar more competitive. Fossil generation costs increase due to fuel costs, pricing of emissions and reduced full load operating hours. Consequently, RE can be developed at a lower price than coal-fired power in the short-term. With the further decline of energy costs and integration costs, the scale of transformation will accelerate on a system cost basis. The initial investment cost (including unit, construction, taxes, etc.) of onshore wind power in 2035 and 2050 decrease to CNY 6 200 /kW and CNY 5 950/kW, respectively. Offshore wind power in 2035 and 2050 decreases to CNY 8 900/kW and CNY 7 800/kW or less. Costs for utility scale photovoltaic power generation in 2035 and 2050 fall to CNY 2 870/kW and CNY 2 460/kW, respectively.	
Electricity demand and electrification	Electricity demand reaches 6 800 TWh by 2020, 9 000 TWh in 2035, and 11 700 TWh in 2050, when the electrification level will be 46%.	Electricity demand reaches 7 000 TWh by 2020, 11 400 TWh in 2035, and 14 000 TWh in 2050, when the electrification level will be 63%.

Demand response	It is assumed that, by 2030, demand response (DR) technology will be widely used. By 2030, industrial demand response provides up to 8 GW of flexibility. By 2050, this rises to 14 GW.	By 2030, industrial demand response provides up to 41 GW of flexibility. By 2050, this rises to 69 GW.
	Additionally, aluminium smelters provide 5 GW of DR flexible capacity in 2025, falling to 4 GW and 3 GW by 2035 and 2050, respectively. By 2030, 100% of electric vehicles will have smart charging. Vehicle to Gas (V2G) is introduced from 2030 and by 2050 50% of electric vehicles deliver power to the grid when needed.	
Developing well-functioning spot markets	Generation rights will be introduced, such as rights awarded to generators based on a perceived fair principle of allocation between market participants and generation assets. Designed full-load operating hours according to technology types will be gradually removed and replaced by economic dispatch, so that power generation is scheduled on the basis of economic merit order. Interprovincial transmission scheduling will be introduced, in which flow schedules are adopted initially by setting constant levels of flow for daytime and night time. These fixed schedules will be further relaxed by mobilising the flexibility among regions to achieve a larger-scale balancing. The provincial markets were introduced before 2020. The first cross-provincial unified power markets emerge in 2022. Regional power markets based on regional power grids is formed by 2035. A unified national market is formed from 2040.	

Table 5.7: Investment cost reductions (CNY/kW) relating to typical emerging technologies.

Year		Wind			PV		Chemical storage
		On-shore	DG*	Off-shore	Utility scale	DG	
2020	Investment	6 900	8 250	15 000	3 600	3 420	Investment cost is CNY 1.5/Wh, and the life cycle is 4 000 rounds.
	O&M	145	154	290	68.4	85.5	
2025	Investment	6 500	7 700	12 800	3 300	3 135	Investment cost is CNY 1.2/Wh, and the cost of 'DG+storage' is competitive for commercial users.
	O&M	142	150	285	67.2	84.5	
2035	Investment	6 200	7 250	8 900	2 870	2 640	Investment cost is CNY 1/Wh. The life cycle is more than 10 000 rounds.
	O&M	139	144	277	65.5	87.8	
2050	Investment	5 950	6 830	7 800	2 460	2 265	Investment cost is CNY 0.5/Wh. Applications to provide flexibility to grid are cost competitive.
	O&M	135	140	270	63.7	88.3	

** DG refers to distributed generation*

Figure 5.1: Timeline of regional spot power market establishment.

In addition to dispatching existing sources, assumptions are made about new flexible sources. The projections in both scenarios assume market signals that enable participation of end-users in balancing power markets, including:

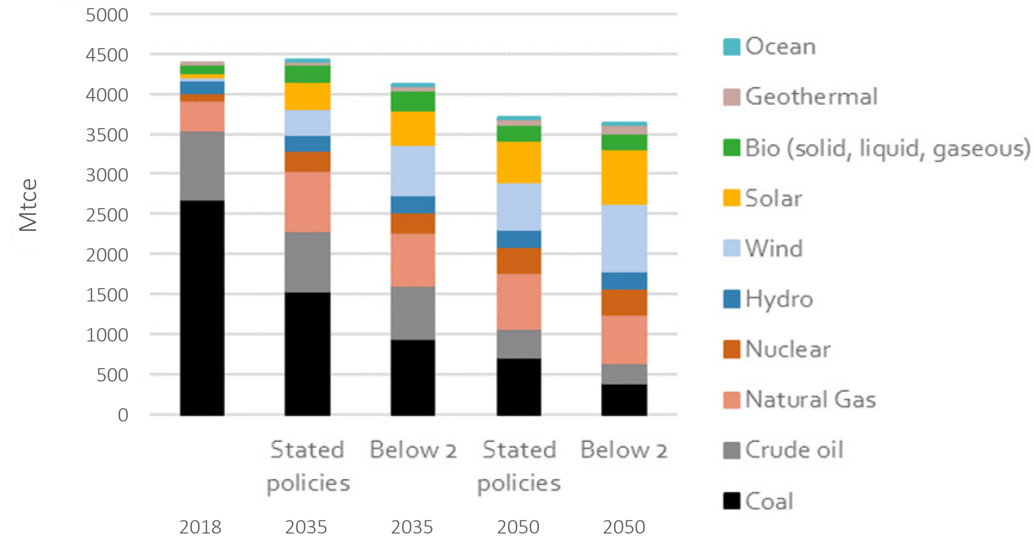
- Demand-side flexibility, such as reducing air conditioning loads or shifting industrial processes.
- Smart charging of electric vehicles at times with low system marginal costs and correspondingly low market prices, so avoiding times with high market prices.

5.3.3 Key results

Primary energy consumption mix is diversified as low-carbon sources replace coal

By 2035, coal's contribution towards primary energy consumption is reduced by 51% in the Stated Policies Scenario and 62% in the Below 2°C Scenario. By 2050, coal consumption in the Stated Policies Scenario drops by 73% of 2018 levels, while in the Below 2°C Scenario the figure is 82%. In this way, coal, which accounted for approximately 61% of primary energy supply in 2018, accounts for 30%/23% in the Stated Policies Scenario and Below 2°C Scenario respectively in 2035 and 16%/11% in 2050. These shares are calculated using the physical energy content method.

Figure 5.2: Primary energy consumption in 2035 and 2050 compared to 2018 (Mtce).

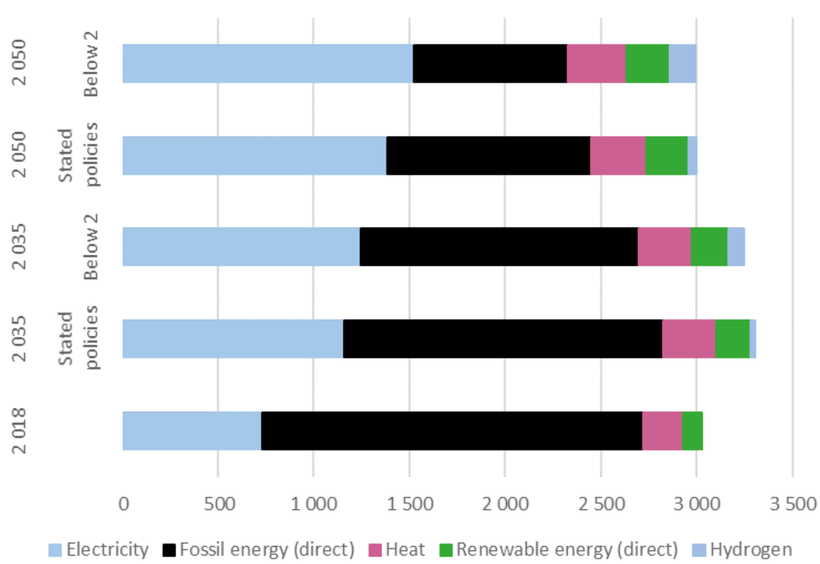


Using the physical energy content method, the non-fossil energy consumption share expands to 32% by 2035 in the Stated Policies Scenario and 42% in the Below 2°C Scenario. Using the coal substitution method of primary energy accounting that is commonly used in Chinese energy statistics and policy targets, the non-fossil energy proportion becomes 47% and 59% in the two scenarios respectively for the same year. Thus by 2035, the non-fossil energy proportion will far exceed the official policy target of 20% by 2030. It is clear that the 2030 target needs to be raised .

Final energy consumption stabilises at current levels

Energy savings, together with economic restructuring, enable total final energy consumption in 2050 to be on a par with 2018, around 3 160 Mtce/yr. In the period to 2035, final energy consumption increases by approximately 10% to around 3 460 Mtce/yr in the Stated Policies Scenario and to around 3 350 Mtce/yr in the Below 2°C Scenario, before returning to its previous level (slightly below previous level in the Below 2°C Scenario).

Figure 5.3: Final energy consumption in 2035 and 2050 compared to 2018 (Mtce).



The energy transition is thereby able to achieve the targeted economic expansion with similar levels of final energy consumption, by means of a process of emphasis in the economic structure, improvements in the energy efficiency of devices and production measures, as well as shifting away from direct use and combustion of fossil-fuels and towards consumption of electricity.

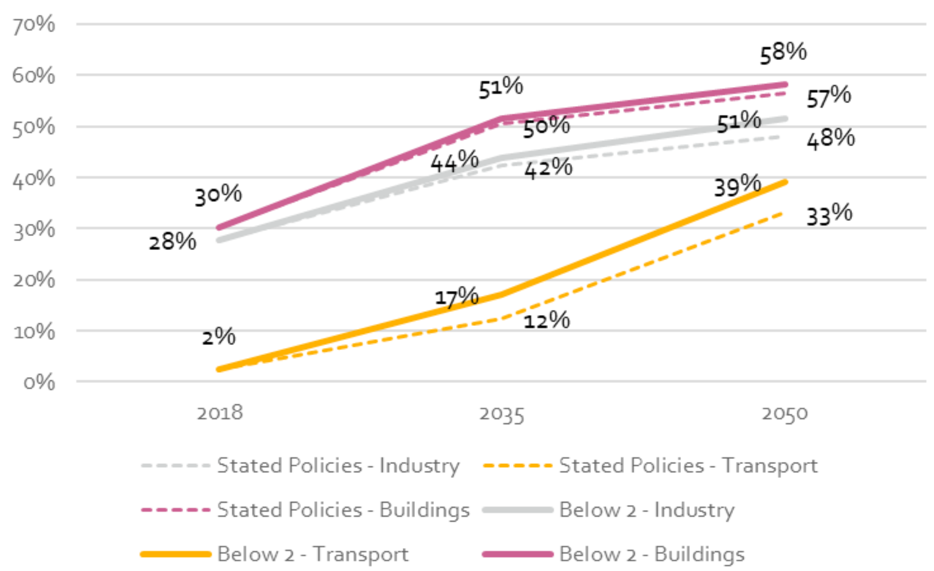
Along with the inter and inner structural changes, China will continue its economic growth while driving down its energy demand. The end result will be a more balanced structure. Future energy growth will be centred on the transportation and building sectors (both residential and commercial). Final energy use in the industrial, transport and building sectors will change from the current 54%:14%:25% to 44%:18%:34% in 2035 and then to 41%:26%:38% in 2050. The stable decline of industrial energy consumption benefits from an on-going industrial upgrade which reins in current energy-intensive and polluting activities and boosts energy efficiency. A widespread electrification of transport offsets the incremental energy demand brought about by car ownership growth and restricts its growth. Strong demand growth in the buildings sector is anticipated due to continuing economic growth, urbanisation and increased expectations of domestic comforts.

Electrification enhances the reach of decarbonised electricity supply

The IEA states in World Energy Outlook 2018[5] that 'A doubling of electricity demand in developing economies, puts cleaner, universally available and affordable electricity at the centre of strategies for economic development and emissions reductions.' Due to the cost-reductions in renewable electricity supply sources, electricity becomes an increasingly cost-competitive energy carrier and thereby a means to replace direct consumption of fossil fuels.

The electrification rate increases from approximately 26% in 2018 to 43% in the Stated Policies Scenario and 48% in the Below 2°C Scenario by 2035[6]. Electrification expands further to 54% by 2050 in the Stated Policies Scenario and 66% in the Below 2°C Scenario.

Figure 5.4: Development of electrification in transport, industry and buildings in the two scenarios.



5 International Energy Agency. 'World Energy Outlook.' Paris (2018). https://webstore.iea.org/world-energy-outlook-2018

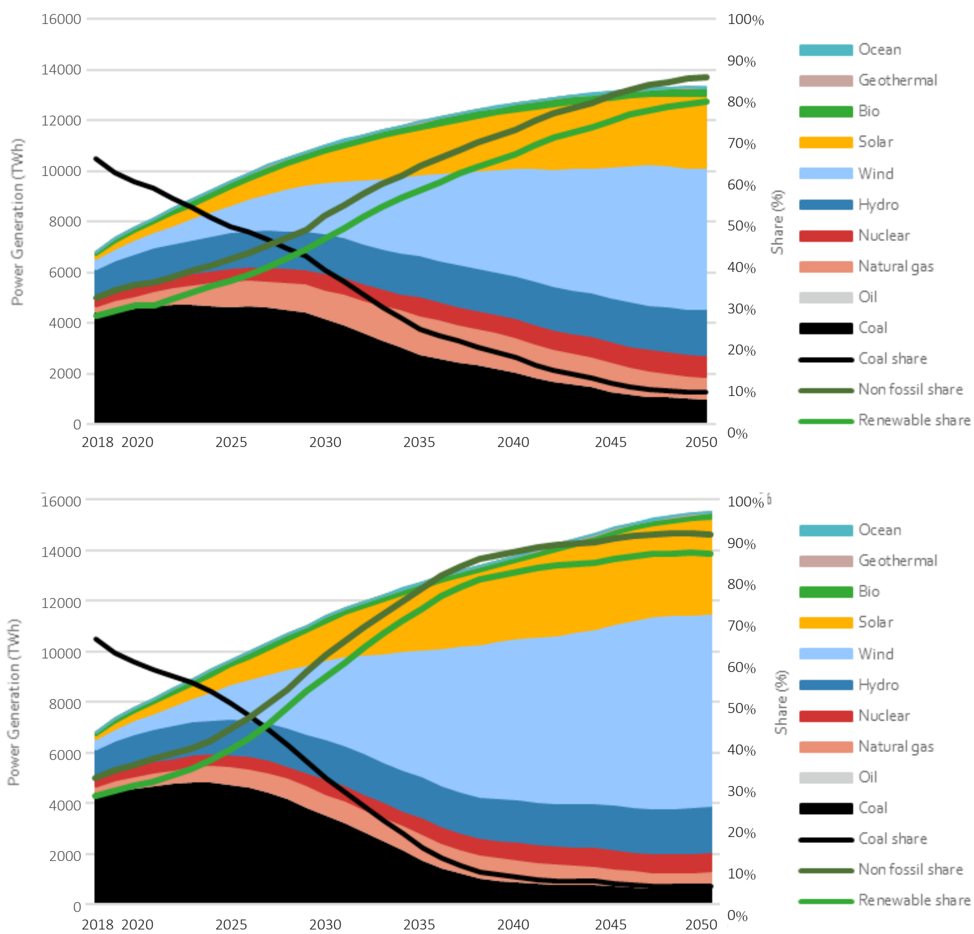
6 The electrification rate is defined as the electricity generation / final energy consumption (including power plants own consumption).

By 2050, the transport sector has reached 39% electrification in the Below 2°C Scenario, from 2% in 2018. Electrification in industry rises from 28% to 51% and in the buildings sector from 30% to 58%.

Electricity is decarbonised through expansion of non-fossil electricity sources
By 2035, the Stated Policies Scenario sees the non-fossil share of electricity supply more than double to 64% from about 31% in 2018. The Below 2°C Scenario goes even further, achieving 78% non-fossil supply by 2035. By 2050, the non-fossil electricity supply is 86% in the Stated Policies Scenario and 91% in the Below 2°C Scenario. Both development pathways presuppose firm implementation of key policies including the ongoing power market reform which will ensure a competitive level playing field for renewable electricity. This involves fossil-fuels bearing an increasing proportion of the societal costs of their emissions e.g. through further development of the emissions trading system which is currently being deployed.

Electricity from wind and solar account for the majority of this transition, with 42% of the electricity supply coming from wind and solar by 2035 in the Stated Policies Scenario. This development is enhanced in the Below 2°C Scenario, with 58% of the total electricity generation coming from wind and solar in 2035. By 2050, wind and solar electricity accounts for 63% and 73% in the Stated Policies Scenario and Below 2°C Scenario, respectively.

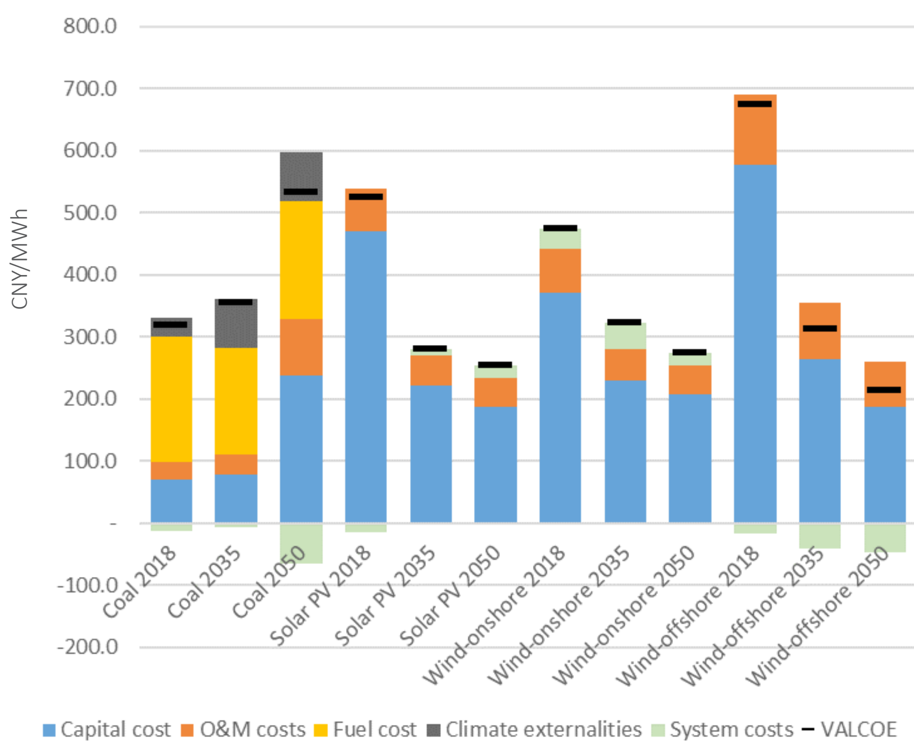
Figure 5.5: Generation by technology through to 2050 in the Stated Policies Scenario (top) and Below 2°C Scenario (bottom).



Cost of wind and solar is a key driver of a financially viable energy transition, but successful system integration is key.
The primary driver for this massive expansion of wind and solar is the cost-competitiveness of their electricity supply. While today wind and solar for the most part remain slightly more expensive than coal power, cost reductions are on track to end this. Wind and solar will be on a par with coal during the 14th Five-Year Plan period and afterwards will drop below the price of coal power. This is crucially important for the planning of the energy transition: the combined political aspirations of decarbonisation, clean air policy and future fossil fuel independence depend on it.

The competitiveness of new coal power is reduced significantly in the medium and long-term. The role of coal power changes from providing baseload electricity supply, to providing support for the power system as the renewable penetration share is increased.

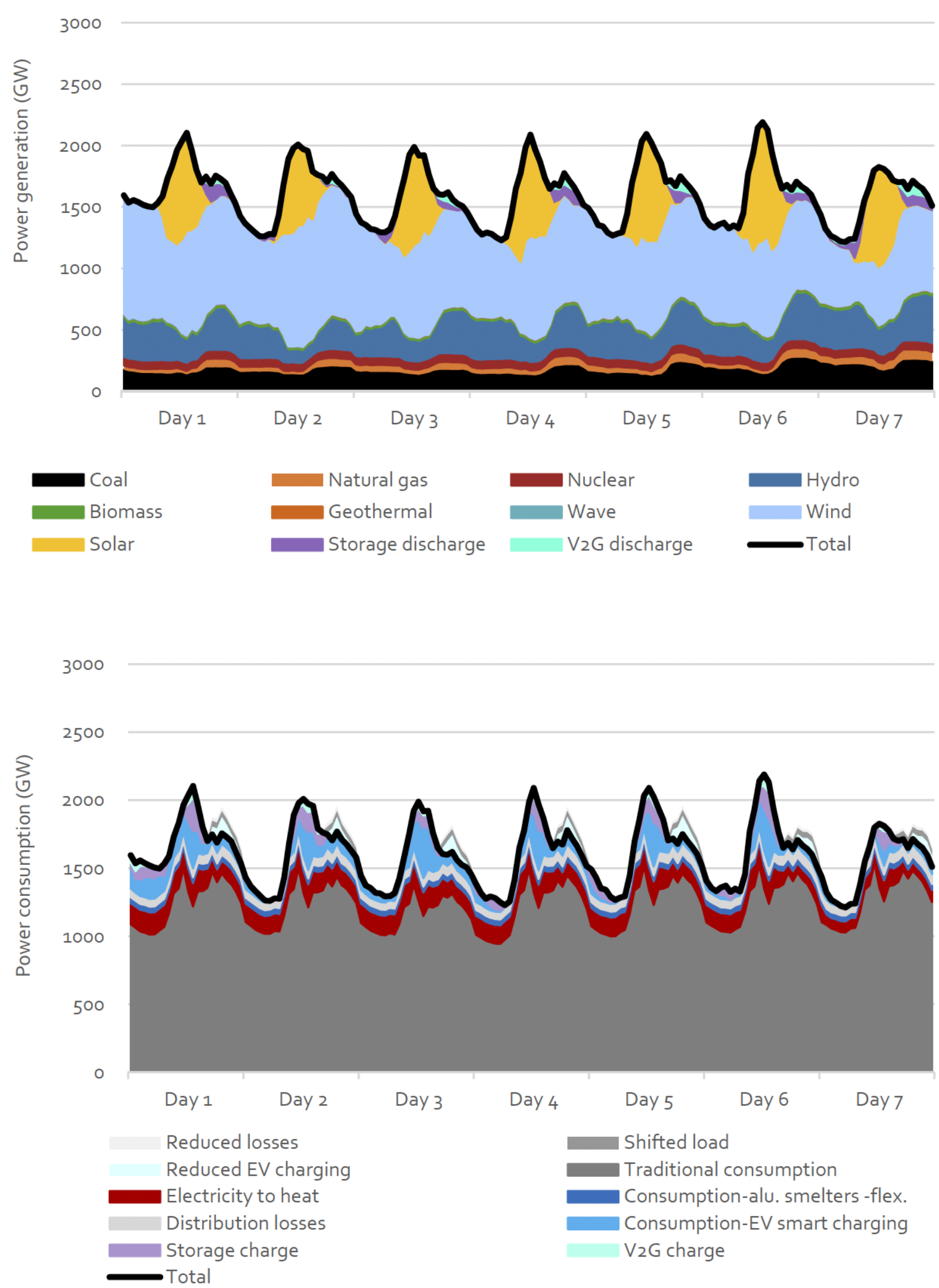
Figure 5.6: Levelised cost of electricity from new coal, wind and solar (utility scale PV) including value adjustments (system costs) and average operating hours from the Stated Policies Scenario.



Note: For 2018, average full-load hours (FLH) for the technology are used in the calculations; for 2035 and 2050 the average FLHs for the respective technologies in the Stated Policies Scenario is used. The system costs reflect the difference between the specific technology's average system value of generation and the average overall technologies in the Stated Policies Scenario for that year. In a market setting, this reflects the higher (or lower) energy price that can be captured by the technology vis-à-vis the average. Two key factors determine this for the technologies averaged over all of China, namely the timing and location of generation vs. the needs in the system.

Cost efficient system integration is a central challenge of energy transition
Variable renewable electricity provides the lowest cost electricity and constitutes one of the lowest cost options for displacing other fossil energy consumption at utility scale. The transition is made cost-efficient in the scenarios by utilising all available cost-effective sources. This includes a host of technical messages in both the power generation-side and the consumption-side. Various flexible sources, including storage, V2G, industrial load shifting, and smart EV charging are mobilised to accommodate the power system fluctuation caused by the high share of VREs. The system will include new technologies as well as retrofitting and designing thermal plants for flexible operation, using the flexibility of hydro reservoirs, while expanding and utilising the power transmission grid efficiently.

Figure 5.7: Profiles for power generation (top) and consumption (bottom) in China in winter 2050 (Below 2°C Scenario).

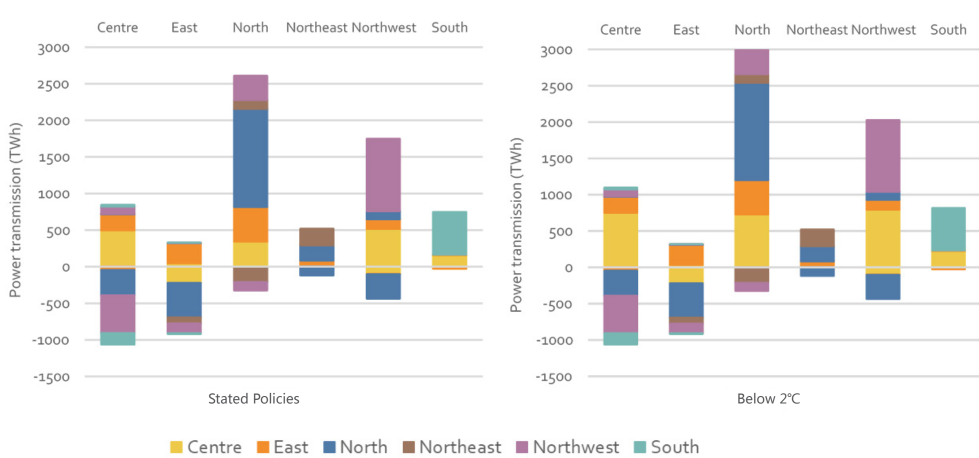


Interprovincial transmission expansion and flexible operation is important for the integration of high penetration of renewable generation
Interprovincial grid expansion is critical to provide stability and balancing support, especially when the grid needs to integrate a high penetration of variable renewable sources. In the model, transmission grid expansion is planned according to least-cost principles in order to transfer electricity efficiently and ensure system security. In the short term, it is assumed that all lines currently planned or under construction will be completed. After 2020, new lines are added to support electricity demand growth and integrate more renewables in the power system.

From 2020 to 2050, total interprovincial grid capacity within different regions is expanded to 682 GW (amounting to an 89% increase) in the Stated Policies Scenario and 781 GW (amounting to a 116% increase) in the Below 2°C Scenario, from 361 GW in 2020. Interregional grid capacity and power transmission shows similar trends as within the regions and the growth is even sharper. In the Below 2°C Scenario, interregional grid capacity is expanded from 411 GW in 2020 to 506 GW in 2025, amounting to a 23% increase. The corresponding growth is smoother in the Stated Policies Scenario, with a 16% increase. The capacity expansion becomes faster later on. Overall capacity in 2050 is more than doubled in the Below 2°C Scenario and in the Stated Policies Scenario, compared to 2020.

Figure 5.8: Power transmission between regions in 2020.

Figure 5.9: Power transmission between regions in 2050.



6. MODELS

6.1 Energy system models in China and the EU

Introduction
Decisions about energy systems need to be based on robust analyses and modelling. Energy system models are computational models that simulate how energy is produced, transformed, and consumed, taking into account socio-economic behaviours and physical constraints.

The models generate insights regarding a range of issues, including energy supply and demand, climate change mitigation pathways and the impact of energy, environmental and economic policies.

Modelling the energy system is challenging because of the immense complexity of system components, the economy-wide interlinkages between sectors, and behaviour of consumers and producers. In recent years, the development of variable renewable energy, distributed energy, electrification, and flexible demand has made modelling even more challenging.

In particular, in long term modelling assumptions about political decisions, economic incentives and social behaviour can have a significant impact on results, but they are difficult to predict. Often these kinds of uncertainties are treated via different future scenarios, which form the basis of the modelling exercise.

China energy system models
A variety of economic models has been developed in China over the past three decades, but sophisticated energy system-specific models are relatively few and have been devised only recently. The development has been described in CREO 2018 (CNREC, 2018)[7].

The earliest energy system models in China were developed in the 1980s. Most of these were simple models which contributed to energy demand forecasts.It was not until the 1990s that more advanced energy system models started to be developed in China.

For example, in 1997 the State Council Development and Research Institute, in collaboration with the Development Centre of OECD, devised China's first computable general equilibrium (CGE) model.

In 1999, the Institute of Quantitative and Technical Economics of the Chinese Academy of Social Sciences also developed a CGE model in collaboration with Monash University. The Energy Research Institute of the State Planning Commission started building the Integrated Policy Assessment Model for China (IPAC) in collaboration

7 CNREC. (2018). China Renewable Energy Outlook 2018. CNREC.

with Japan's National Institute for Environmental Studies, based on the Asian-Pacific Integrated Model.

In the 2000s, modelling practices started to blossom in China. A MARKAL-China model was developed by a research team from Tsinghua University in 2001 and has since then been adopted and incorporated into the energy system planning of several regions, including Beijing and Shanghai.

In 2004, the same Tsinghua team integrated the top-down MACRO model with the bottom-up MARKAL model to create a MARCAL-MACRO China model for the study of carbon mitigation strategies and their impact on the energy system. Also, Shanghai University of Finance and Economics built an energy-economy-environment model for the analysis of 'green GDP' in Shanghai's industrial sector.

The most important energy system models currently used for analysing China's energy system are summarised below in Table 6.1 (CNREC, 2018).

The table does not constitute a comprehensive list: many models in China, such as those used by China Electric Power Research Institute and State Grid Economic and Technological Research Institute, are highly confidential, and no public documentation or studies are available. In addition, other models are used in academic settings which have not been widely applied in decision-making.

Table 6.1: Important energy system models currently used in China.

Model	Full name	Type	Geographic Resolution	Planning Horizon	Primary User
MRIO	multiregional input output model	top-down input/output	regional	short-term	Chinese Academy of Sciences
EPPEI Planning Model	EPPEI generation planning model	bottom-up optimisation	national	Medium-to long-term	Electric Power Planning & Engineering Institute
EPS	energy policy solutions/ simulator	system dynamics	national	long-term	National Centre for Climate Change Strategy and International Cooperation, NDRC ERI
IPAC-ERI	integrated policy assessment model	hybrid	national, regional, provincial	long-term	NDRC ERI

CREAM (CGE, LEAP, EDO)	China renewable energy analysis model	hybrid	national	long-term	NDRC ERI/ CNREC
CGE-NCEPU	computable general equilibrium model	top-down CGE	national	short-term	North China Electric Power University
GCAM-China	global integrated assessment model	market equilibrium	national	long-term	Pacific Northwest National Laboratory
MSCGE	multisector computable generation equilibrium model	top-down CGE	national	medium-term	State Council Development Research Centre
GESP	generation electricity system planning model	bottom-up optimisation	national, regional	medium-to long-term	State Grid Energy Research Institute
DCGE-SIC	dynamic computable general equilibrium model	top-down CGE	provincial	short-term	State Information Centre
China TIMES	integrated MARKAL-EFOM system model for China	bottom-up optimisation	national	long-term	Tsinghua University
MARKAL-MACRO China	market allocation model and macroeconomic model	hybrid	national	long-term	Tsinghua University
Tsinghua-MARKAL	market allocation model	bottom-up optimisation	regional	long-term	Tsinghua University
SWITCH-China	solar and wind energy integrated with transmission and conventional sources - China	bottom-up optimisation	national	medium- to long-term	UC Berkeley, Stony Brook University
MESSAGE	model for energy supply strategy alternatives and their general environmental impact	bottom-up optimisation	national	long-term	University of the Chinese Academy of Sciences

EU energy system models

Numerous models exist at the European level. Obtaining a comprehensive overview of these models and their scope is a difficult task, making model comparison exercises resource-intensive.

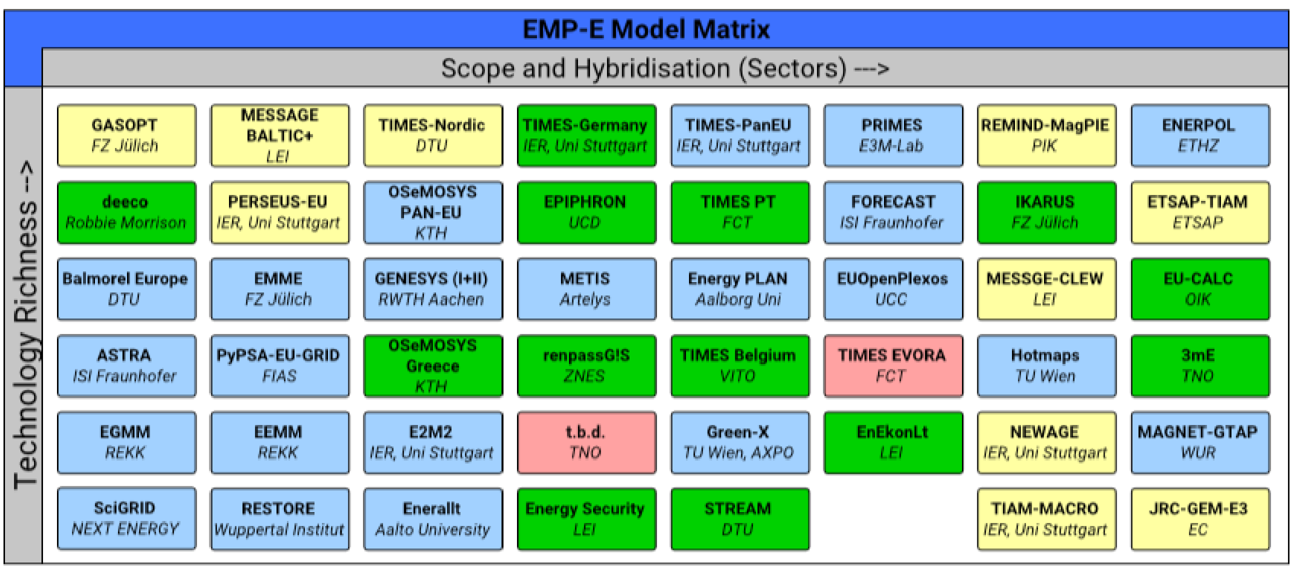
Since the first initiatives to provide an overview and categorisation and attempt to compare energy system models e.g. Huntington, H.G, 1982[8], there have been many studies in the field offering different approaches to this task.

An important approach to describing and categorising energy system models in EU is currently under way in connection with the formation of the Energy Modelling Platform for Europe (EMP-E). EMP-E is a platform for cooperation between modelers and decision makers.

At an initial conference in 2017, the EMP-E platform was established as part of the Horizon 2020 EU framework Programme for Research and Innovation. EMP-E aims to provide a peer-reviewed digest of model and policy insights for European energy scenario projects.

The 2017 EMP-E conference attracted 90 participants, and 47 different energy system models were described and categorised (Müller, Gardumi, & Hülk, 2017). The result is indicated in Table 6.2 which also shows model names and primary users /developers (research institutions/universities).

Figure 6.1: EMP-E model matrix: blue - EU, green - national, red - regional, yellow - other) (Müller, Gardumi, & Hülk, 2017)[9]



8 Huntington, H.G. (1982). Modelling for insights not numbers; the experiences of of the energy modelling forum, Omega.

9 Müller, B., Gardumi, F., & Hülk, L. (2017). Comprehensive representation of models for energy system analyses-Insights from EMP-E. Energy Strategy Reviews.

The models are categorised in three ways: 1) technology richness, 2) scope and hybridisation (from single sector to multi-sectorial analysis), and 3) geographic focus:

- Colours indicate geographic focus: blue-EU, green national, yellow-other

- The x-axis of the model matrix displays the scope and hybridisation of the models, starting from left (one sector) to right (multiple sectors). From the perspective of energy system modelling, final energy sectors (electricity, heat, liquid fuels, gas) and demand sectors (households, industry, commercial/retail, transportation/mobility) are often differentiated. However, the EMP-E 2017 meeting included models that took other sectors into consideration, such as ecology, land use, health, and behaviours. Therefore, no breakdown into sectors was suggested on the axis, nor a scale with the number of sectors, leaving the interpretation to the modelers.

- The y-axis indicates the richness in technology. On the bottom, models with aggregated representation of technologies (such as economy-wide models) are featured. On the top, models with high technology resolution are represented, such as bottom-up models. As for the x-axis, given the variety of models in the matrix and the broad definition of the term technology, no scale of technology richness was provided.

The EMP-E is planned to provide an online platform for continuous exchange between modelers working on the European energy system and transition.

Conclusion
Both in China and the EU there has been and is a strong development of energy system models. The models are widely used tools to gain a better understanding of the energy system, its potential evolution and its optimal configuration. Alternatively, they are used, for instance, to evaluate the optimal penetration of technologies or to assess possible impacts of specific measures.

Therefore, in terms of EU-China cooperation (under the ECECP), it is important to support current and future model capabilities in the EU and China.

6.2 Model candidates and selection of models to be applied

At the online launch of the project on 17-19 March 2020, SGERI and ERI/CNREC each presented their planning and market models.

It was decided that both models should be applied to demonstrate the outcomes from ENTSO-E methodologies on China transmission planning. The SGERI model should be used with the SGERI scenarios and the ERI/CNREC model with the ERI/CNREC scenarios, respectively.

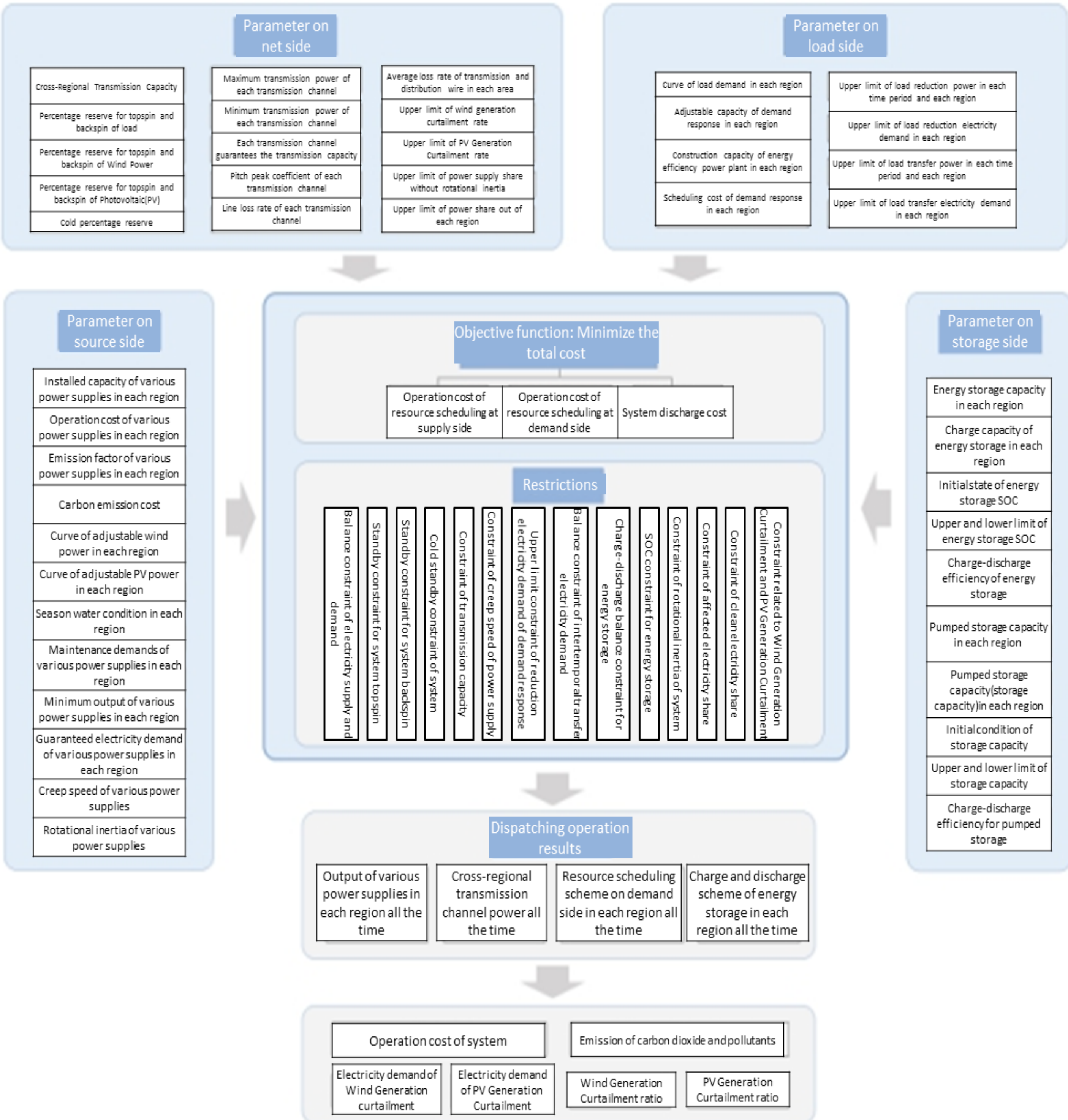
However, it was later concluded that the resolution on SGERI's model was too low (simulation based on regions instead of provinces). Instead, only ERI/CNREC's model has been used for screening scenarios and CBA simulations.

Nevertheless, SGERI's model is also described in this chapter (Section 6.3) for the sake of completeness.

6.3 Short description of main features of SGERI model

The model is called multi-regional coordinated source-grid-load-storage operation simulation of power system. It is used for optimisation and simulation of system operation status based on the planning outcomes for China's power system. Firstly, the source-grid-load-storage coordination planning prospect scheme in the main target year is verified; secondly, the operation method of China's power system in the main target year is proposed. In this model, the optimal solution of various power outputs, transmission power of cross-regional transmission channels, demand response and storage capacity on a typical day within the power grid simulation period of seven regions in China can be obtained synchronously. As for the application on China's regional case study, the model program includes over 36 000 formulae, about 160 000 exogenous variables and about 32 000 endogenous variables. A schematic diagram of the model principle is shown in the following figure, see next page.

Figure 6.2: Schematic diagram of source-grid-load-storage coordination-operation simulation model of power system.



Mathematical formulas in the model

As a mathematical optimisation issue, the model consists of an objective function and some constraints. The objective is to minimise the overall costs including the generation cost, DR cost and carbon emission cost.

$$\min\ F=\sum_{t=1}^{H}\sum_{r=1}^{R}\sum_{i=1}^{N}\left(P_{i,t}\cdot FC_i\right)+\sum_{r=1}^{R}\sum_{t=1}^{H}\left(DRC_t\cdot Eh_t\right)+Pr_C\cdot\sum_{t=1}^{H}\sum_{r=1}^{R}\sum_{i=1}^{N}\left(e_i\cdot P_{i,t}\cdot I_{i,t}\right)$$

The model includes the following 19 constraints. Among them, in order to ensure that the system reserve capacity can cope with the variability of new energy generation, the impact of PV and wind power on up and down spinning reserve constraints are considered.

(1) Constraint on power balance.

$$\sum_{i=1}^{N}\left(P_{r,i,t}\right)-\sum_{g\in\Omega_{r1Y}}Pt_{g,t}+\sum_{g\in\Omega_{Y1r}}Pt_{g,t}\cdot\left(1-l_g\right)+DRC_{r,t}+DRSo_{r,t}-DRSi_{r,t}+Cc_{r,t}=Load_{r,t}$$
$$\left(r=1,2,\ldots,R;\quad t=1,2,\ldots,H\right)$$

(2) Constraint on up spinning reserve.

$$\sum_{i=1}^{N}\left(P_{r,i,t,\max}-P_{r,i,t}\right)\cdot I_{r,i,t}+DRC_{r,t,\max}-DRC_{r,t}+DRSo_{r,t,\max}-DRSo_{r,t}+DRSi_{r,t}$$
$$+Cc_{r,t,\max}-Cc_{r,t}\geq a_1\cdot Load_{r,t}+b_1\cdot Pw_{r,t}+c_1\cdot Pp_{r,t}$$
$$\left(r=1,2,\ldots,R;\quad t=1,2,\ldots,H\right)$$

(3) Constraint on down spinning reserve.

$$\sum_{i=1}^{N}\left(P_{r,i,t}-P_{r,i,t,\min}\right)\cdot I_{r,i,t}+DRC_{r,t}+DRSo_{r,t}+DRSi_{r,t,\max}-DRSi_{r,t}$$
$$+Cc_{r,t}-Cc_{r,t,\min}\geq a_2\cdot Load_{r,t}+b_2\cdot Pw_{r,t}+c_2\cdot Pp_{r,t}$$
$$\left(r=1,2,\ldots,R;\quad t=1,2,\ldots,H\right)$$

(4) Constraint on non-spinning reserve.

$$\sum_{i=1}^{N}\left[P_{r,i,t,\max}\cdot\left(1-I_{r,i,t}\right)\right]\geq a_3\cdot Load_{r,t}\qquad\left(r=1,2,\ldots,R;\quad t=1,2,\ldots,H\right)$$

(5) Constraint on the output range of power sources.

$$P_{i,\min}\cdot I_{i,t}\leq P_{r,i,t}\cdot I_{r,i,t}\leq P_{i,\max}\cdot I_{i,t}$$

(6) Constraint on the ramp-up rates of power sources.

$$-Rd_i \leq \frac{P_{rjt} - P_{rjt-1}}{P_{rjt-1}} \leq Ru_i$$

(7) Constraint on available wind power.

$$Pw_{rt} \leq W_{rt} \cdot Cw_r$$

(8) Constraint on available PV power.

$$Pp_{rt} \leq S_{rt} \cdot Cp_r$$

(9) Constraint on DR load curtailment.

$$DRC_{rt} \leq DRC_{rt\max} \qquad (r = 1, 2, \ldots, R; \quad t = 1, 2, \ldots, H)$$

(10) Constraint on DR load shift out.

$$DRSo_{rt} \leq DRSo_{rt\max} \qquad (r = 1, 2, \ldots, R; \quad t = 1, 2, \ldots, H)$$

(11) Constraint on DR load shift in.

$$DRSi_{rt} \leq DRSi_{rt\max} \qquad (r = 1, 2, \ldots, R; \quad t = 1, 2, \ldots, H)$$

(12) Constraint on DR load shift balance.

$$\sum_{t=1}^{H} DRSo_{r,t} = \sum_{t=1}^{H} DRSi_{rt} \qquad (r = 1, 2, \ldots, R)$$

(13) Constraint on charge & discharge balance.

$$\sum_{t=1}^{H} \left[\max(Cc_{rt}, 0) \right] = \sum_{t=1}^{H} \left[-\min(Cc_{r,t}, 0) \right] \qquad (r = 1, 2, \ldots, R)$$

(14) Constraint on State of Charge of energy storage facilities.

$$SOC_{r\min} \leq \frac{Sci_r + \sum_{t=1}^{t} \left[-\min(Cc_{rt}, 0) \right] \cdot (1 - \eta_c) - \sum_{t=1}^{t} \left[\max(Cc_{rt}, 0) \right]}{Ec_r} \leq SOC_{r\max}$$

$$(r = 1, 2, \ldots, R; \quad t = 1, 2, \ldots, H)$$

(15) Constraint on the share of power sources with no inertia.

$$\frac{Pw_{rt} + Pp_{rt}}{\sum_{i=1}^{N} \left(P_{rit} \right) + Pw_{rt} + Pp_{rt}} \leq VP_{\max} \qquad (r = 1, 2, \ldots, R; \quad t = 1, 2, \ldots, H)$$

(16)Constraint on the share of power import.

$$\frac{\sum_{g\in\Omega_{r1t}} Pt_{g,t}\cdot\left(1-l_g\right)}{Load_{r,t}} \le IP_{\max} \qquad \left(r=1,2,\ldots,R; \quad t=1,2,\ldots,H\right)$$

(17) Constraint on the share of power export.

$$\frac{\sum_{t=1}^{H}\sum_{i\in\Omega_{cp}}\left(P_{r,i,t}\right)}{\sum_{t=1}^{H}\sum_{i=1}^{N}\left(P_{r,i,t}\right)} \ge Rcp_r \qquad \left(r=1,2,\ldots,R\right)$$

(18) Constraint on wind power curtailment rate.

$$\frac{\sum_{t=1}^{H}\left(W_{r,t}\cdot Cw_r - Pw_{r,t}\right)}{\sum_{t=1}^{H}\left(W_{r,t}\cdot Cw_r\right)} \le Rwc_r \qquad \left(r=1,2,\ldots,R\right)$$

(19) Constraint on PV power curtailment rate.

$$\frac{\sum_{t=1}^{H}\left(S_{r,t}\cdot Cp_r - Pp_{r,t}\right)}{\sum_{t=1}^{H}\left(S_{r,t}\cdot Cp_r\right)} \le Rpc_r \qquad \left(r=1,2,\ldots,R\right)$$

Inputs and outputs of the model

(1) Inputs:

- The capacity of various power sources, cross-regional transmission, demand response and energy storage facilities in each region in the target year to be simulated.
- The load demand curve in each region.
- The available resource curve of PV and wind power in each region.
- The maximum and minimum output coefficients, ramp-up rate, and fuel cost of each power source in each region.
- The maximum and minimum output coefficients of each transmission channel.
- The upper limits on the capacity and electricity of load curtailment and load shift, and the cost of DR.
- The efficiency and state of charge (SOC) limits of pumped storage and other energy storage facilities.
- The reserve rate coefficients considering the impacts of PV, wind power and load demand variability.
- Acceptable maximum curtailment rate of PV and wind generation.
- The upper limit on the share of power export/import in each region.
- The upper limit on the share of power sources with no inertia.

(2) Outputs:

- output of various power sources in various regions at each hour.
- the power transmission of each cross-region channel at each hour.
- the operation status of demand response and energy storage in various regions at each hour.
- the indicators on system cost and emissions.

6.4 Short description of the ERI/CNREC (EDO) model

The scenario development in CREO is supported by the ERI's energy system modelling tool, consisting of interlinked models and covering the energy sector of mainland China.

6.4.1 Modelling structure

Since it was established in 2011, the ERI has focused on developing comprehensive modelling tools to analyse the energy and socio-economic impact of development and integration of renewable energy in the Chinese energy system.

Final energy demands are directed in the END-USE model
The END-USE model, based on the Long-range Energy Alternatives Planning system (LEAP), represents bottom-up modelling of end-use demand and how this demand is satisfied. End-uses are driven by assumed developments in key activity levels in the economy, including projections for production relating to key energy intensive products (steel, cement, chemicals, etc), and the economic value added for other industries.

These drivers translate to energy consumption when combined with assumptions such as industrial output changes, floor area development, energy efficiency improvement, device and fuel shifting (mainly in the industrial and transport sectors), as well as adjustments for end-use behavioural features.

LEAP also covers transformation activities aside from district heating and power, including upstream refinery activity such as hydrogen production from the electrolysis process, biofuel production via different technical routines, oil-refining, etc.

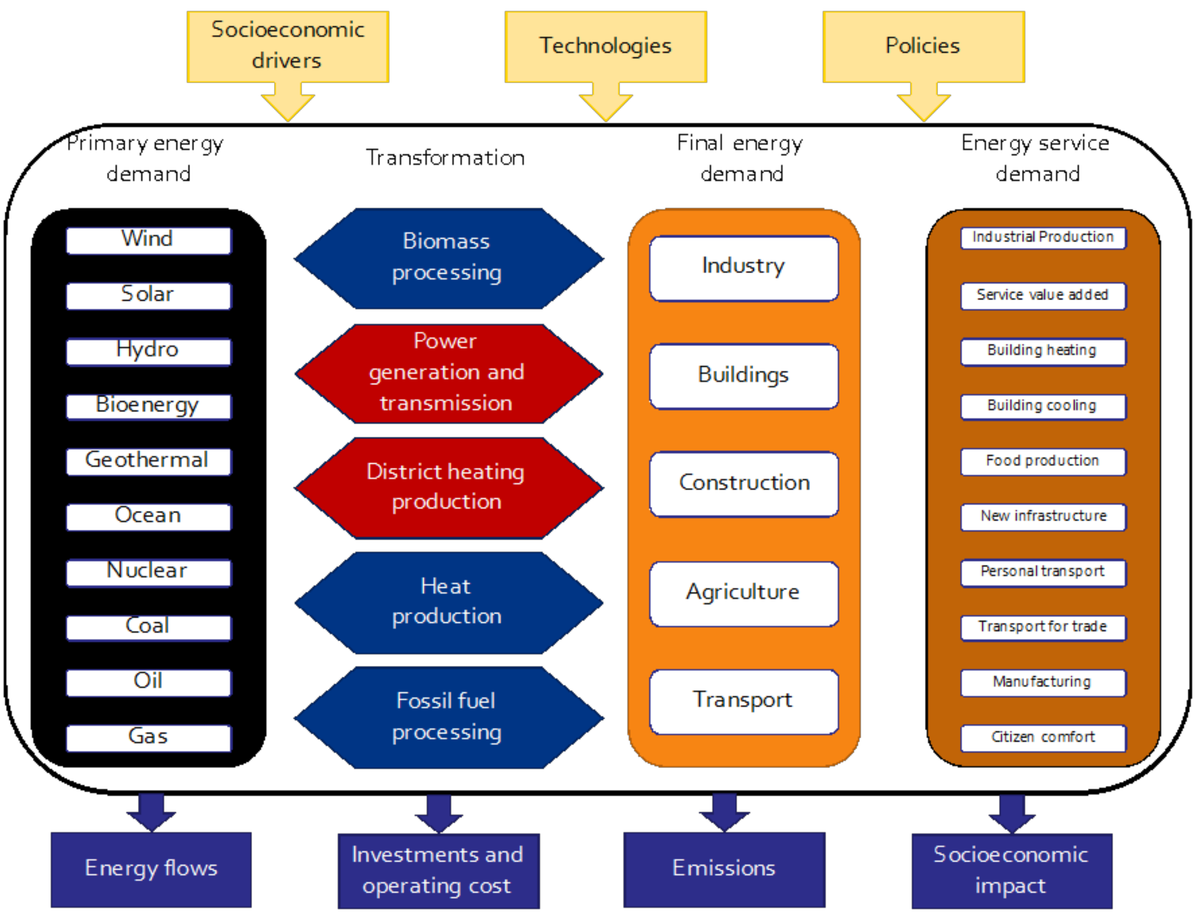
Power and district heating sectors are modelled in EDO
The EDO model is a fundamental model of power and district heating systems, built on the Balmorel model (www.balmorel.com). The power system is represented at provincial level, taking into account interprovincial grid constraints and expansion options. The model includes all relevant production units, i.e. thermal (including CHP), wind, solar (including CSP), hydro, power storage, heat boilers, heat storage, heat pumps, etc. on the supply side. Additionally, it considers options for demand-side flexibility, e.g. from industry, smart charging of electric vehicles, as well as the option of a fully integrated coupling with the district heating sector.

The model can represent the current dispatch in the Chinese power system on an hourly basis, with limitations on the thermal power plants and interprovincial exchange of power; it can also represent the dispatch in a power market, provincial, regional, or national, based on the least-cost marginal price optimisation. Key characteristics relate to the detailed representation of variability of load and supply (e.g. from VRE sources) as well as flexibility and flexibility potentials, which can operate optimally and be deployed efficiently in capacity expansion mode. As the Balmorel model is open source, it has allowed for flexible customisation and enhancements including core features and 'add-ons' to tailor the model for application to China, and for interaction with the CNREC suite of models. EDO was introduced in 2012 and has since been continuously used and enhanced, including in the production of earlier CREO reports.

Combined summary tool

Quantitative results from the two models are combined in an integrated Excel-based tool, which provides an overall view of the energy system, e.g. combining fuel consumption from the power and heating systems from EDO, with direct consumption in end-use sectors and consumption in other transformation sectors from LEAP.

Figure 6.3: The energy system modelled by CNREC modelling tools.



6.4.2 EDO (Electricity and District Heating Optimisation) model

Scenario consistency in the power and district heating sector is ensured using the EDO model. EDO is both a capacity expansion model and an optimal unit commitment and economic dispatch model. Essentially, the model finds the cost-optimal solution for the power and district heating sectors by minimising total costs including fuel costs, capital, operation and maintenance, subject to constraints imposed on the solution such as specific targets or policies that must be achieved. Policy and scenario assumptions are thereby implemented to guide the model results towards the scenario narrative, rather than allowing the least-cost algorithm solely to determine the capacity mix which achieves the overarching objectives of the scenarios.

Key modules of EDO model
The CREAM-EDO model operates according to the following well-known power system modelling concepts using user settings and input data:

- Economic dispatch optimisation – finding the optimal level of generation from each unit to satisfy demand in each area of a grid, at each step subject to power grid limitations, technical constraints and other limitations.

- Unit commitment – similar to economic dispatch optimisation but with the added complexity of deciding when, and which, units should be started and stopped. This adds complexity to the cost and technical representation of units as start-ups and shutdowns are costly operations and discrete decisions, which affect subsequent decisions.

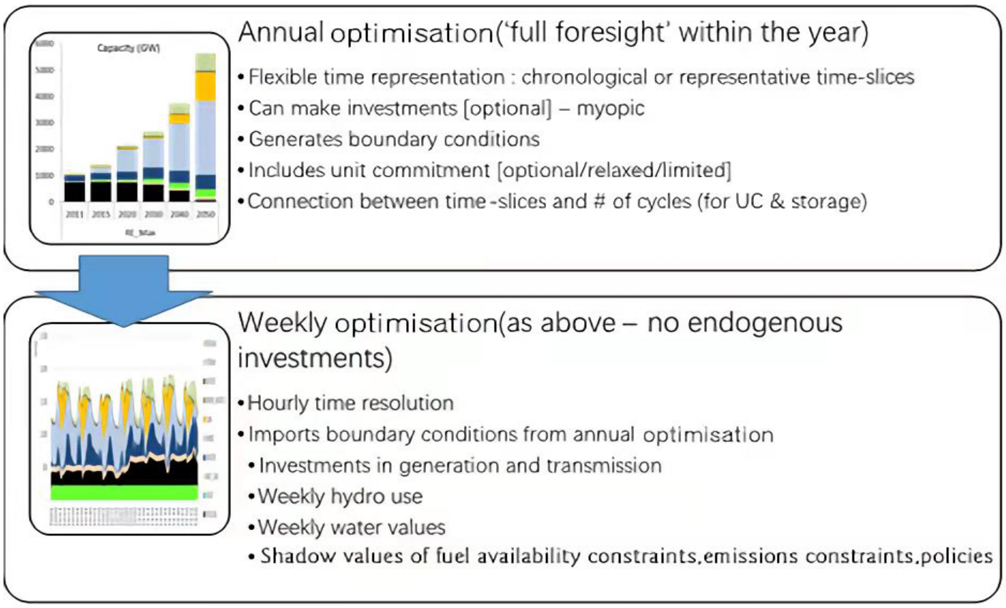
- Capacity expansion – provides for capacities to be endogenously determined by the model. Thereby the model can be allowed to make investments in generation, transmission and storage based on the needs and economics of the system.

Fundamentally, the model generates a series of linear optimisation programs (or mixed-integer linear programs), each covering either a week or a year. Standard commercial optimisation algorithms solve these mathematical problems.

A model run consists of one or more linear programs solved either in parallel or sequentially. In general, each year is solved sequentially without reference to the years beyond the year in question.

The model basically runs in two different modes which can interact. The first mode looks at a full year. In this mode, the user configures the time resolution. Normally, for computational reasons, this will be less than full hourly resolution. The second mode looks at a full week at hourly resolution. The model therefore runs 52 times for each week of the year simulated. Each of these modes can be run for successive years creating a pathway for development of the power and district heating systems. If the user allows investing in the annual model, the capacity installed by the model in one year is available in subsequent years until the end of technical lifetime.

Figure 6.4: Flow diagram of EDO operation.



Inputs and outputs
CREAM-EDO contains input data describing the capacities and capabilities of the current system. This includes the following:

- **Technologies** are defined as either individual unit, unit types or aggregations of units. These are associated with technical and economic characteristics, e.g. capacities for production and/or storage, efficiencies, fixed and variable costs and associated fuels.
- **Fuels** are defined with associated characteristics: emission coefficients, renewable content, and prices.
- **Resource potentials** or minimum fuel usage requirements can be associated at various levels from countries to single plants. Seasonal and hourly variations in availability (e.g. wind and hydro) shall be specified.
- **Electricity and heat demand** projections are input on a regional and area level.
- **Power transmission capacities** internally in each country (or at sub-country level) and on cross-border interconnections as well as import/export with other countries. Capacities, losses, and costs of transmission are defined with reference to two adjacent regions.
- **Taxes and subsidies** include national taxes and subsidies on production. Consumption or fuel inputs are dependent on geography, fuel types or technology types.
- **Environmental restrictions or penalties** on emission types (CO_2, SO_2, NO_x). Additionally, regional policies can be factored in using add-on modules, including current and future policies that may influence deployment or operations.

An EDO calculation yields results in terms of setting values for quantities and prices (shadow costs) for millions of variables. To make sense out of this in an analytical content, data must be pivoted, filtered and/or aggregated to provide meaningful insights in the problem being analysed. At its core, the data output can be characterised as follows:

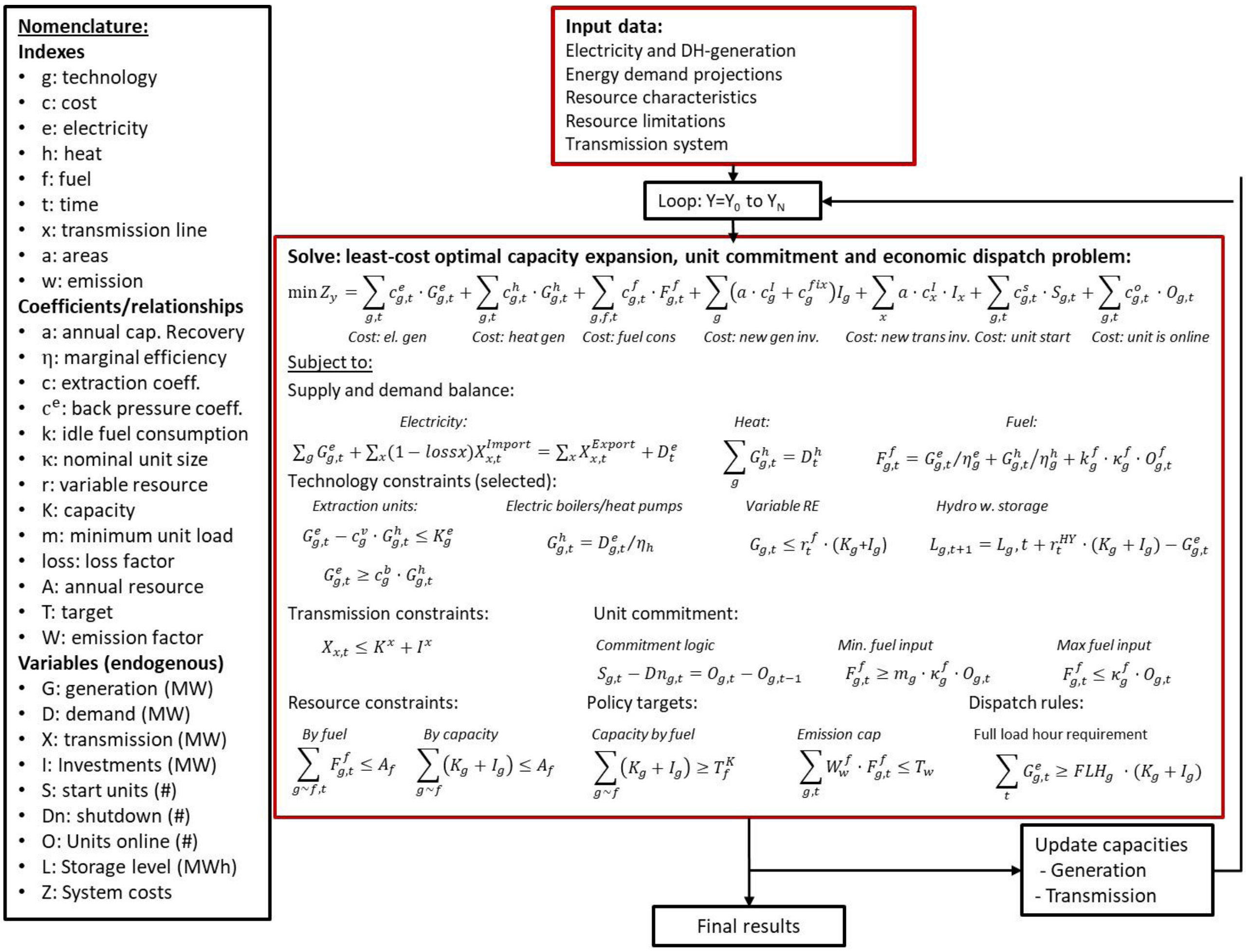
- **Generation of electricity** and heat associated with units in geographical locations and each simulation time step.
- **Consumption of electricity, heat, and primary energy (fuels)** distinguished by geography, units (fuel) and simulation time step.
- **Transmission of electricity** between connected regions.
- **Prices of electricity** can be extracted distinguished by region and time steps in the simulation. Similarly, a fair market value of other limited resources can be extracted from e.g. fuels, CO_2-emission permits or generated heat.
- **Investments** in electricity and heat generation capacity, transmission and storage capacity can be extracted as endogenous variables when running the capacity expansion model version. Economic rent from location limitations (e.g. for wind), transmission capacity and other capacity scarcity can similarly be evaluated on the background of shadow prices.
- **Emissions** from the generation of electricity and district heat as distinguished by geography, units, and time steps.

Covering regions

CREAM-EDO is configured to cover 31 provinces in mainland China including the four provincial-level municipalities. Inner Mongolia is divided into eastern and western parts, creating a total of 32 distinct geographical regions in the model. Within each region, the model calculates generation, consumption and storage operations for power and district heating units, and the transmission of power between provinces. Associated with these activities, the model calculates fuel consumption, emissions, and the economic costs of operating this system. The model provides these values for each time-step in the simulation. This is important, as power must be generated at the same time as it is consumed and therefore in each time step, the balance between supply and demand must be maintained at every point in the system. The time resolution is customised but can go down to an hourly level.

Above provincial level, regional grids are also represented in EDO. According to the current grid area, these areas are Northeast, North, East, Central, South and Northwest China.

Figure 6.5: Representation of model optimisation problem.



7. GRID REPRESENTATION IN MODELS

7.1 Introduction

Transmission project benefits are calculated as the difference between a simulation which does include the project and a simulation which does not include the project. In Section 4.6 and Figure 4.8 two proposed methods for project assessment are described (TOOT and PINT).

In both cases, it is important to define the initial state of the grid in which none of future potential transmission projects are included. In our case, we will define the initial state of the grid as the present grid in 2020.

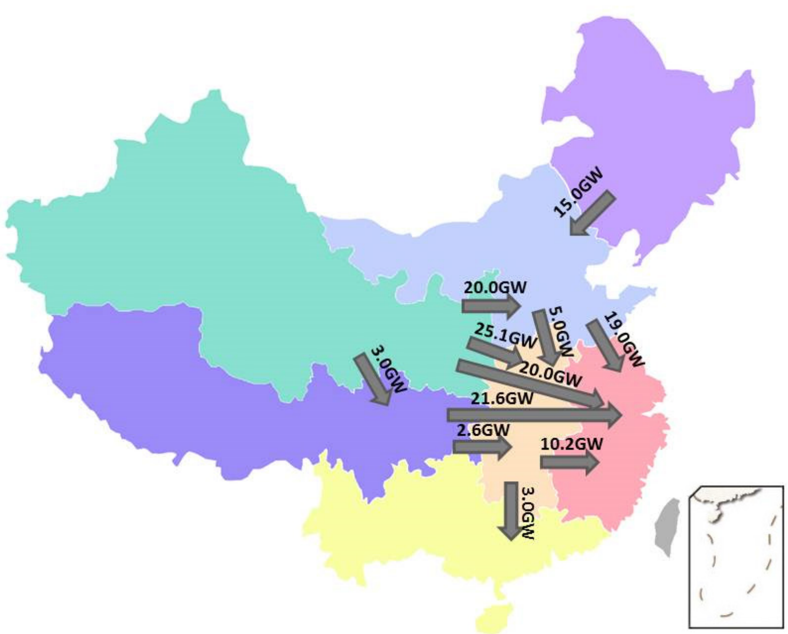
Sections 7.2 and 7.3 show the initial grid representation in the two models (SGERI model and ERI/CNREC model) in 2020.

7.2 SGERI initial state of grid

Figure 7.1 shows the SGERI model footprint and 2020 capacities of transmission lines between model areas.

It follows that the model resolution corresponds to China's seven power system regions.

Figure 7.1: SGERI model footprint and capacities between model areas (regions), 2020.



7.3 ERI/CNREC initial state of grid

As described in Chapter 6, the electricity grid in the ERI/CNREC model for China is represented at a provincial level (see Section 6.4). Each province is treated as a node in the network with its own specific generation capacity portfolio and electricity demand. It is assumed that there is no congestion within a province. Regional grids are built on top of provincial grids.

- The first layer represents Regional Grids, and policies and targets are formulated within these borders. According to the current grid area, these areas are Northeast, North, East, Central, South and Northwest China.
- The second layer is essentially the Provincial level, and here the electrical system and transmission are defined. In general, they are termed regions in the model, as they can diverge from actual administrative boundaries. For instance, Inner Mongolia is subdivided into two regions. Regions are seen as 'copper plates' and free of congestion in terms of electricity generation and demand.

The entities can be abstract or can be given specific names according to the geographical area represented. This approach to geographical entities provides flexibility in the modelling scope and means the structure of the power and district heating systems can be customised to any application. This flexible definition of geography enables evaluation of specific bottlenecks by scoping the model appropriately.

The geographical subdivision also introduces a flexibility concept by making a distinction between large areas and the data associated with them, and large areas included in a particular simulation.

Figure 7.2: Provincial grid areas assumed in EDO.

Figure 7.3: Grid structure in 2020.

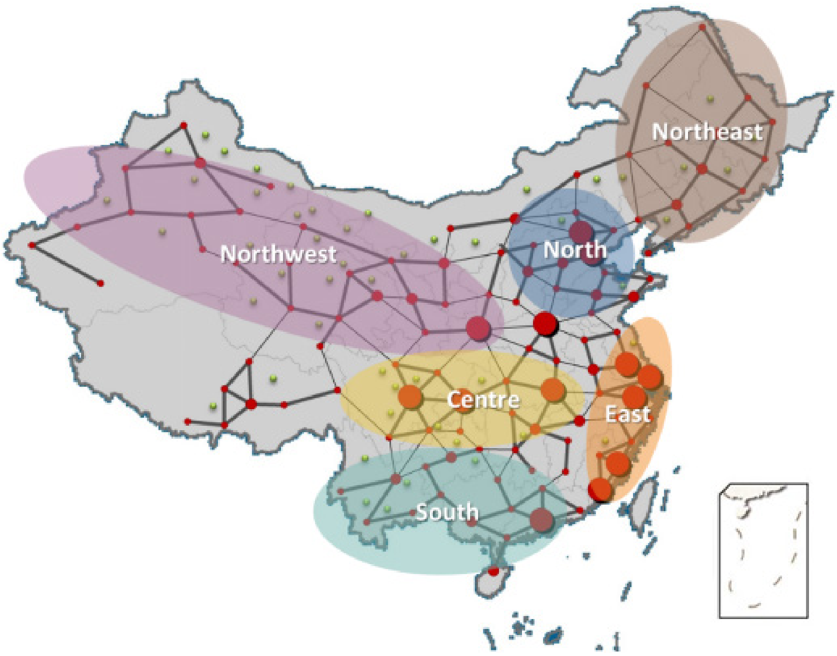


Table 7.1: Inter-regional capacity (GW) in 2020 and 2025.

		Centre	East	North	Northeast	Northwest	South
2020	Centre	79					
	East	27	158				
	North	9	18	195			
	Northeast	-	10	46	48		
	Northwest	26	18	37	-	123	
	South	13	1	-	-	-	118
2025 SP	Centre	102					
	East	27	158				
	North	13	23	197			
	Northeast	-	10	46	48		
	Northwest	50	18	37	-	140	
	South	13	1	-	-	-	124
2025 B2	Centre	110					
	East	30	158				
	North	21	25	231			
	Northeast	-	10	46	48		
	Northwest	51	18	37	-	140	
	South	13	1	-	-	-	127

Table 7.2: Inter-regional power transmission (TWh) in 2020 and 2025.

		Centre	East	North	Northeast	Northwest	South
2020	Centre	162					
	East	12	109				
	North	40	144	424			
	Northeast	-	86	81	118		
	Northwest	191	149	180	-	347	
	South	58	10	-	-	-	361
2025 SP	Centre	370					
	East	21	107				
	North	97	185	521			
	Northeast	-	86	135	154		
	Northwest	375	149	58	-	405	
	South	84	10	-	-	-	363
2025 B2	Centre	424					
	East	7	115				
	North	157	205	640			
	Northeast	-	86	149	155		
	Northwest	406	149	56	-	405	
	South	82	10	-	-	-	417

8. SCREENING OF TRANSMISSION GRID INVESTMENTS TOWARDS 2030

8.1 General

This chapter demonstrates the EU/ENTSO-E methodology of screening China's power transmission investments. The methodology is demonstrated by applying ERI/CNREC's scenarios and energy system model (EDO).

8.2 Scenarios for the Chinese power system

CREO 2019 uses scenarios to analyse how renewable energy can be used in the Chinese energy system. The scenarios provide a clear and consistent vision for long-term development which can be used as the basis for short-term decisions. Two scenarios are used[10]: The Stated Policies Scenario expresses the impact of a firm implementation of announced polices, while the Below 2°C Scenario shows a pathway for China to achieve its ambitious vision for an ecological civilisation and the role it could take to meet the objectives of the Paris Agreement.

The scenarios are modelled in detailed bottom-up models for the end-use sectors and for the power sector. Specific assumptions for macroeconomic indicators, demographic indicators and targets or restrictions to the scenarios' energy systems are used as input to the models to guide the development trends in the desired direction and to ensure fulfilment of the goals for the energy system development. Within these boundaries, the power sector model is driven by an overall cost-optimisation to ensure cost-efficient energy system transformation and dispatch.

Stated Policies Scenario. The scenario assumes full and firm implementation of energy sector and related policies expressed in the 13th Five-Year Plan and in the 19th Party Congress announcements. The scenario also includes the NDC climate target for a peak in emissions before 2030, the effects of the Blue-Sky Protection Plan, aspects of the Energy Production and Consumption Revolution Strategy, and the National Emissions Trading Scheme.

Below 2°C Scenario. The scenario complies with all long-term goals to build a clean, low-carbon, safe and efficient energy system. China's role is essential in global efforts to comply with the temperature objectives of the Paris Agreement.

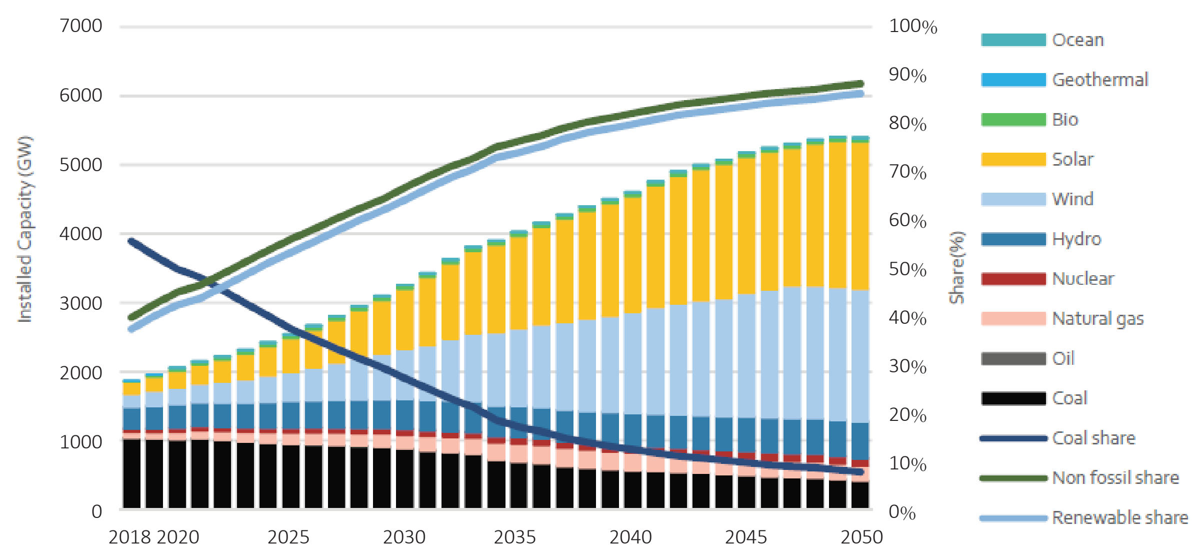
Towards 2050, both scenarios show significant increases in power generation from

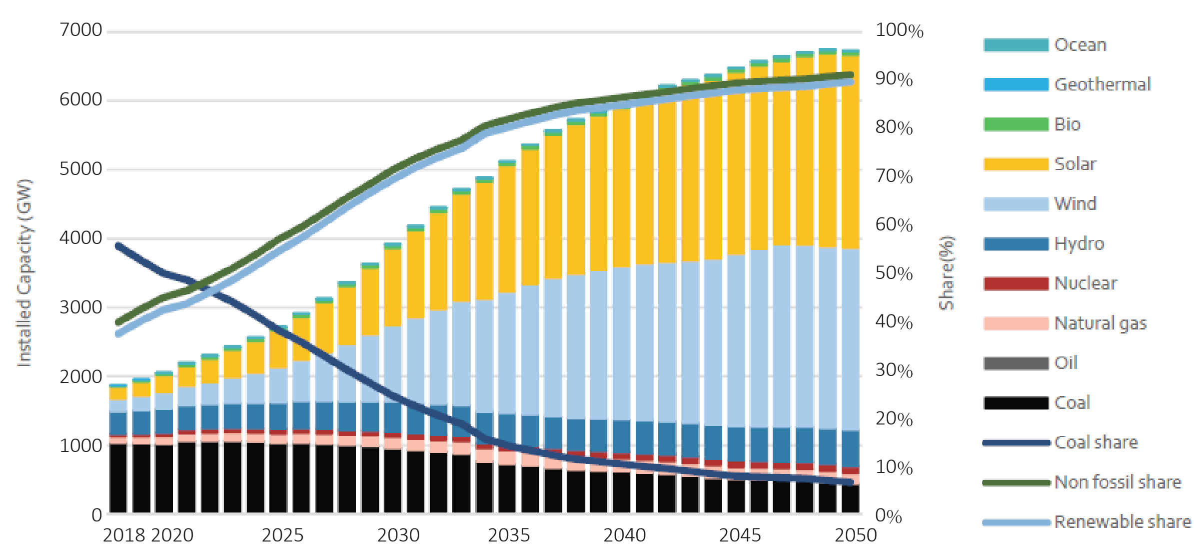
10 The two Chinese scenarios are taken from CREO 2019. The scenarios are described in more detail in section 5.3

variable renewable energy, which will account for at least 80% of total generation in 2050. By 2030, variable renewable energy accounts for between 45% and 55%,

compared to a level of around 28% in 2020 (see Figure 8.1). The increasing amount of generation capacity from wind and solar power and the distribution of renewable energy resources and demand centres demonstrate the importance of the transmission system.

Figure 8.1: Stated Policies Scenario (top) and Below 2°C Scenario (bottom) for the development of the Chinese power system.





8.3 Reference grid

The electricity grid in China is represented at a provincial level. Each province is treated as a node in the network with its own specific generation capacity portfolio and electricity demand. It is assumed that there is no congestion within a province. Provinces are grouped into regional grids, which can have common policies or targets (Figure 8.2).

- **Regional grids**
  Regional grids may have common policies and targets within their borders. According to the current grid area, the Regional Grids are Northeast, North, East, Central, South and Northwest China.

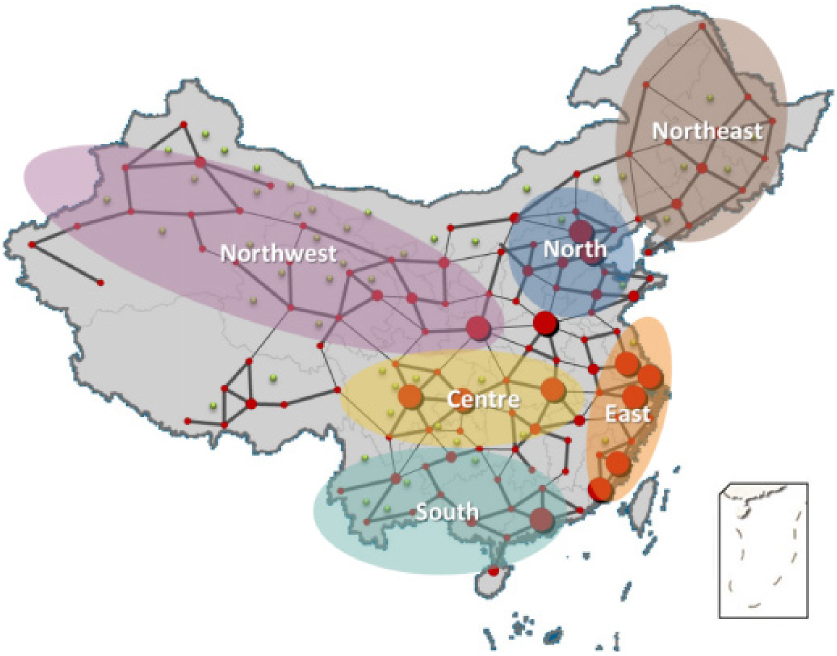
- **Provincial level**
  The second layer is essentially the provincial level, where the electrical system and the transmission system are defined. In general, they are termed regions in the model, as they can diverge from actual administrative boundaries. For instance, Inner Mongolia is subdivided into two regions. Regions are seen as 'copper plates' and are deemed to have no congestion in terms of electricity generation and demand.

The entities can be abstract or can be given specific names according to the geographical area represented. This approach to geographical entities provides flexibility in the modelling scope and means the structure of the power and district heating systems can be customised to any application. This flexible definition of geography enables evaluation of specific bottlenecks by scoping the model appropriately.

The geographical subdivision also introduces a flexibility concept by drawing a distinction between large areas and the data associated with them, and large areas included in a particular simulation.

Figure 8.2: Regional grid areas assumed in EDO.

Figure 8.3: Grid structure in 2020.



The transmission capacities for 2020 and 2025 are based on the existing grid (Figure 8.3) and firmly planned interconnectors (Table 8.1). This is the frozen grid used as a reference for the screening process.

Table 8.1: Transmission capacity between regional grid areas (GW) in 2020 and 2025. Numbers in diagonals of table show grid reinforcements within the regional grid areas.

		Centre	East	North	Northeast	Northwest	South
2020	Centre	79					
	East	27	158				
	North	9	18	195			
	Northeast	-	10	46	48		
	Northwest	26	18	37	-	123	
	South	13	1	-	-	-	118
2025 SP	Centre	102					
	East	27	158				
	North	13	23	197			
	Northeast	-	10	46	48		
	Northwest	50	18	37	-	140	
	South	13	1	-	-	-	124
2025 B2	Centre	110					
	East	30	158				
	North	21	25	231			
	Northeast	-	10	46	48		
	Northwest	51	18	37	-	140	
	South	13	1	-	-	-	127

In addition to the grid connections as mentioned above, more connections that are under construction and in the planning stages are also included in the reference grid. The additional lines are as follows:

- The line between Qinghai and Henan, due to come into operation in 2021.
- The line between Shanxi and Hubei, due to come into operation in 2022.

8.4 Transmission system buildout

New transmission projects considered in the screening process are connections between adjacent provinces as well as long distance connections between provinces that are not adjacent, such as the proposed connection between Sichuan and Jiangxi. Long distance connections are included, from the perspective of power generation capacities planned or under construction and the distance to load centres. In total, 76 connections are considered for reinforcement of the frozen grid in the screening process towards 2030.

The potential for transmission system buildout is analysed against the background of generation capacity and demand development defined in the Stated Policies Scenario and the Below 2°C Scenario. Both scenarios were originally developed using the EDO-model to co-optimise both generation and transmission system investments – i.e. normal annual investment calculation (NAIC). However, the aim here is primarily to demonstrate the ENTSO-E methodology of screening on China's electricity system and secondarily to check the robustness of transmission grid investments across the two scenarios. Therefore, grid investments beyond the existing grid and firmly planned grid expansions are removed from the scenarios, leading to a scenario with the same generation capacities, but lower transmission grid capacity. This is referred to as Remove grid investment annual calculation (RGIAC).

Normal annual investment calculation (NAIC) - 2030. In this case, the EDO model optimises both transmission capacity and generation capacity. This case shows the provincial level electricity price differences in the optimal cost situation.

Remove grid investment annual calculation (RGIAC) - 2030. Based on the NAIC case result, this calculation removes grid investments but retains generation investments. The calculation shows the provincial level electricity price differences if no further grid investments are undertaken, while foreseen generation capacity investments continue.

The estimates for the cost of expanding the transmission system are based on the distances and generalised cost assumptions used for the CREO 2019[11].

11 China Renewable Energy Outlook

8.5 Modelling and result analyses

Quantification and analysis of the need for and effect of new transmission lines require a number of result measures, which are defined in the EDO model. These result measures are based on the dispatch and investment optimisation performed in the model simulations and are used to assist in the screening process.

Result measures regarding screening and CBA. Three new measures are used to assist the evaluation of existing transmission lines or potential projects.

- **Average price spread (CNY/MWh):** This is the price spread between annual average marginal electricity costs between two price areas. High average price spreads could indicate a high potential for transmission expansion. This measure is suitable for comparing with the average marginal electricity value of the price areas.

- **Price spread on transmission line (CNY/MWh):** This is the difference in marginal electricity costs between each end of a transmission line. This is calculated hour by hour as a positive or negative value between point A and B. The average of the absolute differences in marginal electricity costs value is a measure to demonstrate congestion on an existing transmission line and/or potential benefit of a new project.

- **Marginal value of transmission (CNY/MW):** This represents the value of having 1 MW additional transmission capacity from point A to B. The value is equal to the sum of the absolute price differences calculated in the price spread. High values indicate a good potential for transmission expansion projects. In a capacity expansion simulation, the value can be compared to the investment cost of an expansion option which is not being utilised to see how much lower the investment cost should be for the project to be built.

Value of lost load (VOLL). If the given system of generation and transmission capacities (including transmission investment options) cannot supply the defined demand, power shortages will occur. The cost of this shortage is equal to the value of lost load (VOLL) and should be considered in system cost assessments. Value of lost load cannot be estimated within the EDO model but can be factored into the calculations. Previous studies have shown a broad range of VOLL using investigation or input-output methods (Lin 2006, He 2007, Tan X 2008, Wang 2011). The VOLL value in this report is set to CNY 43 /kWh according to the results of previous studies and expert experience.

The screening process identifies new transmission system investments (new lines or reinforcement of existing lines) that provide the highest SEW benefit compared to the associated investment costs for the expansion in question.

8.6 Screening criteria and process

'Benefit over cost ratio' is introduced to estimate the value of investing in a new connection or expanding the capacity of an existing connection. It is calculated as MWh price spread over the connection / (MW construction cost[12] of the connection * annuity factor) for a certain year. The lines are ranked by the averaged 'benefit over cost ratios' over two scenarios. The ones that have high values have greater potential to be selected to expand in the screening process. Once the 'benefit over cost ratio' of a connection is equal or less than a specified reference value, it can be concluded that the connection is no longer a worthwhile investment.

The process starts with simulating the EDO model using only the reference grid without the addition of new transmission projects (RGIAC). By iterations (steps) a number of new projects are identified through screening criteria and added to the next step of simulations. After each step the total system costs are estimated by the EDO model. This process is continued until the SEW (or total system costs) of the step is lower (or system costs higher) than in the previous step.

Screening process:

1. Calculations are carried out in the ERI/CNREC's model setup using the EDO model.
2. Calculations are conducted for two scenarios in 2030: the Stated Policies Scenario and the Below 2°C Scenario. Each step is calculated for both scenarios in parallel, and the average of the results are taken as the evaluation criteria.
3. The starting point is the basis grid or RGIAC grid (see Section 8.4). This is called Step 0.
4. For both scenarios
   a. Calculate average marginal cost timestep by timestep in each region and each province in 2030. Unserved demand (loss of load) will significantly impact average marginal prices.
   b. Calculate the marginal value of transmission capacity in CNY/MW for each scenario.
   c. Calculate the average marginal value of transmission capacity divided by the relative 'standard cost' of increasing capacity at all borders. This may include AC or DC line cost. Cost depends on distance, voltage etc. This is called the 'benefit over cost ratio'.
   d. Calculate average benefit over cost ratio for both scenarios.
5. Rank all 'marginal value of transmission capacity at border/ standard cost'.
6. Choose to expand the lines with the highest ranking by a standardised transmission capacity of 100, 2 000, 4 000 or 8 000 MW depending on distance, voltage, loss of load needs, etc. There may be other considerations apart from ranking. Regions with high electricity prices will likely show high value of adding transmission capacity to neighbouring regions, but it is not necessarily beneficial to increase capacity on all lines at the same time.
7. Conduct model (EDO) simulation including x expansions for both scenarios.
8. Following the calculations in point 7, calculate costs and benefits for the entire system compared to the starting point in step 4a. Difference in costs

12 The generalized cost assumptions for transmission lines have been adopted from CREO 2019/CREO 2020 (Chinese Renewable Energy Outlook)

are capital cost (CNY/yr) + operations and maintenance (CNY/yr) for the expansions of the grid. Capital costs for the transmission expansions are calculated as investment costs with a 40-year lifetime and an interest rate of 4.7% (real). Difference in benefits (SEW) are calculated according to the CBA methodology describing SEW. As an approximation, the difference in benefits can be estimated as the reduction in total annual variable generation costs (CNY/yr).

9. If benefits > costs repeat steps 4-8. Now 'grid' = 'grid plus expansions from current iteration'.
10. If benefits < costs, the grid expansion of the previous iteration defines the list of potential expansions to be included in the subsequent CBA-analyses. The current iteration will not be used, as benefits have been proven to be too low.

8.7 Illustration of calculation steps

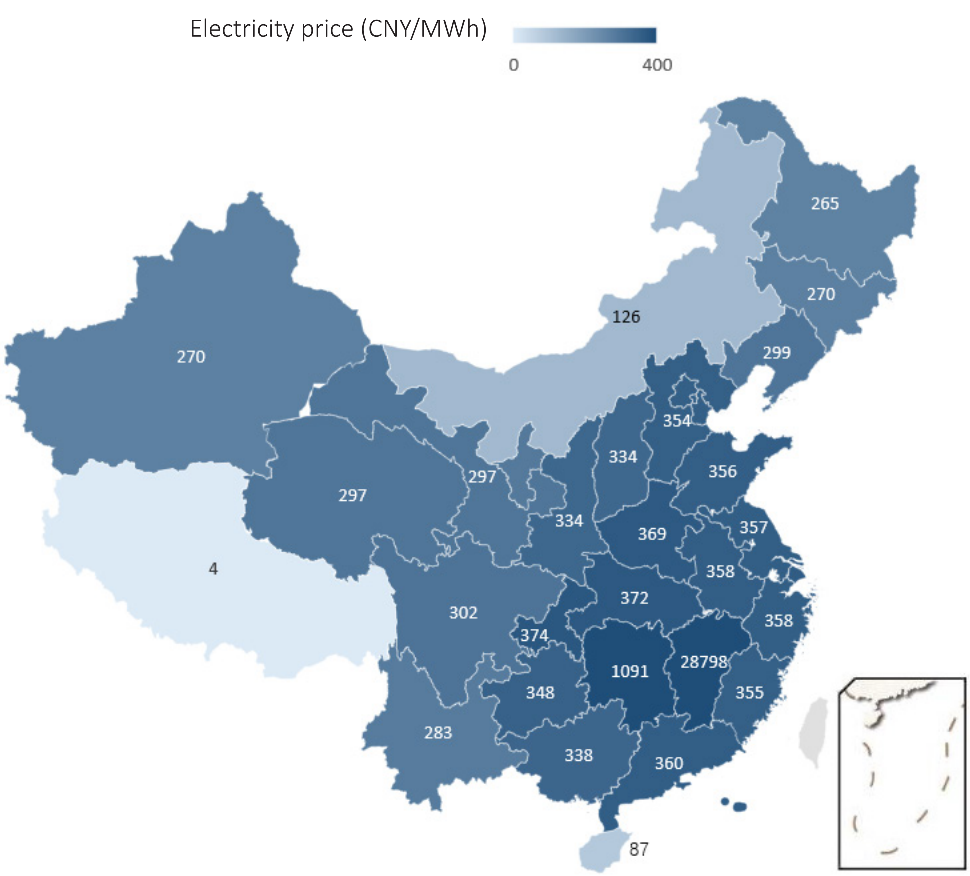
The simulation of the scenarios shows high values of expanding the transmission system capacities (Step 0 in Table 8.2). The underlying average marginal electricity prices in the RGIAC case are shown in Figure 8.4. The following section provides further explanation of the decisions taken from step 0 to step 1 in order to describe the screening process.

Table 8.2: Benefit over cost ratio for the first 5 steps of the screening process for selected connections.

Benefit over cost ratio	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5
Hubei - Jiangxi	1 885	109	44	44	44	40
Shanxi - West-Inner Mongolia	9	9	9	8	8	7
Guangdong - Hainan	5	0	2	2	2	2
Qinghai - Tibet	6	7	6	6	1	1
Hubei - Hunan	46	130	129	129	68	45
East-Inner Mongolia - Shanxi	5	6	6	5	5	5
Hunan - Guangdong	34	95	94	94	50	33
Henan - Shaanxi	4	4	4	4	4	4
Ningxia - West-Inner Mongolia	8	8	8	8	8	8
Hebei - West-Inner Mongolia	7	7	7	7	7	6
Chongqing - Xinjiang	2	2	3	3	3	3
Hunan - Henan	29	82	81	81	43	29
Anhui - Jiangxi	1 728	101	40	41	41	37
Fujian - Jiangxi	1 518	88	35	35	35	32

Guizhou - Hunan	29	80	79	79	42	28
East-Inner Mongolia - Hebei	5	5	5	5	5	4
Heilongjiang - Jilin	3	3	3	3	3	3
Chongqing - Sichuan	7	6	6	6	6	6
Sichuan - Jiangxi	791	47	19	20	20	18
Hunan - Sichuan	18	49	49	49	27	18
Gansu - West-Inner Mongolia	6	6	6	6	6	5
Henan - Hebei	4	4	4	4	4	4
Hebei - Shandong	2	3	3	3	3	3
Anhui - Shandong	2	3	3	3	3	3
Gansu - Qinghai	4	4	4	4	4	4
Henan - Shanxi	3	4	4	4	4	4
Hebei - Shanxi	3	3	3	3	3	4
Liaoning - Jilin	3	3	3	3	3	3
Hubei - Shaanxi	3	3	3	3	3	3
Gansu - Shandong	2	2	2	2	2	2
Yunnan - Guizhou	2	2	2	2	2	2

Figure 8.4: Electricity price distribution in RGIAC case.



Apart from the most important criterion - 'benefit over cost ratio' - other aspects are also considered when narrowing down the list of connections. These additional considerations reduce the risk of overinvestment in one step and to avoid the risk that a few bad expansion choices might adversely affect the evaluation of the entire step.

Issues with unserved demand
In the RGIAC (step 0 in the screening process), all the connections to Jiangxi face high 'benefit over cost ratios' due to the potential high value of avoiding loss of load in Jiangxi Province. This benefit can only be realised once, and thus the connection with the highest value (Hubei to Jiangxi) is expanded in the first step.

High marginal cost of electricity generation
Due to a lack of sufficient cost-efficient power generation resources in Hunan, the connections linked with Hunan also show high 'benefit over cost ratios' as well. Therefore, the connection between Hubei and Hunan appears promising for expansion in the first step of screening as it has the highest 'benefit over cost ratio'. However, given that the expansion of the 'Hubei – Jiangxi' connection might have an influence on the 'cost-benefit ratio' of the 'Hubei - Hunan' connection, the potential expansion is pushed back to a later step.

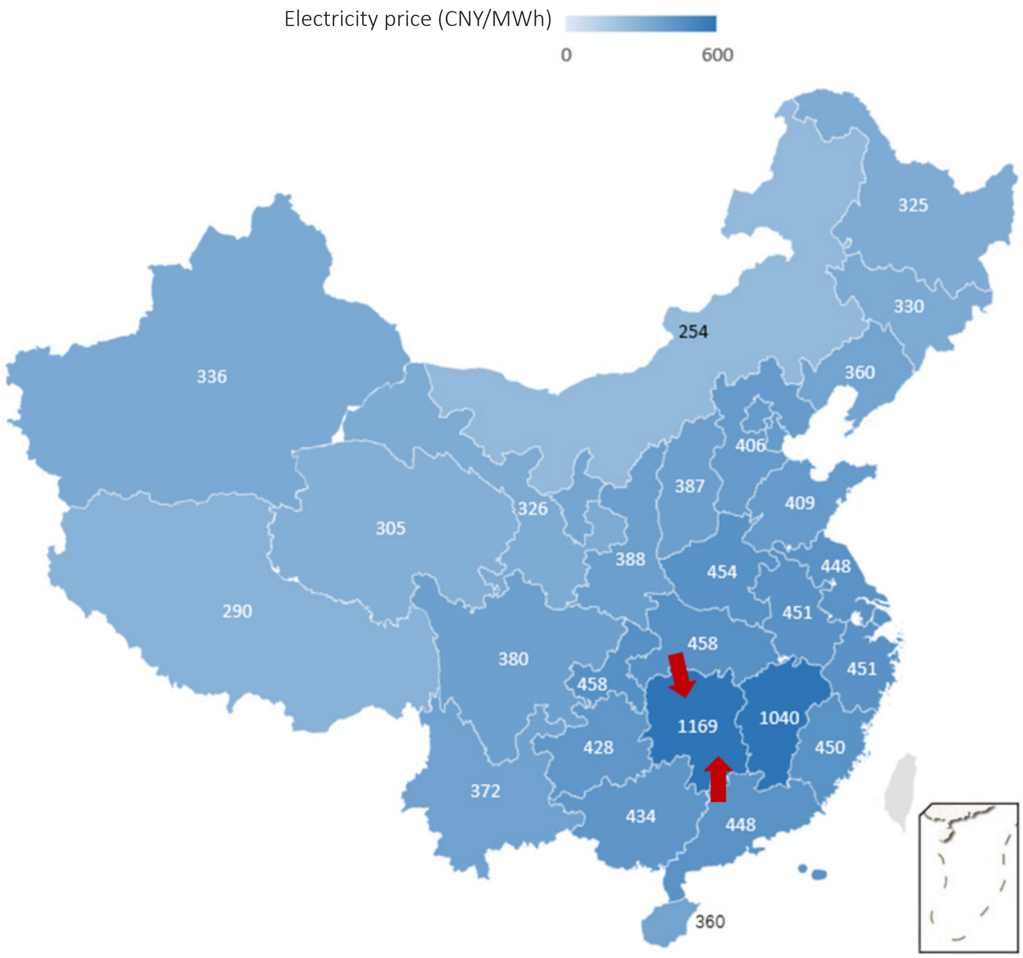
Integration of renewable energy
West-Inner Mongolia, which has a high share of renewable energy resources and a number of connections to neighbouring regions has a high ranking, just below the group to Jiangxi and the group to Hunan. In the first step, the 'Shanxi - West-Inner Mongolia' connection is selected to be expanded as it shows the highest value in this group.

Guangdong-Hainan
The 'Guangdong - Hainan' connection also shows a high 'benefit-cost ratio'. Considering that Hainan has only one connection with mainland China, the decision is made to expand this connection in Step 1 by just 100 MW.

Beyond the first step and additional criteria
Step 1 concludes with the selection of three connections for expansion in the following step, and one connection is chosen to be investigated further in the following steps, but not expanded at this stage.

Value of several connections
The examples given above demonstrate the principle of choosing the most valuable connection for expansion among a number of alternatives: In the first step of screening, only one connection is selected from each group of connections. In Step 5, two connections to Hunan from Guangdong and Hubei are expanded, after individual connections to Hubei and Guangdong have been selected in steps 3 and 4, respectively (see Figure 8.5).

Figure 8.5: Average marginal electricity prices in Step 5.

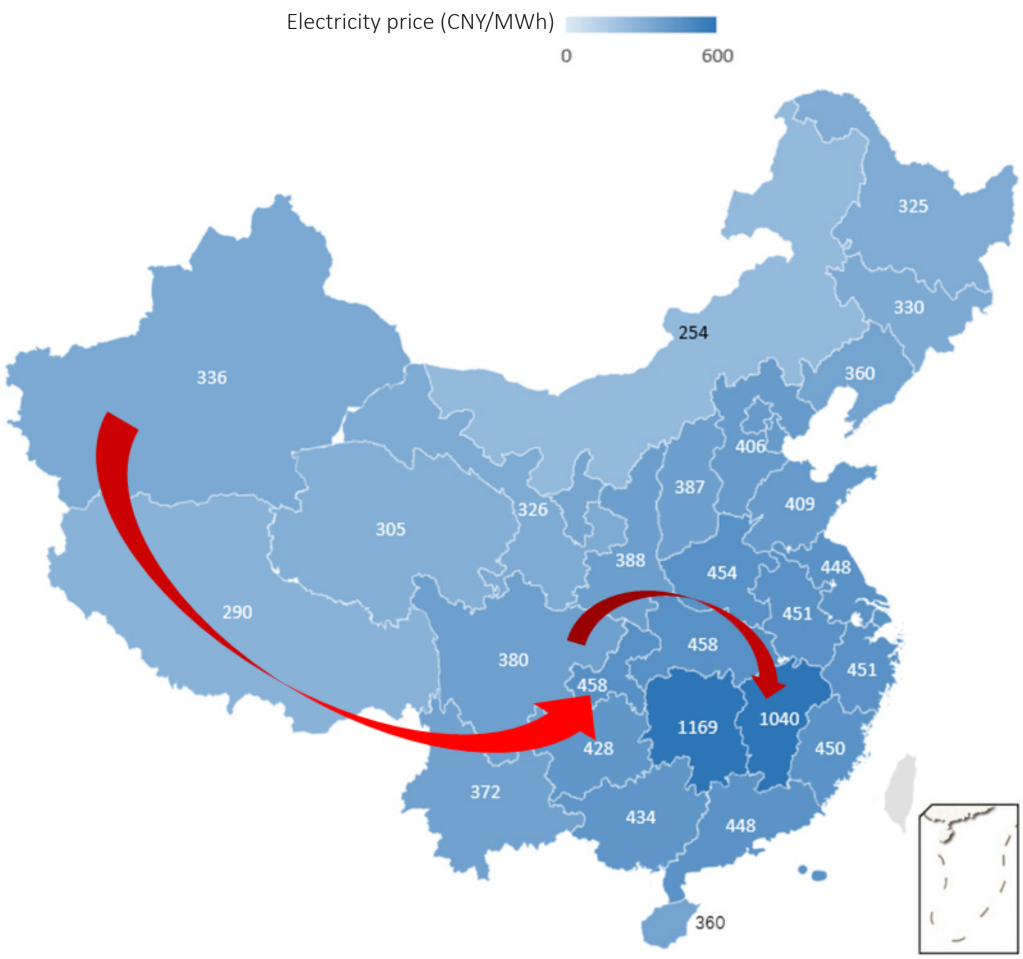


Long distance flows

Energy flow is also an important criterion in the screening process. The energy flow in China goes from west to east and from north to south, due to unevenly distributed resources and energy demand. Therefore, it is usually the case that a high 'benefit over cost ratio' cannot be harvested by expanding the capacity of a connection with a high 'benefit over cost ratio', but by allowing a series of expansions of the capacities to allow energy to flow from the power sources to the load centre. In such cases, a long-distance connection is more effective for adjustment of the energy flow rather than expanding a series of lines in adjacent provinces. Therefore, an additional consideration in the screening process is the energy flow conditions of the whole country. It is possible that a high 'benefit over cost ratio' could be reduced by investing in other connections but not solely the line with a high 'benefit over cost ratio'.

In another example, using Step 5 results in the selection of the connection between Chongqing and Xinjiang (Figure 8.6). In Step 5, the connection between Sichuan and Chongqing shows a high 'benefit over cost ratio', while the 'benefit over cost ratio' of the connection between Chongqing and Xinjiang rises when the price in Chongqing is raised. As Sichuan is also responsible for transmitting power to Jiangxi, where the price is much higher than in Chongqing, a choice is made to expand the capacity of the connection between Chongqing and Xinjiang, while power in Sichuan is reserved for Jiangxi. These decisions mean that the 'benefit over cost ratios' of the connection between Chongqing and Sichuan (Step 5) and of the connection between Sichuan and Jiangxi (Step 8) are both reduced.

Figure 8.6: Evaluating long distance connections (Step 5).



8.8 Screening results

Transmission capacity
Through the iterations of the screening process using the criteria explained above, 14 steps have been identified and simulated using the EDO model. Table 8.3 shows which projects were selected in each step and the size of the transmission capacity for the projects.

Table 8.3 shows the added transmission capacity for each of the steps in the screening process. From the reference grid, each step adds a list of projects identified using the screening criteria mentioned above. A specific step includes projects from previous steps, e.g. Step 3 includes the transmission capacity expansions found in Steps 1 and 2.

Table 8.3: Additional transmission capacity per step in MW.

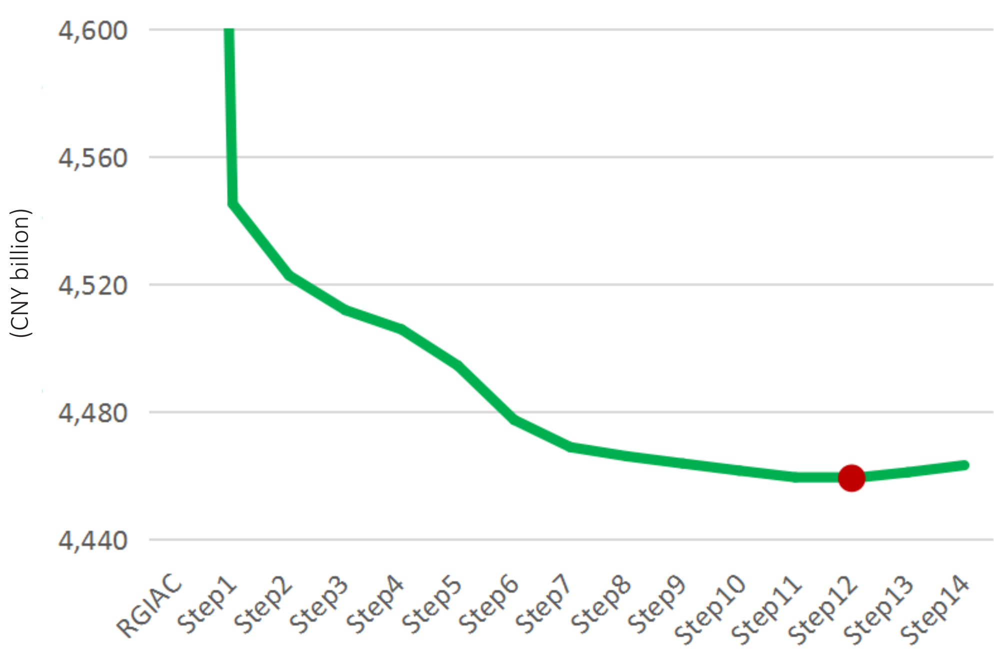
Transmission capacity (MW)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10	Step 11	Step 12	Total
Hubei - Jiangxi	8 000	2 000	-	-	1 000	2 000	1 000	-	-	-	-	-	14 000
Shanxi - West-Inner Mongolia	4 000	8 000	8 000	4 000	-	2 000	400	400	400	400	2 400	-	30 000
Guangdong - Hainan	100	100	100	100	-	-	-	-	-	-	-	-	400
Qinghai - Tibet	-	4 000	2 000	2 000	-	-	-	-	-	-	-	-	8 000
Hubei - Hunan	-	-	400	-	200	200	400	-	-	-	-	-	1 200
East-Inner Mongolia - Shanxi	-	-	2 000	2 000	400	400	800	400	400	400	1 200	-	8 000
Hunan - Guangdong	-	-	-	400	200	-	200	-	-	-	-	-	800
Henan - Shaanxi	-	-	-	1 000	2 000	400	400	-	-	200	2 000	-	6 000
Ningxia - West-Inner Mongolia	-	-	-	-	400	400	400	400	400	400	1 600	-	4 000
Hebei - West-Inner Mongolia	-	-	-	-	4 000	-	4 000	4 000	4 000	4 000	4 000	4 000	28 000
Chongqing - Xinjiang	-	-	-	-	4 000	-	-	-	-	4 000	-	4 000	12 000
Hunan - Henan	-	-	-	-	-	4 000	-	-	-	-	-	-	4 000
Anhui - Jiangxi	-	-	-	-	-	-	400	-	-	-	-	-	400
Fujian - Jiangxi	-	-	-	-	-	-	400	-	-	-	-	-	400
Guizhou - Hunan	-	-	-	-	-	-	400	-	-	-	-	-	400
East-Inner Mongolia-Hebei	-	-	-	-	-	-	800	400	-	400	2 400	4 000	8 000
Heilongjiang - Jilin	-	-	-	-	-	-	400	400	-	-	400	-	1 200
Chongqing - Sichuan	-	-	-	-	-	-	400	400	-	400	800	-	2 000
Sichuan - Jiangxi	-	-	-	-	-	-	-	4 000	-	-	-	-	4 000
Hunan - Sichuan	-	-	-	-	-	-	-	2 000	-	-	-	-	2 000
Gansu - West-Inner Mongolia	-	-	-	-	-	-	-	400	400	400	800	-	2 000
Henan - Hebei	-	-	-	-	-	-	-	2 000	4 000	400	1 600	4 000	12 000
Hebei - Shandong	-	-	-	-	-	-	-	-	400	400	1 200	6 000	8 000
Anhui - Shandong	-	-	-	-	-	-	-	-	4 000	-	4 000	4 000	12 000
Gansu - Qinghai	-	-	-	-	-	-	-	-	-	2 000	2 000	-	4 000
Henan - Shanxi	-	-	-	-	-	-	-	-	-	4 000	4 000	-	8 000
Hebei - Shanxi	-	-	-	-	-	-	-	-	-	4 000	-	4 000	8 000
Liaoning - Jilin	-	-	-	-	-	-	-	-	-	-	1 200	-	1 200
Hubei - Shaanxi	-	-	-	-	-	-	-	-	-	-	4 000	4 000	8 000
Gansu - Shandong	-	-	-	-	-	-	-	-	-	-	2 000	2 000	4 000
Yunnan - Guizhou	-	-	-	-	-	-	-	-	-	-	-	4 000	4 000

System costs
Steps 13 and 14 show increasing total system costs compared to the previous steps. This indicates that the transmission projects identified in the first 12 steps would yield the best solution for the system in terms of social economic welfare.

In the following section some main results of the steps of the screening process are shown. As discussed above, the paths towards the future are provided by the Stated Policies Scenario and the Below 2°C Scenario. The steps shown above are added to both scenarios with their respective generation capacity expansion looking into the year 2030. The results of each step are shown here as an average of the two scenarios. The socio-economic value of a transmission project will differ in the two scenarios and the realised value of transmission projects in 2030 is subject to uncertainty. Robustness of the results is therefore ensured by subjecting the transmission projects to two different future scenarios and averaging the results.

Average total system cost for the power and heat system decreases significantly in the first steps of the screening process (Figure 8.7). These costs include all CAPEX for both generation and transmission capacity as well as the variable costs associated with the generation of heat and power in the coherent system. This includes fuel costs, variable operation and maintenance, start/stop costs on plants, operational reserve payment and emission taxes.

Figure 8.7: Total system costs at each step of the screening process.

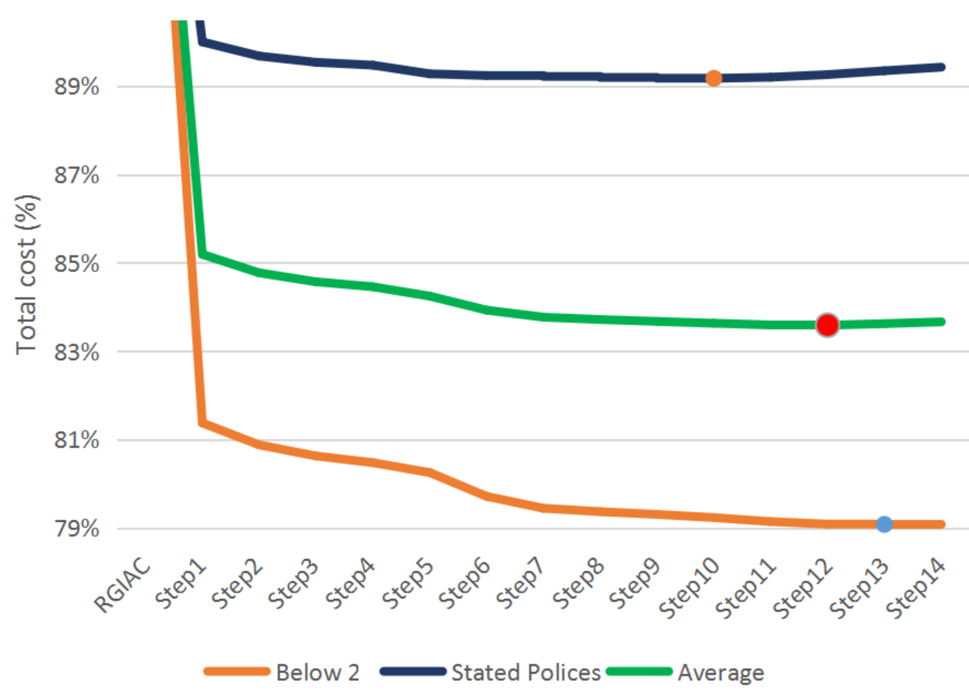


Average total system costs are reduced for each step until Step 12 where they start to increase. The addition of transmission projects allows for a more efficient economic dispatch across the system giving the opportunity to utilise the new transmission lines to replace expensive generation with cheaper alternatives e.g. gas with coal or coal with wind or solar.

Total system cost in the individual scenarios differ, and a particular step might be beneficial in one scenario but not the other. Figure 8.8 shows the reductions in total system costs compared to the reference for the two scenarios and their combined average (respective RGIAC power systems, see Section 8.4). This demonstrates that the steps of the screening process can be somewhat sensitive to the system in which they are being investigated. In the Below 2°C Scenario the lowest system cost is found in Step 13 while Step 10 shows the lowest costs in the Stated Policies Scenario. On average, lowest system costs are found in Step 12.

This indicates a higher need for transmission capacity in the Below 2°C Scenario, owing to the larger share of renewable energy and thus a higher need for integration through transmission lines compared to the Stated Policies Scenario. The figure also demonstrates the importance of having robust results when determining transmission projects. The early steps are beneficial in both scenarios, but in the final steps the benefit depends on the detailed configuration of the power system in the two investigated scenarios.

Figure 8.8: Total system costs compared to the reference (=100 %) in each step of the screening process.



The reference (RGIAC, see Section 8.4) shows a significant amount of unserved demand or lost load which has a high monetary value (CNY 42.796 /kWh) resulting in a high total system cost. The transmission projects in Step 1 alleviates a large part of this issue, reducing the costs of lost load by approximately 95%. Each step shows further reductions in costs, because a cheaper option for the supply of electricity and district heat can be found by adding transmission projects. Going from Step 12 to Step 13, total system costs increase, meaning that the cost savings of the improved dispatch cannot cover the capital costs of the transmission projects added in Step 13. This indicates that Step 12 will be the best solution in terms of transmission capacity within the scenarios for generation capacity found in the Below 2°C Scenario and Stated policy Scenario. Step 12 consists of a total of 206 GW of added transmission capacity resulting in a cost reduction of around CNY 900 billion or 17% of total system costs compared to the RGIAC. The main provinces that are expanding the transmission capacity are Inner Mongolia, Shanxi and Shandong.

Climate and environmental impact

The impact of additional transmission capacity is not purely financial. It is also important to investigate the environmental impact by examining the effects on emissions in each of the screening steps.

Figure 8.9: CO_2 emission in kiloton for each step in the screening process.

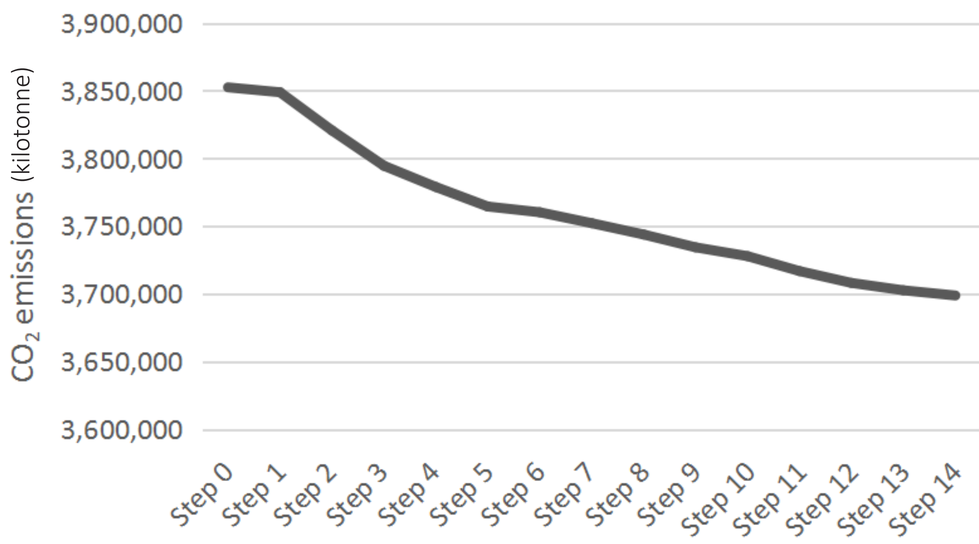
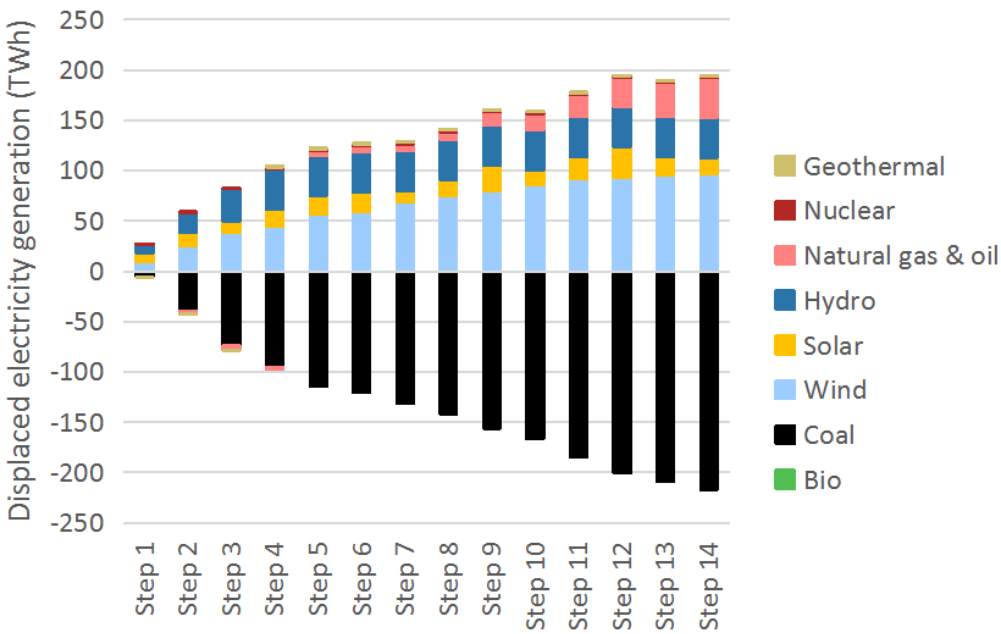


Figure 8.9 shows how new transmission lines assist in the reduction of greenhouse gases. By adding transmission capacity, the system can displace high-emission generation with low or no-emission generation. The reduction in CO_2 emissions in Step 14 is 4% of the total compared to the RGIAC. Following the trend of the curve it can be extrapolated that further reductions could be found through new transmission projects. However, as shown in Figure 8.7 the costs do not favour additional transmission capacity after Step 12.

Impact on generation
In the RGIAC there is a need for additional lines to allow for transmission of renewable generation. This is demonstrated in Figure 8.10 where around 200 TWh of coal generation is displaced in the final steps with 150 TWh of renewable generation and 40 TWh in natural gas fired generation. The rest is nuclear, geothermal, and reduced losses in transmission and storages.

Figure 8.10: Changes in electricity generation in Steps 1-14 compared to the RGIAC.

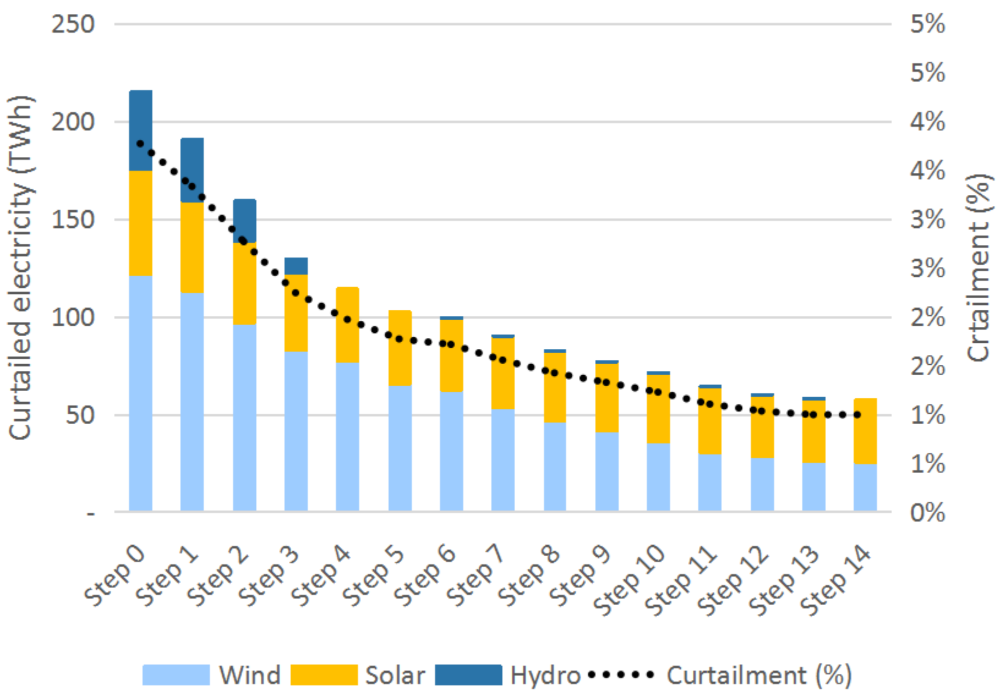


As the generation capacities are fixed in all steps, additional generation from wind and solar power stem from reduction of curtailments (Figure 8.11). Without access to transmission capacity, some of the potential renewable generation cannot be transported to load centres and is instead curtailed. In Inner Mongolia in particular, a significant amount of RE generation cannot be utilised without further transmission buildout. The same is true in Tibet, Sichuan, and Qinghai, where the transmission steps help improve the situation and reduce the total level of curtailment from about 4% to 1%.

8.9 Selection of a portfolio of lines for cost-benefit analysis

A selection of lines is chosen for detailed individual cost-benefit analysis following the TOOT-process. In the ENTSO-E process, projects are evaluated based on the actual projected transmission capacity added between two regions.

Figure 8.11: Curtailment of renewable generation in each of the steps in the screening process.



The lines chosen for further individual CBA-analysis are 'Hubei-Jiangxi', 'Chongqing-Xinjiang' and 'Hubei-Shaanxi'

The selection has been done based on the screening results, see Sections 8.7 and 8.8. The lines are believed to be representative of future expansion of the Chinese grid.

The Hubei-Jiangxi line could be vital in solving problems with unserved demand, and the screening process has identified a total expansion potential of 14 GW.

Chongqing-Xinjiang is a long-distance project already under consideration and the screening process resulted in a potential for expansion of 12 GW in total.

The 'Hubei-Shaanxi' project will promote the intensive development of energy supplies in the north of Shanxi Province and large-scale power delivery.

Further details for the selected lines are as follows:

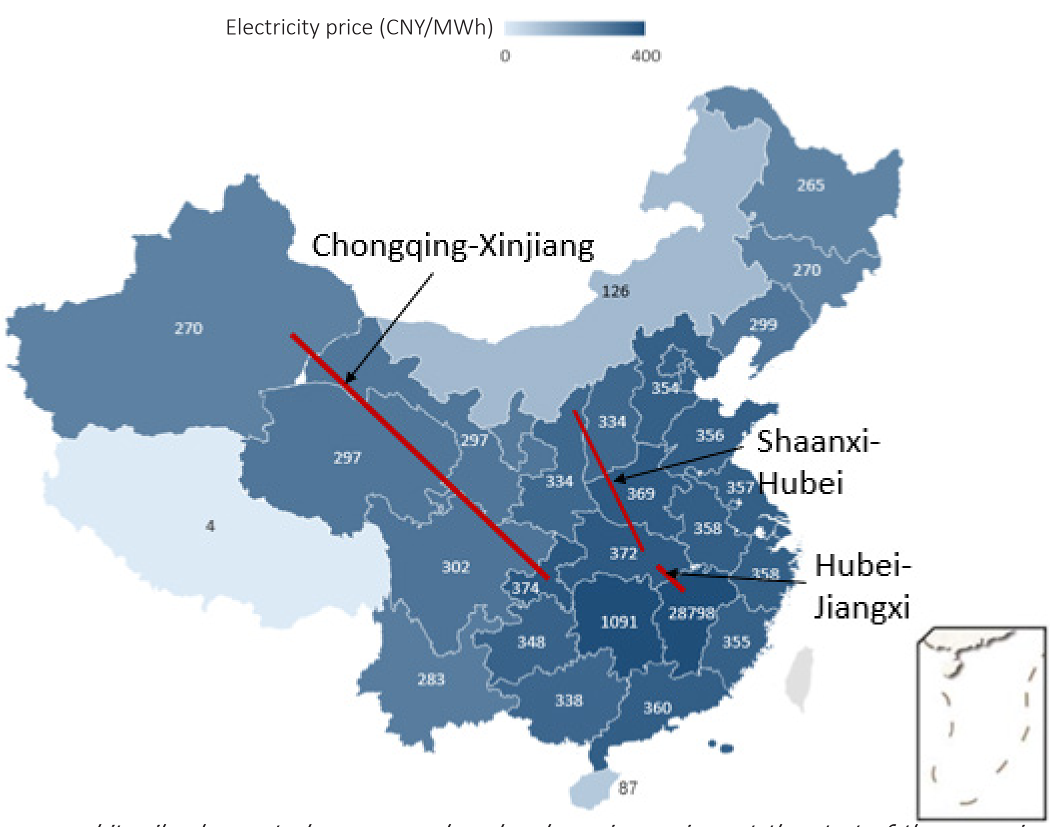
- The line between Hubei and Jiangxi is the first line selected for expansion in the screening process. The line resolves the lack of power supply in Jiangxi Province in the first place and helps to reduce the high prices in Jiangxi by introducing comparably cheap and flexible hydro power from Hubei to Jiangxi through an expanded transmission line. By investigating the cost and benefit of this connection, the value of the expanded capacity of transmission line on enabling flexibility as well as on relieving the shortage of-electricity could be further analysed.

- The line between Chongqing and Xinjiang is a long-distance transmission line that brings cheap and locally redundant electricity from Xinjiang to Chongqing, where power supply is tight and more expensive. The cost benefit analysis provides an angle for evaluation of the strategy for establishing long distance transmission lines given the particular conditions in China, i.e. highly mismatched resource potential and power demand, as well as fast increasing power demand in populated regions.

- The projected northern Shaanxi-Hubei ±800 kV UHVDC line starts from Yulin, Shaanxi, passes through Shanxi, Henan, and Hubei Provinces, and ends at Wuhan, Hubei[13]. The project will promote the intensive development of energy supplies in the northern Shaanxi and large-scale power delivery, stimulate efficient use of energy resources, realise the transformation of resource advantages into economic advantages, and promote coordinated regional development.

The lines recommended for further CBA assessment are shown in Figure 8.12.

Figure 8.12: Proposed lines for further CBA assessment.



(Prices are arbitrarily chosen to be average day-ahead province prices at the start of the screening process, see Section 8.7)

13 The power supply resource data for Hubei should be reassessed in the detailed planning phase.

8.10 Methodological adjustments

During the detailed work on the screening process, a number of adjustments to the methodology were implemented, which differentiate it from the ENTSO-E grid planning process. The differences are in part related to the fact that the main concerns of the current project were implementation and demonstration of principles, while some details had to be reduced. In other parts, adjustments were made to improve the accuracy of the screening process for the specific characteristics of the Chinese power system and the projected scenarios.

- **Grid losses**
  Grid losses and the impact of transmission system reinforcement on grid losses were not taken into account. The methodology has the potential to include modelling of grid losses, but the required level of detail regarding the technical characteristics of different parts of the transmission system were not available and would have required analysis efforts beyond the scope of this project.

- **Standard expansion sizes**
  The scale of beneficial transmission projects in the Chinese power system ranges from a few hundred MW to several GW. Using a standard size for reinforcement of the different transmission lines would have required a large number of steps and could not have taken into account the different cost aspects between smaller AC projects and large, long distance and high-capacity DC-projects. Therefore, the size of the added transmission lines in the different steps has been adjusted for the specific case under consideration.

- **Number of lines per step**
  The number of lines included in each step varies according to the expected interrelated effect and the potential value gain. Therefore, in the first steps fewer lines have been chosen for expansion, as the very high value of transmission system expansions in parts of the system is expected to significantly impact the values in other parts of the system. After a number of steps, the value of transmission system expansion across the system is more comparable, and a larger number of lines are added in each step. At the same time, findings from the first steps increase confidence in the system behaviour and allow subsequent larger steps.

- **Level of cost-benefit ratio**
  The screening process was continued until total system cost increased. In a more cautious approach, the screening process could include a requirement that benefits are greater than the cost using a fixed margin, e.g. 25%.

- **Implementation of scenarios**
  The evaluation of the value of transmission system expansion in two different scenarios for the power generation capacities was integrated in each step, and the lines for expansion were chosen based on the average of the value in both scenarios. An alternative approach would have been to carry out the entire screening process for each scenario individually and compare the resulting grid.

9. ENTSO-E METHODOLOGY FOR CBA OF CHINESE TRANSMISSION PROJECTS

9.1 Adjustment of methodology to the Chinese framework

During the screening process a subset of potential transmission investments were selected for detailed individual cost-benefit analysis.

In the ENTSO-E process in Europe, projects are evaluated based on their actual projected transmission capacity added between two regions.

However, the result of the screening process for China[14] shows that for a number of potential lines to be built in the period towards 2030, beneficial transmission capacity expansion is higher than a single project would add. The value of the first project will be different from the value of the last project (assuming no changes in the surrounding system).

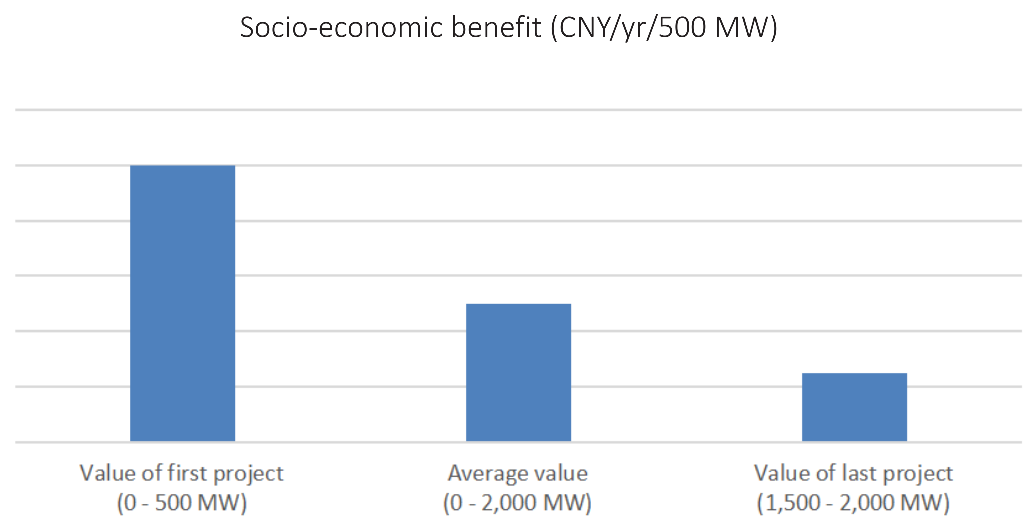
This leaves a number of options for the cost-benefit analysis (illustrated in Figure 9.1). Here total transmission expansion in the screening process is assumed to be 2 000 MW in steps of 500 MW:

- **Value of total transmission expansion of given line.**
  This calculation compares a situation with and without the entire transmission expansion in question.
- **Value of first project.**
  This calculation compares a situation without transmission expansion to a situation where the transmission capacity is increased by one project.
- **Value of last project.**
  This calculation compares a situation without the final step of transmission expansion with one where the final step is included.

In the subsequent CBA analyses for Chinese projects all three approaches have been illustrated.

14 See Chapter 8 and Screening Report, December 2020 (A4.1.1: ENTSO-E Grid Planning Modelling Showcase for China, EU – China ECECP platform).

Figure 9.1: Illustration of socio-economic value of first project, final project, and average of total expansion. Here, total transmission expansion is assumed to be 2 000 MW in steps of 500 MW.



9.2 Selection of lines from screening for detailed CBA analysis

The lines chosen for further individual CBA-analysis are 'Hubei-Jiangxi', 'Chongqing-Xinjiang' and 'Hubei-Shaanxi'. (See description of transmission lines in Section 8.9).

The main data for the recommended lines to be further CBA assessed is shown in Table 9.1. The lines are shown in Figure 8.12.

Table 9.1: Key parameters of selected transmission lines for CBA analysis[15].

Connection	Capacity	Voltage level	AC/DC	Length
Hubei-Jiangxi	14 000 MW	750 kV	AC	390 km
Chongqing-Xinjiang	12 000 MW	±800 kV	DC	2 300 km
Hubei-Shaanxi	8 000 MW	±800 kV	DC	1 136 km

9.3 CBA analysis of selected transmission lines

In the CBA analysis for Chinese projects, the focus is on CBA parameters generated through market modelling. This choice has been made because markets and market modelling are fairly new concepts in China. Therefore, the greatest value to China from the present study is to demonstrate the application of these new concepts under Chinese conditions. For the costs, an estimate is made based on length of line, technology (AC/DC), voltage, etc.

15 The voltage level of 750 kV stated for the Hubei-Jiangxi line should be re-evaluated in the detailed planning process.

The selected CBA parameters are:

- SEW.
- Costs for fuel (included in SEW).
- CO_2 reduction (included in SEW).
- RES integration: Reduction in curtailment (GWh/yr).
- CAPEX for investment in question.
- OPEX for the investment in question.

Grid losses and the impact of transmission system reinforcement on grid losses have not been taken into account. The methodology has the potential to include modelling of grid losses, but the required level of detail on the technical characteristics of different parts of the transmission system were not available and it would have required analysis efforts beyond the scope of this project to provide the data.

9.4 CBA results in the year 2030

This section presents the results of the CBA analysis for each of the three selected transmission expansions. The results demonstrate the effects on the parameters described above for each of three lines as illustrated by the example in Figure 9.1. The actual capacities have been chosen as the first 2 000 MW of the entire project, the final 2 000 MW and the full project as identified in the screening process.

During the screening process an estimate for the best portfolio of transmission lines was found in Step 12 (see Figure 8.7 and Table 8.3). Therefore, the transmission system corresponding to Step 12 is used as the reference transmission grid (TOOT method applied, see Section 4.6 and Figure 4.8) and the results will in the following be shown as the difference to Step 12.

Calculations of economic benefits have been calculated for both Chinese scenarios: Stated Policies Scenario and Below 2°C Scenario (see Section 5.3). The results presented in the tables and graphs represent average values for the two scenarios. Table 9.2 presents an overview of CBA assessments.

Table 9.2: Overview of CBA assessment cases.

Connection cases	Hubei-Jiangxi (HJ)	Chongqing-Xinjiang (CX)	Hubei-Shaanxi (SH)
Case: Full expansion	14 GW	12 GW	8 GW
Case: first 2 GW	2 GW	2 GW	2 GW
Case: last 2 GW	2 GW	2 GW	2 GW

9.4.1 Hubei-Jiangxi (HJ)

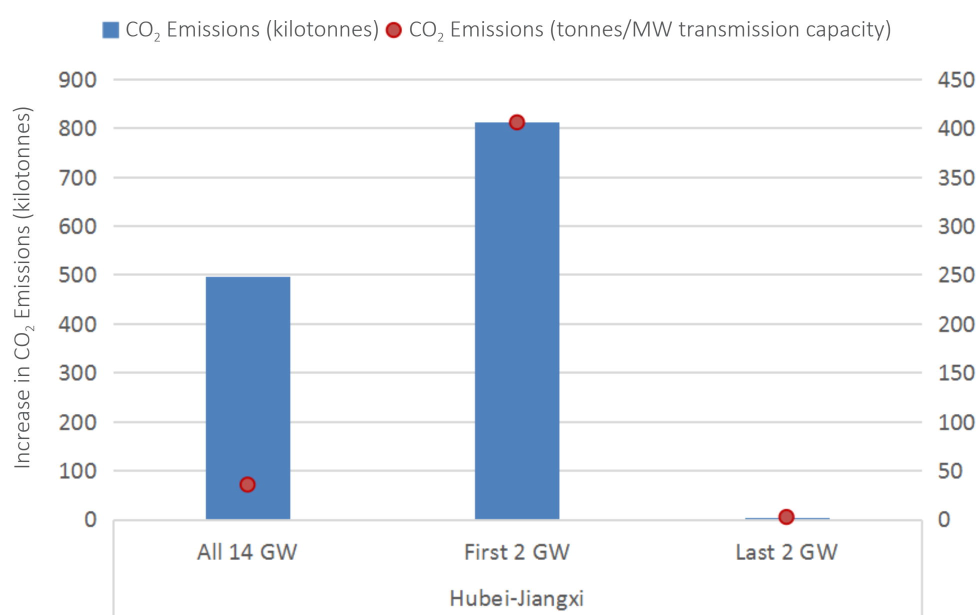
The cost benefit assessment is summarised in Table 9.3. It follows that the reduction in lost load following the transmission expansion totally dominates the benefit-numbers. (Value of lost load is assumed to be CNY 40 000/MWh).

Table 9.3: Annual cost benefit in CNY million.

Annual cost-benefit	Hubei-Jiangxi		
	All 14 GW	First 2 GW	Last 2 GW
Fuel Cost	1 947	269	206
Variable O&M	123	42	-35
Start-up and ancillary services	118	83	-26
Taxes, quotas, and subsidies	162	-32	-6
Total dispatch benefit	**2 350**	**362**	**138**
Value of lost load	105 756	60 330	4
Capital cost transmission	-1 852	-265	-265
Total cost benefit	**106 254**	**60 427**	**-122**

The results in Table 9.3 shows positive net benefits for the first 2 GW and for the full expansion of 14 GW. However, the final 2 GW expansion comes out negative.

Figure 9.2: Increase in CO_2 emission for the full project, the first 2 GW and the last 2 GW of the Hubei-Jiangxi line in kilotons/yr and the respective CO_2 emission change per MW transmission capacity. Positive values show an increase in CO_2 emissions.



The line reduces lost load and will therefore lead to increased CO_2 emissions ('lost load' has no emissions). However, this is less than 0.02% of the total emissions (Figure 9.2).

Alternatives to transmission line expansions might be new local generation from e.g. oil peakers, which could lead to even higher CO_2 emissions.

Figure 9.3: Change in electricity generation for the full project, the first 2 GW and the last 2 GW of the Hubei-Jiangxi line in TWh/yr. Positive values show an increase in generation due to transmission buildout.

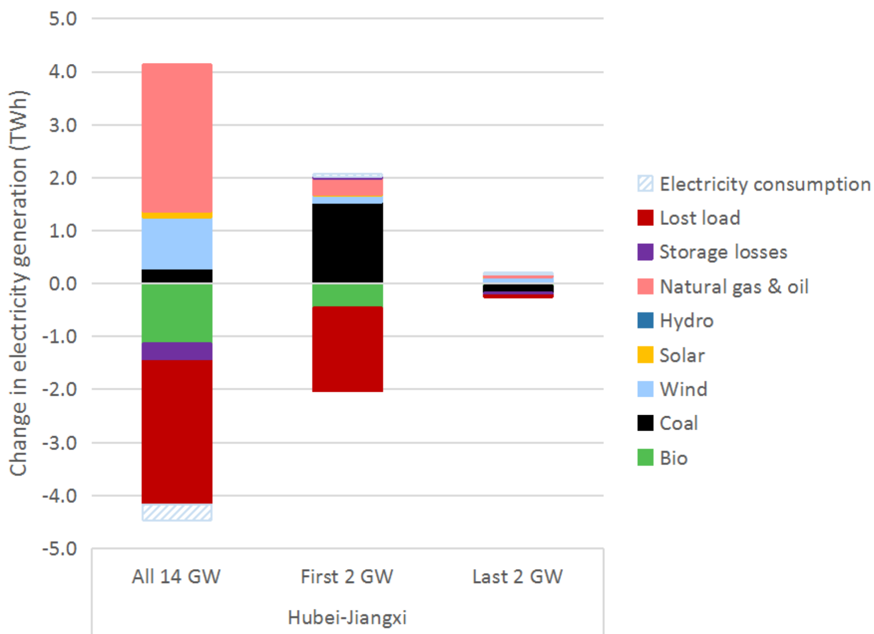
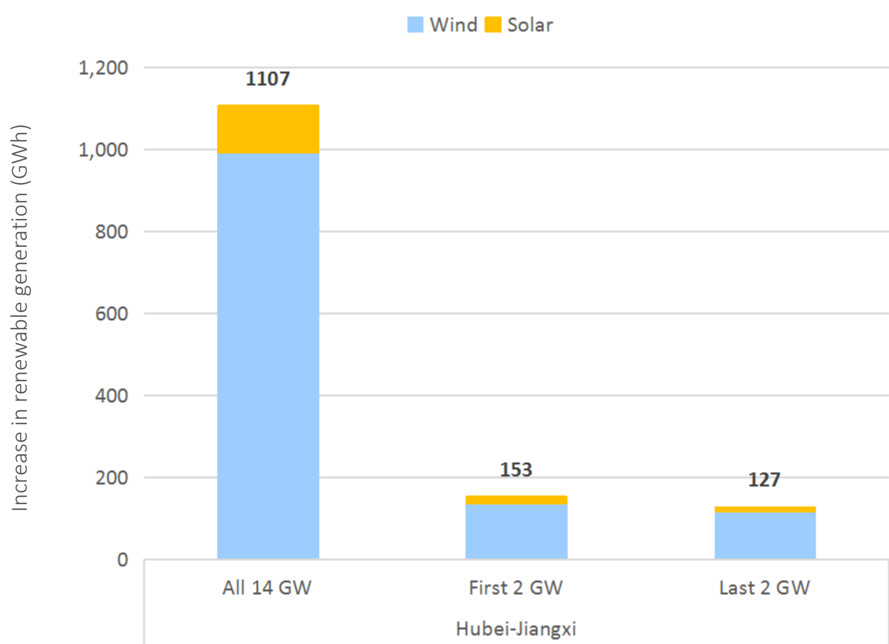


Figure 9.4: Increase in renewable electricity generation for the full project, the first 2 GW and the last 2 GW of the Hubei-Jiangxi line in GWh. The increase is due to reduction in curtailment of wind and PV.



As shown in Figure 9.3, available thermal capacity is utilised to supply otherwise lost load when the line is built out. This causes the increase in CO_2 emissions. However, there is also an increase in renewable generation.

The increase in generation of solar and wind (Figure 9.4) is caused by the addition of the transmission capacity with allows for better utilisation of the wind turbines and solar parks. The increase in generation is equal to the reduction in curtailments.

Figure 9.5 and Figure 9.6 show the duration curves in the two scenarios for price difference at transmission end points (Hubei to Jiangxi) after 14 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of buildout.

Figure 9.5: Duration curves for price difference at transmission endpoints (Hubei to Jiangxi) after 14 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of buildout. Below 2˚C Scenario, numbers in CNY/MWh.

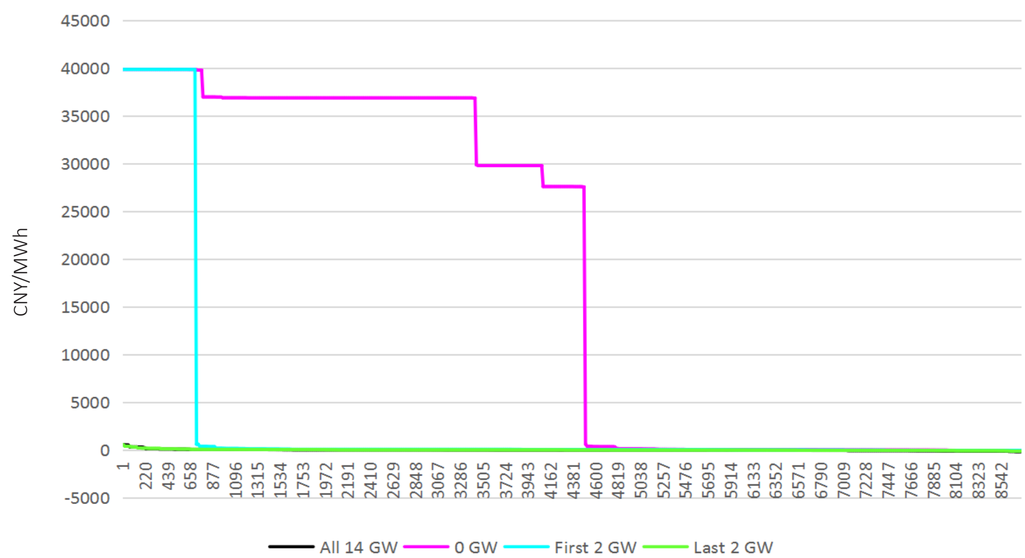


Figure 9.6: Duration curves for price difference at transmission endpoints (Hubei to Jiangxi) after 14 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of buildout. Stated Policies Scenario, numbers in CNY/MWh.

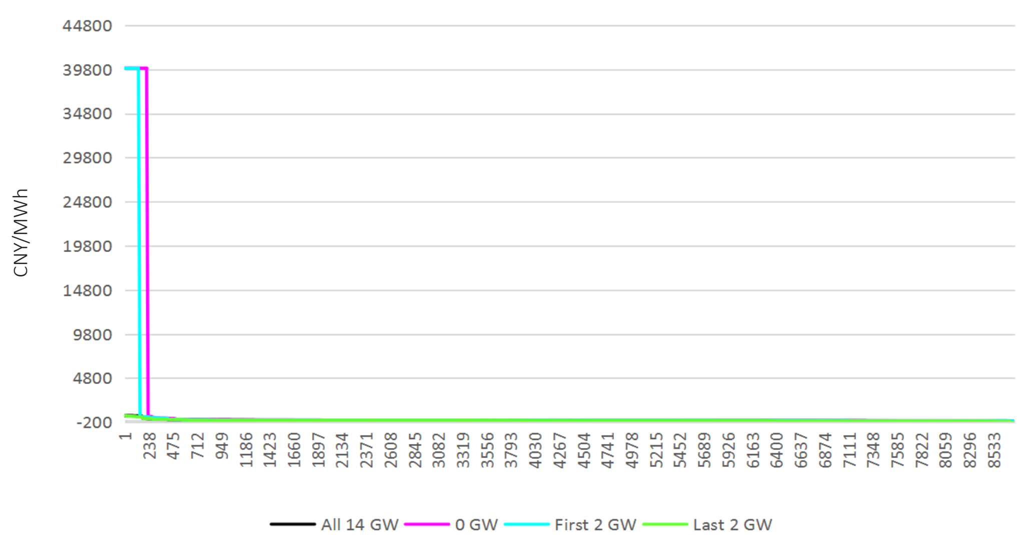


Table 9.4 is based on Figure 9.5 and Figure 9.6. The numbers in the table denote the marginal value of transmission expansion at different stages of transmission buildout. The marginal values are calculated as the sum of hourly price differences (over the year) at the endpoints of the line in the different stages of building out.

Table 9.4: Marginal value of transmission expansion. Numbers in CNY million/MW/yr.

Marginal value of expansion	Hubei-Jiangxi			
	0 GW	First 2 GW	Last 2 GW	All 14 GW
Below 2°C	159.85	28.55	0.36	0.38
Stated Policies	9.62	6.40	0.36	0.38

Annual investment cost per MW: CNY 0.13 million.

It follows that marginal value of expansion is higher than marginal cost of expansion in all cases.

However, the calculation with and without the last 2 GW (Table 9.3 Annual cost benefit in CNY million) shows a slightly negative overall result for cost-benefit. In theory this is not a contradiction: the marginal benefit expresses the value of an infinitesimal expansion at a given reference, while Table 9.3 shows results for a full 2 GW expansion.

9.4.2 Chongqing-Xinjiang (CX)

The cost benefit assessment is summarised in Table 9.5. It follows that all expansions have a positive net benefit.

Table 9.5: Annual cost benefit in CNY million.

Annual cost-benefit	Chongqing-Xinjiang		
	All 12 GW	First 2 GW	Last 2 GW
Fuel Cost	6 157	1 166	907
Variable O&M	-43	-18	-14
Start-up and ancillary services	197	61	-11
Taxes, quotas, and subsidies	581	156	58
Total dispatch benefit	**6 892**	**1 364**	**939**
Value of lost load	-2	-2	-0
Capital cost transmission	-4 773	-796	-796
Total cost benefit	**2 117**	**566**	**143**

The following figures show the CBA-results for Chongqing-Xinjiang in the same sequence as the one applied to Hubei-Jiangxi.

It follows that all expansions lead to less CO_2 emissions (Figure 9.7) as coal is replaced with natural gas and wind (Figure 9.8). The increased wind in the system is due to reduced curtailments (Figure 9.9).

Figure 9.7: Increase in CO_2 emissions for the full project, the first 2 GW and the last 2 GW of the Chongqing-Xinjiang line in kilotons/yr and the respective CO_2 emission change per MW transmission capacity. Positive values represent the increase in CO_2 emissions.

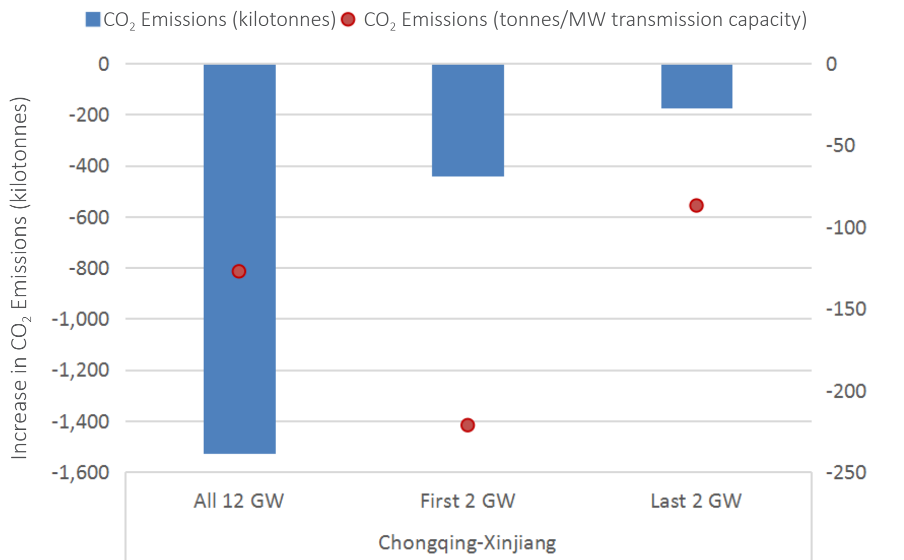


Figure 9.8: Change in electricity generation for the full project, the first 2 GW and the last 2 GW of the Chongqing-Xinjiang line in TWh/yr. Positive values represent an increase in generation due to transmission buildout.

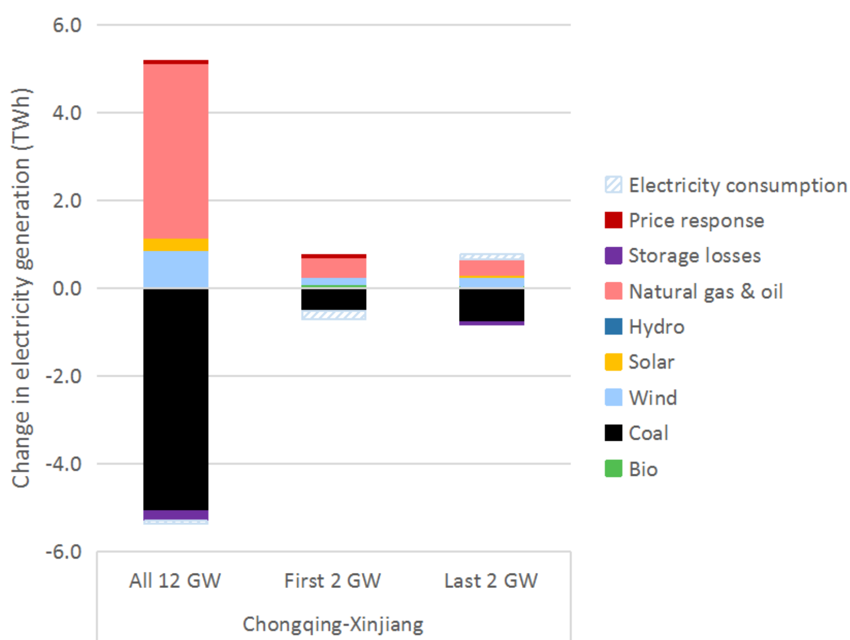


Figure 9.9: Increase in renewable electricity generation for the full project, the first 2 GW and the last 2 GW of the Chongqing-Xinjiang line in GWh/yr. The increase is due to the reduction in curtailment of wind and PV.

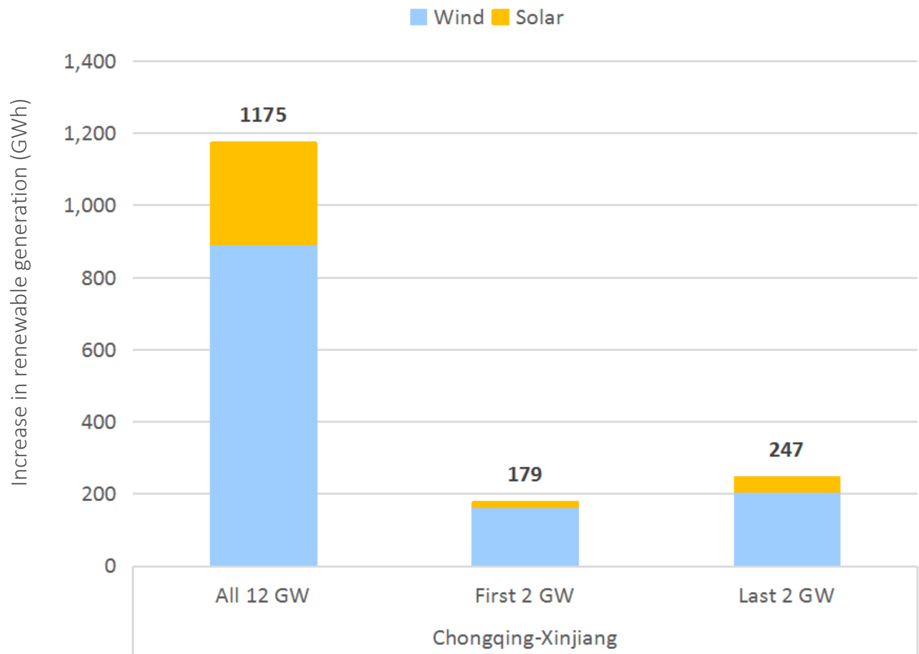


Figure 9.10 and Figure 9.11 show the duration curves for price difference at transmission endpoints in the two scenarios in the different expansion cases.

The sum of hourly price differences over the year at a given stage of expansion is equal to the marginal value of transmission expansion. The values are presented in Table 9.6.

Figure 9.10: Duration curves for price difference at transmission endpoints (Chongqing to Xinjiang) after 12 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of buildout. Below 2˚C Scenario, numbers in CNY/MWh.

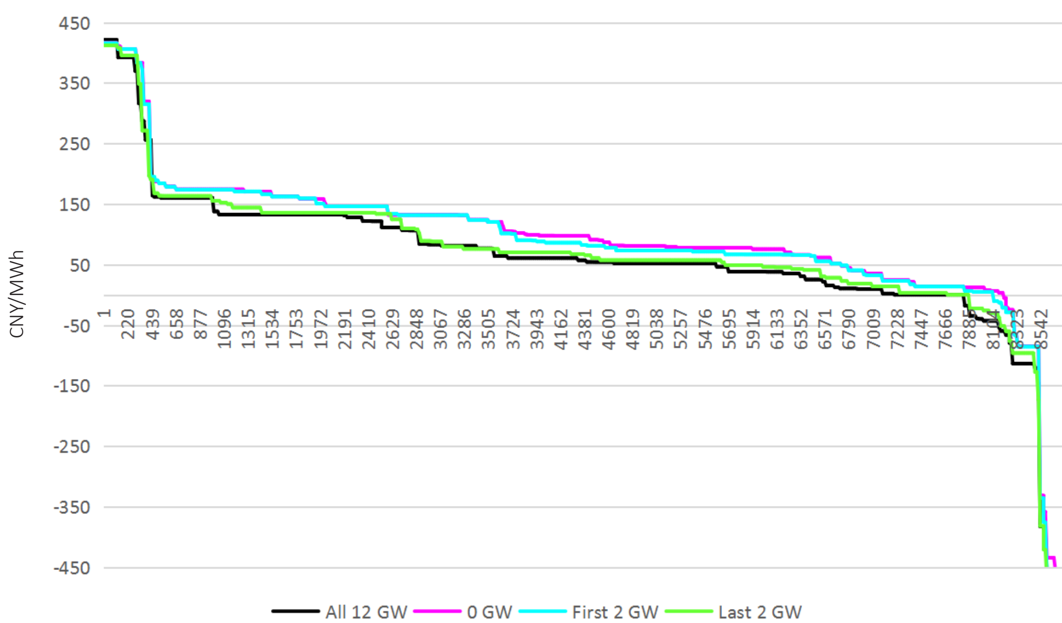


Figure 9.11: Duration curves for price difference at transmission endpoints (Chongqing to Xinjiang) after 12 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of buildout. Stated Policies Scenario, numbers in CNY/MWh.

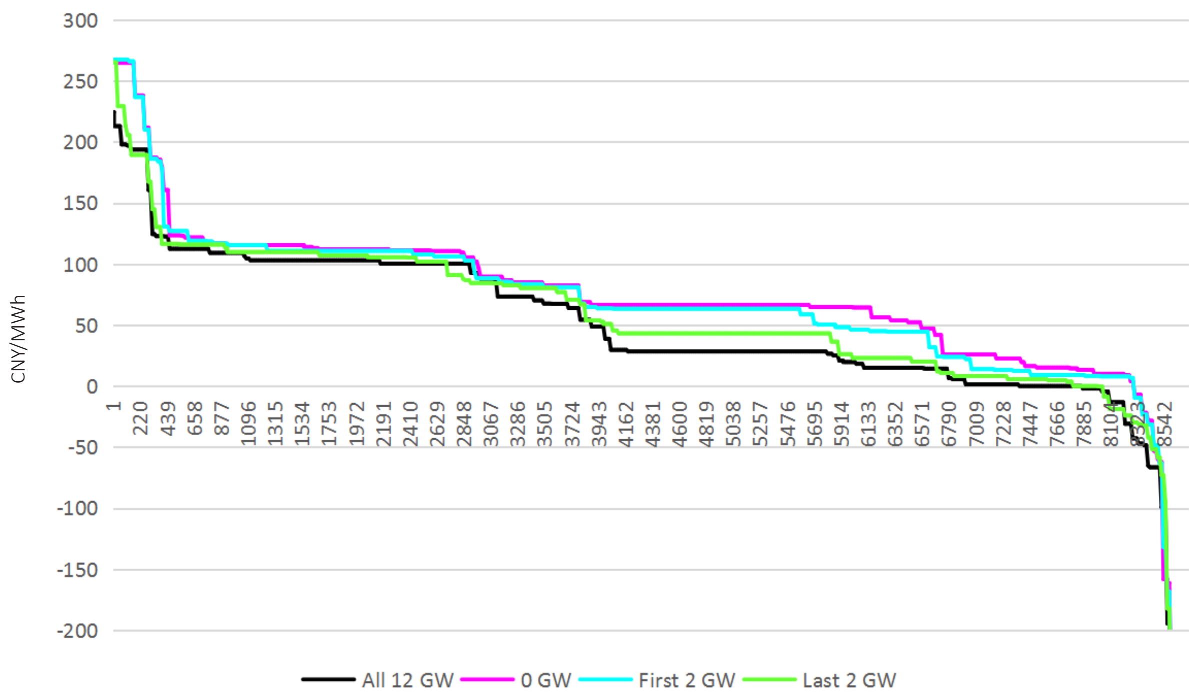


Table 9.6: Marginal value of expansion. Numbers in CNY million/MW/yr.

Marginal value of expansion	Chongqing-Xinjiang			
	0 GW	First 2 GW	Last 2 GW	All 12 GW
Below 2°C	1.05	1.03	0.89	0.84
Stated Policies	0.75	0.72	0.64	0.59

Annual investment cost per MW: CNY 0.40 million.

It follows that marginal value of expansion is higher than marginal cost of expansion in all cases. This accords with conclusions from Table 9.5.

9.4.3 Hubei-Shaanxi (SH)

The cost benefit assessment is summarised in Table 9.7. It follows that all expansions have a positive net benefit.

Table 9.7: Annual cost benefit. Numbers in CNY million.

Annual cost-benefit	Hubei-Shaanxi		
	All 8 GW	First 2 GW	Last 2 GW
Fuel Cost	2 169	605	536
Variable O&M	-15	22	-4
Start-up and ancillary services	87	0	31
Taxes, quotas and subsidies	-97	-28	-49
Total dispatch benefit	**2 144**	**599**	**514**
Value of lost load	3	-1	2
Capital cost transmission	-1 788	-447	-447
Total cost benefit	**359**	**151**	**69**

The following figures show the CBA-results for Hubei-Shaanxi in the same sequence as that applied to Hubei-Jiangxi and Chongqing-Xinjiang.

Figure 9.12: Increase in CO_2 emissions for the full project, the first 2 GW and the last 2 GW of the Hubei-Shaanxi line in kilotons/yr and the respective CO_2 emission change per MW transmission capacity.

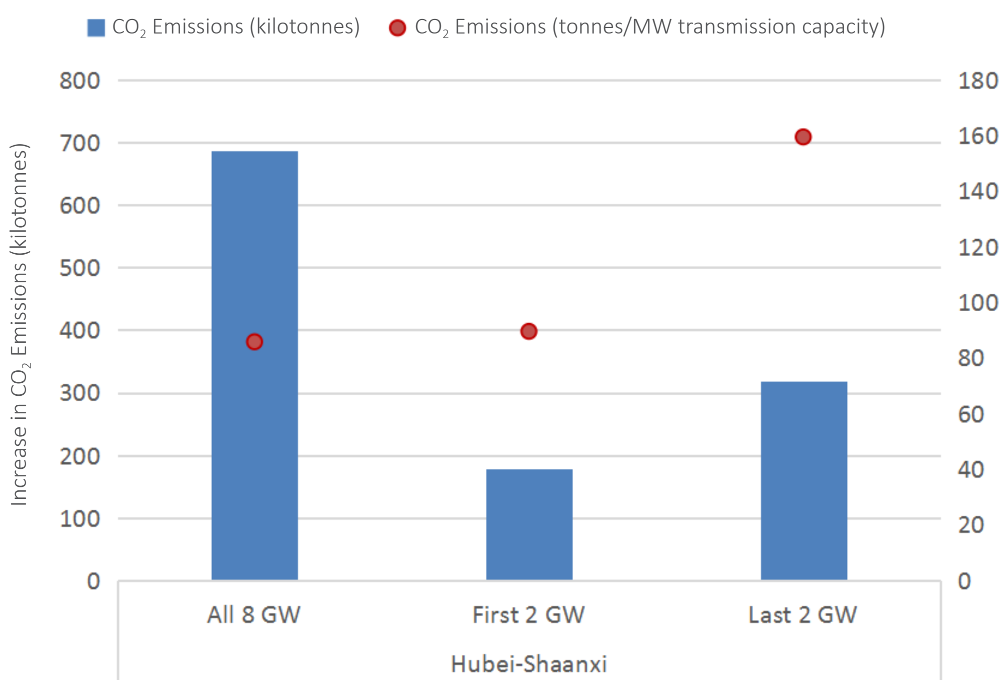
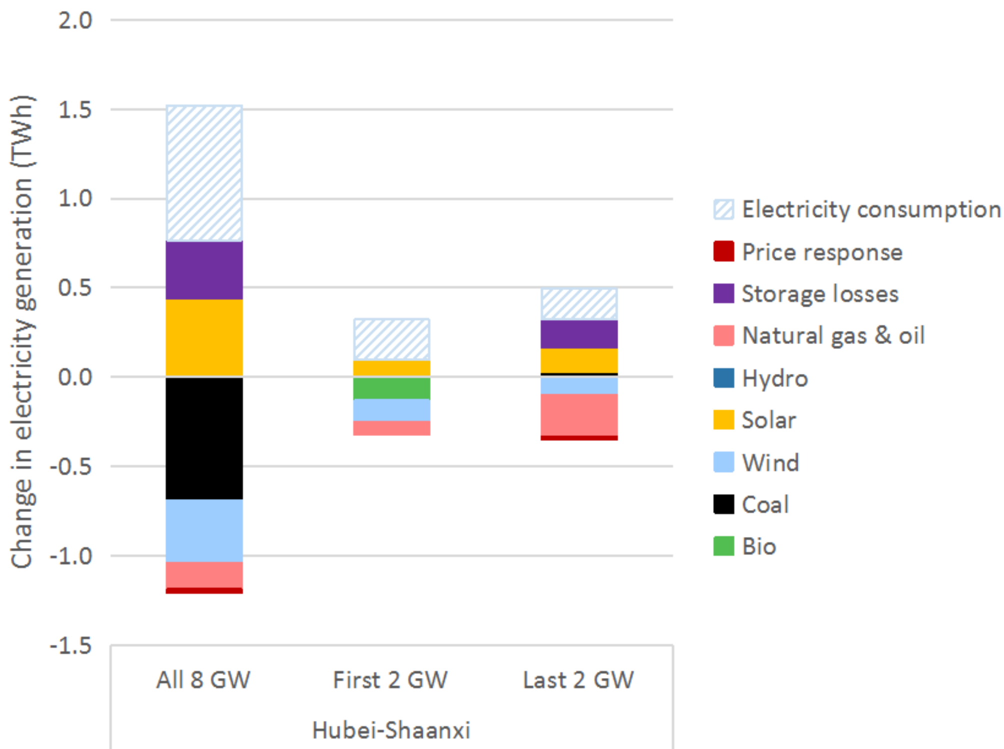


Figure 9.13: Change in electricity generation for the full project, the first 2 GW and the last 2 GW of the Hubei-Shaanxi line in TWh/yr. Positive values mean an increase in generation due to transmission buildout.



In Figure 9.13, the electricity consumption shows that when the transmission line is added, total electricity consumption decreases (shown as positive generation = decreasing consumption). The change in electricity consumption is mainly due to changes in use of electricity for heating, i.e. heat pumps, geothermal and electric boilers. The change leads to higher CO_2 emissions as shown in Figure 9.12. The reason is that higher power prices lead to more heat production from separate fossil fuelled heat boilers.

Figure 9.14 shows an increase in solar generation but a decrease in wind generation when adding the transmission line. This result is somewhat arbitrary, as wind compared to solar is assumed to have a slightly higher variable cost.

Figure 9.14: Increase in renewable electricity generation for the full project, the first 2 GW and the last 2 GW of the Hubei-Shaanxi line in GWh. A change in generation of renewables (wind and PV) is caused by changes in curtailments.

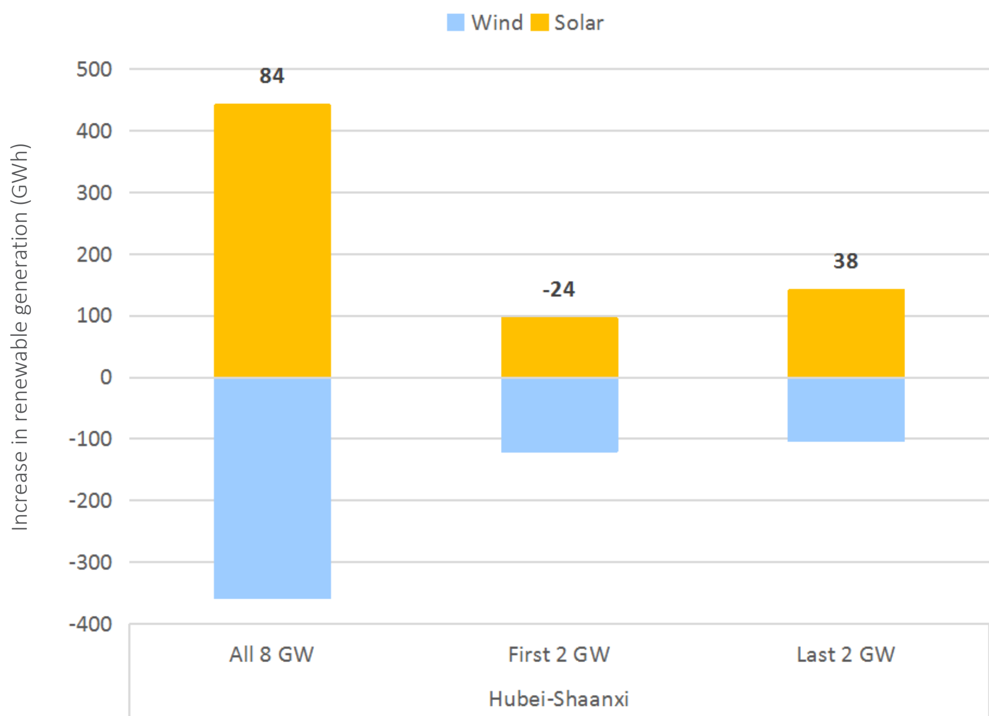


Figure 9.15 and Figure 9.16 show the duration curves for price difference at transmission endpoints in the two scenarios in the different expansion cases.

The sum of hourly price differences over the year at a given stage of expansion is equal to the marginal value of transmission expansion. The values are presented in Table 9.8.

It follows that marginal value of expansion is higher than marginal cost of expansion in all cases. This accords with the conclusions in Table 9.7.

Table 9.8: Marginal value of expansion. Numbers in CNY million/MW/yr

Marginal value of expansion	Hubei-Shaanxi			
	0 GW	First 2 GW	Last 2 GW	All 8 GW
Below 2°C	0.62	0.61	0.58	0.57
Stated Policies	0.50	0.49	0.47	0.46

Annual investment cost per MW: CNY 0.22 million.

Figure 9.15: Duration curves for price difference at transmission endpoints (Hubei to Shaanxi) after 8 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of buildout. Below 2˚C Scenario, numbers in CNY/MWh.

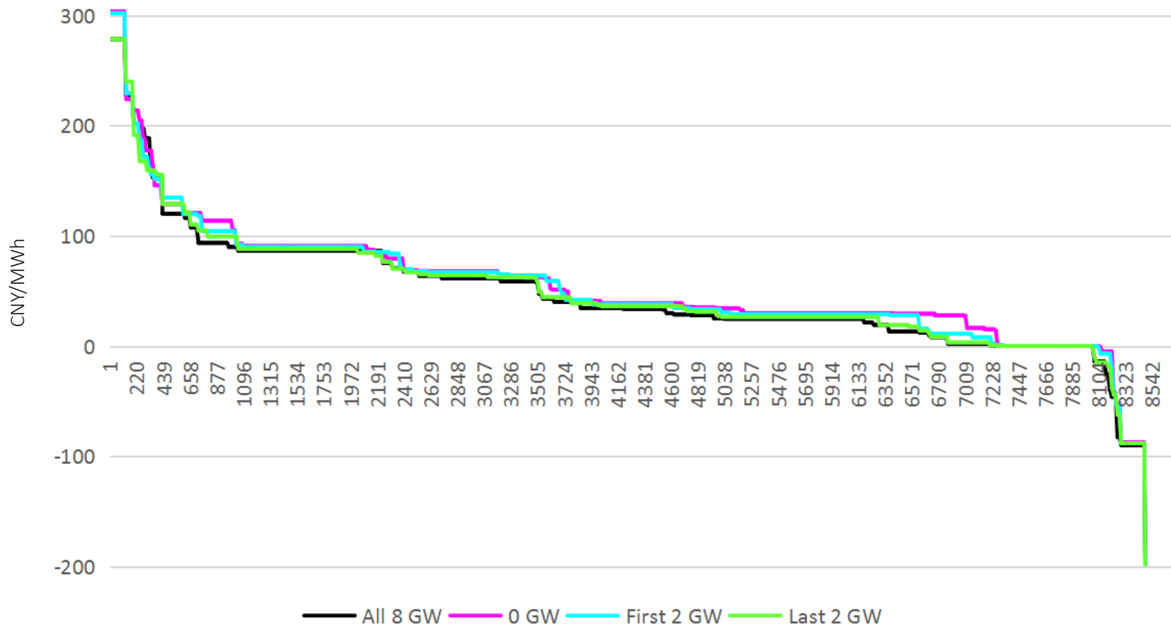
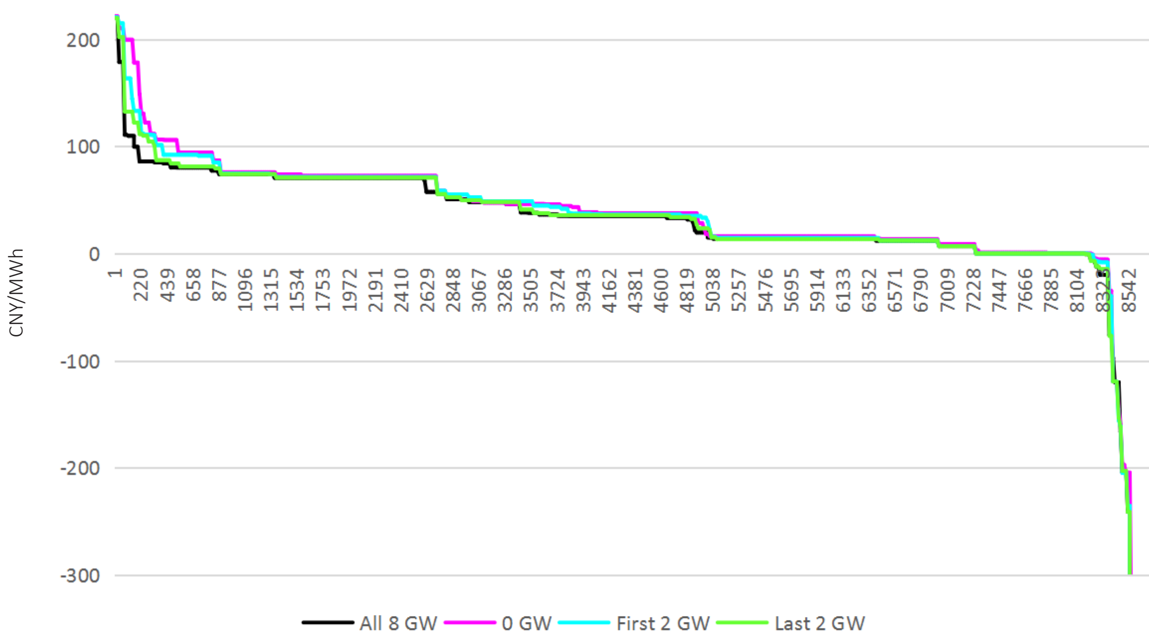


Figure 9.16: Duration curves for price difference at transmission endpoints (Hubei to Shaanxi) after 8 GW, at start (0 GW), after the first 2 GW and before the last 2 GW of buildout. Stated Policies Scenario, numbers in CNY/MWh.



10. PROPOSAL FOR FOLLOW UP STUDY TO A4.1.1

In the European TSO context, power and gas system assessment has long been discussed between the ENTSOs (ENTSO-E and ENTSO-gas), the European regulator (ACER) and the European Commission. According to Regulation (EU) No 347/2013, the ENTSOs must develop a 'consistent and interlinked electricity and gas market and network model including both electricity and gas transmission infrastructure'.

The ENTSOs did deliver an interlinked model with focus on common scenario building but ACER took the view that a number of additional aspects should be investigated in more detail. This would make it possible to include interlinkage issues in the cost benefit calculations for power and gas projects in the TYNDP for power and gas.

**Figure 10.1: Illustration of interlinkage between power and gas systems
A: Separate system approach. B: Interlinked systems.**

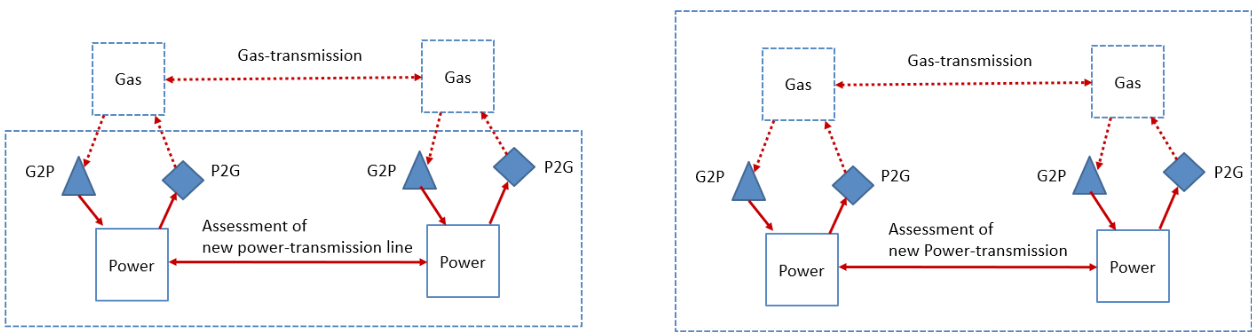


Figure A : CBA for power system

Figure B: CBA for interlinked power and gas system

Source: EA Energy Analysis

In Figure 10.1 the linkages between the gas and power system are illustrated by G2P and P2G. The latter is assumed to be important for future production of green gases and green liquid fuels as substitution for fossil fuels in pursuing climate neutral energy targets. In reality, there are more linkages between the two systems, but here the linkages are limited to G2P and P2G for the sake of simplicity.

It is clear that confining the assessment of e.g. a new power line to an estimate of the impact on the power system has potential shortcomings (Figure 10.1A). A new power line may also have a significant impact on the gas system when it comes to amount of gas supply to power stations, amount of green gas production (P2G) and amount of gas flow in the gas transmission lines (Figure 10.1B).

Gas is expected to play an important role in the coming years in China as coal is being reduced. It would therefore be beneficial to enhance power system models (e.g. the ERI's EDO model) in China with a gas module, as well as the ability to represent the various aspects of Power-to-X. Such a change would significantly enhance the energy system modelling capability.

This project has comprised transmission planning in a market framework. In afterthought also the present Chinese generation planning needs to change with the market reforms as has been the case in Europe. This topic could be another study area in the future cooperation between China and Europe.

ANNEX 1

CEC Pre-screening analysis methodology

Summary:

The following text outlines a simple approach for a pre-screening analysis developed by CEC.

The idea is to compare cost (Levelised Cost of Energy, LCOE) of a new line/ reinforcement of existing line to the price differences at the endpoints of the line.

LCOE in CNY/kWh = {(overnight capital cost * capital recovery factor + fixed O&M cost)/ (8760 * capacity factor)} + variable O&M cost.

LCOE cost is compared with the benchmark price of coal power in the provinces which the line connects. The difference in benchmark prices (CNY/kWh) of the line's endpoints is a proxy for the benefit of transporting power over the line.

Based on these results the benefit/cost ratio or benefit minus cost can be calculated for the transmission lines.

1. Project cost estimation

1.1 Cost estimates for transmission projects

The total investment of the project is calculated according to the cost data of power generation projects in 2019 published by China Electric Power Project Cost Administration of CEC. In 2019, the unit cost range[16] of 500 kV~1000 kV AC overhead line project is 2.64 million/km~7.08 million/km, and the unit cost range of ±500 kV~±800 kV DC overhead line project is 2.49 million/ km~4.95 million/km. The unit cost range of 500 kV~1000 kV substation project is 1.59 million/kVA ~3.7 million/kVA. The unit costs of ±500 kV and ±800 kV converter stations are 7.49 million/kW and 5.92 million/kW, respectively. The national average cost of transmission line, substation and converter station of the power grid project is shown in the table below.

16 The monetary unit is CNY in this section.

Table 1: Unit cost of a transmission line project of 500 kV and above (CNY).

Voltage level	Unit cost (million/km)
AC overhead line engineering	
500 kV	2.64
750 kV	2.99
1000 kV	7.08
DC overhead line engineering	
±500 kV	2.49
±750 kV	4.95

Note: The unit cost of the transmission line project has been converted into the cost level of single circuit line.

Table 2: Unit cost of substation and converter station (CNY).

Voltage level	Unit cost (million/kVA; million/kW)
Substation	
500 kV	1.59
750 kV	1.48
1000 kV	3.70
Converter station	
±500 kV	7.49
±800 kV	5.92

For example:

The ±800 kV HVDC transmission project, 2 000 km, transmission rated power of 8 million kW. According to the above cost index, it can be estimated that the total investment of the UHVDC project a is CNY 24.536 billion.

It should be noted that the above calculation is based on the national average cost of the corresponding voltage level. In practice, the cost of a specific transmission project will be adjusted based on the actual terrain and other special requirements. At the same time, the estimated total investment will be adjusted based on the national average cost.

1.2 Cost estimation method

The total investment cost of the project includes the estimated total investment of the project and the financial cost during the construction period of the project. Among them:

- The construction period of the project is taken to be three years.
- The loan interest rate of financial expenses in the construction period is taken to be 5.0% of the market quotation rate (LPR) for loans with a term of more than five years.
- The loan amount of the project is taken to be average distribution in three years.

According to the above parameters and calculation method, it can be calculated that the financial cost of a UHVDC transmission project over a construction period is CNY 1.472 billion. The total investment cost of the project is CNY 26.008 billion.

Calculation of the transmission price
The 'simple levelled cost of energy calculator' model is used to calculate the cost of a UHV transmission line project.

1.3 Simple levelised cost of energy calculator

A simple LCOE model gives a metric that allows the comparison of the combination of capital costs, O&M and performance. Although LCOE is the minimum price at which energy must be sold for an energy project to break even, the LCOE calculator can also be used to calculate transmission price by setting the fuel cost at zero. The simple levelised cost of energy is calculated using the following formula:

LCOE = {(overnight capital cost * capital recovery factor + fixed O&M cost)/ (8760 * capacity factor)} + variable O&M cost.

Table 3: The main parameters of the model.

	INDEX	UNIT
1	Periods	Years
2	Discount Rate	%
3	Capital Cost	$/kW
4	Capacity Factor	%
5	Fixed O&M Cost	$/kW-yr
6	Variable O&M Cost	$/kWh

Table 4: Main assumptions.

	Parameters	UNIT	Assumptions
1	Life span	Years	30
2	Long term loan interest rate	%	5.0
3	HVDC Converter Station loss	%	1.5
4	line loss rate	%	-----
5	discount rate	%	6.0
6	Variable O&M Cost	$/kWh	$/kWh

1.4. Model parameter setting

- The design life of the project is taken to be 30 years.
- The discount rate is taken to be 6.0%. The project investment consists of two parts: one part is capital, accounting for 20% of the total investment with 10% return on the capital; the other part is loans, accounting for 80% of the total investment with a 5% interest rate.
- Transmission line utilisation.

DC transmission line is considered in two scenarios: one is 5 000 full capacity hours of power grid projects annually and the other is 5 500 full capacity hours of power grid projects annually. AC transmission line is considered in two scenarios: one is 4 000 hours of power grid projects annually, the other is 4 500 hours of power grid projects annually. The transmission loss is converted into full capacity hours equivalent.

- Transmission loss rate of converter station is taken to be 1.5%.
- The loss rates of the transmission lines are calculated with reference to the line loss rate of existing UHVDC projects such as Ling Shao HVDC, Binjin DC, Xiangshang DC, JinSu DC, Tianzhong HVDC, etc. All the transmission loss rates of UHV AC / DC projects were verified by the NDRC in the regulatory period of transmission pricing.
- Operation and maintenance cost are taken to be 3% of the project investment cost.
- Value-added tax is taken to be 13%, according to the latest documents of the Ministry of Finance and the State Administration of Taxation.

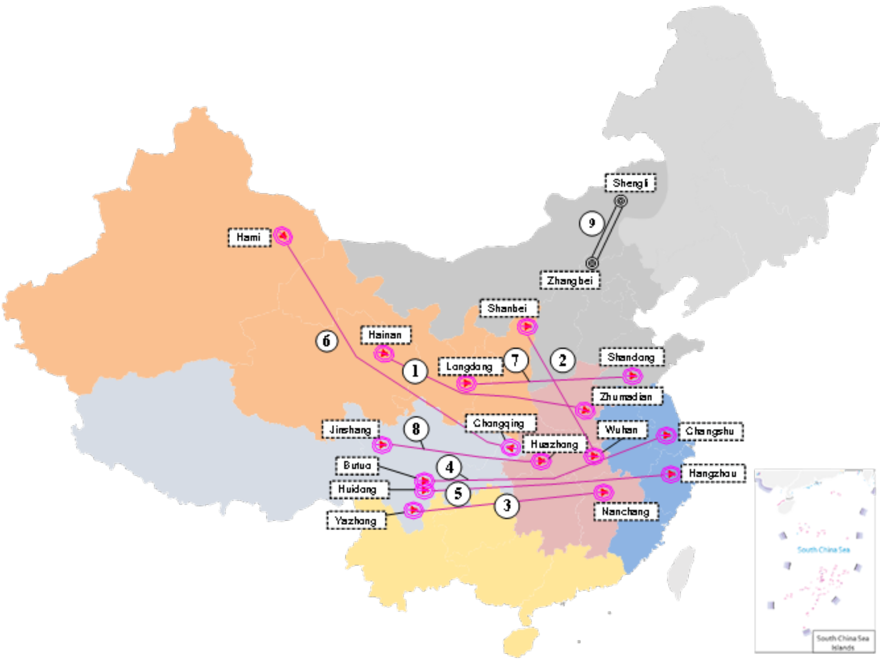
2. Outcomes

Following comprehensive consideration of market space, optimal allocation of resources, policy orientation and power grid security, nine UHV projects were selected, including eight ±800 kV UHVDC transmission projects and one 1 000 kV UHVAC transmission project, as shown:

Table 5: List of 9 UHV projects selected.

No.	Name	Year for start of operation	Endpoints of line	Length(km)	Voltage(kV)	Technology (AC/DC)
1	Qinghai - Henan (Under construction)	2021	Hainan, Zhumadian	1 587	±800	DC
2	Shanbei - Hubei (Confirmed)	2022	Shanbei, Wuhan	1 136	±800	DC
3	Yazhong - Jiangxi	2022	Yazhong, Nanchang	1 711	±800	DC
4	Baihetan - Jiangsu	2023	Butuo, Changshu	2 087	±800	DC
5	Baihetan - Zhejiang	2024	Huidong, Hangzhou	2 195	±800	DC
6	Hami - Chongqing	2026	Hami, Chongqing	2 300	±800	DC
7	Longdong - Shandong	2027	Longdong, Shandong	1 300	±800	DC
8	Jinshang - Huazhong	2028	Jinshang, Huazhong	1 800	±800	DC
9	Zhangbei - Shengli	2025	Zhangbei, Shengli	460	1000	AC

Figure 1: The nine trans-regional transmission projects planned to be built in the next ten years.



Through the above calculation method, the estimated total investment of the project, the investment per kilowatt and the utilisation rate of the transmission line are calculated as follows.

Table 6: Calculation results of relevant index parameters.

No.	Name	Estimated total investment (CNY billion)	Total investment (CNY billion)	Investment per kWh (CNY/kW)	Loss line rate (%)	Fixed O&M cost (CNY/kW/yr)	Utilisation rate (s1)(%)	Utilisation rate (s2)(%)
1	Q-H	22.6	24.3	3 037	6.0	91.1	53.7	59.0
2	S-H	18.5	19.9	2 486	4.7	74.6	54.4	59.8
3	Y-J	24.6	26.4	3 306	6.3	99.2	53.5	58.8
4	B-J	30.7	33.0	4 125	7.4	123.8	52.9	58.2
5	B-Z	25.5	27.4	3 427	7.7	102.8	52.7	58.0
6	H-C	25.0	26.9	3 359	8.0	100.8	52.5	57.8
7	L-S	20.0	21.5	2 688	5.2	80.6	54.1	59.5
8	J-H	25.0	26.9	3 359	6.6	100.8	53.3	58.7
9	Z-S	4.0	4.3	717	1.5	21.5	45.0	50.6

Note: Zhangbei-Shengli transmission line only includes line investment.

Inputting the calculation results of the above relevant index parameters into the 'simple levelled cost of energy calculator model', we can obtain the prices of UHV projects under two scenarios of full capacity utilisation rates. See Table 7 for details.

Table 7: Average cost of UHV project.

No.	Name	LCOE (Tax not included) (CNY cent/kWh)		LCOE (Tax included) (CNY cent/kWh)	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
1	Qinghai - Henan	6.65	6.05	7.51	6.84
2	Shanbei - Hubei	5.37	4.89	6.07	5.53
3	Yazhong - Jiangxi	7.27	6.61	8.22	7.47
4	Baihetan - Jiangsu	9.17	8.33	10.36	9.41
5	Baihetan - Zhejiang	7.65	6.95	8.64	7.85
6	Hami - Chongqing	7.52	6.83	8.50	7.72
7	Longdong - Shandong	5.84	5.31	6.60	6.00
8	Jinshang - Huazhong	7.41	6.73	8.37	7.60
9	Zhangbei - Shengli	1.87	1.67	2.11	1.89

Comparing the prices of transmission projects with the coal generation benchmark prices for sending and receiving systems, the economic benefits of nine UHV transmission projects are shown in Table 8.

Table 8: Economic benefits of UHV transmission project (CNY cent/kWh).

No.	Sending system		Receiving system		Benefits	
	System name	Benchmark price of coal power (CNY cent/kWh)	System name	Benchmark price of coal power (CNY cent/kWh)	Scenario 1	Scenario 2
1	Qinghai	22.77	Henan	37.79	7.51	8.18
2	Shanbei	35.45	Hubei	41.61	0.09	0.63
3	Yazhong	33.21	Jiangxi	41.43	0.00	0.75
4	Baihetan	28.74	Jiangsu	39.10	0.00	0.95
5	Baihetan	32.89	Zhejiang	41.53	0.00	0.79
6	Hami	25.00	Chongqing	39.64	6.14	6.92
7	Longdong	29.78	Shandong	39.49	3.11	3.71
8	Jinshang	34.31	Huazhong	42.68	0.00	0.77
9	Zhangbei	37.20	Shengli	39.49	0.18	0.40

Among them, the economic benefit of Qinghai-Henan and Hami-Chongqing lines are the highest, at CNY 0.06/kWh. Yazhong-Jiangxi, Baihetan-Jiangsu, Baihetan-Zhejiang and Jingchang-Huanghong power transmission projects will transmit electricity from some of the large hydropower stations.

The economic and environmental benefits of the above-mentioned UHV transmission channels are as follows.

A. Economic benefits
On the one hand, through market-oriented transactions, the receiving provinces can reduce the power consumption price. At present, the proportion of electric power participating in market-oriented transactions is about 40%, and the price reduction per kilowatt hour is about CNY 0.03/kWh. The reduction in electricity cost achieved by each transmission line is calculated as follows:

Table 9: Reduce the power consumption cost of customers in receiving provinces.

No.	Name	Scenario 1			Scenario 2		
		Electricity delivered (billion kWh)	Market trading electricity (billion kWh)	Reduced electricity cost (CNY billion)	Electricity delivered (billion kWh)	Market trading electricity (billion kWh)	Reduced electricity cost (CNY billion)
1	Qinghai - Henan	37.6	15.0	0.45	41.4	16.5	0.50
2	Shanbei - Hubei	38.1	15.2	0.46	41.9	16.8	0.50
3	Yazhong - Jiangxi	37.5	15.0	0.45	41.2	16.5	0.49
4	Baihetan - Jiangsu	37.0	14.8	0.44	40.8	16.3	0.49
5	Baihetan - Zhejiang	36.9	14.8	0.44	40.6	16.2	0.49
6	Hami - Chongqing	36.8	14.7	0.44	40.5	16.2	0.49
7	Longdong - Shandong	37.9	15.2	0.46	41.7	16.7	0.50
8	Jinshang - Huazhong	37.4	14.9	0.45	41.1	16.4	0.49
9	Zhangbei - Shengli	31.5	12.6	0.38	35.5	14.2	0.43

The above-mentioned UHVDC transmission projects can each reduce the power consumption cost of the receiving province users by between CNY 440 million and CNY 500 million each year by means of market-oriented transactions. Zhangbei-Shengli, an UHVAC transmission project, can reduce the power consumption cost of users in receiving provinces by between CNY 380 million and CNY 430 million each year.

B. Environmental benefits

The transmission of hydropower and other non-fossil energy electricity helps receiving provinces to reduce CO_2 emissions and accelerate energy transition.

Table 10: UHV transmission projects help reduce CO_2 emissions.

No.	Name	Scenario 1		Scenario 2	
		Electricity delivered (billion kWh)	Reduced CO_2 emissions (million tons)	Electricity delivered (billion kWh)	Reduced CO_2 emissions (million tonnes)
1	Qinghai - Henan	37.6	31.5	41.4	34.7
2	Shanbei - Hubei	38.1	31.9	41.9	35.1
3	Yazhong - Jiangxi	37.5	31.4	41.2	34.5
4	Baihetan - Jiangsu	37.0	31.0	40.8	34.2
5	Baihetan - Zhejiang	36.9	30.9	40.6	34.0
6	Hami - Chongqing	36.8	30.8	40.5	33.9
7	Longdong - Shandong	37.9	31.8	41.7	34.9
8	Jinshang - Huazhong	37.4	31.3	41.1	34.4
9	Zhangbei - Shengli	31.5	26.4	35.5	29.7

ANNEX 2

SGERI: Description of the first five future long distance transmission lines from Annex 1

1. Qinghai-Henan ±800 kV UHVDC Transmission Project

The Qinghai-Tibet-Henan ±800 kV UHVDC project line starts from Qinghai Province, passes through Qinghai, Gansu, Shanxi and Henan Provinces, and ends at Zhumadian, Henan. The total length of the transmission line is 1 587 kilometres. The rated transmission capacity is 8 million kilowatts. Total investment is CNY 22.6 billion. The project was approved by the NDRC in October 2018 and will be completed and brought onstream in 2021.

This project is completely dependent on the complementary capabilities of clean energy to supply power independently. It will be the first UHV channel built specifically for clean energy delivery. It is a major innovation in China's development and application of UHV transmission technology to promote the large-scale integration of new energy generation. This project can send power directly from the Qinghai energy base to Central China’s load centre to meet the needs of Central China’s economic development and load growth, and effectively alleviate the mid-to-long-term power supply and demand contradiction in Central China. It will effectively promote the consumption of clean electricity in the western region, ensure national energy security, help Qinghai to fight poverty, and boost Henan's energy transformation and development.

2. Northern Shaanxi (Shanbei)-Hubei ±800 kV UHVDC Transmission Project

The northern Shaanxi-Hubei ±800 kV UHVDC project line starts from Yulin, Shaanxi, passes through Shanxi, Henan and Hubei Provinces, and ends at Wuhan, Hubei. The total length of the line is 1 136 kilometres, the rated transmission capacity is 8 million kilowatts, and total investment is CNY 18.5 billion. The project will be completed and brought onstream in 2022.

The project will strongly support the intensive development of energy bases in northern Shaanxi and large-scale power delivery, promote efficient use of energy resources, realise the transformation of resource advantages into economic advantages, and stimulate coordinated regional development. After the project is completed, 40 billion kilowatt-hours of electricity will be transferred every year, driving investment in power supply and other related industries to more than CNY 70 billion.

3. Yazhong-Jiangxi ±800 kV UHVDC Transmission Project

The Yazhong-Jiangxi ±800 kV UHVDC project line starts from Yanyuan, Sichuan, passes through Sichuan, Yunnan, Guizhou, Hunan and Jiangxi Provinces, and ends at Fuzhou, Jiangxi. The total length of the line is 1 711 kilometres, the rated transmission capacity is 8 million kilowatts, and total investment is CNY 24.6 billion. The project will be completed and brought onstream in 2022.

The project is a major step for the State Grid: it serves the energy strategy of 'West-East power transmission', ensures the consumption of hydropower in the west, and meets the green development needs of the central and eastern regions. After completion of the project, it will deliver more than 40 billion kWh of electricity every year, reduce standard coal consumption by about 16 million tons, and cut CO_2 emissions by about 40 million tons. This will effectively resolve Sichuan's problem of hydropower curtailment. After the project is completed and brought onstream, it will deliver 4 million kilowatts of capacity to Hunan Province through the UHV AC transmission and transformation network. At that point, the Hunan UHV grid will be built and the improvements to the main grid structure will be developed, while transmission capacity in the Qishao UHVDC will be boosted. The maximum power supply capacity of Hunan Power Grid will increase by more than 8 million kilowatts, effectively making up the power gap.

4. Baihetan-Jiangsu ±800 kV UHVDC Transmission Project

The Baihetan-Jiangsu ±800 kV UHVDC project line starts from Butuo, Sichuan, passes through Sichuan, Chongqing, Hubei, Anhui and Jiangsu provinces/cities, and ends at Changshu, Jiangsu. The total length of the line is 2 087 kilometres, the rated transmission capacity is 8 million kilowatts, and total investment is CNY 30.7 billion. The project will be completed and brought onstream in 2023.

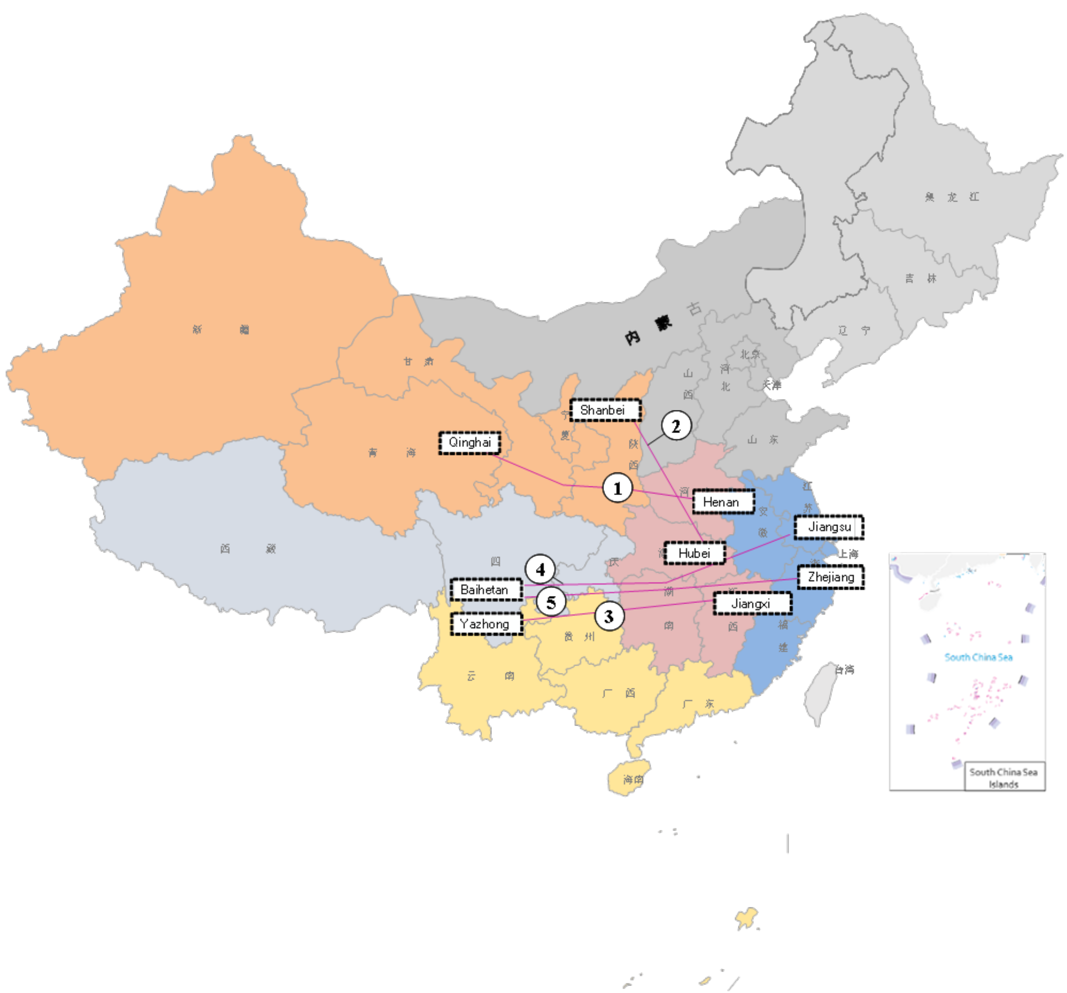
The Baihetan-Jiangsu Project is key to China's implementation of the 'West-East power transmission' strategy. It is a major clean energy project that promotes the adjustment of the national energy structure and energy conservation and emissions reduction. After completion of the project, the large-scale power transmission from Baihetan Hydropower Station will be guaranteed, and the surplus power transmission capacity of the channel in summer can be used to alleviate the problem of water abandonment in Sichuan. After the Baihetan-Jiangsu project is put into operation, transmission capacity will reach 8 million kilowatts, which will meet the development of local economy and load in Jiangsu. This will cooperate with existing UHV projects in East China to give full play to the advantages of UHV grid large capacity, long distance, and low loss. Benefits from this project include increasing the proportion of Jiangsu's clean energy consumption, enhancing the coordinated development of various power sources, and effectively alleviating the mid-to-long-term power supply and demand contradictions in East China.

5. Baihetan-Zhejiang ±800 kV UHVDC Transmission Project

The Baihetan-Zhejiang ±800 kV UHVDC project line starts from Huidong, Sichuan, passes through Sichuan, Chongqing, Hubei, Anhui and Jiangsu Provinces, and ends in Hangzhou, Zhejiang. The total length of the line is 2 195 kilometres, the rated transmission capacity is 8 million kilowatts, and total investment is CNY 25.5 billion. The project will be completed and brought onstream in 2024.

Once the project has been completed and brought into operation, it will meet the export demands of Baihetan Hydropower Station, increase the transmission of surplus hydropower in Sichuan, reduce hydropower curtailment losses, and meet the load growth demand of Zhejiang Province.

Figure 1: Map with five selected long distance transmission lines.



ANNEX 3

Minutes of the ENTSO-E China Showcasing Project Steering Meeting

13 Oct 2020, developed by

- Chen Liang, Contracting and Procurement Expert, ECECP, chen.liang@icf.com
- Helena Uhde, Junior Postgraduate Fellow, ECECP, helena.uhde@ececp.eu

Agenda

Agenda- SG meeting

CET	Topic	
9.00 - 9.10	Welcome	DGENER
9.10 - 9.20	Welcome	NEA
9.20 - 9.45	Project	Overall project outline (EA)
		Activity and workplan (EA)
		Main deliverables – reporting (EA)
9.45 - 10.00	SG comments	Round of comments from SG
10.00 - 10.10	Present transmission planning in China	Present Transmission planning in China (SGERI)
10.10 - 10.25	Market development in China and Screening	Status of power market development (CEC) Status of Screening (CEC)
10.25 - 10.40	Screening	Status for screening of new transmission lines and preliminary screening report (CNREC/ERI)
10.40 - 10.50	SG comments	Round of comments from SG
10.50 - 11.00	Closing remarks	End of meeting, EA

Meeting Summary

Objective of the meeting
This objective of the meeting was to review the ENTSO-E China Showcasing Project work plan and the inception report. Members of the Steering Group (SG) commented on the projects and gave presentations on how they wanted to make use of the methodology. The meeting offered a platform for experts to discuss the research and provide feedback on the inception report.

Opening remarks
Octavian Stamate, Counsellor Climate Action and Energy at the EU Delegation in Beijing, extended a warm welcome to all the participants and underlined the importance of the meeting as it marks the implantation of the second annual work plan (AWP2) of the EU-China Cooperation Platform (ECECP)[17]. He went on to reflect on the recent announcement by President Xi Jinping, on China's aim for CO_2 emissions to peak before 2030 and for carbon neutrality before 2060. This announcement has direct implications for ECECP's work. The EU Delegation is ready to support China towards achieving its ambitious goals.

[Due to connection issues, NEA representatives were only able to join at a later point of the meeting.]

Project overview
Peter Børre Eriksen, team leader of the ENTSO-E China Showcasing Project Steering Meeting, presented an overall outline of the project, introduced the activity and work plan and gave an overview of expected deliverables. The EU and ENTSO-E have the only truly consistent and coordinated process for grid planning on a pan-continental scale - a scale congruent with the Chinese system. This approach includes three steps: scenario building, screening and cost-benefit analysis (CBA). As a multi-indicator assessment, ENTSO-E CBA aims to optimise the social economic welfare of the system, while taking the integration of renewables and security of supply into account. Mr Eriksen stressed that the project relates to the transfer of ENTSO-E methodology, not delivering a transmission plan for China. The work plan, made up of i) the launch event was in March 2020), ii) preliminary screening, iii) screening plus CBA and iv) the final analysis, is accompanied by a list of deliverables, including a planning workshop in December, the presentation of screening results in February and the final workshop and presentation of results in June 2021.

The project overview by the project team leader, Peter Børre Eriksen, was followed by an initial round of comments by the members of the steering group.

Steering Group Comments (Round 1)
Kristian Ruby, Secretary General, EURELECTRIC, acknowledged the importance of this cooperation. The EU and China share the objective of becoming carbon natural around mid-century, with different timelines due to the specific challenges they face. Sharing learnings on decarbonisation between the two strongest global economies is

17 The ENTSO-E Grid Planning Modelling Showcase for China Project is the flagship project of AWP2 of the ECECP.

Figure 1: Ea Energy Analyses - Transmission Planning in Europe.

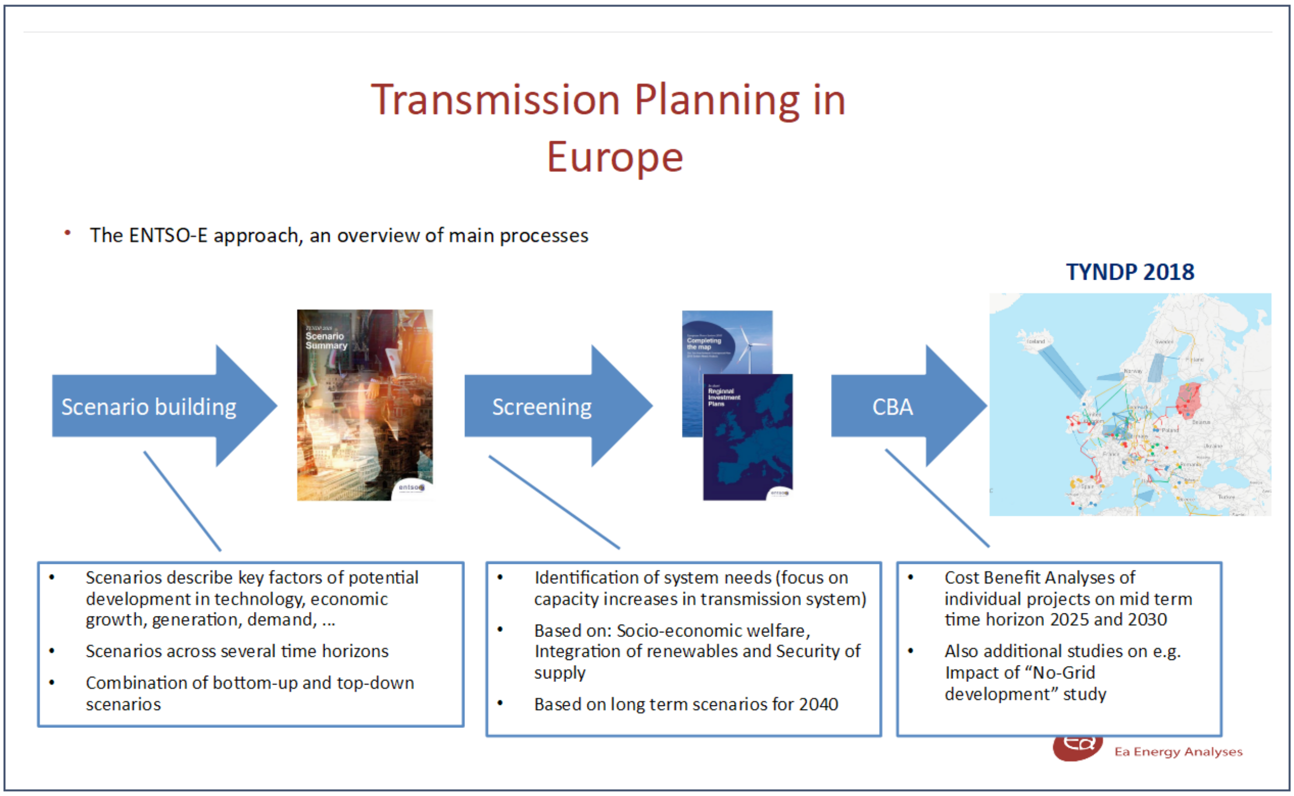


Figure 2: Ea Energy Analyses - Proposed work and activity plan.

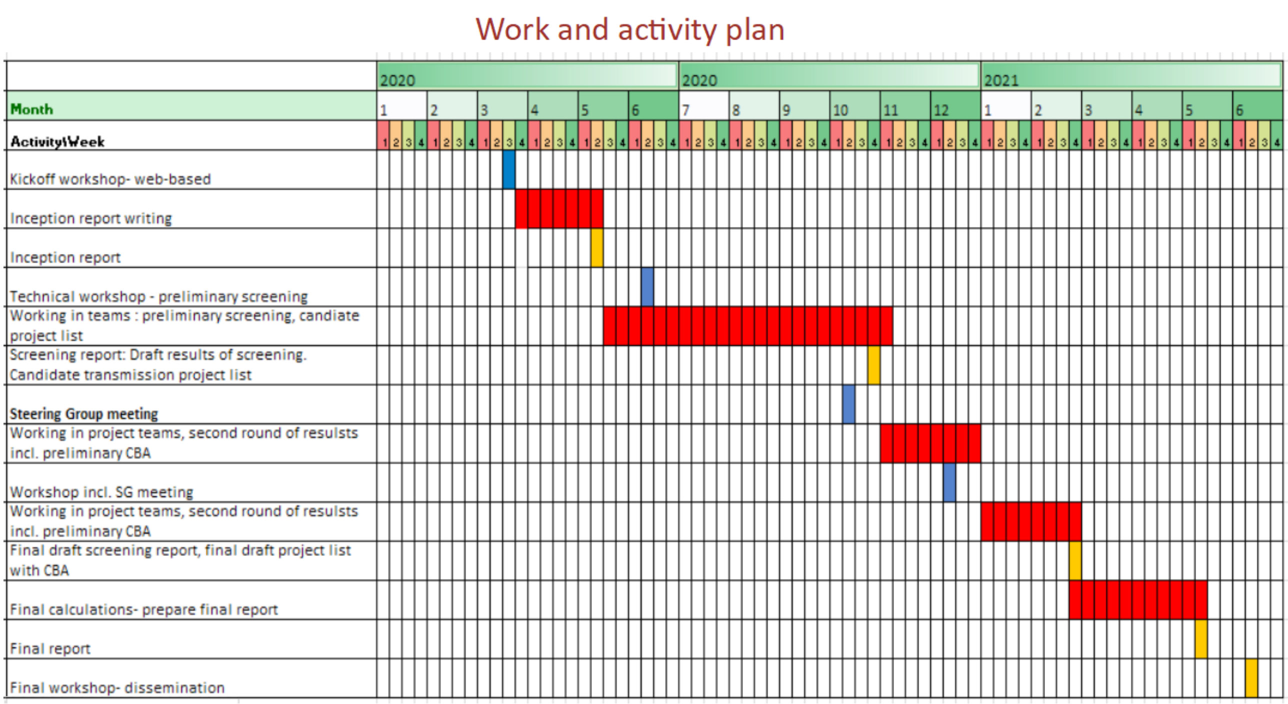


Figure 3: Ea Energy Analyses - Proposed screening process for China.

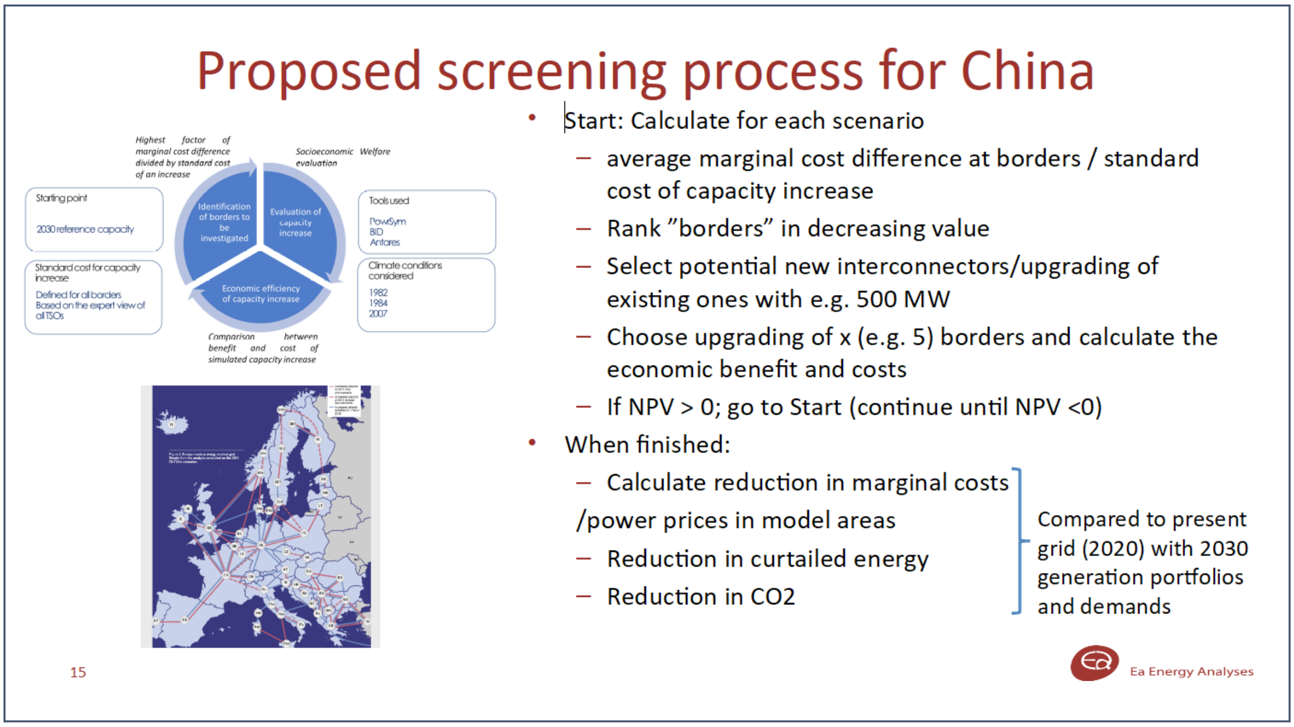
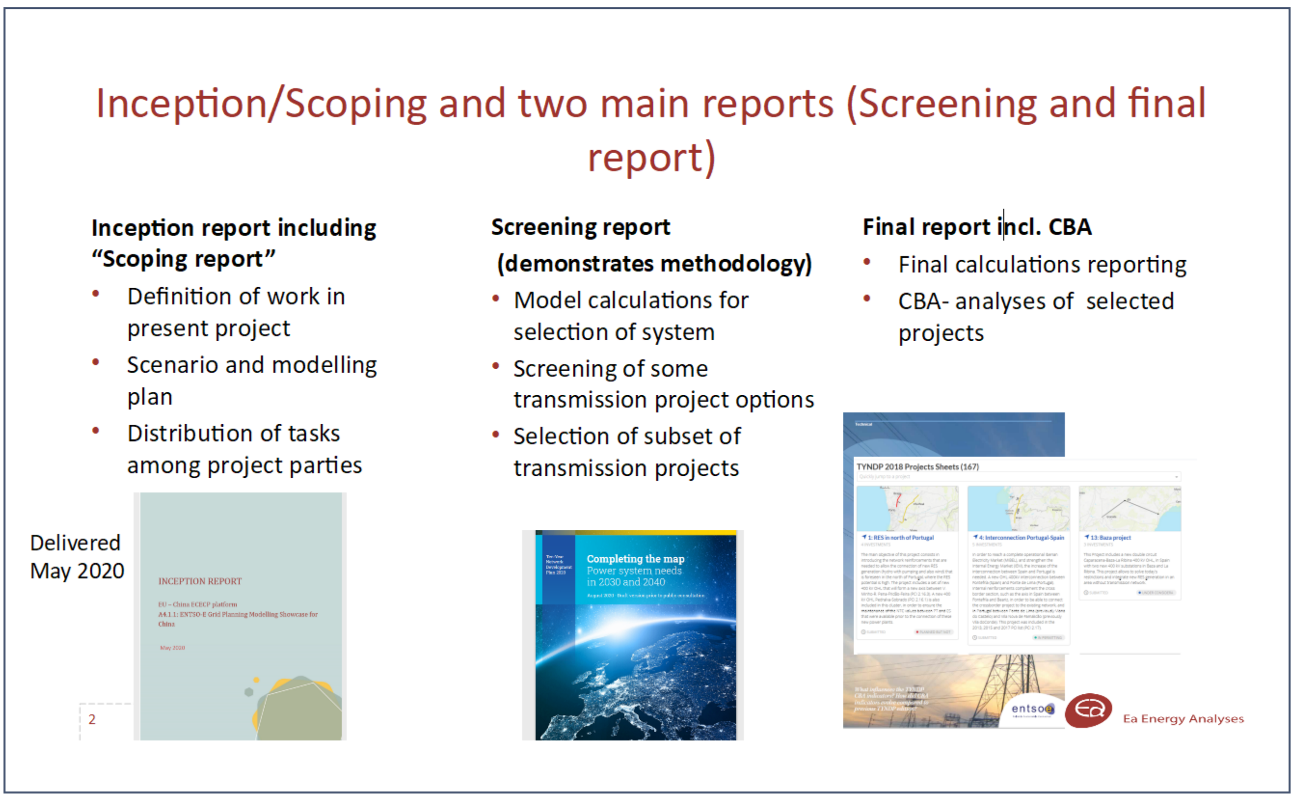


Figure 4: Ea Energy Analyses - Inception/Scoping and the two main reports.



of significant value. EURELECTRIC works with the US, Japan and Australia and can draw from its global experience when cooperating with China. While the scale in China is very different, the modelling approach used in the inception report is very similar to the modelling practised by EURELECTRIC. Mr Ruby highlighted that it is important to ask how a robust CBA can be adopted to ensure that taxpayers' money is spent in the most efficient way possible.

Lei Xiaomeng, senior advisor and personal envoy to Mr YANG Kun, executive president, China Electricity Council, recognised the work that the project team has done over the last two months, based on basic and similar assumptions. In the next stage, it would be important to consider different demands, real electrification scenarios, and different kinds of renewable energy integration scenarios. One of the main difficulties the project team is facing is the collection of data for CBA, thus comprehensive cooperation is vital. Currently, the central government, including NEA, is working on the next five-year power development plan. The work of the project, looking ten years into the future, could be of great value. Mr Lei closed his comments by emphasising that the power sector will play a significant role in China's efforts to achieve the 2030 target. A part of the project could be to forecast and analyse the share of renewable energy that needs to be achieved by 2030.

Kaare Sandholt, chief expert, CNREC, commented that this project provided a good opportunity to look at the European system and explore how the methodology could fit into the Chinese context. There are three key areas for learning:

- Over a time-span of 20 years, the EU has learned how to implement the planning of an unbundled system with prices set by markets and the interaction of a range of different stakeholders. Given that China is on the verge of moving to a system driven by market forces, the country could face similar challenges.

- The European system developed from separated national markets into a European system. This process could be comparable with the integration of provincial markets in China.

- The EU has established that stakeholder involvement and transparency are key factors in the planning process.

Regarding the scope of the project, Mr Sandholt expressed the need to focus on methodological issues and critically evaluate what is or is not effective. Stakeholder involvement and transparency will be merit further study in the future.

Christian Romig, head of consulting in China, AFRY Consulting, explained that it is important to recognise that in future, China's provincial electricity markets will be competitive rather than planned. It will be interesting to see how the system will look like in the late 2020s, 2030s and further into the future, particularly with regards to effective renewable energy integration. An important result of the CBA will be to show the real value of interconnectors for the market. Taking intermediary steps, the prices need to reflect the real value of energy and energy capacity. In addition to prices, which are formed closer to real time, auctions have the potential to allocate capacity more efficiently. Mr Romig concluded that the object of the analysis should be to understand not only the value of interconnectors in the future, but also the intermediate steps prior to construction.

Dr Gianluca Fulli, deputy head of the Energy Security, Distribution and Markets Unit, Joint Research Centre (JRC) of the European Commission, emphasised that the EU and China share ambitious climate targets. For the modelling, Dr Fulli suggested conducting a contingency analysis and comparing different cases, i.e. large scale interconnectors. As the 'scientific branch of the European Commission' - JRC is one of the Directorates-General of the EC -- the JRC is eager to see how the project will develop and happy to provide comments.

Bente Hagem, executive vice president, Statnett pointed out that last year's IEA report[18] provided excellent insights into the challenges faced by China and the potential for this type of cooperation. Ms Hagem acknowledged the high quality of the inception report and suggested the project should be even more transparent on market development and its consequences for China. Market development is a very complex and difficult process: in Europe an efficient market is a prerequisite, even though the real market is not perfect. The question for the modelling is therefore: How to complete CBA without a perfect market?

The steering group's comments were followed by three presentations by representatives from the State Grid Research Institute (SGERI), the Chinese Electricity Council (CEC), and the Energy Research Institute of the NDRC (ERI) on Chinese transmission planning and review processes.

Presentations

Present transmission planning in China

Dr Zhang Ning, Researcher, SGERI, gave an overview of transmission planning in China. In 2019, the State Grid Corporation established the Power Grid Planning Management Committee and the Power Grid Planning Expert Advisory Committee. While the Management Committee examines the work plan and priorities of power grid planning and coordinates the safety, quality and efficiency of power grids, the Expert Advisory Committee provides advice and technical support for the decisions of the Management Committee.

There are four levels of regional branches and provincial companies of the Power Grid Planning Management Committee, including i) headquarters, ii) regional branches iii) provincial companies and iv) local and municipal companies. The four steps of the Chinese transmission planning approach are shown in Figure 5. The key factors in transmission planning include energy requirements, safe and stable operation, and

18 She likely referred to this report: IEA (2019), China Power System Transformation, IEA, Paris https://www.iea.org/reports/china-power-system-transformation.

the integration of power sources in remote areas or power supply for users in remote areas. For high-voltage (especially DC) transmission, the need for resource allocation and complementary and mutually beneficial functions in different regions carry more weight. The final construction depends on the outcome of stakeholder involvement and the considered approval from national government. For low-voltage transmission, the safety and stability of power system operation and the reliability of power supply are the main decision criteria. Since the construction is usually not controversial, the construction mainly depends on local requirements for power supply reliability and the investment situation of grid companies.

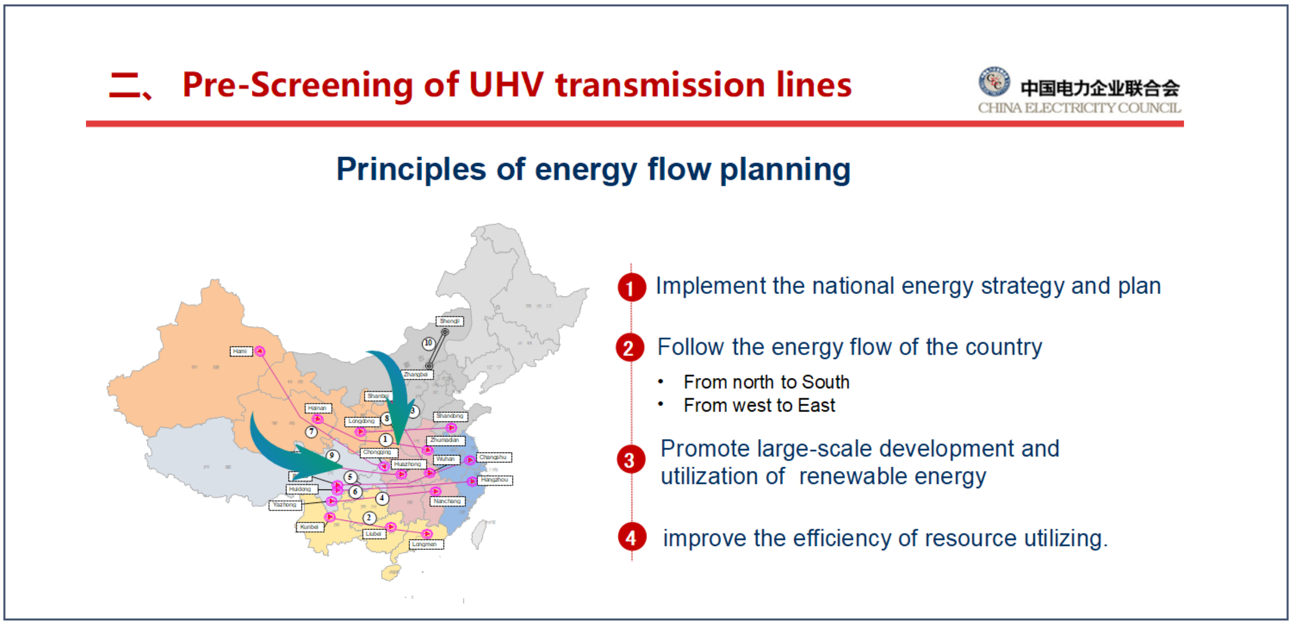
Figure 5: SGERI - Chinese transmission planning approach.

Market development and brief screening analysis of the candidate transmission lines

Ye Jing, senior engineer of the statistical centre for the electricity industry, CEC, gave a presentation on the progress of China’s power market reform and the pre-screening of ultra-high-voltage (UHV) transmission lines. In July 2020, the basic rules for medium and long-term power trading were revised by NDRC and NEA, including more trading products covering years, seasons, months and weeks with distinguishing peak and off-peak. The plan is for intermittent renewables to join the market in a step-by-step process. In order to guarantee renewable energy consumption, mandated quotas are issued annually.

Apart from medium- and long-term trading, eight spot market pilots launched in October 2019. Traded electricity makes up 85.6% of total intra-provincial transactions and 14.4% of inter-provincial electricity transactions. Between 2017 and 2021, the wind curtailment rate decreased significantly from 17% to 4 %, showing improved renewable energy utilisation. Mr Lei further explained the pre-screening of UHV transmission lines, illustrated in Figure 6.

Figure 6: CEC - Pre-Screening of UHV transmission lines.



There are five indicators for this process: i) market space, ii) optimal resource distribution, iii) policy direction, iv) security and stability of the power grid and v) the cost evaluation. The cost evaluation is performed using levelised costs of energy (LCOE) on the basis of economic evaluation over the lifespan of the project and national construction parameters. An example of the cost calculation can be seen in Figure 7. Here, two scenarios are compared, one with 4 000 hrs/yr and another with 4 500 hrs/yr utilisation of the transmission line.

Figure 7: CEC - Cost calculation of transmission lines.

二、 Pre-Screening of UHV transmission lines

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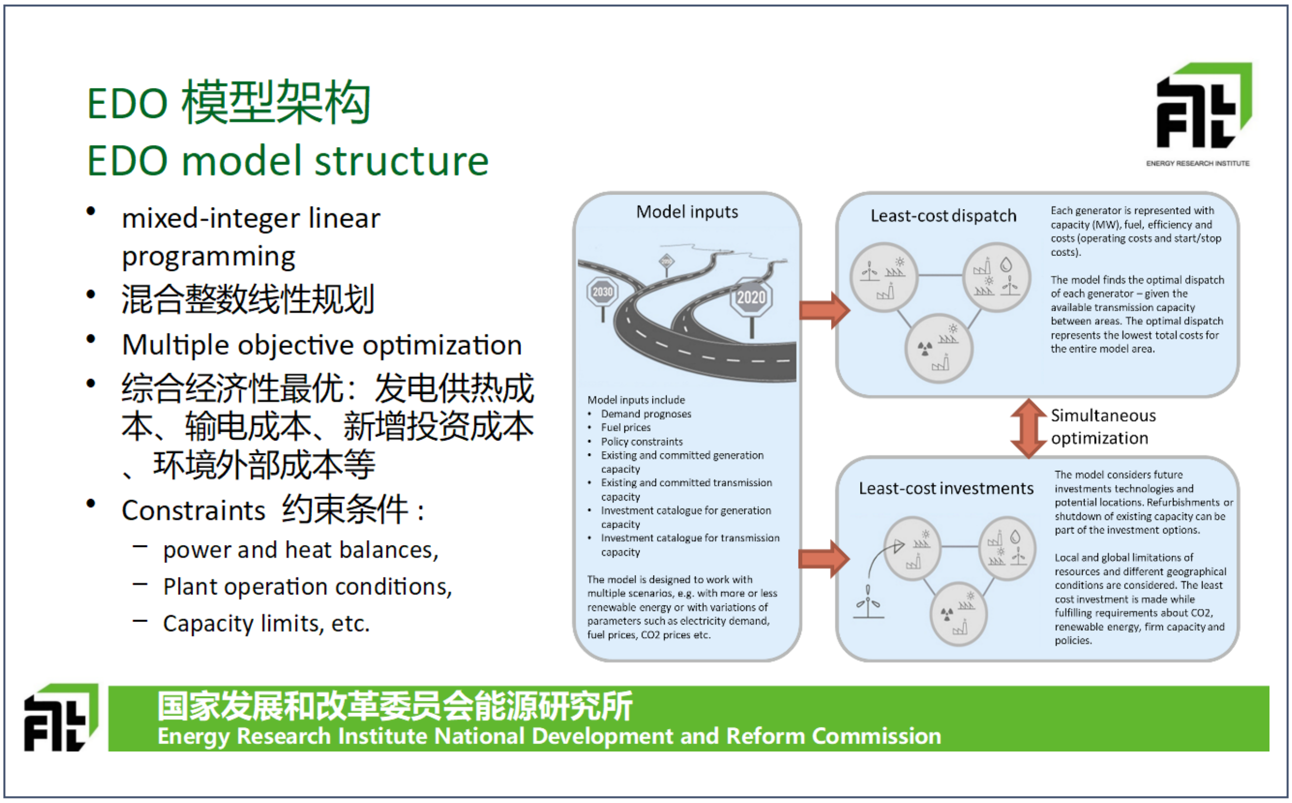
4. Cost calculation of transmission line

Comparing the Electricity price with the Receiving Province

	Sending terminal		receiving terminal		scenarios 1	scenarios 2
	province	benchmark price of the Coal power (¥ cent/kWh)	province	benchmark price of the Coal power (¥ cent/kWh)	Price advantage	Price advantage
1	Qinghai	22.77	Henan	37.79	7.51	8.18
2	Shanbei	35.45	Hubei	41.61	0.09	0.63
3	Yazhong	33.21	Jiangxi	41.43	0.00	0.75
4	Baihetan	28.74	Jiangsu	39.10	0.00	0.95
5	Baihetan	32.89	Zhejiang	41.53	0.00	0.79
6	Hami	25.00	Chongqing	39.64	6.14	6.92
7	Longdong	29.78	Shandong	39.49	3.11	3.71
8	Jinshang	34.31	Huazhong	42.68	0.00	0.77

Progress on transmission expansion screening
Dr Han Xue, assistant professor, ERI, reported on the progress of transmission expansion screening, which is based on the Estimated Dynamic Optimisation (EDO) model, as depicted in Figure 8.

Figure 8: ERI - EDO model structure.



The basic EDO model is extended to extract shadow prices i.e. the price spread along transmission connections. The value of lost load is added and the value of extending capacity is calculated. Further evaluation is based on two scenarios, the Stated Policies Scenario and the Below 2°C Scenario. The reference grid contains all provinces, each treated as a node in the network. Seven regional grids are built on top of the provincial grids.

Over a 10-year timespan (2020-2030), three case studies are conducted, including i) normal annual investment calculation, ii) remove grid investment annual calculation and iii) frozen grid annual investment calculation. The screening process consists of 14 steps and takes into account four main screening criteria: price/cost value, electricity price distribution, energy flow and long distance vs. short distance transmission connection. An example of an evaluation of total system costs over the timeframe is given in Figure 10.

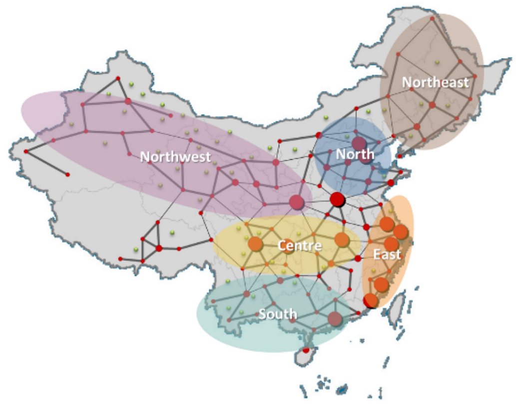
The screening results lead to a number of observations:

- Jiangxi experiences loss of load and there is a significant price difference between Jiangxi and all surrounding provinces.
- Hunan experiences very high prices due to power scarcity. All power sources need to be activated to meet consumption requirements.

Figure 9: ERI - Reference grid.

Reference grid

		Centre	East	North	Northeast	Northwest	South
2020	Centre	79					
	East	27	158				
	North	9	18	195			
	Northeast	-	10	46	48		
	Northwest	26	18	37	-	123	
	South	13	1	-	-	-	118



New lines added:
Qinghai – Henan, under operation since 2021
Shanxi – Hubei, under operation since 2022

76 possible connections out of 496 connections

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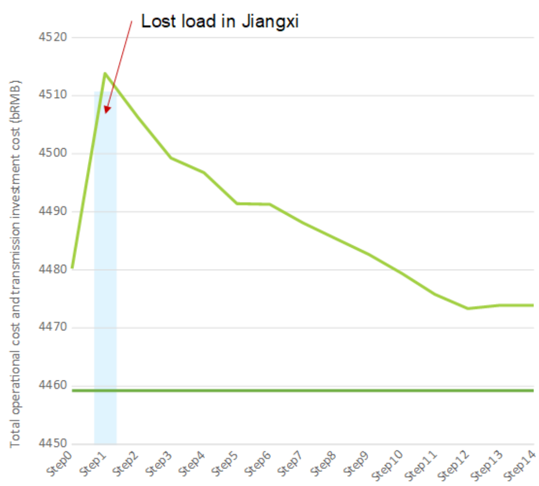
Energy Research Institute National Development and Reform Commission

Figure 10: ERI - Screening results (total system cost).

Screening results (Total system cost)



- The investment in grid keeps increasing , while the system operation cost keeps decreasing.
- The system cost is reduced by 1% from the first step
- But it is not very close to the optimal s olution, where there are two distinguis hed grid structures
- RGIAC simulations in SP reaches optim al faster than in B2, due to less power c apacity and consumption.

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- The price in Tibet is very low, because power generation is much higher than demand. Electricity cannot be exported from the region because of poor connections with the national grid..
- Inner Mongolia and Hainan also experience low prices compared to other provinces.

Given the above observations, four transmission expansions were proposed:

Hubei-Jiangxi, Shanxi and West-Inner Mongolia, Qinghai-Tibet, Guangdong-Hainan.

With the implementation of these expansions, it could be shown: i) the loss of load in Jiangxi has been resolved; ii) the price in Hunan remains high; iii) grid expansion between Tibet and Qinghai remains inadequate.

Finally, Professor Han raised three questions for further discussion:

- 1.How should the interactions of the different grid expansion pathways be evaluated?
- 2.How to approach point to grid or point to point conditions?
- 3.How to balance multiple scenarios?

Professor Han concluded with suggestions for the next steps in the project: an analysis of hourly results, the selection of transmission lines for CBA and drafting of the final report.

After the presentations, the members of the steering committee made further comments.

Comments by the Steering Group (Round 2)
[Since the meeting was a bit delayed, Kristian Ruby and Christian Romig had to leave early due to a prior commitment.]

Lei Xiaomeng, senior advisor and personal envoy of Mr Yang Kun, Executive President, CEC, stated that CNREC/ERI team had provided an excellent analysis with reference to ENTSO-E methodology and gave cases of interconnections between provincial systems based on an economic analysis. He suggested that the changes of the national grid configuration would be treated carefully when considering interconnections between the asynchronised regional systems.

[Due to network issues, his comment was not transmitted in its entirety.]

Kaare Sandholt, chief expert, CNREC, thanked the three speakers for their excellent presentations. He noted in particular that the work on the screening process was presented in a simple way that made it easy to understand the dynamics. In order to answer the three questions raised by Prof Han, he suggested a discussion on what kind of value the screening process adds and further discussion about the uncertainty of different parameters, including the development of different load levels in the provinces. One solution for the common issues would be to find a robust transmission expansion or to have a weighting for the different scenarios. Mr Sandholt concluded by stating that it would be very valuable in the report to have a discussion on the different screening methods and the value of these compared to the current planning approach.

Dr Gianluca Fulli, deputy head of the Energy Security, Distribution and Markets Unit, Joint Research Centre of the European Commission, pointed out that the two questions on how to evaluate the different expansion pathways and how to balance the different scenarios, will require further thought. For the purpose of CBA, it is important to understand how sustainability and reliability are analysed. Dr Fulli concluded by stating that he would be pleased to take part in further discussions.

Bente Hagem, executive vice president of Statnett, thanked the participants for their interesting insights. Speaking from her own experience in the European market, she pointed out that it is important to take market design into account during the screening process, and in particular the question of whether implicit market coupling or an explicit market design (with auctions before the price) are used as a prerequisite. If an implicit market design is used, which is assumed in the inception report looking at China's future coupled market, between 10% and 15% of infrastructure costs could be saved through more efficient use of infrastructure.

Closing remarks
The two hosts, Peter Børre Eriksen, team leader of the ENTSO-E China Showcasing Project Steering Meeting, and Dr Flora Kan, team leader of ECECP, thanked everyone for their constructive participation and apologised for delays and to NEA for the connection problems.

Registered Participants List

#	Name	Organisation	Job Title
SG members			
~~1~~	~~Mr Tomasz Jerzyniak~~ (apologies)	~~DG ENER, European Commission~~	~~International Relations Officer~~
2	Mr Octavian Stamate	EU Delegation in China	Counsellor, Energy and Climate Action
3	Mr Kristian Ruby	Eurelectric	Secretary General
4	Mr Lei Xiaomeng	CEC	Senior Advisor
5	Mr Kaare Sandholt	CNREC	Chief Expert
6	Mr Christian Romig	AFRY consulting	Head of Consulting in China
7	Dr Gianlucca Fulli	EC-JRC (Joint Research Centre)	Deputy Head of the Energy Security, Distribution and Markets Unit
8	Ms Bente Hagem	Statnett	Executive Vice President

9	Mr Peter Børre Erik-sen	Ea Energy Analyses	Task Leader / Consultant
Invited participants & speakers			
10	Mr Dong Bo	CEC	
11	Dr Zhang Ning	SGERI	Researcher
12	Dr Han Xue	ERI	Assistant Professor
13	Mr Lars Bornak	Ea Energy Analyses	Senior Consultant
14	Mr Lars Bregnbaek	CNREC / Ea Energy Analy-ses	Chief Modelling Expert / Partner
15	Prof Shi Jingli	CNREC	Head of Policy Research Department
16	Ms Ye Jing		
17	Liu Chao	NEA	International Department
18	Li Yi		
19	Lv Jing	NEA	General Division of the Electric Power Department
20	Du Cui	NEA	Power Grid Division of the Electric Pow-er Department
21	Mr Hui Jingxuan	ERI	
ECECP Team			
22	Dr Flora Kan	ECECP	Team Leader
23	Ms Liang Chen	ECECP	Support to Team Leader
24	Ms Helena Uhde	ECECP	Junior Postgraduate Fellow
25	Ms Veronika Spurna	ECECP	Junior Postgraduate Fellow

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