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国家可再生能源中心
CHINA NATIONAL RENEWABLE ENERGY CENTRE

CIFF CHILDREN'S INVESTMENT FUND FOUNDATION

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Foreword

Since the beginning of the new century renewable energy has developed rapidly in China. First the focus was on wind energy but within the last five years solar PV has also been deployed at a rapid pace. Today renewable energy together with nuclear power amounts to 12% of China's energy consumption and the target for 2020 is to reach 15% non-fossil energy consumption.

Although the development path has not always been smooth, the Chinese government, the RE developers and the RE manufacturers have been able to gradually overcome development obstacles, introduce adequate support mechanisms and establish sufficient production capacity to drive the introduction of massive new RE capacity. Furthermore, the Chinese grid companies have in recent years been able to establish grid connections for increased RE power capacity, even though the doubling of wind power in some years caused connection delays in several areas.

While China succeeded in reaching ambitious targets for deployment of RE capacity, ensuring integration of the variable energy production from wind and solar power has been a challenge. The strong support to build new capacity has not yet been followed by institutional reforms and changes in mind-sets that allow for all the energy generated to be utilised. Renewable energy has been – and for the most part still is – considered as an add-on to the power system, while coal power plants are considered to constitute the backbone of the power supply. As a consequence, a large amount of electricity from wind and solar power plants is wasted and the air pollution and CO_2 emissions in China are still severe. From both economic and environmental viewpoints this is costly for China, and if left unresolved, it will also hinder the development of an economically and ecologically sustainable energy system in the future.

China National Renewable Energy Centre (CNREC), the Chinese think tank for policy strategy research on renewable energy, has commenced the preparation of a comprehensive outlook for renewable energy to be published annually. The purpose is to give Chinese decision makers a scientific and analysis-based foundation for policy decisions to ensure efficient development and integration of renewable energy as a decisive part of the future Chinese energy system. The foundation for the annual outlook is detailed bottom-up analysis of the full Chinese energy system, analysing cost-effective solutions for deployment and integration of a large share of renewable energy and providing analyses of the impact of energy system transformation on energy security, the economy, and pollution and emissions from the energy sector. This year's China Renewable Energy Outlook presents two main scenarios for the development of the Chinese energy system towards 2030, which are further used to analyse the different policy measures needed to promote the energy transition and efficient renewable energy integration.

The China Renewable Energy Outlook is part of a larger program, "Boosting renewable energy as part of the Chinese energy transition," which is supported by the UK-based charity Children's Investment Fund Foundation, the Danish government and the German government. Through this program CNREC receives strong support from National Renewable Energy Laboratory in the United States of America, from the Danish Energy Agency and Energinet.dk in Denmark as well as from GIZ, Agora Energiewende and DENA in Germany. Furthermore, CNREC has been able to use its strong partnership with IEA and IRENA to ensure qualified support and feed-back on the analyses in the Outlook. The final responsibility for the analyses and recommendations in the Outlook report is solely the responsibility of CNREC.

It is my hope that China Renewable Energy Outlook 2016 will be used as a point of departure for the necessary discussions and deliberations regarding the future direction for the Chinese energy system, and used as a reference for further analyses regarding energy policy strategies for a long-term sustainable "Beautiful China."

WANG Zhongying
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Executive Summary

Background

The Chinese energy system has been developed to meet the growing need for energy in a rapidly expanding economy. In terms of meeting energy needs this has been a tremendous success. However, the development has led to the evolution of an energy system with significant problems that need to be resolved to enable the future growth of the Chinese economy in a sustainable way. The major problems are:

- Massive environmental problems affecting local air quality as well as the global climate
- Negative impact on the water situation and the degradation of land and soil
- Long-term structural problems with energy security, and dependency on imported fossil fuels
- Structural problems in the power sector, leading to economic inefficiency and potential losses for Chinese society.

Since the launch of a special law for renewable energy (RE) in 2006, China has had strong ambitions for development and deployment of RE technologies, and has successfully tripled the generation of power from renewable energy in the power system. Renewable energy is one of the key emerging industries with ambitions to be among the leading industries in China and globally.

However, the institutional and regulatory framework for the energy sector has not yet managed to ensure a genuine integration of variable power production from wind and solar power, and today large amounts of green power is wasted with costs both for individual producers and for the wider Chinese economy.

Furthermore, even though the cost of power from wind and solar generation has decreased over the last five years, wind and solar power are still not directly competitive with coal power production in the absence of accounting for the real cost of coal combusting that include environmental damages and other costs to society.

These problems are mainly caused by a system and framework that favour traditional coal power plants and privileges fossil fuels among local decision makers. Moreover, the lack of a transparent and dynamic power market, where the market prices reflect the relationship between demand and supply on an hourly or sub-hourly basis, seriously hamper the development of a modern, flexible power system able to adapt to variations in energy demand and in generation from wind and solar.

At the same time, the Chinese government has demonstrated a clear ambition for promoting a green and sustainable energy system to the benefit of the environment as well as the Chinese economy. Official policies like the "Policy of Promoting Eco-Civilisation Construction", the "Policy of Promoting Energy production and Consumption Revolution", the ambitious Chinese strategy to address climate changes, and the "Policy of Comprehensively Deepening Economic and Energy Power Reform" are all clear guidelines for development of an energy system which is green, affordable and secure, using market mechanisms as decisive drivers for its implementation.

Building off this strong policy portfolio, the China Renewable Energy Outlook evaluates scenarios and provides critical insights to accelerate the transition to a green environmentally sound and economically efficient energy economy for China.

China Renewable Energy Outlook is divided into three parts. Part 1 gives a brief overview of the development of the energy system to the present time and identifies some of the main challenges and opportunities for future development.

Part 2 analyses two development scenarios for the Chinese energy system. Through detailed modelling and analyses of the power system and the end-use sectors, the impact of the current stated policy strategy on energy system development is illustrated, as well as its impact on the environment, the economy and the security of energy supply. Furthermore, a scenario with higher ambitions for the penetration of renewable energy is analysed, based on a long-term vision for 2050.

Part 3 examines the different policy measures and framework conditions for promoting renewable energy, including flexibility of the power system, development of a power market, flexible interconnectors, cost and pricing issues, the subsidy system, and promotion of distributed generation and RE heating.

A note on calculations: In the report all figures regarding the future energy consumption, and shares of non-fossil fuel and renewable energy are calculated based on the energy content. For some historical figures, the calculation is based on the coal substitution method.[1]

[1]When using the coal substitution method, the electricity produced from renewable energy sources and nuclear power plants is converted to coal used in a power plant to produce the same amount of electricity. In this report energy figures will be based on energy content and not the coal substitution method unless otherwise stated.

Guidelines For The Scenarios

The scenarios in the China Renewable Energy Outlook are consistent pathways of how the future might unfold. Anchored in the present reality, they are not predictions or forecasts, but instead are plausible accounts of how various conditions can combine to bring about challenges and opportunities.

The objective for the scenarios is to analyse if and how a high share of renewable energy in the Chinese energy system could ensure established economic and environmental targets without jeopardizing energy security, and to analyse how the large share of renewable energy not only can be efficiently integrated into the whole energy system but gradually become the energy system backbone in place of coal.

- The Stated Policy scenario is defined by recent policy decisions and in the 13th Five-Year Plan for development towards 2020. In this scenario, the current policies are extended beyond 2020 in acknowledgment of both expected development trends and current policy ambitions regarding institutional power sector reforms. The objective is to investigate how a successful implementation of the current polices can drive energy system development and to what extent the current policy strategies are sufficient to reach the medium-term goals (ca. 2030) set for the Chinese energy system.
- The High RE Penetration scenario is driven by long-term goals (ca. 2050) for the energy system, anticipating that renewable energy should play a decisive role in fulfilling the long-term targets. This scenario constitutes a possible pathway for China's energy transition in a future where additional global warming is contained to within 2 degrees.

The CREO 2016 scenarios have common assumptions regarding economic and demographic development in China. It is assumed that in 2050 China's primary energy supply and end-use energy consumption structure will support a GDP at a level of 2,820,00 billion yuan. The Chinese population is assumed to grow to 1.51 billion people in 2030 and then approach 1.38 billion people in 2050. The urbanisation rate (the share of people living in cities) is assumed to develop from 55% in 2015 to 68% in 2030.

Reduction of the emission of CO_2 from the energy sector is an important driver for energy transition. For the scenarios in CREO 2016 we use CO_2 emission as a measurement of the quality of the scenario more than as an active optimisation constraint. For the Stated Policy scenario, the target for CO_2 emission is to ensure a peak before 2030. The High RE Penetration scenario is projected to peak earlier than 2025 or even before 2020.

Similar to CO_2, the emission of pollutants from the energy sector such as SO_2, NO_x, Hg and other energy-related emissions should be significantly reduced in the scenarios. We do not set specific goals for 2030, but by 2050, China should have lowered the emissions levels to 1980s values. The emission of PM2.5 should meet the World Health Organization standards.

When looking at the environmental impact from the energy sector it makes sense to evaluate the scenarios based on the amount of non-fossil fuels in the system since CO_2 cleaning technologies (such as CCS for fossil fuels) have not yet proven technologically mature or economically feasible. For the long-term development, we find it relevant to have a non-fossil fuel target of 60% or more of the total primary energy demand by 2050. For 2030, the target is 20% or more for the Stated Policy scenario and 33% for the High RE Penetration scenario.

China has the ambition to develop its economy and industry to a level comparable with the moderately developed countries by 2050. If China follows the energy development path of OECD countries regarding energy efficiency and technological progress, the final energy consumption would reach around 4800 - 5300 Mtce in 2050, the transport sector will continue to be a large consumer of oil, and the CO_2 emission targets could not be reached. To achieve the emission reduction targets, the clearest path is to increase the use of electricity in the end-use sectors to substitute for coal and oil consumption. Combined with a strategy for development of RE in the power sector, electrification can improve efficiency and ensure better use of wind and solar energy, thereby reducing the primary energy consumption. With a target of 60% electricity in the final energy demand in 2050, the total final energy demand would be around 3200 Mtce.

According to the decisions by the previous as well as current government of China, construction of nuclear power plants in the inland and in large-scale construction in the Yangtze River Basin will not happen. The development of the western regions has priority for a “green mountains and clear water are as good as mountains of gold and silver（绿水青山就是金山银山）” strategy, which implies that the development should primarily be based on renewable energy. Before the fourth generation of nuclear power technology is in commercial operation, it is assumed that China will not open the inland deployment of nuclear power. Based on this, we consider nuclear power development to be within the range of 100 GW in 2050, solely deployed in coastal areas.

The development of wind power and solar power combined with power market implementation will necessitate additional flexibility in the power system. We expect that around 70% of coal power plants in 2030 will be ready for flexible operation and by 2050 all thermal power plants are projected to achieve flexible operation. Demand-side response technology is expected to be widely used by 2030. Electric vehicles are used as miniature energy storage stations and have sufficient capacity for power system peaking in cities. By 2050, China's electric vehicle stock is expected to be at least 400 million, equivalent to 80% of all vehicles.

We assume the transmission grid and the regional interconnectors to be an integrated part of the power market, and that the regional coordination between east, west, north and south inter-regional power grids will be strengthened with further grid developments. The barriers for institutional and economic cooperation between provinces and regions are expected to be removed, and the sharing of benefits would prevail over provincial sub-optimisation. During the period of the 13th Five-Year Plan (from the present to 2016-2020), we assume a coordinated development of the power grid on regional and provincial levels to be able to integrate on the order of 300-350 GW of wind power and 200-220 GW of solar power. By 2030, the China grid would basically be built and managed to effectively integrate all produced renewable power generation as an energy-friendly internet-like smart grid.

The power system is the core of the future energy system, and a well-functioning electricity market is fundamental to modern power system development. The purpose of China's power system reform is to "let the market play a decisive role in the allocation of resources." China's electric power system reform needs to establish a complete and systematic framework for power system operation by 2020. By 2025, the task of power system reform will be completed in a comprehensive way, and China will establish a strongly competitive electricity market.

Main Findings And Conclusions

Two Pathways For The Chinese Energy System

Two different pathways for the development of the Chinese energy system to 2030 have been analysed. The Stated Policy scenario describes a pathway based on current stated economic and energy policies, and the High Renewable Energy (RE) Penetration scenario shows a pathway with higher ambitions for renewable energy development, based on long-term visions for 2050.

The Stated Policy scenario fulfils minimum requirements but limits the pace of energy system transition

The current ambitions for RE development correspond to minimum requirements for fulfilling the energy and environmental goals set for China to achieve by 2030.

High RE Penetration scenario – a faster, cleaner and feasible pathway

In this scenario, coal is still the dominant fuel and the transition toward a sustainable energy system is rather slow. Prolonging a high share of coal in the power sector may postpone the reorientation of the end-use consumption from fossil fuels to electricity and reduce the benefits of transport sector electrification. It further risks keeping Chinese industry and economy on a "fossil-fuel" track rather than genuinely promoting the development of high-tech RE manufacturing industry and related job creation. Finally, while the scenario complies with China's Nationally Determined Contribution (NDC) to greenhouse gas emissions reduction, it does not comply with a global 2-degree climate strategy with China playing a leadership role.

The High RE Penetration scenario is a faster pathway to a sustainable energy system benefiting all of Chinese society. Although the High RE Penetration scenario mainly differs from the Stated Policy scenario with the amount of new wind and solar PV capacity and with the degree of electrification in the end-use sector, the higher RE ambitions support a significantly different development path in the medium and long term. This pathway is both economically feasible and it sends a clearer signal to the Chinese people and industry that future economic development will be driven by clean energy technologies and the sustainable use of resources. Therefore, it promotes a healthier industrial structure for long-term economic development in China. The scenario ensures that the CO_2 emission from the Chinese energy system is reduced more and faster than in the Stated Policy scenario, with a peak in emission already before 2020.

Hence, the team behind CREO 2016 recommends that China follow a High Renewable Energy Pathway and set up regulatory and incentive frameworks supporting this fast track, including a firm implementation of the power market reform.

Re In The Power System: From Add-On To Backbone

Power Sector Reform Necessary

Currently, the policy framework and economic incentives are mainly designed to encourage a rapid deployment of new thermal power capacity, which no longer is a feasible solution as China adapts to the "new normal" in an economy with lower growth rates, decoupling between GDP and energy growth, and a focus on eliminating the severe air pollution from burning coal and oil. In past decades, RE has been primarily seen as an add-on to the thermal power system and this cannot continue if the benefits of RE are to be realised. From 2030, our analysis indicates that RE can effectively and efficiently become the backbone of the power system. Genuine RE integration also must be ensured in the near term.

Hence, rather than minor adjustments of the current system, the central conflict between the old and new systems should be addressed and solved through a comprehensive redesign of the whole power sector framework, with modernized market and incentive structures for all stakeholders.

Overcapacity As A Threat And An Opportunity

The current continued expansion of coal power, together with lower power consumption growth as a product of evolution in the economy and the more efficient use of energy, leads to a situation where the Chinese power system has more capacity than is needed in the short term. The increasing development of overcapacity is a clear threat to the energy transition, with a risk of investment lock-in that will end up as stranded investments. However, the overcapacity situation also offers an opportunity to reform the power market while appropriately using the available capacity to assure a smooth, reliable transition of the Chinese power system.

The excess power capacity will, however, in combination with the market reform, lead to higher overall costs, but lower spot market prices and increased risk for investors. For RE technologies with high investment costs and low operating costs, such a situation requires special attention to ensure the economic feasibility of investments and a stable framework for future RE deployments within the power sector reform.

Integration Of Re

Large Shares Of Re Can Be Integrated And Curtailment Avoided

The power system analyses in CREO 2016 demonstrate that efficient integration of RE into the power system can be achieved without technical problems and with economic benefits, provided the right regulatory and economic frameworks are in place. A Chinese wholesale market for electricity would be the main driver for integration and cost efficiency.

The current high curtailment shares for RE are a waste of money for society and add significantly to the pollution from the power sector, because burning coal is being prioritised over use of available RE power which is already bought and paid for. The analyses show that high curtailment shares can be avoided, even with large amounts of RE power production.

New Providers Of Flexibility

When RE takes the role of backbone of the power system, the coal power plants must find new ways to operate. In an efficient power market, flexible coal and flexible combined heat and power (CHP) are the new providers of flexibility, together with a dynamic and flexible use of interconnectors between provinces and regions.

At the same time, ambitious deployment of electric vehicles (EV) in China can give new opportunities for power system flexibility through smart-charging: the number of electric cars is potentially huge and constitutes a decentralised resource in the system. Also, a broad range of demand response possibilities, if appropriately enabled, can help increase the necessary flexibility of the power system.

The analyses show that pumped-hydro storage can play a role in balancing supply and demand, but other electricity storage technologies will not yet be competitive in the 2030 timeframe. The EV expansion also creates a sizable new resource in the repurposing of retired EV batteries, which together with demand response can provide power system flexibility of last resort.

Power Markets For Cost Efficiency And Re Integration

A well-designed and efficient power market is one of the strongest enablers for cost-effective integration of variable energy production from renewable energy sources, according to international experience. Through transparent price setting and dynamically reflecting the value of power in accordance with supply and demand, the power market creates strong economic incentives for flexibility of thermal power plants, for dynamic use of grid interconnectors, and for purchase of RE power with low marginal costs. In both scenarios, a well-functioning power market is implemented gradually from the current non-market set-up to a full power market operating in 2025.

The analyses show that a large Chinese power market (or several linked markets) will facilitate the flow of power between provinces and regions, smooth RE power production variability through wide-area aggregation, leverage flexible dispatch of thermal power plants, and significantly lower curtailment of wind and solar generation.

A firm and well-planned implementation of the power market reform is recommended. Clear signals to the market players about the end-goal and pace of implementation are important in order to avoid stranded investments and in order to prepare market players for a more competitive environment. A step-wise plan with gradual market opening, leading to a full competitive market for all of China before 2030, could be the blue-print for implementation.

Coal Reduction

Coal Reduced But Still Dominant In The Power Sector

The scenarios show that coal can be rapidly phased out in both scenarios in the end-use sectors, substituted by measures such as energy efficiency and the use of electricity and natural gas.

However, coal will still have a dominant role in the power sector through 2030 in the Stated Policy scenario. A more ambitious deployment of RE will accelerate the reduced use of coal and further enable the long-term energy transition.

Flexible use of coal power will be the new opportunity for coal power plants to stay in the power market– and at the same time reduce net coal consumption.

External Costs Should Be Reflected In The Price Of Coal

Coal mining and combustion have serious environmental impacts which currently are not reflected in the price of coal. Carbon pricing and coal taxation should be implemented to ensure a level playing field between coal and renewable energy, and coal subsidies should be reduced and eventually removed.

Exchange Of Power On Interconnectors

The power system analyses demonstrate that flexible exchange of electricity on regional interconnectors (including long distance lines) is pivotal for the whole energy system to achieve minimised cost and effective RE integration. However, the current power pricing policy and administrative rules are major barriers to the flexible use of interconnectors, leading to higher costs for the whole society. Hence interconnectors must become part of the power market reform - they should be made available on the markets and operated according to market principles.

On the technical side, flexible use of interconnectors must be taken into consideration in the design of new interconnectors, and technical barriers for flexible use of existing interconnectors should be removed.

Improved Support Mechanisms For Deployment Of Re

The current support system for renewable energy has successfully fulfilled the overall targets for deployment. However, with the changing policy framework for the energy sector, including the implementation of the power sector reform and with pressure for cost-efficient deployment of the different RE technologies, there is a need for implementing new ways to support the future deployment. In the CREO report several policy measures are analysed.

Targets And Quota Systems

On the technical side, flexible use of interconnectors must be taken into consideration in the design of new interconnectors, and technical barriers for flexible use of existing interconnectors should be removed.

An energy target guiding system for the development and use of renewable energy on a provincial level would give the power grid companies, the power trading companies and the power generators incentives for promoting RE technologies as a share of the total energy consumption in the provinces. The quota system could be combined with a trading mechanism, e.g., green certificates, to ensure optimal implementation.

Several problems regarding relationships to other pricing mechanisms and other issues should be resolved in order to ensure efficient implementation of a certificate trading system. Additional research on this topic is recommended, including transfer of the most recent experiences from other countries regarding efficient support systems.

The implementation of an obligation for the power grid companies to purchase the full production from RE power plants (guaranteed purchase) is also analysed. Such an obligation would reduce the amount of curtailed power generation from wind and solar PV plants. Its practical implementation should be based on local conditions regarding resource availability and supported by coordination with thermal generators. It is recommended that a guaranteed purchase mechanism be implemented as part of a more comprehensive pricing and power market reform since the guaranteed purchase mechanism alone cannot automatically solve the full curtailment problem.

New Pricing Mechanisms

As the power sector reform evolves, the overall pricing environment for RE and thermal generation should move toward a level playing field, including accounting for the environmental impacts of power generation. Within this overall market structure change, the pricing of renewable energy should follow the market development and transition to a market premium system instead of a fixed price system (FIT), while simultaneous reforms are implemented for fossil fuel generators. The various technologies have different support needs, and the subsidies for well-developed technologies should be lower or with a shorter timespan than those for immature technologies. The positive international experiences regarding tendering procedures for deployment of RE should be evaluated and translated to a Chinese context. A tendering system for well-developed technologies could potentially lower the need for national subsidy funds.

The future need for subsidy support should also be seen in the light of the possibilities of reducing the cost of energy from RE technologies through technology improvements and innovation. Both investment costs and operating costs can be reduced, and the efficiency and operating hours without outages can be increased. This report estimates that such improvements could significantly reduce the need for subsidies in the future.

Chapter 1

The Need For Energy Transition In China

The Development Of The Chinese Energy System

Energy As A Precondition For Growth

Access to energy is one of the most decisive preconditions for a country's economic growth.

The economic growth in China has led to a substantial increase in the living standards of the Chinese people. The gross national income is almost 30 times bigger in 2015 than in 1990 (1653 RMB per capita in 1990 to 49,351 RMB per capita in 2015 according to statistics from the World Bank) and more than 600 million people have been lifted out of poverty from 1990 to 2010 (see Figure 1).

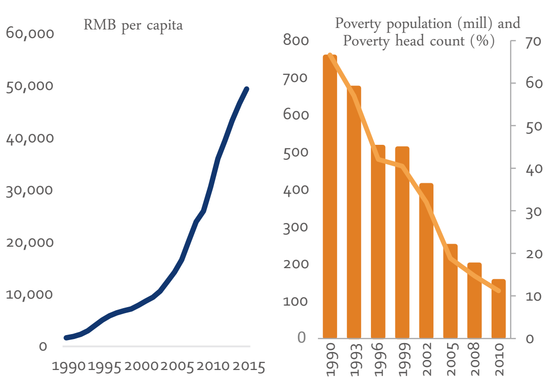


Figure 1: Gross National Product (GDP) per capita in China 1990-2015 (left) and poverty indicators (right). The yellow line is poverty head count, and the blue bar is the number of poor, both based on daily income less than $1.90. Source: Word Bank Open Data, August 2016

For China, the past 25 years' growth and improvement of the living standards has been accompanied by a similar level of energy consumption growth. During the period 1980-2015, the total primary energy consumption in China increased by 6.7 times, up to 4,300 million tons of standard coal equivalent (Mtce), (1 Mtce = 0.7 million ton oil equivalent (Mtoe)).

Primary Energy Consumption

Industry has been the main driver for energy consumption, and it has consistently had a share of about 70% of total final energy consumption. The building sector, including residential energy consumption, has been the second largest sector, and since 2005 the transport sector has developed to the third largest sector, mainly reliant on oil products.

The growth in primary energy consumption has stabilised over the past two years. During the first three years of the 12th five-year period, the consumption still grew around 5% per year, or an addition of 190 Mtce p.a.

After 2013 the consumption has been stable because of the shift in China's economy to a "new normal" situation with lower growth rates and structural changes.

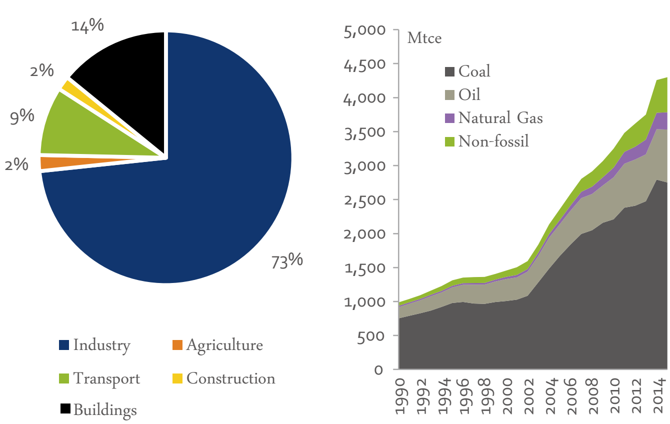


Figure 2: China's primary energy consumption by sectors (2013) (left), and China's primary energy consumption and the composition from 1990 to 2015 (right) Source: National Bureau of Statistics, China statistical yearbook 1980-2015

This indicates that China's energy development may have entered a new era that is significantly different from what it was in the past decade.

The Power Sector

The Chinese power sector has also developed rapidly during the last 25 years. Power production has been dominated by hydro power and coal power with massive investments in new capacity. Since 2005, China has had focus on developing wind power as a supplement, and since 2010 solar power has also been developed as part of the diversification of power generation. Both coal resources and renewable energy resources are mainly located in the northern part of China, while the power consumption mainly is concentrated in the south-eastern part of China. The large hydro power plants are mainly developed in south-western China. Hence, the power transmission system has been developed to be able to transfer large amounts of electricity across the country. Also, the Chinese railway transport is dominated by transport of coal from the coal mines in northern China to the coal power plants in southern China.

The Different Fuels

Coal has been dominant in China's energy mix historically and consumption has risen significantly over the past 20-years. Only recently, the consumption of coal has stagnated. Coal consumption in 2015 reached 3,970 million ton, which is 150 million ton less than 2014.

China's coal consumption still accounts for about half of global coal consumption. China is still the largest consumer of coal in the world and the share of coal in China's energy consumption structure is still over 30 percent higher than the global average. In addition, centralized consumption of coal, for example, using coal for power generation, still represents less than half of coal consumption in China; large amounts of coal are utilized in a decentralized manner. And this has become a major source of air pollution.

Oil consumption shows an overall upward trend. During the period 1980-2012, China's oil consumption took up a 19% share on average. By 2015, its oil consumption rose to 0.54 billion tons. Currently, China's oil consumption is about 12.9% of the world's total, making the country the second largest consumer of oil in the world. China became a net oil importer in the early 1990s. By 2007, the country's net oil imports exceeded 50% of its oil consumption and by 2015 oil imports increased further to over 60% of oil consumption.

Historically, China's natural gas consumption has been low, accounting for about 2%

of total energy consumption before 2000. With increased development efforts and rising imports over the past few years, natural gas consumption has increased rapidly. In 2008, natural gas consumption exceeded over 100 Mtce, accounting for 3.5% of primary energy consumption; in 2015, it reached approx. 190.6 billion m_3, or an equivalent of 254 Mtce, representing a 5.9% share in energy consumption.

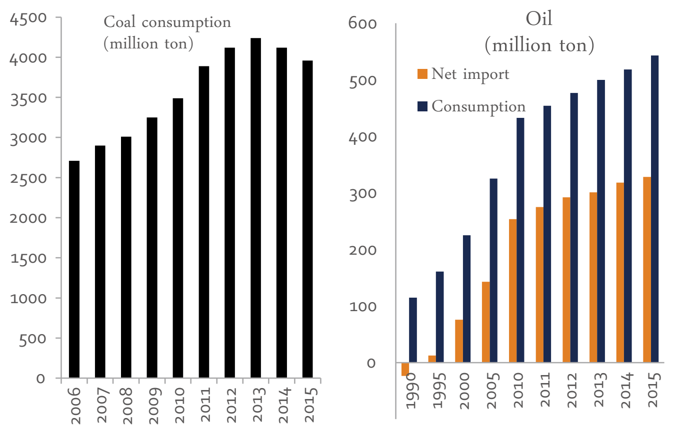


Figure 3: Development of coal and oil consumption (million ton). Source: China Energy Statistical Yearbook 2015

From a global perspective, however, China's natural gas consumption only constitute 5.7% of the world's consumption.

Despite the continuously rising share of natural gas, China is still facing quite a lot of structural and institutional obstacles, such as incomplete basic infrastructure, high transmission and transportation costs and relatively high natural gas prices, among others.

The promise of renewable energy has only recently begun to be realized, and this report explores the potential for China to take greater advantage of its rich renewable resources and build off the recent and forthcoming advances in these technologies. Since 2006, China has demonstrated remarkable progress in the exploitation and utilization of renewable energy, driven by the Renewable Energy Law launched in 2006. China has set up a policy system supporting the development of RE with feed-in-tariffs for PV, waste incineration and onshore and offshore wind power. And a subsidy for distributed PV power generation is also in effect. In accordance with the Renewable Energy Law, the RE development fund has been established to finance the RE subsidies. China has evolved a system of RE standards and has set up testing and certification capabilities for RE products.

By the end of 2015, the installed capacity of conventional hydropower reached 300 GW and annual power generation thereof exceeded 1,100 TWh. Installed capacity of grid-connected wind power has reached 129 GW with annual power generation 185 TWh, accounting for 3.3% of total power consumption throughout China, becoming the third largest power source nationwide. China has evolved into the largest market in the world in terms of newly-added photovoltaic (PV) capacity, exceeding a total of 43 GW by the end of 2015 and having an area of solar collectors for heating exceeding 400 million square meters. Annual utilization of biomass energy sources has risen to around 33 Mtce.

Current Challenges For The Chinese Energy Sector

From an energy supply point of view, the rapid development of the Chinese energy system was successful. Chinese industry experiences no scarcity in electricity supply today and the goals of securing electricity for all in China was reached in 2015.

Despite this, the energy sector faces serious and intertwined challenges regarding the key criteria for a well-functioning energy sector: environmental impact, energy security, and economic efficiency.

Resource Waste And Depletion

Extensive, inefficient energy exploitation and utilization has resulted in huge amounts of resources being wasted and depleted. China's overall coal resource recovery rate is only 30%, and coal gangue utilization rate only around 66%. Second, low efficiency in energy processing, conversion, storage and transportation has caused huge losses. Currently, China's comprehensive efficiency in energy processing, conversion, storage, transportation and final utilization is only 38%, nearly 10% lower than that of developed nations. Further, coal consumption in power generation, thermal efficiency of industrial boilers and furnaces, power consumption rate of power plants, and transmission loss rate are notably higher than the levels of developed nations. Thirdly, energy utilization level remains low. There is a huge gap between China and developed nations. China's energy consumption per unit of GDP is 1.8 times the global average, 2.3 times the US level, and 3.8 times the Japanese level. It is not only higher than developed nations, such as the US and Japan, but also newly industrialized nations like Brazil. Unit consumption of major energy-intensive products is still 15%-40% higher than the world's advanced level. China's building energy efficiency, on average, is about 1/2 of other countries with similar climate; and the country's oil consumption rates of trucks and inland water transport ships are 30% and 20%, respectively, higher than the world's advanced levels.

Environmental Problems

Intensive exploitation of energy resources over a long period has already caused many serious ecological environment disasters. Intensive exploitation of coal resources causes serious damage to mining areas and the surrounding ecological environment. Each year, China adds over 40,000 ha of new coal mined-out areas. To date, over one million ha. of the mined-out areas have been formed. In the north-western region, coal exploitation has caused nearly 245 km^2 of areas suffering from water loss and soil erosion. There are more than 1,500 gangue piles, which occupy nearly 20,000 ha of land, across China. Each year, more than 0.2 million tons of hazardous gases are emitted due to spontaneous combustion of coal gangue. In addition, development of oil and natural gas resources is one of the reasons for the formation of groundwater drawdown funnel in North China. Due to groundwater overdraft, the world's largest "groundwater drawdown funnel" has been formed in North China. One of the key reasons that cause this problem is exploitation of oil and natural gas resources, which consumes huge amounts of water resources, lowers the level of groundwater layer, and therefore contributes to an imbalance of water circulation.

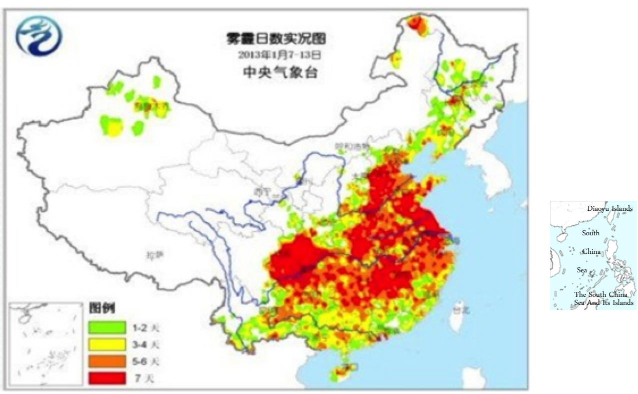
Air Pollution

Large-scale, extensive utilization of fossil energy brings about serious atmospheric pollution. According to the Global Environmental Performance Index, managed by Yale University, China has the worst air quality of 180 countries evaluated. Both PM2.5 exposures and NO_2 exposure in China are worse off in today than in 2006, and as considered through a weighted air quality index no country has a lower air quality than China.

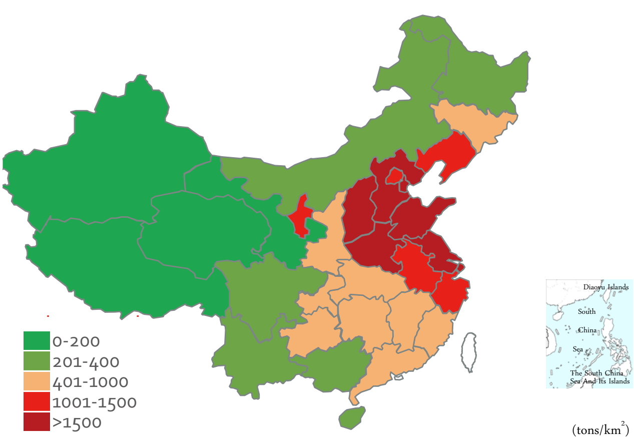
Fossil fuel consumption is a key source of atmospheric pollution. China has long been the world's largest emitter of SO_2, NO_x, smoke powder, mercury from anthropogenic sources and inhalable particles. Most of these originated from the burning of fossil fuels.

Excessively high-coal consumption density in the central and eastern part of China constitutes a major cause of heavy haze. Since 2013, severe haze hovering over large areas has appeared from time to time in most parts of China. Relevant studies suggest 50-60% of the PM2.5 concentrations might be attributed to coal consumption. Beijing-Tianjin-Hebei, Yangtze River Delta Region and Guangdong, whose coal consumption per unit of national territorial area reach up to 1,794, 2,267 and 981 tons/km^2, respectively, are among the areas most seriously affected by atmospheric pollution.

In addition, utilization of large amounts of low-grade, high-emission coarse coal further aggravates regional environmental degradation. In 2012, China's final direct coal consumption reached 870 million tons, most of which was used for large-scale industrial boilers and furnaces, as well as for residential living. Pollutant emission intensity is much higher in this area. According to statistics, SO_2 emissions attributed to direct coal utilization by end users account for over 40% of total emissions from coal combustion.



a) Haze situation in Jan. 2013



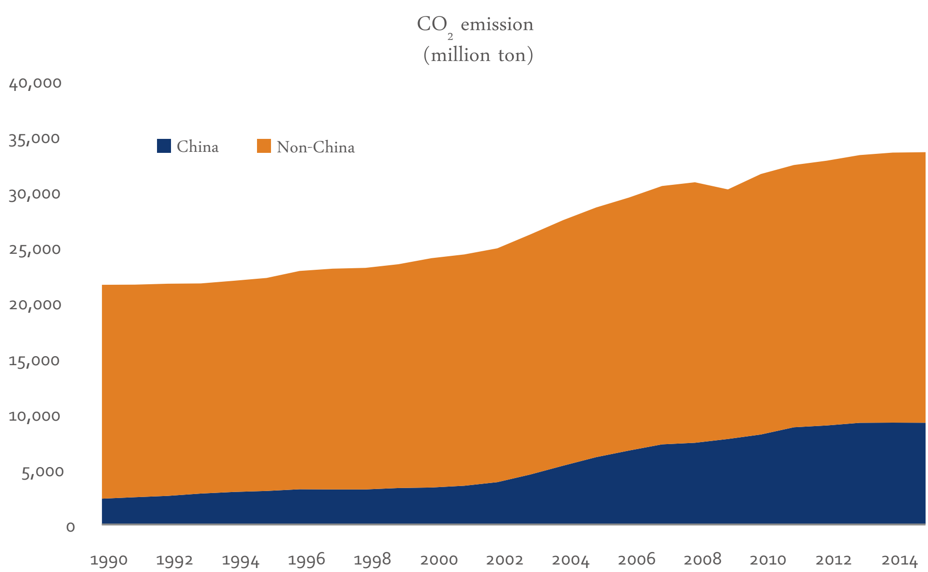
b) China's coal consumption density in 2012

Figure 4: China's haze situation shows a high correlation with coal consumption density.

CO_2 Emission

The coal-centred, high-carbon energy structure is the main source of GHG emissions. Combating climate change has become a key topic whenever human sustainable development is discussed. The Paris Agreement, which was reached by the international community in 2015, sets out specific arrangements for global actions to combat climate change after 2020 and sets the tone for a new global climate governance mechanism after 2020. It is estimated that over 80% of the emissions of China, now the world's largest CO_2 emitter, is caused by fossil fuel consumption. Over 2/3 of CO_2 emissions are attributed to coal combustion. In the 2014 APEC conference, Chinese and US leaders released a joint announcement on climate change. China is committed to achieving peak CO_2 emissions around 2030 and to making best efforts to peak early. China intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. These goals require that further efforts be made to speed up the substitution of fossil fuels (particularly coal) with clean energy.

Figure 5: Global CO_2 emission (million ton). Source: BP Statistical Review of World Energy 2016



Energy Security

As previously mentioned, the energy security for individual consumers in China is high and everyone has access to electricity. However, looking at the long-term security of energy supply, the current energy system faces challenges due to the extensive use of limited fossil fuel resources.

Traditionally, China has benefitted from its large coal resources, only recently becoming a net importer of coal. However, China's estimated domestic reserves will be exhausted before 2050 if consumption stays on the current level, according to the most recent BP statistics.

The rapid growth in China's oil demand has consequently increased China's oil import dependence. From being a net exporter of oil in the early 1990s, its net oil imports accounted for 60% of China's total oil consumption in 2015.

China's natural gas consumption has been relatively low historically, but fuelled by increasing imports, consumption has risen rapidly. In 2015, China's natural gas consumption was about 190.6 billion cubic meters, or 254 million tons of standard coal. Around 32% of this quantity, or 60 billion cubic meters, was imported.

All in all, among other aspects addressed in this report, a continuation of the current development path will lead to a clear dependency on the import of oil products and natural gas and at the same time exhaust the Chinese reserves of coal or at least increased dependency on imported coal in the medium and long term.

Economic Efficiency

The current institutional and regulatory framework for the Chinese energy sector reflect in many ways the need to fulfil the demand for energy from a rapidly expanding economy. This is particularly clear in the power sector, where establishment of new power plants and new power grids are supported by favourable economic conditions, with guaranteed obligations for the grid companies to purchase a certain amount of electricity from the thermal power plants.

The rationale for this situation is, however, rapidly changing. The Chinese economy has already moved to a "new normal" where economic growth is significantly lower than previously, and where the industrial structure is rapidly changing from heavy, energy-intensive industry to light industry and services with much less energy consumption per value added.

This shift in the Chinese economy has led to a lower growth in energy consumption and a stable consumption level for electricity, which again removes the urgent need to continue to rapidly build new power plants.

With much less need for new power capacity and with a continuation of the favourable conditions for power producers to establish new capacity, there is a clear risk for overinvestments in the power sector and even a "stranded cost" situation where the investments in power production cannot be recovered or where new power plants weaken the economics of existing power plants.

In general, the power sector also lacks the necessary regulations and rules for cost-efficient dispatch. Although a power sector reform was introduced in 2003, the reform process only implemented the unbundling of grid and generation (partly, since the grid companies still own some generation). Price reforms and a whole-sale market for electricity were not implemented. Therefore, no genuine competition between power generators instituted, and price setting is still determined by government. All-in-all, the current situation implies an immense risk for economic inefficiency both in investment in, and operation of, the power system.

A special case is the curtailment of renewable energy production (see more about this later) where power production from wind and solar power plants is wasted, mainly due to inflexibility of the thermal-dominated power system and contract structures. This leads to economic losses, not only for the owners of the RE power plants, but for Chinese society as well.

Urgent Challenges Must Be Addressed

To sum up, the Chinese energy system has been developed to meet the growing need for energy in a rapidly expanding economy and is poised to transform to adapt the changing economic, and natural environments, taking advantage of technological innovation and progress. In terms of meeting energy needs this has been a tremendous success. However, the development has led to the evolution of an energy system with significant problems that need to be resolved in order to enable the future growth of the Chinese economy in a sustainable way. The major problems are:

- Massive environmental problems affecting local air pollution as well as the global climate
- Negative impact on the water situation and the degradation of land and soil
- Long-term structural problems with energy security and dependency on imported fossil fuels
- Structural problems in the power sector, leading to economic in-efficiency and potential
- losses for the Chinese society.

Challenges For Renewable Energy In China

Development Of Re In China

Before 2005 the only relevant RE source in China was hydro power, which together with coal dominated the power generation mix. In 2005 the Renewable Energy Law was drafted (coming into force in 2006) as a clear signal of the Chinese government's dedication to develop and deploy other forms of renewable energy. Renewable energy is a key component of Chinese energy policy as and is also considered as an important part of the future Chinese industrial mix.

From 2005 to 2009 wind power was developed during a series of tenders for establishing large "wind bases". After 2009, the tendering procedure was replaced by a feed-in tariff for wind power (with different tariffs for different regions). This policy has successfully supported deployment of a large capacity of wind power, with a current deployment level of around 30 GW per year.

Since 2011, solar PV deployment was an additional priority and a feed-in tariff for solar PV was introduced. Since then, the capacity has soared and the current deployment level is around 15 GW per year.Since 2011, solar PV deployment was an additional priority and a feed-in tariff for solar PV was introduced. Since then, the capacity has soared and the current deployment level is around 15 GW per year.

Biomass is used for combined heat and power production (9.91 GW installed capacity in 2015), for biogas production and for heating purposes. The development has been slightly increasing for several years.

Outside of the power sector, individual solar water heating has been a major success with a deployment of around 414 million m^2 in 2014.

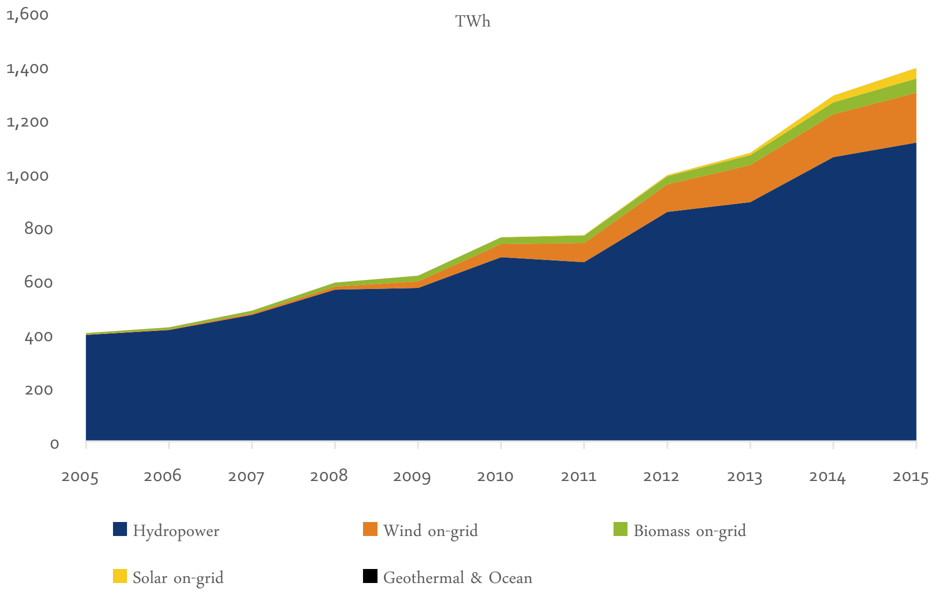


Figure 6: Power generation from renewable energy in China 2005-2015 (TWh). Source: CNREC 2016

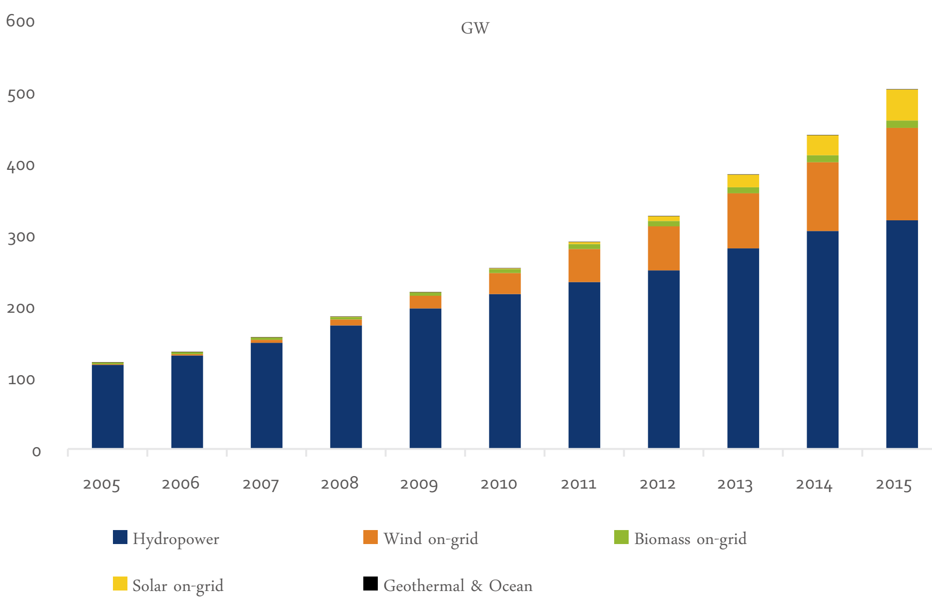


Figure 7: Installed RE power production capacity (accumulative) 2005 – 2015 for the different RE technologies (GW)

Barriers For Further Deployment Of Re

Until now the Chinese government has managed to clear the obstacles for deployment of renewable energy and the targets in the five-year plans have been achieved. However, a number of serious barriers and challenges might hinder the future development of the different technologies.

Re Power Still Needs Subsidies

Even though the cost of power from wind power and solar power has decreased over the last five years, wind and solar power are still not directly competitive with coal power production in the absence of accounting for the real cost of coal combusting, to include environmental damages and other costs to society. However, the cost of renewable energy must be continued to be reduced in order to ensure reasonable cost for consumers and industry in the future.

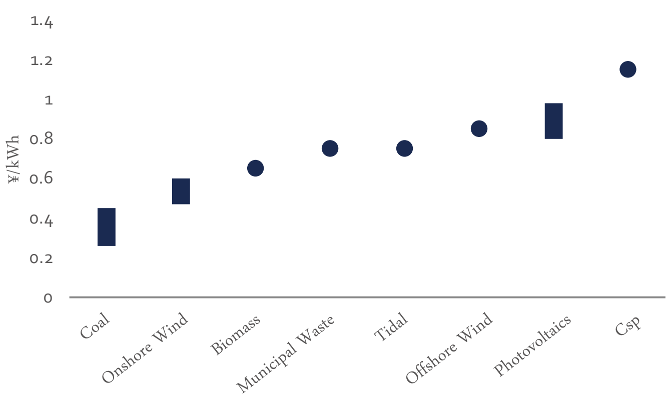


Figure 8: Comparison of power prices for different technologies in the Chinese energy system (RMB/kWh)
Source: CNREC

Currently the subsidies for renewable energy are covered by a surcharge on the electricity price. The surcharge has been raised several times recent years, but the deployment of new capacity puts strong pressure on the need for subsidies, unless the need for subsidies are reduced.

Serious Challenges To Grid Integration

Many RE technologies produce power characterized by intermittency and uncertainty. RE generation cannot be predictably dispatched, very different from conventional sources such as controllable coal power and hydropower.

With RE scale-up, especially the rapid growth of RE in the "Three Norths" region for China (including China's northwest, northeast, and north), there occurred serious challenges for grid integration of wind power since 2011.

According to statistics, the total wind power curtailment in 2011 reached 10TWh and the peak of wind power curtailment occurred in 2012 with 20.8 TWh total, or 17% of the total electricity generated by wind. All society focused on the issues of wind power grid integration and curtailment. Therefore, more measures were taken to address the issues, including the construction and commissioning of 750-kV transmission lines in northwest of China and the cross-region transmission capacity expansion in northwestand northeast.

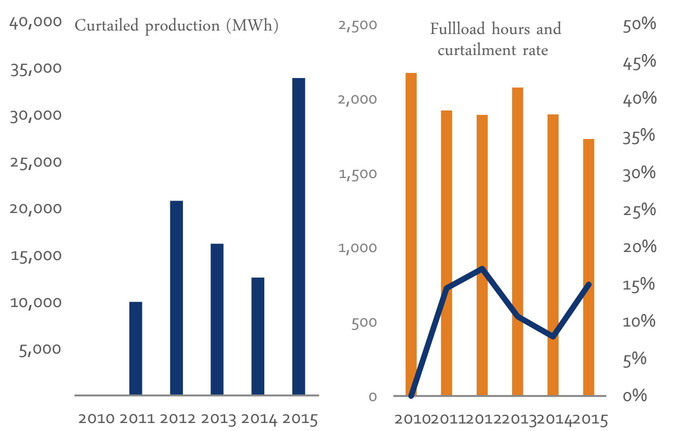


Figure 9: Curtailed production of wind power in 2010-2015 (MWh) (left) and number of full load hours (yellow) and curtailment rate in percentage of potential wind power production (%) (right)

Power utilities increased the priority of wind power dispatch and more wind farms installed auto-control systems. Based on such measures, wind power curtailment was reduced significantly in 2013 to around 10%, or 16.2TWh. 2014 was a "less windy" year and there were 1893 utilization hours of wind power on average with an 8% wind curtailment ratio, 4% less than that in 2012. However, the wind curtailment was higher in wind resource-rich areas in 2014, including Xinjiang Autonomous Region and Jilin Province, where wind power curtailment could reach 15%. Even in Hebei, Heilongjiang and Gansu Provinces more than 10% of wind power was curtailed. Such statistics show that there is still a lack of effective power operations and management systems to effectively accommodate RE power in such regions.

In 2015, a "high wind" year, in the context of slower demand growth of energy and power, the issues of wind power utilization exploded, with large-scale and large-area wind power curtailment and shedding occurring in wind resource-rich areas. Moreover, with the scale-up of solar power in the same year, solar power curtailment existed in some regions as well. There was more than 30% wind power and solar power curtailment in Gansu Province and Xinjiang Autonomous Region in 2015, even more than 50% in some months. The serious issues of RE grid integration and utilization significantly challenged China's power system construction and operation patterns, and represents a critical factor impacting the sustainable development of RE.

The technology innovation capacity of China's RE industry needs further improvements, and there are no fundamental changes to dependence on foreign sources for the core RE technologies. The international competitiveness of China's RE technology industry is still weak. All these innovation issues will be addressed based on the continuous improvement of China's academy-research-production system and innovation capacity of enterprises. However, the subsidy and grid integration issues are still the critical factors impacting the sustainable and healthy development of China's RE industry.

Why The Issues And Challenges?

Despite the issues of economics and intermittency which are the obvious challenges for RE, the RE-developed countries have sound measures to address the shortcomings. Also, during the global RE development process, there has been never such large-scale and large–area RE power grid integration issues as those which occur in China. Some countries adopted sound tariff adjustment systems, which fully reflected the comprehensive social and environmental benefits offered by RE, to address the economic issues of RE. In China's RE development environment, there are three major constraints in system and mechanism:

Constraint 1: The necessary sound adjustment of the energy system dominated by conventional energy is behind the demand for RE development. The current energy management and operation system was established according to the features of conventional energy, characterized by controllability and flexible dispatch. The systems for dispatch and operation, technologies for power consumption management, and the systems of power production and pricing for transmission and distribution were also established to manage large power sources and large power grids. When intermittent power sources arose, the regulations of power supply operation, power use, and power dispatch must be adjusted. However, power systems are still following the original patterns and have not yet been adjusted to accommodate RE. The recent wind power and solar power curtailments, which have become more severe, show that the intermittent power sources such as wind power and solar power are discriminated against and even rejected by the conventional energy system, even though they are protected by the "guaranteed full purchase" language in China's RE Law.

Constraint 2: China has not solved the institutional issues of RE's emergence into the energy system. The current energy development strategy has given priority to RE development However, at national level and local levels, during the energy production base construction, planning of the energy transmission infrastructure, or final energy supply structure improvements, there are few considerations of RE's roles and contributions. The energy system development strategy, has focus still on traditional energy sources such as coal, oil and gas, reflects no confidence or patience for RE's contribution by central or local government sectors and institutions. Such positioning of RE among the key multi-level strategic layouts, such as energy planning, base construction, and regional development, heavily impact on RE development. More important, with the scale-up of RE, there is no new mechanism to respond to various conflict, including the new conflicts by increasing renewable energy in power systems. Such conflicts are not being eased through sound market mechanisms such as pricing and management measures. The difficulties of RE grid integration and utilization are growing.

Constraint 3: There is no suitable mechanism to balance the benefit of market players to match the clean energy sustainable development. Significantly, it is reflected by the current market adjustment instruments, mainly including energy pricing and tariff systems, which do not include the external costs of resources and environmental impacts. For instance, the public bears the damage from exposure to pollutants such as smog caused by fossil fuel production and burning in the long run. But the real cost of fossil fuel should also include its scarcity and non-renewable nature. These are not reflected in the current pricing system, which only cover the cost for exploration and extraction. Resource extraction brings permanent damage to land and underground water resources. The consumption of fossil fuels negatively impacts air quality and public health. Such external costs are easily neglected, but represents the real long-term subsidies to fossil fuel extraction and utilization. The public seems not aware of these hidden subsidies to coal, which again makes it difficult for the public to accept explicit funding support to RE. As a result, fossil fuel is being encouraged and over-produced and over-consumed. In return, RE increasingly lacks a fair market environment and finds it difficult to get social recognition. RE is always constrained by the cap of its subsidy. The market failure caused by the externality problem should be adjusted through the instruments of pricing and tariff, which has been proved success by some other countries. But in China, the low acceptance of the public and market to clean and low-carbon technologies, and the “twisted” pricing and tariff systems strongly limit the deployment potential of RE.

The Policy Framework For Energy Transition

In 2013, in addressing economic and social development together with resource and environmental challenges, the 18th Communist Part of China (CPC) National Congress and the Third Plenary Session of the 18th CPC Central Committee approved the “Decision of the Central Committee of the Communist Party of China on Some Major Issues Concerning Comprehensively Deepening the Reform.” The Decision clarifies several strategically important missions, including deepening economic system reform and promoting ecological civilization. Addressing the energy sector, the Decision includes an action plan for air pollution control and prevention, and also addresses capping coal consumption and efforts to actively reduce coal consumption (especially in key regions including Beijing city, Tianjin city and Hebei province) while increasing the utilization of clean energy. These measures provide a strong driving force for energy system transition and the deployment of non-fossil fuels.

Eco-Civilization

Promoting Eco-Civilization Drives Non-Fossil Fuel Development

At 18th CPC National Congress, China identified ecological civilization as a component of the "five-in-one" strategic layout. The five themes are economic development, political development, cultural development, social development, and ecological development. The Decision states, in its focus on constructing a Beautiful China, that China will:

- Accelerate progress toward a new ecological civilization;
- Improve the system for land use, resource conservation and utilization, and protection of the natural environment;
- Adopt ecological civilization and environmental protection as important objectives to drive policy and action;

In other words, China shall prioritise harmonization of resources, economy and societal development as key assessment indicators.

In 2015, the CPC and the State Council further announced the "Opinions on accelerating the construction of ecological civilization," including the following main points relevant to energy, resource and environment:

Optimizing land resource use. This includes setting and strictly enforcing a cap on resource consumption, and identifying clear thresholds for environmental quality and ecological protection. Strategic energy resources are to be controlled, and total energy consumption well managed.

Adjusting the energy mix. Clean energy, RE and green industry will be developed. This includes accelerating the deployment of wind power and solar PV power generation, as well as biomass, bio-energy, bio-gas, geothermal energy, and ocean energy. On a system level, emphasis will be on developing distributed energy resources to augment centralized power; constructing an intelligent power grid; promoting efficient power generation and dispatch; and prioritizing RE power generation resources. The intent is to continuously improve the share of RE in the energy consumption mix.

Improving economic policies. Pricing reforms are to be deepened for natural resources and their products, with market principles guiding the pricing of commodities. Environmental damage cost recovery will be factored into pricing, and prices will reflect high levels of energy consumption and pollution associated with particular products. Tax policies will reflect the priority of energy conservation, environmental protection, clean energy and the construction of ecological civilization. Energy conservation and carbon emission trading systems will be established.

These key measures to address ecological civilization cover diverse sectors relevant to energy system development: land use planning, industrial upgrades, RE deployment, resource conservation and environmental protection, market mechanisms, law and regulations, and evaluation. Against the background of the construction of ecological civilization, energy sector development is of central importance. Fossil fuel consumption should be reduced; energy provision and use optimized; and the focus on improving the ecological environment increased. China should proceed to reduce high energy consumption industry while improving industrial productivity; accelerate elimination of small-scale and distributed coal fired boilers; expand the supply of exported power, natural gas and non-fossil fuel energy; and reduce high carbon fossil fuel energy consumption. China should substitute clean energy for new coal projects and reduce total coal consumption. To constrain fossil fuel energy while meeting the demand for economic and social development, China should increase the share of clean energy. Through vigorous expansion of low-carbon energy, new energy, and RE, China can meet most new energy demand, and effectively substitute the high-carbon fossil fuel energy consumed in all sectors and industries. China could therefore realize the control of high-carbon fossil fuel energy consumption and accelerate achievement of the peak of fossil fuel energy consumption and its subsequent reduction.

Energy Revolution

A Revolution in Energy Production and Consumption Guides the Development of Non-Fossil Fuel

At a meeting in June 2014, the central financial and economic leadership group pointed out that China has become the top energy producer and consumer in the world. China has successfully established a complex energy supply system based on coal, oil, natural gas, nuclear energy and RE. The levels of technology and equipment have significantly increased in recent decades, and production and living standards have been notably improved. However, China also faces challenges of keeping up with the energy demand, a set of energy supply constraints, severe damage to the natural environment by energy production and consumption, and with energy technologies generally behind the level of advanced countries.

Faced with the new changes of energy supply and demand, China promotes a revolution in energy production and consumption. One goal is to suppress wasteful energy consumption throughout all sectors of the economy and to strengthen consumption based on diligence and thrift throughout society. A second goal to establish a diverse energy supply system that bolsters national security. China will promote the efficient and clean utilization of coal, focus on non-fossil energy sources, and establish a diverse energy supply with coal, oil, gas, nuclear energy, and RE, and at the same time strengthen the energy transmission and distribution system and energy storage infrastructure. Third, China will upgrade its industry, becoming self-sufficient with innovative low-carbon energy technologies and industrial processes. Fourth, to advance energy system development, China will strongly promote energy sector reform including by establishing effective, competitive market structures, with a market-driven energy pricing system, and with a strong supporting energy regulatory and legal structures. Finally, international cooperation related to energy production and consumption will be enhanced to leverage international resources and strengthen energy security through market opening.

It is in China's interest to rapidly implement an energy revolution based on clean renewable energy. RE is clean, green and low-carbon energy, representing the global energy technology trend, and is the primary driver of the energy revolution and an emerging industry growth point. Currently China has established the target of about 20% non-fossil fuel energy share of primary energy consumption, and is intensively preparing a strategy for achieving the energy production and consumption revolution by 2030, extending through 2050. Meanwhile RE deployments are scaling up. By 2015, the total RE consumption reached 509 Mtce, i.e., 11.7% of the primary energy consumption, and in total, the non-fossil fuel energy amounting for 12.8% of the primary energy consumption, exceeding the non-fossil fuel target announced in the 12th Five Year Plan. In Yunnan, Gansu and Qinghai Provinces and in Inner Mongolia and Xinjiang Autonomous Regions, hydropower, wind power and solar power have become the main power sources. The example of such RE-developed regions will drive more regions all over the country into strong RE development. And fundamentally it will change the energy mix and production and consumption patterns, constituting an energy revolution.

Climate Change

Addressing climate change by identifying middle and long term targets for non-fossil fuel development

At the end of 2015 at COP_{21}, the Paris Agreement was announced. It identified an average global temperature growth target of 2 degrees Celsius compared with the pre-industrial value, with an aspiration to limit the increase to 1.5 degrees. China committed to its Intended Nationally Determined Contribution (INDC) in June 2015, announcing that by 2030 a CO_2 emission peak will be reached; CO^2 emissions per unit GDP will be reduced by 60-65% compared with the 2005 value; and 20% of primary energy consumption will be provided by non-fossil fuel. To reach these targets, China is developing an energy strategy with 2030 and 2050 objectives.China ratified the Paris agreement alongside the US at the G20 forum in Hangzhou in September 2016.

Economic And Power Sector Reforms

Economic and Power Sector Reforms Will Improve the RE Policy Environment

Per the 2013 Decision, the critical point of the economic system is to balance the relationship between government and market, with the market finally deciding the resource distribution and the government efficiently playing its guiding role. The 18th session of the Third Plenary of the CPC required that significant progress will be made before 2020 in key economic sectors.

Under the energy sector reform, the transformation of government functions to a focus on regulation will streamline microeconomic dynamics. Transparency of roles in market operations will improve economic efficiency. Further, the reform is breaking monopolies and accelerating infrastructure sector reform, including of the energy sector. The relative functions of government and enterprises will be clearly defined. Public resource distribution will be market-oriented, which will facilitate open and fair energy and power markets. Third, China will formulate a market-oriented pricing system, and liberalize pricing in the competitive segments. Market operations will prevail in segments where the market can play a constructive role; prices will be liberalized except for cases of important public utilities, public welfare services and other natural monopolies regulated by government. Fourth, China will reform the prices for natural resources to support energy conservation and GHG emission reduction. Carbon emission trading will be developed, and policies for fair competitiveness of RE in the energy market will be established.

As power reform advances, it has become clear that it is difficult to transform the power industry, optimize the power mix, and continuously increase RE power share without an effective and modern power market system. In March 2015, the document titled "Opinions on further deepening of the reform of electric power system" (No. 9, 2015) emphasized energy conservation and emissions reduction, establishment of an effective and competitive market structure, promotion of an optimized energy mix, and an increased share of RE and distributed power generation in the power supply. On 26 November 2015, NDRC released important documents supporting energy reform, including “The Implementation Opinions on Promoting Power Market Establishment”, “The Implementation Opinions on Orderly Liberalizing Power Electricity Planning”, and “The Implementation Opinions on Promoting Power Electricity Sale Side Reform”. These documents mean that the previous document "Opinions on further deepening of the reform of electric power system" has been put into substantial implementation, providing strong new drivers of power market reform and accelerated transition to a low-carbon power system.

China’s power reform acknowledges national and international experiences and lessons on power market establishment, and also puts more focus on establishing an effective and competitive market system. The power reform follows the framework of “regulating the middle segments but liberalizing the two ends”: liberalize the competitive power pricing except for transmission and distribution, open the power sales business to the private sector, open power generation and consumption planning (except for the public welfare and other identified segments), and formulate market-oriented energy pricing systems. “The Implementation Opinions on Promoting Power Market Establishment” clearly states that the fair, standard and efficient power trading platform will be established, market competitiveness will be introduced, market barriers broken, and the power grid opened without discrimination. Eligible regions are to gradually establish market-oriented power and electricity balance systems based on mid-term and long-term trading supplemented by spot trading. The power market will be established, minimizing risk through mid-term and long-term trading with prices set through a spot market.

The power market system will be fully competitive, and developed in an orderly manner for rapid implementation throughout China in support of the green power revolution. A power system with diverse, flexible power sources and demand side response technologies and based on RE power--especially wind power and solar power-- needs a fully competitive power market. The power market will also provide for ancillary services, including flexibility form sources such as the considerable coal generation capacity. Coal power generation units can transfer their role from the current “power supply” into “load dispatch,” their annual full load operation hours could reduce to less than 2000 hours[3], and they could also enjoy peak load dispatch prices. Such changes will the green revolution in the power sector supply side.

[3]In Denmark, such coal power generation units normally operate within 20%-100% of their rated nameplate power, or even lower.

CHAPTER 2

Pathways For Energy Transition Towards 2030

Guidelines For Energy Transition Pathways

The Chinese energy transition becomes an inevitable undertaking in the face of emerging and persistent challenges. However, given various conflicting interests across multiple dimensions, and the profound implications of energy transition on many other sectors and on society it is a daunting task to map out a clear transition pathway toward a sustainable energy future.

Xi Jinping, in his introduction to the 13^{th} Five-Year Plan, pointed out that "the combination of goal-oriented and problem-oriented approach should be applied, both for clarifying the visions for a well-off society in 2050 and for addressing the urgent challenges today and finding clear ways and means to solve the problems." For our work this means that we should base our analyses on the long-term vision for Chinese society, clarifying how a sustainable energy system could be envisioned in 2050. At the same time, we must address the near-term problems and challenges, ensuring the right steps are taken towards 2020 as stipulated in the 13^{th} Five-Year Plan and towards 2030 through the 2030 Energy Development Strategy.

In this context energy system scenarios are well suited to both highlighting realistic long-term visions and addressing near- and medium-term challenges and barriers. Detailed bottom-up modelling of the Chinese energy system is key to understanding the complexities of energy system development. The scenarios can consider integration of variable energy production, such as from wind and solar generation, and they can provide results for evaluating the performance of the prospective energy system with respect to economic, environmental and energy security considerations. Furthermore, through modelling we can analyse the impact of different policy measures and their interactions, which makes the analyses useful for policy makers.

As general guidance for our analyses we find it useful to apply a threefold, "three lines," framework combined with a "non-zero sum" development driver.

The "three lines" framework defines three main guidelines for evaluating the value of energy system transformation:

1. The economic development imperative, the "bottom line," must be sufficient to ensure that China's social and economic development can reach the level of the moderately developed countries, comparable to the level of well-developed countries today. This implies that China's GDP should reach 282 trillion yuan (in 2010 yuan) in 2050.
2. The environmental imperative, the "red line," which will ensure a sustainable environment without ecological degradation. The red line implies that the energy system should contribute to reducing national CO_2 emissions to a level comparable with the situation in the late 1970s or early 1980s, and that PM2.5 and other air pollution emissions should follow World Health Organisation standards.
3. The social imperative, the "life-line," which will ensure that China has sufficient energy for national development in a way that does not conflict with the first two imperatives. This calls for sufficient development of green energy production with a low environmental impact and for more widespread use of "green" electricity for end-use purposes to reduce the impact of fossil fuels and at the same time strengthen the living conditions of the Chinese people.

In addition to these "three lines," the transition process must be conducted in a way that gives mutual benefits to the involved stakeholders without favouring individuals or narrow group interests. The energy transition must be a "non-zero sum game" where the whole society gains from the added value of the transition. This means that the energy transition process should give clear priority to cost-efficient and energy-efficient measures and framework conditions.

The "non-zero sum game" principle points to the following guidelines for the implementation process:

- The market should be a decisive driver for the process. Demand and supply balance should be a key driver, while the demand for environmental protection should be reflected in energy pricing.
- The economy should be sustainable. Development of a sustainable energy system will reduce the direct and indirect costs of ecological degradation. At the same time, the energy system should deliver cost-efficient energy, ensuring industrial development and innovation within

the manufacturing industry, and the energy infrastructure should support this with highly innovative solutions for development of an energy internet.

- Long-term and short-term planning should be combined and interactive. The visions for the long-term development of the Chinese energy system should take into account the current infrastructure and investments, without losing sight of the long-term strategic goals regarding the economy, environment and security. And the short-term planning as expressed in the Five-Year Plan and the 2030 Energy Development Strategy should be guided by the long-term visions and ensure that the development path is in line with those visions, even though the long-term goals cannot be reached in the short and medium terms.
- Soft and hard measures should support the energy transition. "Soft measures" such as institutional reforms and policy measures must be part of the energy transition process together with "hard measures" ensuring energy innovation and development of the physical infrastructure. The two types of measures must go hand in hand, mutually reinforcing each other by removing structural and physical barriers in support of a successful and efficient energy system transformation.

Main Framework Assumptions

China Renewable Energy Outlook uses scenarios for the analysis of national energy system development towards 2030. Scenarios are consistent stories about how the future might unfold. Anchored in the present reality, they are not predictions or forecasts, but instead are plausible accounts of how various conditions can combine to bring challenges and opportunities.

The objective for the scenarios is to analyse if and how a high share of renewable energy in the Chinese energy system can ensure the economic and environmental targets without jeopardizing the energy security, and how the large share of renewable energy efficiently not only can be integrated into the whole energy system, but gradually take over the role as the energy system back-bone.

In CREO 2016 two main scenarios have been defined:

- The Stated Policy Scenario is the starting point for analysis of energy system transformation. It is defined in recent policy decisions and in the 13th Five-Year Plan for development towards 2020. In this scenario, the current policies are assumed to be extended beyond 2020 in acknowledgment of expected development trends and current policy ambitions regarding institutional power sector reforms. Given the assumed extension of present policies beyond the 13th Five-Year Plan, the Stated Policy Scenario is a predictive scenario, illustrating the impact of the current policy in the years to come. The objective for this scenario is to investigate how a successful implementation of the current polices can drive energy system development and to what extent the current policy strategies are sufficient to reach the medium-term goals (ca. 2030) set for the Chinese energy system.

- The High RE Penetration Scenario is driven by the long-term goals (ca. 2050) for the energy system, anticipating that renewable energy should play a decisive role in fulfilling the long-term targets. The scenario carries forward the assumptions and constraints underpinning the 2050 high-proportion development scenario of the "China 2050 High Scaled Renewable Energy Scenario and Pathway Study". This constitutes a possible pathway for China's energy transition in a future where global warming is contained to within 2 degrees.

Both scenarios are "positive" scenarios where the policy implementation is assumed to be successfully carried out. We have chosen not to define a regular "baseline" or "business-as-usual" scenario because we are more curious about how China can move forward in the right direction than we are concerned about artificial base-line scenarios, which might only serve as a grey background for the more positive scenarios. On the other hand, we realise that both scenarios employed in this study could be too optimistic regarding the success of policy implementation. The reform processes are not straightforward linear, and the practical implementation at both national and provincial levels has embedded pitfalls and obstacles where conflicting interests should be mitigated. We think, however, that clear and forward-looking scenarios will help pave the way for the implementation process, based on objective scientific analyses, substantiated results, and the recommendations that proceed from them.

Economic And Social Development Assumptions

The CREO 2016 scenarios share commom assumptions regarding economic and demographic development in China.

China's long-term strategy is to develop a modern society with a wealth comparable with the level that developed countries have today. As part of this modernization the economic structure will transform from highly energy-intensive industries to less energy-consuming industries and services. While the strategic direction is clear the speed and the level of economic growth are more uncertain.

In the scenarios, it is assumed that in 2050 China's the primary energy supply and the end-use energy consumption structure will support a GDP at a level of 2,820 billion yuan.

For development of the Chinese population is assumed to grow to 1.51 billion people in 2030 and 1.38 billion people in 2050. The urbanisation rate (the share of people living in cities) is assumed to develop from 55% in 2015 to 68% in 2030.

For national energy self-sufficiency, we assume a target of 90% in 2050.

Environmental Constraints

Reduction of the emission of CO_2 from the energy sector is an important driver. For the scenarios in CREO 2016 we use CO_2 emission as a measurement for the quality of the scenario more than as an active optimisation constraint.

For the Stated Policy scenario, the target for CO_2 emission is to ensure a peak before 2030. The High RE Penetration Scenario should peak earlier than 2025 or even before 2020[1] .

Like CO_2, the emission of pollutants from the energy sector, such as SO_2, NO_x, Hg and other energy-related emissions, should be significantly reduced in the scenarios. We do not set specific goals for 2030, but by 2050, China should have lowered the emissions levels to 1980s values. The emission of PM2.5 should meet the World Health Organization standards.

[1]For the long-term, the vision is determined by the global target to meet the 2 degree or even 1.5-degree standard. This translates to a specific target of 3,500 million tons CO_2 in 2050 for the High RE Penetration Scenario (considering China's share of global population and share of GDP). For the Stated Policy Scenario, we estimate the target to be 5000 million tons CO_2 in 2050.

Non-Fossil Energy Targets

When looking at the environmental impact from the energy sector it makes sense to evaluate the scenarios based on the amount of non-fossil fuels in the system since CO_2-cleaning technologies (such as CCS for fossil fuels) have not yet proven technologically mature or economically feasible. For the long-term development, we find it relevant to have a non-fossil fuel target of 60% or more of the total primary energy demand by 2050. For 2030 the target is 20% or more for the Stated Policy Scenario and 33% for the High RE Penetration Scenario.

Electrification Of End-Use Sectors

Starting from the ambition to develop the economy and industry to a level comparable with the moderately developed countries by 2050. If China follows the energy development path of OECD countries regarding energy efficiency and technological progress, the final energy consumption would reach around 4800 - 5300 Mtce in 2050, the transport sector will be a large consumer of oil, and the CO_2

emission targets could not be reached.

To achieve the emission reduction targets, a clear path is to increase the use of electricity in the end-use sectors to substitute for coal and oil consumption. Combined with a strategy for development of RE in the power sector, electrification can improve efficiency and ensure better use of wind and solar energy, thereby reducing the primary energy consumption. With a target of 60% electricity in the final energy demand in 2050, the total final energy demand would be around 3200 Mtce.

Development Of Nuclear Capacity

Decisions regarding the development of nuclear power in China include several factors of a social and political nature. Per decisions by the previous and current government of China, construction of nuclear power plants in the inland and in large-scale construction of the Yangtze River Basin will not happen. The development of the western regions has priority for a "green mountains and clear water are as good as mountains of gold and silver（绿水青山就是金山银山）" strategy, which implies that the development should primarily be based on renewable energy. Before the fourth generation of nuclear power technology is in commercial operation, it is assumed that China will not open the inland deployment of nuclear power. Based on this, we consider the nuclear power development to be within the range of 100 GW in 2050, solely deployed in coastal areas.

Wind And Solar Capacity

The deployment of wind and solar is limited by resource constraints. These constraints are further elaborated in the next chapter.

Thermal Power Plant Peak

The development of wind power and solar power combined with power market implementation will call for more flexibility in the power sector. We expect that around 70% of the coal power plants in 2030 will be ready for flexible operation and by 2050 all thermal power plant can achieve flexible operation.

Demand Side Response Technology

Demand-side response technology is expected to be widely used by 2030. Electric vehicles are used as miniature energy storage power stations and have sufficient capacity for power system peaking in cities. By 2050, China's electric vehicle stock is expected to be at least 400 million, equivalent to 80% of all vehicles.

Friendly Grid Development

The development of the power transmission grid should follow the principles of "innovation, coordination, green, open, sharing." We expect the transmission grid and the regional interconnectors to be an integrated part of the power market, and that the regional coordination between east, west, north and south inter-regional power grids will be strengthened with further grid developments. The barriers for institutional and economic cooperation between provinces and regions are expected to be removed, and the sharing of benefits would prevail over provincial sub-optimisation. During the thirteen five-year plan period, we expect a coordinated development of the power grid on regional and provincial levels to be able to integrate on the order of 300-350 GW wind power installed capacity and 200-220 GW solar power installed by 2020. By 2030, the China grid would basically be built to transport renewable energy power as the main task, as an energy-friendly internet-like smart grid.

Power Market Development

The power system is the core of the future energy system, and the electricity market is fundamental to power system development. The purpose of China's power system reform is to "let the market play a decisive role in the allocation of resources." China's electric power system reform needs to establish a complete and systematic framework for power system operation by 2020. By 2025, the task of power system reform will be completed in a comprehensive way, and China will establish a strongly competitive electricity market.

CNREC's Modelling Tools

In this work, modelling tools are essentially used to fill in the blanks. The models provide depth and detail, and ensuring consistency between the energy scenario targets and the simulated performance of the energy system. The feasibility of the prospective energy system, given performance targets and constraints, is revealed through modelling.

China National Renewable Energy Centre (CNREC) has developed a special modelling suite suitable for analysing renewable energy in an energy system context. The model suite combines three separate models:

- A bottom-up power sector model, EDO, that includes the combined heat and power generation important for the dispatch of power plants in China. The model simulates the power and district heating system on a provincial level, as well as the energy flow on interconnector and long-distance transmission lines. It models detailed system dispatch with unit commitments based on economic dispatch with constraints. Further, the model makes investment decisions for generation and transmission based on least-cost optimisation.
- A model for the final energy consumption and transformation outside of the power sector, END-USE, which makes projections for future energy demand and direct energy use for the different economic sectors. The development in each of the sectors and subsectors is determined by such drivers as changes of energy intensity and division of fuel shares.
- A macroeconomic model, CGE, which is a general equilibrium model for the Chinese economy with focus on the energy sector and on energy sector transformation. The model analyses the impact of energy system transformation on GDP, job creation and destruction, and other macro-economic impacts.

By combining these three models, the suite gives an annual picture of the energy flow in the Chinese energy system, from end-use demand to primary energy supply, as illustrated in Error! Reference source not found.

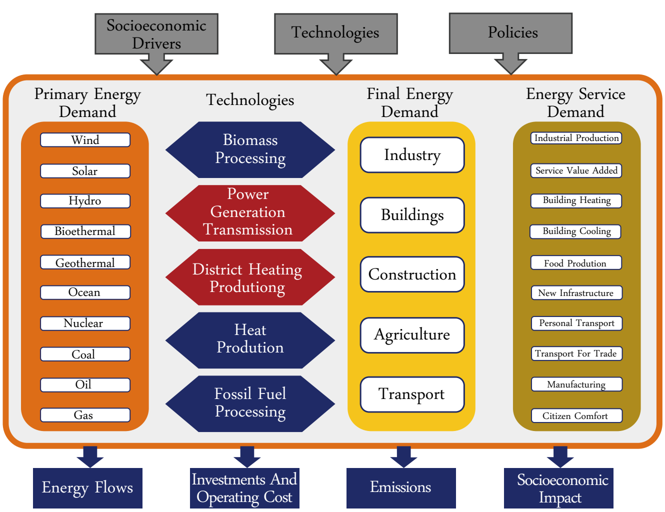


Figure 10: The energy system modelled in CREPDASAM, with main drivers and main results

The figure also shows the main drivers for energy system development such as socioeconomic dynamics, technology development, and policy measures, as well as the main output from the models in the form of energy flows, investments and operation costs, emissions and socioeconomic impacts on Chinese society.

CHAPTER 3

Energy System Scenarios

The main outcome of the scenario analysis is a set of consistent pictures of how the energy system could develop. These pictures provide overview as well as detail, and a foundation for more detailed discussion of the key issues regarding the implementation of the scenario pathways and the energy transition. Outputs are divided into four different viewpoints:

- The total energy consumption picture
- The final energy consumption picture
- The power and district heating sector picture
- The flexible power system picture.

The Total Energy Consumption Picture

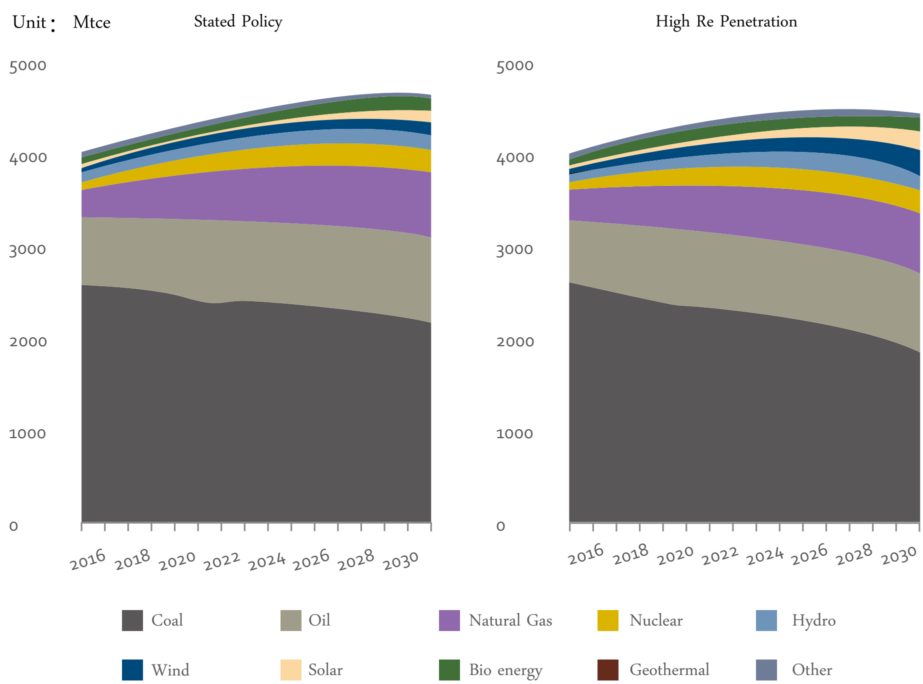
In 2015 the total primary energy demand amounted to 4,300 Mtce (coal substitution method), accounting for non-thermal renewables and nuclear power.

The energy system is dominated by coal, both in the electricity sector and in the industry sector. Coal amounts to 65% of the total primary energy supply and 42% of the total final energy demand. Oil is the dominant fuel in the transport sector, accounting for more than 99% of the energy demand.

Renewable energy is mainly used for electricity production. Outside of the power sector, biomass and solar heating contribute to the energy demand in the building and industrial sectors. The share of renewable energy is 7% of the total primary energy supply (16% using the coal substitution method).

In both scenarios, the primary energy demand increases from 2015 levels; however, the rate of growth moves towards a plateau and in both scenarios, the total primary energy demand starts decreasing in 2030 (Figure 11).

Figure 11: Total Primary Energy Consumption divided among fuels in the two scenarios. Figures are based on energy content, not the coal substitution method.



Coal Consumption

In both scenarios, the coal consumption decreases throughout the period, although the decrease is more rapid in the High RE Penetration Scenario. Coal consumption rapidly decreases in the end use sectors due to energy efficiency improvements and electrification, and in the power sector coal is substituted by natural gas, nuclear power and renewable energy.

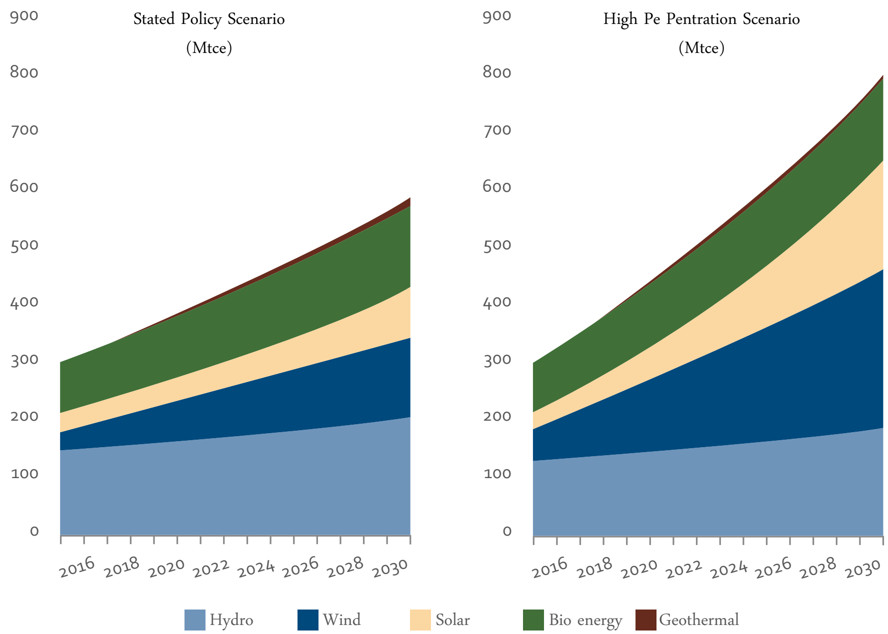
The share of coal falls from 65% of the total primary energy consumption in 2016 to 47% in 2030 in the Stated Policy scenario and 42% in the High RE Penetration scenario. In

2030 the total coal consumption is 2217 Mtce in the Stated Policy scenario and 1896 Mtce in the High RE Penetration scenario.

Renewable Energy

In the Stated Policy Scenario, renewable energy is doubled from 2015 to 2030 and tripled in the High RE Penetration Scenario (Figure 12). The main differences are in the generation of wind power and solar power. Hydro, wind and solar technologies are mainly used for electricity production, while half of the biomass is used in the end-use sector, mainly for individual heating. The share of renewable energy of the total primary energy consumption in 2030 is 12% for the Stated Policy Scenario and 18% for the High RE Penetration Scenario.

Figure 12: Development of renewable energy production in the Chinese energy system in the period 2016-2030 (in Mtce)



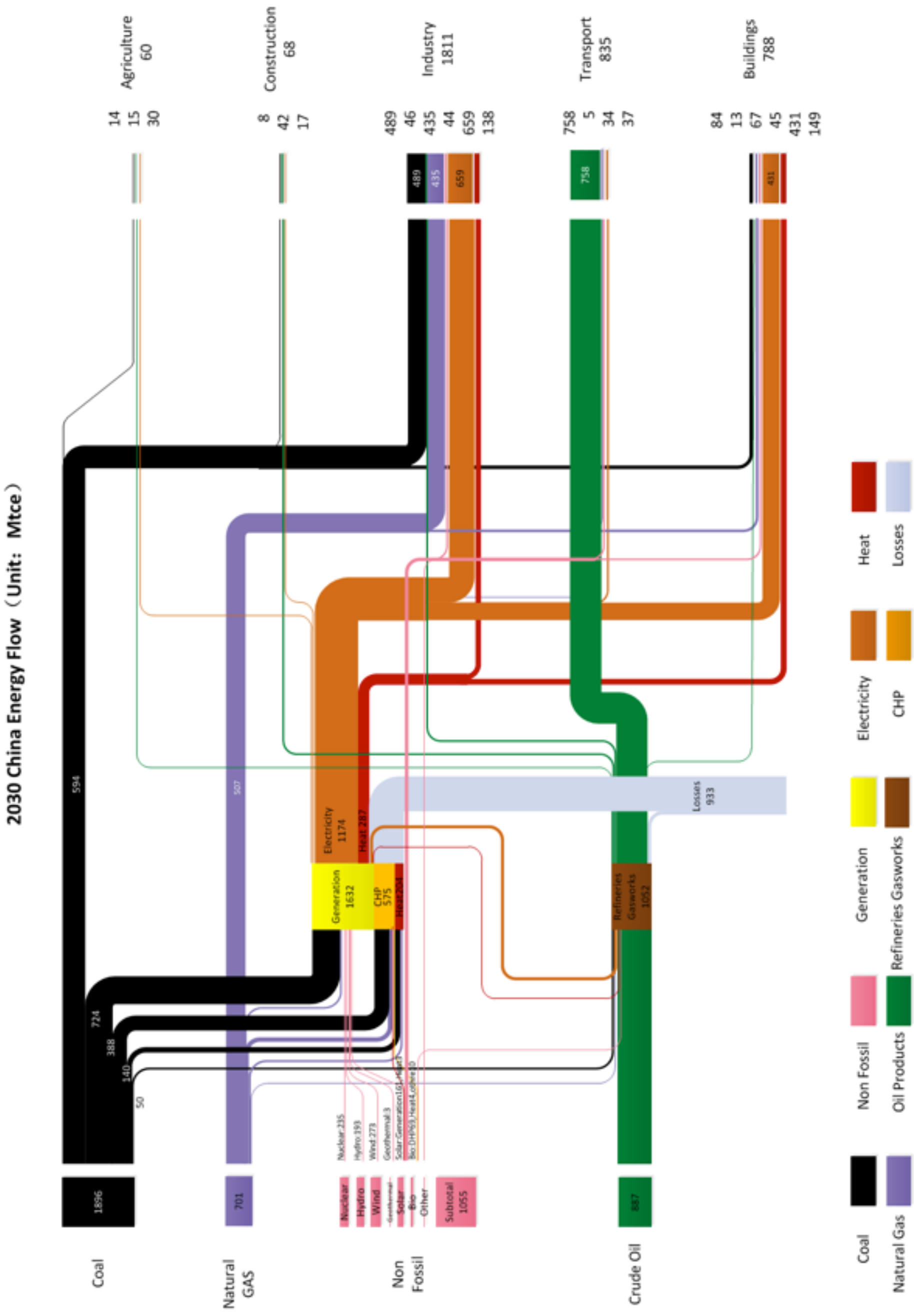


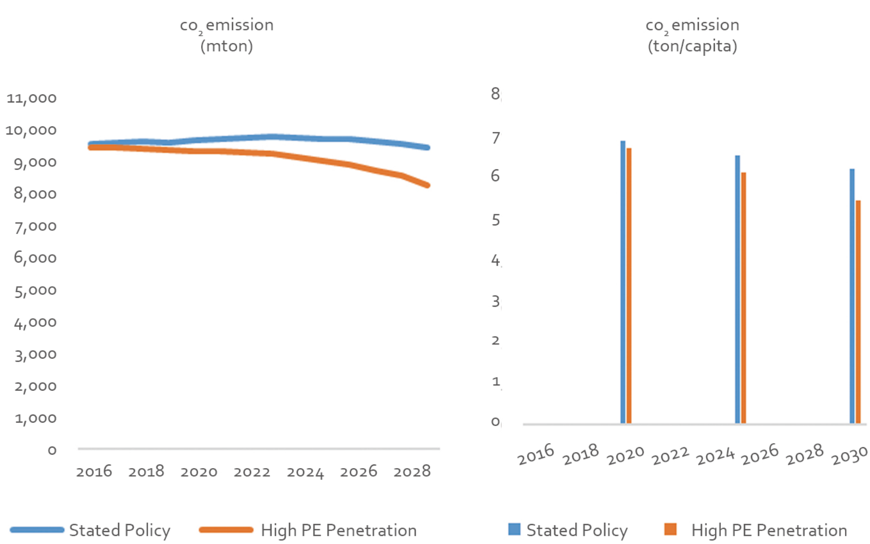
Figure 13: Energy balance for the High RE Penetration Scenario in 2030 (in Mtce)

CO_2 Emission

In both scenarios CO_2 emissions peak before 2030. In the Stated Policy scenario, CO_2 emissions peak rather late (2027) with a modest decline to a level of 9500 Mton by 2030. In the High RE Penetration scenario, CO_2 emissions peak earlier (2017) with a more rapid reduction in the years after. In 2030, emissions in this scenario are around 8,250 Mton. The deeper CO_2 emission reductions in the High RE Penetration Scenario are due to more power production from renewables and more electricity use in the end-use sectors, especially in the transport sector and in industry.

The per capita emissions also decline faster and more significantly in the High RE Penetration Scenario. In 2030, the specific emission is 5.47 tons per capita in the High RE Penetration Scenario compared to 6.23 tons per capita in the Stated Policy Scenario.

Figure 14: Development of CO_2 emissions from the energy sector (in Mton) and specific CO_2 emissions per capita (in tons per capita) for both scenarios

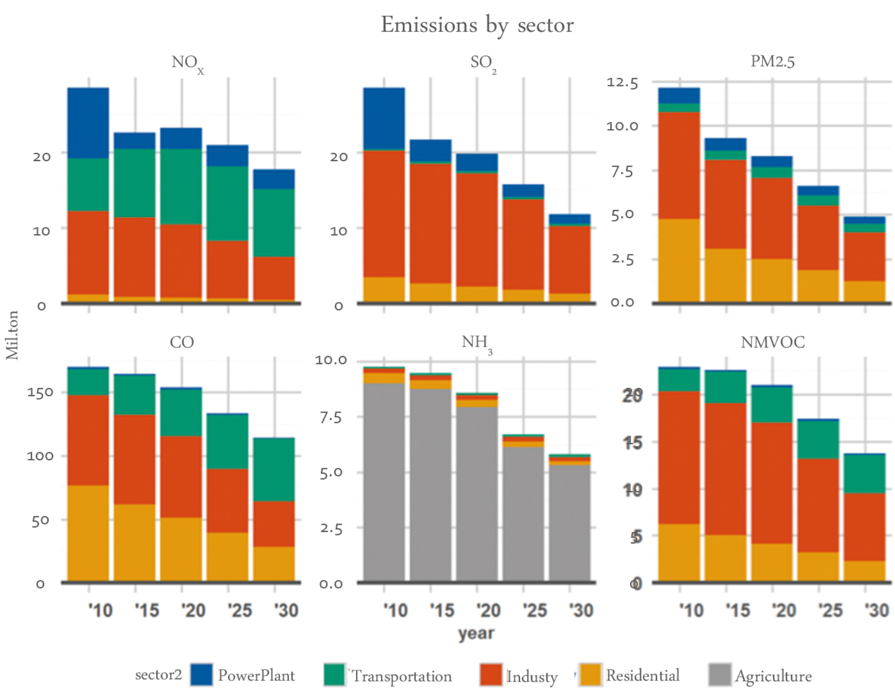


Air Pollution

The air pollution from the energy sector is calculated based on fuel consumption, and estimated conversion factors for the future development of cleaning technologies, and requirements from the Chinese government.

With the assumptions of efficient implementation and enforcement of regulations and controls, the air pollution in China will drop from the current high level across all sectors. In the future, the industrial and transportation sectors will be the biggest polluters, while pollution from the power sector will be reduced due to flue gas cleaning and reduction of fossil fuel power generation. Figure 15 shows the result of the air pollution calculations based on energy consumption in the High RE Penetration Scenario to 2030.

Figure 15: Emissions of NO_x, SO_2, PM2.5, CO_2, NH_3 and NMVOC (in Mton) from 2010 to 2030 in the High RE Penetration Scenario.



In connection with the China Renewable Energy Outlook, a study on the health impact of air pollution in China has been carried out using the output from the modelled CREO scenarios[1].

[1]Assessing the externality cost of developing renewable energy in China, Dai Hancheng, Zhang Yanxu, Xie Xiang, 2016.

The health impact from air pollution is mainly related to emission of PM2.5 and O_3. The reduction in both these pollutants will markedly improve the ambient air quality in key regions in China. According to accepted health impact methodologies, morbidity and mortality will decrease, as well as productivity will increase. Figure 16 shows the calculated morbidity caused by these two emitters in the two scenarios and Figure 17 illustrates the calculated mortality. Both scenarios have reduced morbidity and mortality, however, the High RE Penetration Scenario has a more profound health benefit due to the lower consumption of coal and oil and due to the increased electrification of the transport and industry sector.

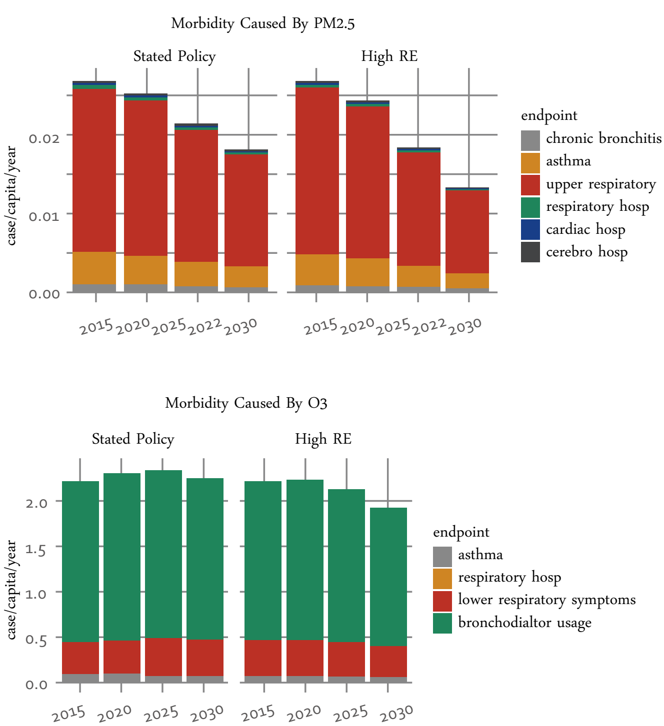


Figure 16: Morbidity caused by PM2.5 and O_3 in the High RE Penetration Scenario in cases per capita/year

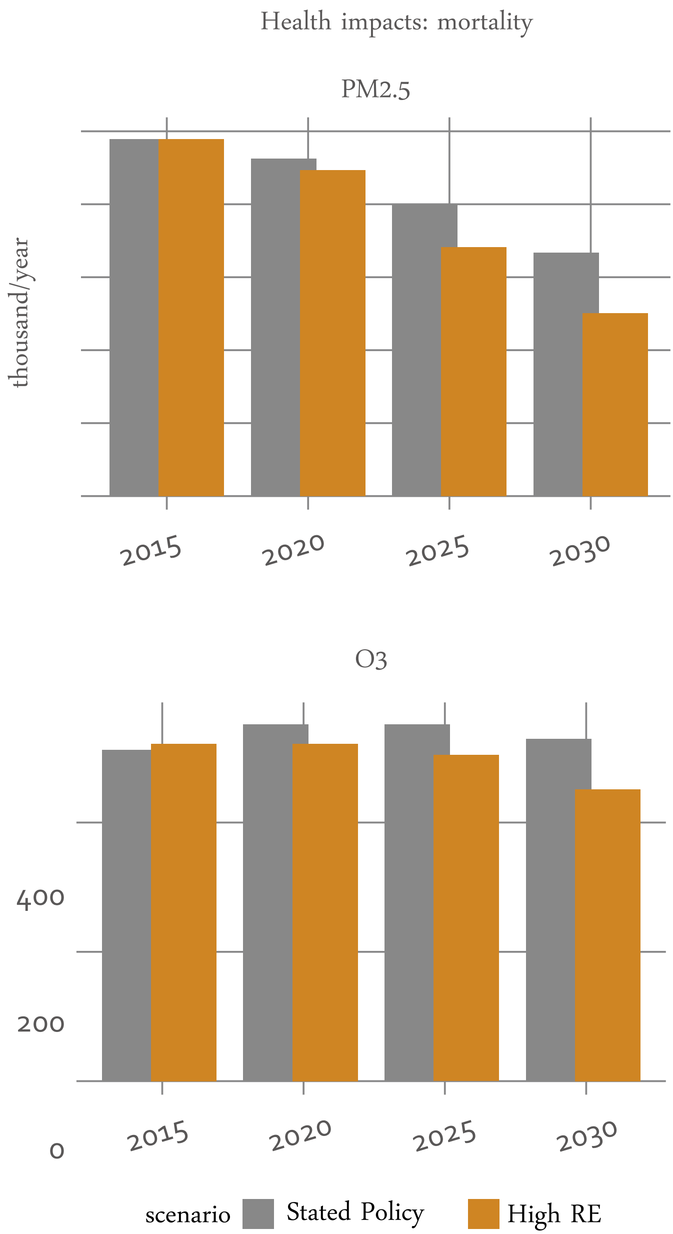


Figure 17: Mortality in China due to emissions of PM2.5 and O_3 in the two scenarios (in thousands per year)

The Final Energy Consumption Picture

The development of final energy consumption is modelled for the five main sectors in the Chinese economy. Generally, the energy services provided are the same in the two scenarios and the assumptions regarding energy efficiency and energy savings are similar. The main difference between the two scenarios is more electricity use in the industrial and transport sectors.

Today, the industry sector dominates energy consumption with a share of 50% of total final energy demand. Figure 18 shows the final energy consumption by sector in 2015 and in 2030 for the Stated Policy Scenario. In 2030 the total final energy consumption is larger than in 2015. The growth is mainly in the buildings and transport sectors, while energy consumption in the industrial sector decreases.

In the end-use sectors, renewable energy contributions are mainly from bioenergy and solar heating. The primary use is for heating in industry and buildings, and a small share of biofuels for transport. In both scenarios, the use of bioenergy and solar heating increase slightly. In the High RE Penetration Scenario, more bioenergy is used for transport.

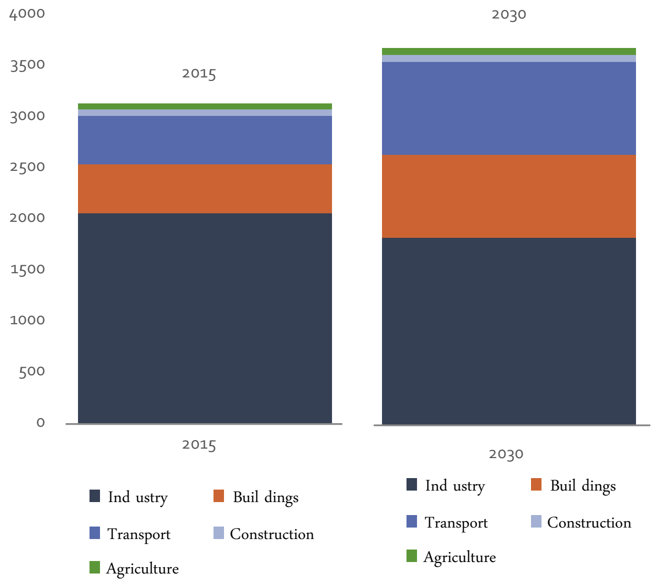


Figure 18: Final energy consumption (Mtce) in 2015 and 2030 in the Stated Policy Scenario divided among economic sectors

In both scenarios electricity is introduced as a substitute for coal in the industrial and transport sectors. In the High RE Penetration Scenario the electrification is a moderately more aggressive than in the Stated Policy Scenario, which leads to a lower total final energy demand (Figure 19).

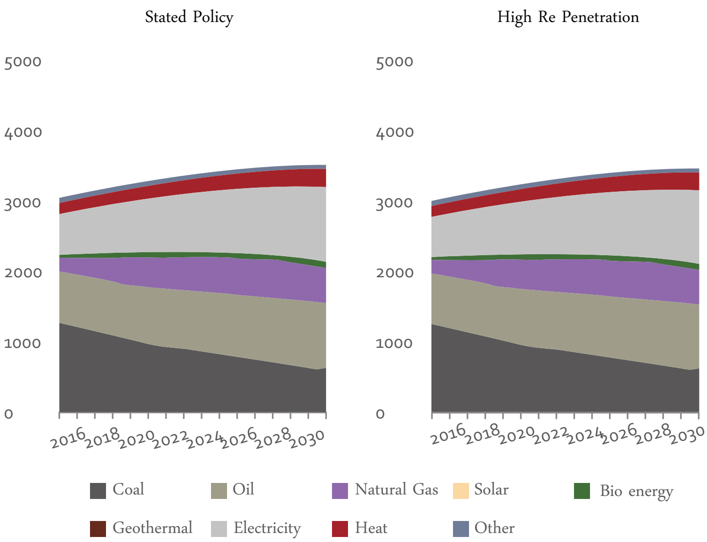


Figure 19: Total Final Energy Consumption

The Power And District Heating Picture

When looking at renewable energy development, the power sector has a special role. First, some of the main RE technologies, wind and solar PV, are electricity generators. Secondly, the variable power production from these resources presents special conditions and challenges for power system dispatch, with significant influence on the operation of thermal power plants and interconnectors. In a Chinese context, the linkages between power and heat production offer significant opportunities for optimisation and efficient use of resources. Finally, economically optimal use of the RE resources is shown to be critically dependent on the development of a power market that reflects cost-efficient dispatch of electricity generation and transmission.

Methodology For The Power Sector Scenarios

The EDO model is an economic dispatch optimization, unit commitment and capacity expansion model which, subject to a given scenario's boundary conditions, determines the optimal deployment of power and district heating generation capacity, power transmission capacity and the optimal operation of this capacity to satisfy load requirements. The model is configured to cover 31 provinces in China including the 4 provincial-level municipalities. Inner Mongolia is divided into the eastern and western parts, creating a total of 32 distinct geographical regions in the model. The model is run in two steps, first to determine the optimal capacity deployment, and second to verify the operations with simulations at an hourly level.

Where the scenario assumptions diverge for the power sector

As a starting point, RE capacities as of the end of 2015 were:

- Wind: 130 GW
- Solar: 43 GW
- Biomass, biogas and MSW: 10 GW

Stated Policies Scenario

Technology sub-targets for installed capacity are set for:

- Wind power: 210 GW by 2020 and 500 GW by 2030
- Solar power: 170 GW by 2020 and 500 GW by 2030 (hereof 58 GW and 250 GW respectively as distributed generation)
- Biomass, biogas and municipal solid waste (MSW): 15 GW by 2020, and 20 GW by 2030

High RE Penetration Scenario

The High Penetration scenario depicts a pathway towards 90% RE power in 2050.
Additionally, technology sub-targets for installed capacity are set for:

- Wind power: 350 GW by 2020 and 1,000 GW by 2030
- Solar power: 210 GW by 2020 and 1,100 GW by 2030

(hereof 95 GW and 550 GW respectively for 2020 and 2030 as distributed)

- Biomass, biogas and MSW: 20 GW by 2020 and 25 GW by 2030

Power demand and electrification

Power demand increases from 5,550 TWh in 2015 to:

- Stated Policies Scenario: 6,700 TWh in 2020 and 9,400 TWh in 2030.
- High RE Penetration: 6,970 TWh in 2020 and 9,930 TWh in 2030.

Flexible demand response in the High RE Penetration Scenario

The High RE Scenario assumes the roll out of a demand response program resulting in:

- Load shifting of electricity consumption in industry, thereby providing flexibility of up to 1.2% of peak demand in 2030
- Peak clipping programs, mainly AC loads, providing flexibility up to 1.3% of peak demand in 2030.

Lastly, an electric vehicle deployment of roughly 100 million vehicles, 2/3 of which are assumed to charge intelligently, can provide roughly 370 GW of charging/discharging capacity. In addition, retired EV btteries can been repurposed for stationary storage.

Power Supply Capacity Development Overview

The total installed power capacity in the Stated Policies scenario grows from about 1,500 GW in 2015 to 1,900 GW in 2020 and 2,700 GW in 2030. In the High RE scenario, the total installed capacity increases to 2,000 GW in 2020 and almost 3,700 GW in 2030.

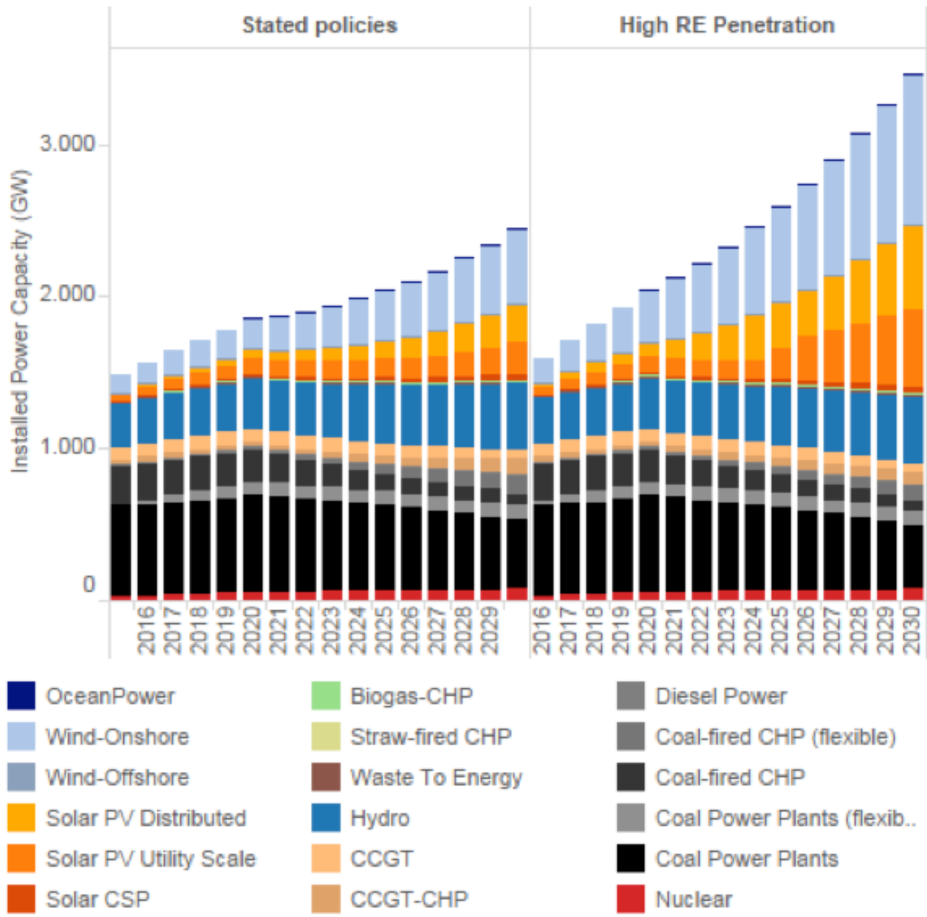


Figure 20: Installed power generation capacity in the two scenarios (not including storage).

The capacity development is predominantly driven by explicit assumptions based on planning targets. With increasing penetration of RE technologies, particularly wind and solar, which generally have lower capacity factors than most thermal plants, the growth in overall capacity exceeds the growth in power demand. In the High RE scenario, higher electricity load growth and increasing RE penetration, results in higher total capacity installation vis-à-vis the Stated Policies scenario. This is especially relevant where investigating the impact of existing polices and policy objectives as in the Stated Polices scenario. In the scenarios, policies are expressed primarily as minimum development targets for renewable energy, which in the absence of direct representation of explicit supporting mechanisms in the model set-up, represent inputs consistent with the stated policies.

Wind Power

The capacity development varies according to the timeframe, e.g., the period until 2020 includes provincial-level wind capacity targets of 165 GW out of the 210 GW wind power target in the Stated Policies scenario. Further, 5 GW of offshore wind power is required by 2020, and 10 GW by 2022. Offshore wind power is naturally limited to the coastal provinces of Jiangsu, Shandong, Shanghai, Hebei, Guangdong, Fujian, Zhejiang, Guangxi, Liaoning, Tianjin and Hainan.

These are based on the 13th Five Year Plan targets, which for 2020 state a minimum wind power target of 210 GW, but that China shall strive to reach 250 GW.

By 2030, the 13th 5-year planning documents indicate that wind capacity shall exceed 500 GW. As such, 2030 wind power capacity in the Stated Policies Scenario is 500 GW.

Meanwhile, in the High RE Scenario, the wind capacity targets are increased to 350 GW in 2020 and 1,000 GW in 2030. For the additional 500 GW, the location is not specified by policy, and the deployment location is identified based on economic considerations and with respect to regional resource potentials.

The total potentials for wind power are currently estimated to be:

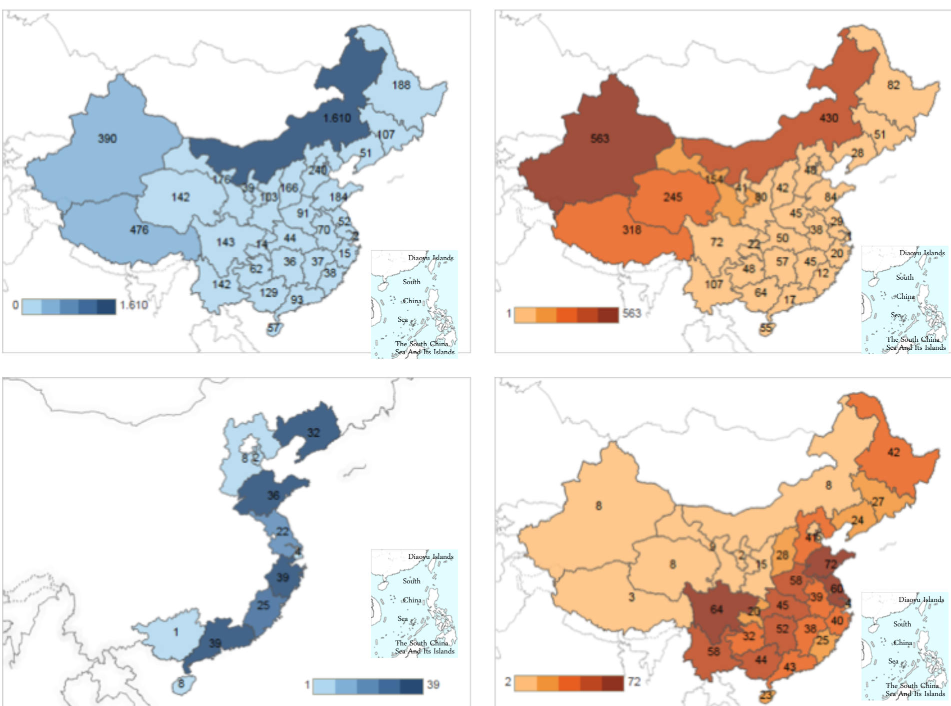
- Onshore 4,899 GW
- Offshore 217 GW.

The onshore potential is divided into three levels of resource quality within each province, plus a fourth level based on existing installations in 2015. The most abundant offshore wind energy resources are mainly in China's southeast coast in the Taiwan Strait. For the scenario analyses, it is estimated that the potential for off-shore wind power is 210 GW for a water depth of 5-25 meters.

The regional distribution of wind and solar resource potentials is depicted in Figure 21.

The onshore potential is divided into three levels of resource quality within each province, plus a fourth level based on existing installations in 2015. The most abundant offshore wind energy resources are mainly in China's southeast coast in the Taiwan Strait. For the scenario analyses, it is estimated that the potential for off-shore wind power is 210 GW for a water depth of 5-25 meters.

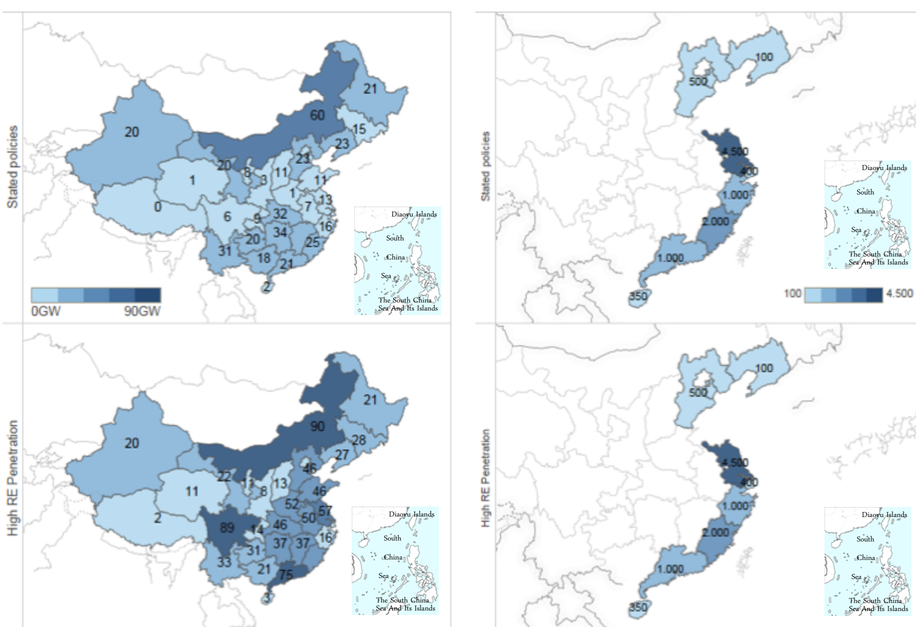
Figure 21: Distribution of potential for wind and solar installations (GW). Top left: Onshore wind, Bottom left: Offshore wind, Top right: Utility-scale solar, Bottom right: Distributed solar.



Currently, onshore wind power is mainly located in large wind farms in north, northeast and northwest China (the so-called "Three Norths"), and currently account for over 70% of the total wind power installations. But this pattern is starting to change with new installations, as central and eastern of China is increasingly deploying distributed wind power. In 2016-2020, additional wind power installations of around 130 GW are planned. Among these, in the "Three Norths" region, central and eastern China, and southern China capacity additions total 80 GW, 40 GW and 10 GW respectively, i.e., 61%, 31% and 8% respectively.

Offshore wind power is mainly located in east and south of China, with new planned on-grid capacity of 8.8 GW. Jiangsu Province and Fujian Province will be the key areas with offshore wind power installations, followed by Guangdong Province.

Figure 22: Wind power deployment by 2030 in the two scenarios. Left: Onshore wind deployment (GW). Right: Offshore wind deployment (MW).



Solar

For solar power, the Stated Policies Scenario sets a minimum capacity development of 170 GW by 2020 and 500 GW by 2030. Of the 170 GW in 2020, 58 GW is distributed PV, and 10 GW is concentrating solar power (CSP). For the 2030 figure of 500 GW, 250 GW is distributed PV, and 40 GW is CSP. Again, these minimum targets are based on the 13th Five Year Plan targets, which for 2020 state a minimum solar target of 110 GW, but that China shall strive to reach 170 GW; for 2030, China shall surpass 500 GW. The High RE Scenario raises the combined PV solar capacity target to 210 GW in 2020 (of which 95 GW is distributed), and 1,100 GW in 2030 (550 GW distributed).

While explicit provincial level targets also exist for most of the required capacity development based on the 13th Five-Year Plan, the additional capacity in the High RE Scenario determines the cost optimal location for additional generation.

Based on the China Metrological Administration's (CMA) Centre for Wind and Solar Energy Resources Assessment data for solar PV power generating capacity potential, and with consideration of other factors, i.e., usable land areas, development costs and transmission conditions, it is concluded that China's potential for centralized solar PV power plants may be as high as 2600 GW.

Distributed solar PV resource potential based on the EDO model includes potential for distributed power generation on buildings or other locations, such as the surface of fishponds, on agricultural greenhouses, and in areas along highways or railways. The distributed resource potential of buildings is mainly based on China's building area statistics (50 billion m^2 as of 2014), and on other factors such as future urbanization rate, newly-added building area per year, usable areas and energy consumption per unit building area.

The total potential for solar power is estimated at 3,800 GW, and is divided into four categories:

1. Distributed PV on buildings (541 GW)
2. Other distributed PV (407 GW)
3. Utility-scale PV (2,607 GW)
4. Concentrating Solar Power (248 GW)

These technical potentials at the national level significantly exceed the requirements for development until 2030, but the regional potentials limit deployment possibilities while still reaching the national capacity targets. As illustrated on Figure 21, the bulk of solar power potential is in the northwest and in Inner Mongolia, while distributed PV potential is particularly high in China's urbanised east, central and south. In both scenarios, distributed solar PV is expanded on buildings especially in economically-developed regions, i.e., Beijing-Tianjin-Hebei, Pearl River Delta and Yangtze River Delta. Distributed generation is therefore deployed close to the load centres and therefore has limited exposure to grid constraints, as well as grid scheduling issues which factor into the scenarios especially in the short-term.

In the southwest region, efforts will be mainly focused on development of GW-level power generating bases where hydro and solar power support each other with the support of existing large-scale hydropower bases in Yunnan and Guangxi. In the Stated Policies and High RE Penetration scenarios, targets reaches 115 GW and 170 GW, respectively.

In the western region, efforts will be focused on development of GW-level solar PV power generating bases intended for local consumption, and where possible transmitted via Ultra High Voltage (UHV) power transmission to southern and eastern load centres. This will be combined with the Silk Road Economic Belt development and land desertification control. In the Stated Policies and High RE scenarios, capacity reaches 63 and 148 GW, respectively.

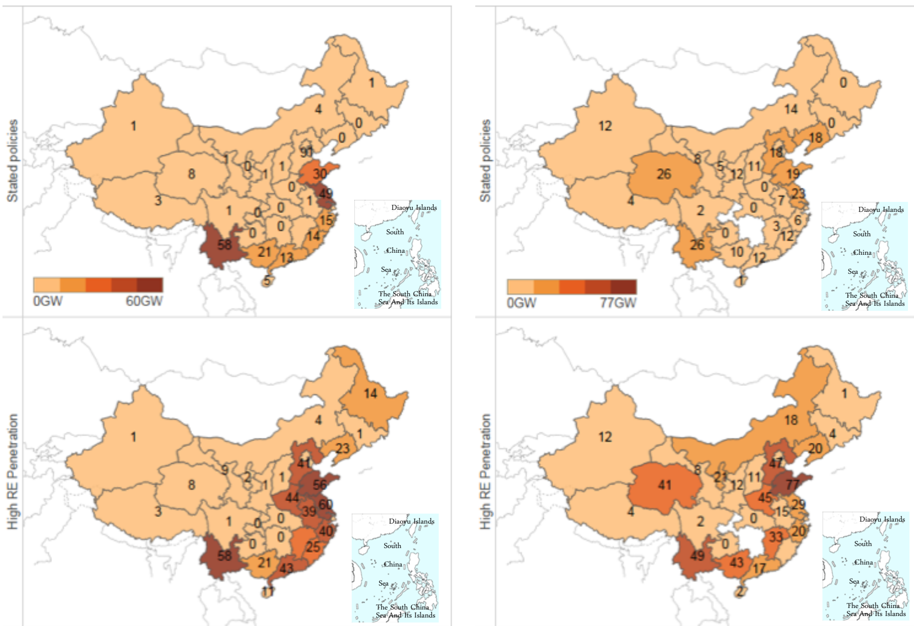


Figure 23: Solar capacity deployment by 2030 in the two scenarios.
Left: Distributed solar PV capacity both on buildings and other types of DG installations.
Right: Large scale installations including predominantly PV installations but also CSP.

Key areas for solar thermal power generation will mainly be the west region where solar direct radiation resources are abundant. Solar thermal power plants will be set up in Qinghai, Gansu, Inner Mongolia and Xinjiang, with a total capacity of 40 GW.

Biomass

Biomass and biogas have a combined maximum available heating value of 5,400 PJ by 2020 and 6,300 PJ by 2030, while the maximum available municipal solid waste (MSW) amounts to 1000 PJ in 2020, and 6,300 PJ in 2030.

With respect to biomass, biogas and MSW, in the Stated Policies Scenario the cumulative installed generation capacity is 15 GW by 2020, and 20 GW by 2030. In the High RE Penetration Scenario, these targets are increased to 20 GW by 2020, and 25 GW by 2030.

Ocean Energy

The development of ocean energy within the 2030 timeframe is negligible, with only 50 MW installed by 2020, based on demonstration projects approved as part of the 13th five-year plan, and 500 MW by 2030, based on considerations in the 13th Five Year Ocean Energy Plan. These targets are out of an identified potential of 14.7 GW of wave energy and 1,665 MW of tidal energy (ibid) which could be exploited in the long term. Ocean energy, like offshore wind, is naturally limited to deployment in coastal provinces.

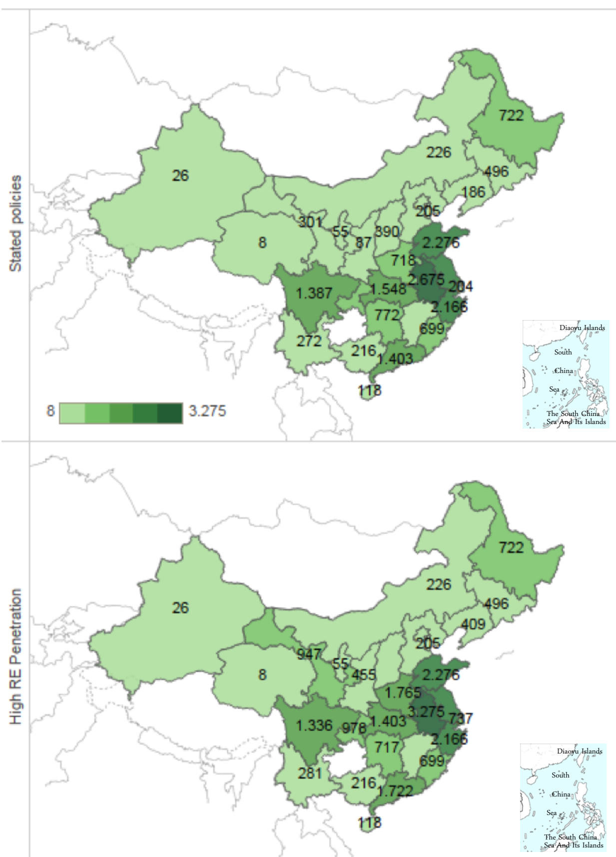


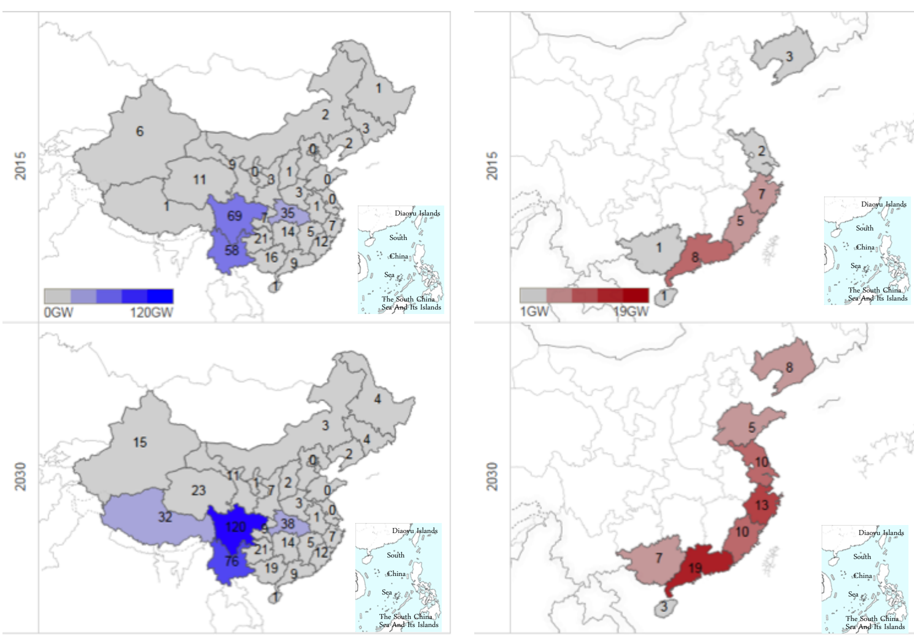
Figure 24: Biomass power capacity in 2030 in the two scenarios (MW).

The scenarios do not contain variations on the deployment of hydro and nuclear power. While these technologies have profound implications for the decarbonisation of the Chinese power system, they are not the focus of the CREO scenario analyses. Further, available data does not allow for sufficiently detailed analysis of the cost variations of different hydropower projects, as these are much more site-specific. Figure 25 shows the assumed development of hydropower and nuclear power in both scenarios.

Hydro

By the end of 2015 hydro power capacity was 320 GW. Until 2020, the assumed development follows the official development plan, resulting in accumulated capacity of 356 GW. By 2030, the assumed capacity reaches 460 GW. This does not account for pumped-hydro storage.

Figure 25: Development of hydro power capacity (left) and nuclear capacity (right) between 2015 and 2030 common for both scenarios.



Nuclear

According to the decisions by the previous as well as current government of China, construction of nuclear power plants in the inland and in large-scale construction in the Yangtze River Basin will not happen. The development of the western regions has priority for a "green mountains and clear water are as good as mountains of gold and silver", primarily based on renewable energy. Before the fourth generation of nuclear power technology is in commercial operation, it is assumed that China will not open the inland deployment of nuclear power. Based on this, we consider nuclear power development to be within the range of 100 GW in 2050, solely deployed in coastal areas.

At the end of 2015, China had 27 GW of nuclear power capacity. This capacity is installed in 7 provinces, namely Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi and Hainan. These provinces plan to expand their installed capacity. The first reactor in Shandong comes online in 2016. The net result is that by 2020, the total capacity is planned to reach 53 GW, and by 2030, 75 GW. The scenarios therefore limit nuclear power deployment to these estimates and the coastal provinces.

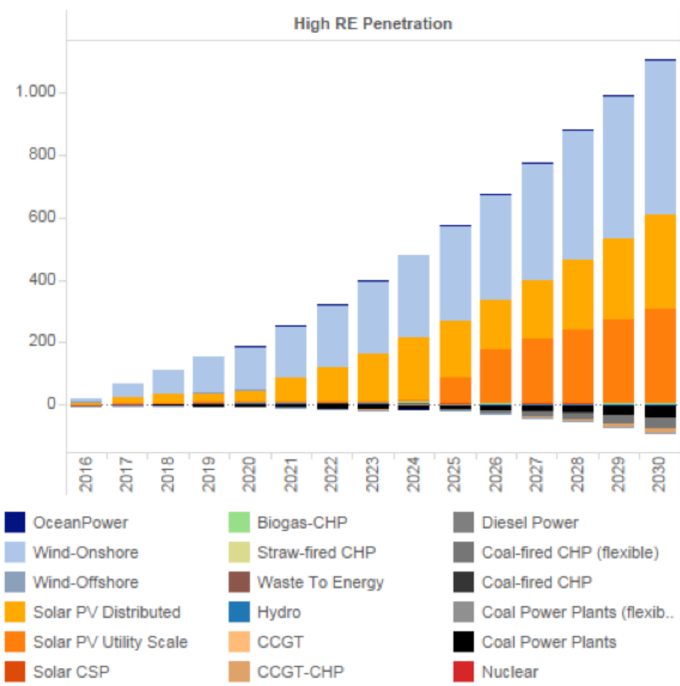


Figure 26: Difference in cumulative installed capacity in the High RE Penetration scenario compared with the Stated Polices scenario.

The key differences between the two scenarios in the power supply are the pace at which renewable energy is installed, and that a larger proportion of the total energy goes through the power system in the High RE Penetration scenario. Also, on an aggregated basis, less coal and natural gas fired capacity is installed in the High RE Penetration scenario.

Fossil Power Generation

At the end of 2015, roughly 200 GW of coal power capacity was under construction, approximately 40 GW was permitted, a further 215 GW was under pre-permit preparation, and an additional 250 GW was announced.

Deployment of new coal power capacity until 2020 is thus evaluated as:

- At least the 200 GW under construction by the end of 2015.
- At most, 455 GW, comprised of the units under construction, permitted and pre-permitted by the end of 2015.

However, considering the National Energy Administration's decision to halt approval of coal plants in 13 provinces, and delay construction of permitted plants in 15 other provinces, a maximum development of roughly 290 GW of new coal capacity is possible by 2020. These minimum and maximum coal power capacity additions are being implemented at the provincial level.

In the key regions of JingJinJi (Beijing, Hebei and Tianjin), the Yangtze River delta, and the Pearl River delta, maximum coal plant capacity is maintained beyond 2020. Furthermore, coal is planned to be phased out from Beijing by 2017.

Coal power capacity initially increases according to the current trend, but drops off after 2020, so that the total installed capacity in 2030 is less than in 2015 in both scenarios. Natural retirements of coal plants will be supplemented in some cases with a mix of flexible and baseload units, both condensing and CHP. From 2020 to 2030, new coal installations are more than offset by retirements of plants that exist today, leading to a net capacity decline.

After 2020, it is assumed that it will be up to the market to ensure that only new coal capacity that is needed will be commissioned, i.e., there are no longer any minimum new-build coal capacity in the model as was the case from 2015 to 2020. Coal capacity therefore peaks in both scenarios in 2020 at 960 GW. In 2030, the Stated Policies scenario has 710 GW of coal-fired capacity, while in the High RE Penetration Scenario total coal-fired capacity falls to 660 GW.

With the increased expansion of renewable energy, coal-fired capacity is thus notably lower in the High RE Penetration Scenario by 2030. However, as increased electrification of end-use energy demand leads to higher electricity demand, the net-capacity decline is initially slower in the High RE Scenario. This merits reflection in relation to the timing and rate of power supply transition with respect to the pace of electrification.

In 2015 around 15% of China's natural gas consumption was in the power sector, including for district heating in CHP units. In the scenarios, this proportion is assumed to increase to reach 20% by 2020 and 30% by 2030. The same quantity of gas is consumed in the two scenarios, however, deployment of gas-fired power (and district heating) generation capacity and the time it is used also differs.

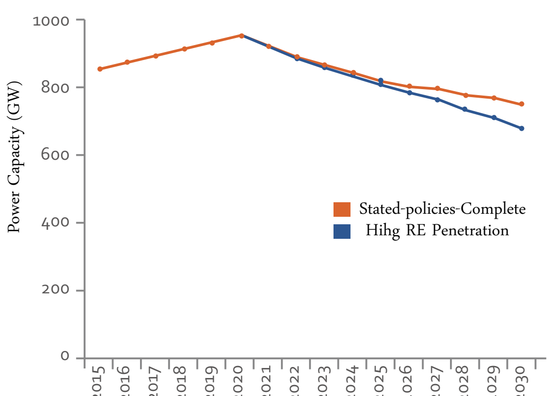


Figure 27: Coal-fired capacity development in the two scenarios

The deployment of natural gas-fired power and district heating generation capacity is driven by environmental concerns, primarily to alleviate deteriorating air quality. As coal-fired power development is constrained in key areas which have access to natural gas, gas-fired generation is being promoted to reduce reliance on coal for power generation. Beijing, Shanghai, Tianjin, Guangzhou, Shenzhen and other large modernised cities will rely on new installed capacity fired by natural gas to generate electricity, as well as heat--particularly in the northern provinces.

Other than politically driven restrictions, the most important factor determining where new coal-fired capacity may be built is the coal price.

Given the low coal prices in Inner Mongolia and Xinjiang, it is not surprising that they are among the provinces with the largest increases in coal capacity from 2015 to 2030. Despite having slightly more expensive coal than Xinjiang, Inner Mongolia realises significantly larger coal capacity growth because it is closer to the major load centres, and the lower transmission costs therefore offset the slightly higher coal costs.

When comparing the coal-fired capacities of the two scenarios in 2030, they are quite similar. However, when comparing the coal-fired capacity in the 2030 scenario to the present situation, one of the most striking differences is the extent to which coal-fired capacity becomes increasingly concentred in a few provinces.

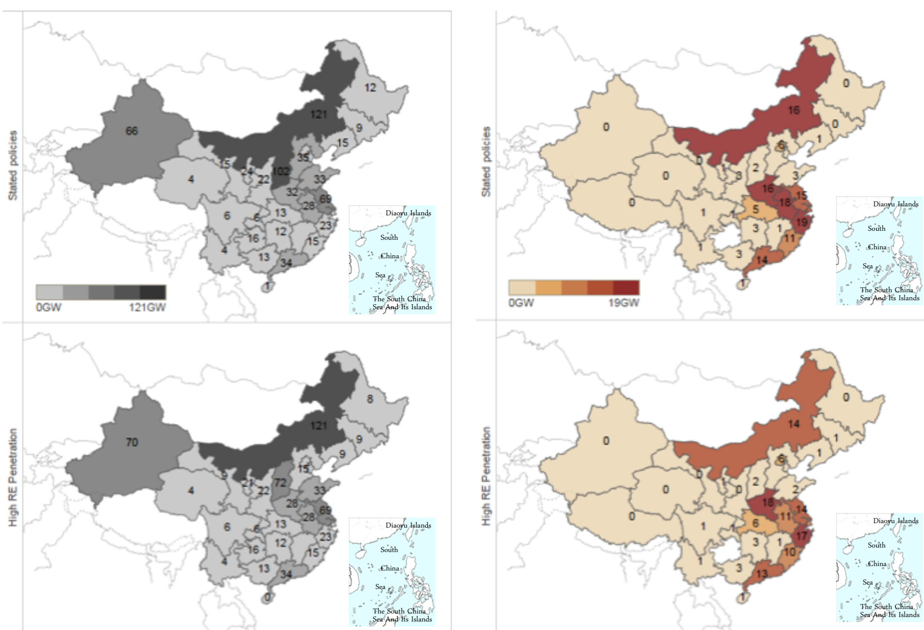


Figure 28: Coal-fired capacity (left) and gas-fired capacity (right) in 2030 in the two scenarios.

By 2030, the 4 provinces with the largest capacity represent roughly 50% of total coal-fired capacity, whereas this was less than 30% in 2015. This consolidation of coal generation reflects several political, economic, and modelling factors. First, provinces in China have historically looked to meet provincial electricity demand with production from within the province, and there has therefore been less focus on transmission of electricity between provinces. However, this trend has been altered by the politically determined establishment of power bases and transmission lines from coal- and RE-abundant provinces in order to transport this lower-cost electricity to load centres with higher electricity production costs. This political decision is bounded in an economic one, namely that coal costs are lower in these provinces, and RE resources are also often superior, thus resulting in lower electricity production costs in these areas.

Both aspects are reflected in the analysis, optimizing on a mainland China basis; while accounting for the facts that coal costs and RE resources that vary from province to province, and transmission costs must also be accounted for. Thus, while also taking transmission costs into account, the results show that economically optimum options will concentrate investment in coal capacity in provinces with the lowest coal costs (assuming there are no restrictions on coal-fired production capacity there).[2]

This rather extensive consolidation of coal-fired capacity could have a number of effects. First, it concentrates the environmental effects within a few provinces, which could lead to local and provincial discontent. On the other hand, the economic benefits associated with jobs in the coal plants and coal mines, and income from the sale of electricity will also become concentrated, which may lead to some dissatisfaction between provinces.

[2]It should be noted that there was not significant data available to differentiate coal prices depending on coal power plant build-out, i.e., that the cost of coal in a province may increase as successive coal plants are built in that province.

Overcapacity Stresses Full Load Hours

The general picture is that between 2015 and 2020 the overcapacity situation will put pressure on the full load hours available to coal plants. After 2020, as the installed capacity balance is gradually allowed to normalise through retirements, the average unit full load hours can converge to levels traditionally considered economical. In addition, units originally established as flexible units (see below) will gain an increasing number of load hours as the capacity balance improves, retaining the important role of balancing plants until 2030.

New Capacity, With Focus On Flexibility

A key result is that both scenarios see significant investment in more flexible coal power plants.

New coal-fired capacity is found to be economic from five options:

- USC 1,000 MW coal units with 48% gross efficiency – 3.3 million RMB/MW
- 660 MW coal units with a 41% gross efficiency – 3.4 million RMB/MW
- Flexible 660 MW unit with 41% gross efficiency – 3.5 million RMB/MW
- Standard 350 MW CHP unit with 41% gross efficiency (in power-only mode) – 4.1 million RMB/MW
- Flexible 350 MW CHP with 41% gross efficiency (in power-only mode) – 4.3 million RMB/MW.

As highlighted in Figure 29, as the variable renewable energy (VRE) penetration increases in both scenarios, new installations of coal power are increasingly in units dubbed as 'flexible,' despite these having higher investment costs, as these units are more economic than inflexible coal generation options. The key takeaway: the value of the improved flexibility is greater than the additional investment costs.

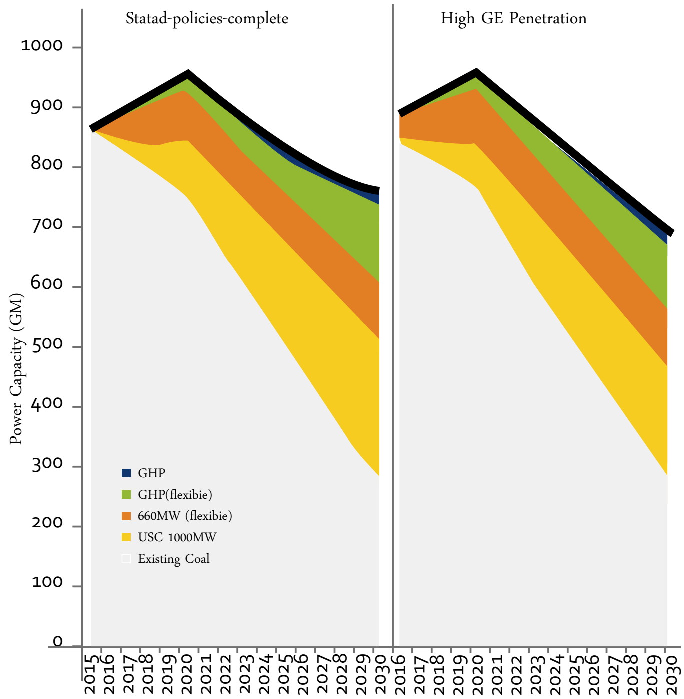


Figure 29: Development of coal power capacity in the Stated Policies Scenario(left) and the High RE Penetration scenario (right)

The Future Of Coal Power In China

In 2020, China may have roughly 1,000 GW of coal-fired capacity in its power system, a system that is facing a future where the traditional baseload operating paradigm is no longer economically feasible. New coal plants will need to have greater flexibility, and existing plants will need to be operated differently, retrofitted or retired. Within the High RE Penetration scenario, economic returns to these more flexible coal generating units will be supported by fundamental drivers in power system economics, i.e., a power price that reflects short term marginal costs.

The flexibility resource associated with the existing coal power plant fleet is large and it substantially reduces the need for other flexibility technologies, which may or may not be developed in the future. Currently the power plant owners have no economic incentives for flexibility. On the contrary, guaranteed full load hours and fixed pricing strongly discourage flexible operation of the coal fired power plants.

However, this situation is about to change. The National Development and Reform Commission and National Energy Administration jointly issued a policy document in July 2016 for public consultancy. It stated that new coal plants put into operation after March 15, 2017 will not have their full load operating hours guaranteed, nor will they be able to sell power at the regulated on-grid tariff. Instead, their generation volumes must be sold via power market trading, with the joint statement encouraging large consumers and generation plants to engage in direct bilateral trade.

In the medium term, the implementation of a power market will give strong incentives for flexible operation. When power markets were liberalised in Europe, it took some time before the industry adapted to the new reality. However, given the present European market situation, with overcapacity and increasing renewable energy penetration, the establishment of new thermal (particularly coal) plants has stopped, as the overcapacity has driven power prices down to the point where baseload plants are not economical.

The question remains whether the reform in China's State-Owned Enterprises will permeate quickly enough to adjust to the new reality. The implementation of a spot market without capacity mechanisms (i.e. an energy-only market where electricity prices reflect short-term marginal costs), would quickly curb the development of overcapacity, assuming the investing companies behave rationally and are profit driven. The market reform itself presents an historic opportunity, but to be successful, it is critical to get the market design right. Experiences from power markets in Europe and the US teach us that market actors provide the services that are priced, thereby making it essential to create the regulation, rules and markets for the products and services required for the power system, and not provide compensation for other services. This means that some services traditionally provided free of charge by thermal generators, i.e., spinning reserves, etc., may need to receive compensation in the future. Meanwhile other services, with or without compensation, may increasingly be delivered by other types of plants, including RE plants, the power grid, or even by demand side management.

To comply with the government's direction for the energy transition, the coal sector needs to undergo a fundamental change of mind-set regarding the future role of coal-fired generation units. Furthermore, the trend involving new coal plant construction without regard to whether it is required, needs to halt. Given the size, importance, and complexity of the Chinese coal-fired generation sector, one must be cautious when attempting to simplify the challenges going forward.

The most prominent issues that must be addressed to both facilitate a transition to a less CO_2-intensive energy sector, while at the same time maintaining the economic viability of coal plants are:

- Reduction of overcapacity
- Improved flexibility
- Payment reflecting short-term marginal costs and system services delivered.

Evolution Of The Power Generation Mix

In 2015, the RE proportion of power generation was 25%. The Stated Policy scenario reaches 37% in 2030, while the High RE Penetration scenario reaches 53%. The non-fossil proportion of power generation goes from 29% in 2015, to 47% and 60% respectively in the two scenarios. The difference in the RE and non-fossil percentages is solely determined by the contribution from nuclear power.

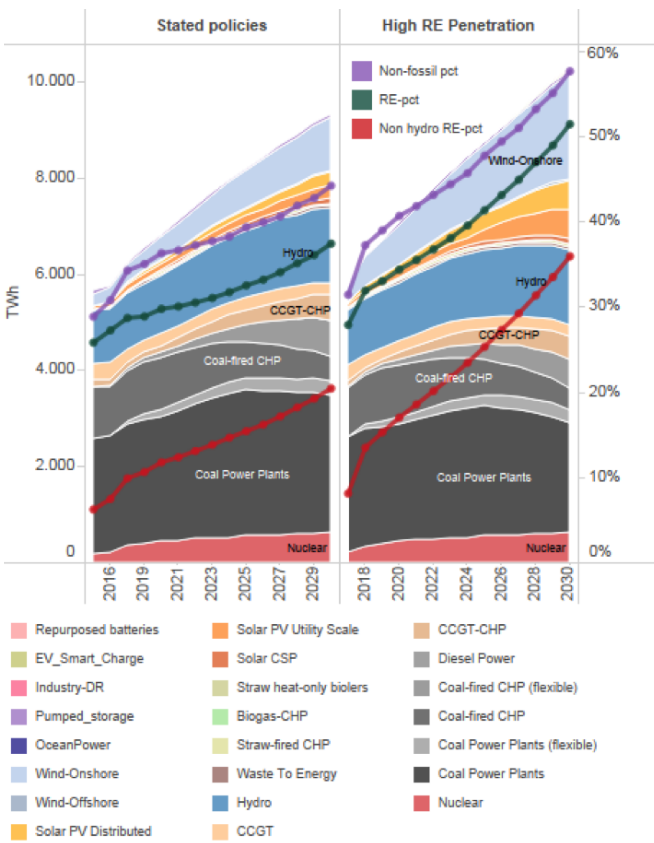
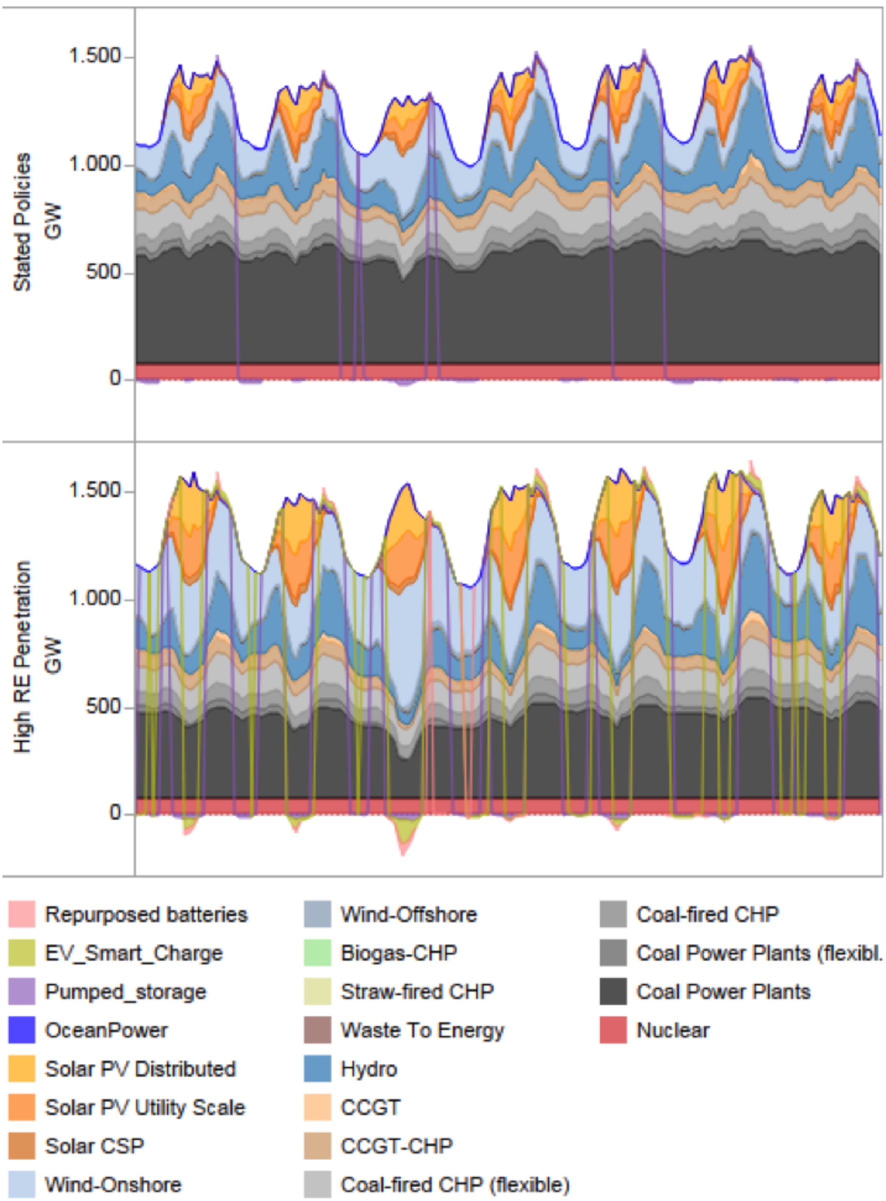


Figure 30: Power generation mix in the two scenarios, as well as the RE-proportion and non-fossil proportion. The dotted lines indicate, as a proportion of the total electricity generation, the non-fossil percentage, the renewable power percentage, and the non-hydro renewable power percentage.

3

In terms of the scenario calculation process, the key capacity expansion and deployment results are supplemented with production simulation model runs taking capacities as input and running at hourly intervals.

Figure 31: Hourly dispatch of China's national power supply and storage in a sample week (12) in 2030 in the two scenarios.



The hourly analysis verifies that the power system can balance supply and demand at the hourly level, for the generation, storage and demand response capacity mix. Furthermore, the detailed analysis shows that balancing can be achieved efficiently with only very limited curtailment of VRE output.

However, this result is based on several assumptions regarding the economic and institutional framework for the power system. These assumptions include holistic planning of deployment and use of power supply, transmission, storage and demand response capabilities; provision of efficient incentives for asset owners to develop and operate in line with overall system objectives, with the specific assumption that the power reform will develop an efficient power market; and that institutional barriers are removed and that operational approaches and perspectives are modified to conform with the reality of a power system with High RE penetration, and particularly high penetration of VRE sources.

Creating Flexibility In The Chinese Power System

The scenarios show that it is possible to make substantial increases in variable renewable energy deployment within the 2030 timeframe, and to do this without increasing, but rather by solving the present curtailment issue. Efficient integration of RE into the power system is not a problem, provided the right regulatory and economic framework is in place. A Chinese wholesale market for electricity would be the main driver for integration and cost efficiency

Large curtailment shares for RE are a waste of money for society and can be avoided, even with large amounts of RE power production.

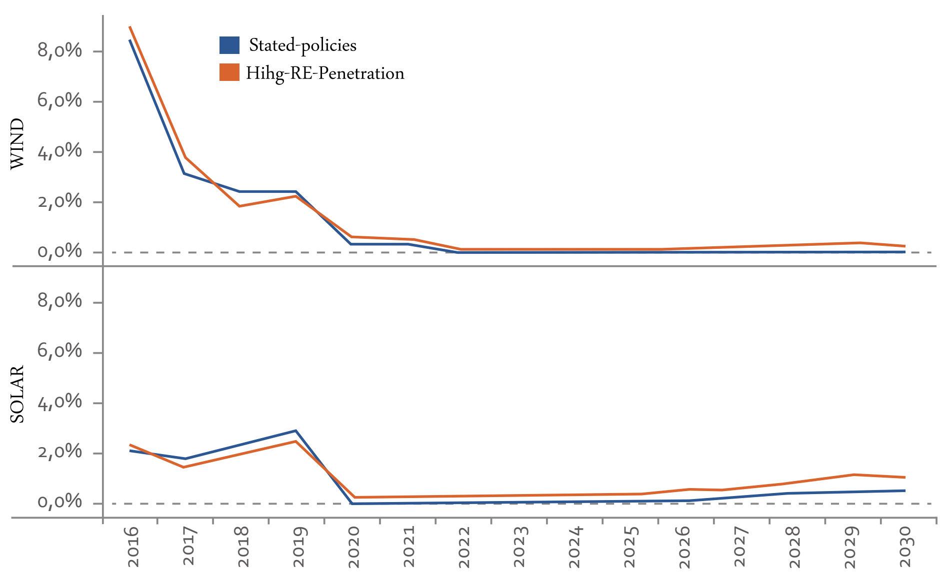
In the scenarios, urtailment is reduced initially by load growth, transmission expansion, reduction in guaranteed full load hours for thermal plants, increased system flexibility and efficient deployment locations.

From 2020, inter-provincial transmission flows follow market-based scheduling each hour, leading to significant curtailment reduction. As VRE penetrations reach higher levels, curtailment slowly climbs, especially for solar power which is more predictably periodic.

Market prices motivate additional flexibility from demand response including EV smart charging (High RE Penetration scenario) and flexible interaction between power and district heating, through storage and power to heat. Flexible coal, flexible CHP, and EVs are the new providers of flexibility, together with a dynamic use of transmission. Pumped-storage plays a role but other electricity storages are less competitive in the 2030 timeframe. In the High RE Penetration scenario, repurposed batteries and demand response provide the system flexibility of last resort. This, along with the successful deployment of EVs, should be caveated to acknowledge uncertainties: if such potentials are not realized or their implementation is found impractical or uneconomic, there are other flexibility sources which could be deployed.

Figure 32: Development of the curtailment percentage for wind and solar in the two scenarios.

Figure 33: demonstrates the complex picture of a fully flexibly-operated power system, as it looks in the High RE Penetration scenario in 2030. While there is a lot of thermal generation operating in this system by 2030, what is there is used quite flexibly, for example, ramping down completely as a strong wind front enters the system on the third day while solar power peaks.



The system contains both pumped storage and chemical storage (i.e., repurposed EV batteries) which are charged mainly during the midday solar peak. The storage capacity is mainly discharged in the evening load peak as the sun sets and power consumption rises. This would also be the time when drivers park and plug in their EVs; however, with automated smart charging it is cheaper for the drivers to shift their charging to the day-time. This consequently assumes that a proportion of vehicles are plugged in during the day, either at homes, at workplaces or at public charging infrastructure.

The example days shown in the Figure are for the heating season, during which electric boilers also operate and consume power to make heat, when the solar and wind power generation is high.

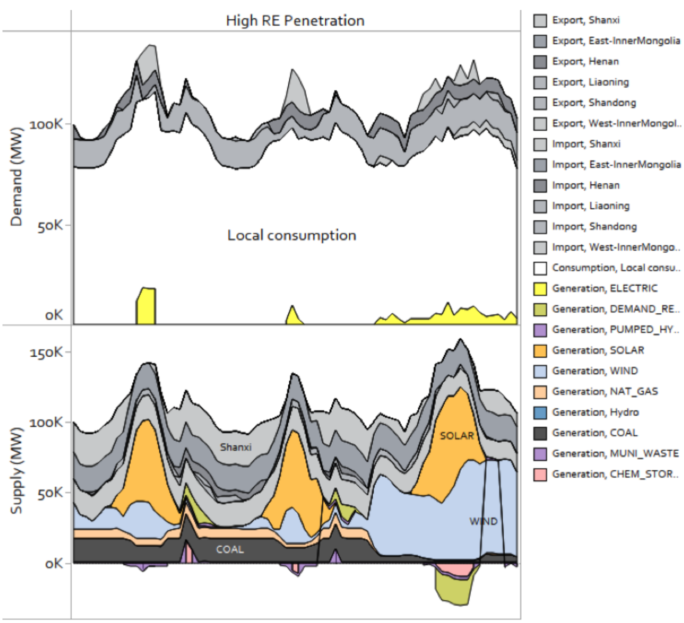


Figure 34: Power system balancing in the combined Beijing, Hebei, Tianjin area over three selected days for illustration of system balancing. The top chart shows the 'demand side,' meaning power leaving the grid in this area. This includes normal electricity consumption load, additional electricity consumption from electric boilers in the district heating system, and exports to connected provincial grids. The bottom chart shows the supply side, including the local generation from different sources (in colours), stacked with the imports from other grids (in greyscale). Below the 0 mark we see storage charging and increased load from demand response including EV charging.

3

One of the most important resources for balancing the system with increasing levels of RE is allowing the interprovincial and interregional grids to operate flexibly at a fine time resolution. The exchange on the interconnectors should be based on market prices set shortly before the time of operation using day ahead markets, 1 hour, 15 minute, 5 minute and real time markets, balancing markets and ancillary reserve markets, and promoting resource sharing over as large a system as possible. Some grid connections may primarily provide baseload transmission, i.e., when the one end has abundant low-marginal-cost power and balancing resources. (As an example, consider the hydro-intensive areas in central China, which also see significant VRE deployment.)

Other transmission lines will fluctuate depending on which grid has the least expensive available power and greatest balancing resources.

Power Grid Development

Generally, when power systems increase the proportion of (variable) renewable energy capacity, the optimal relative capacity and capability of the power grid increases.

The scenarios begin with the existing transmission capacity. This capacity is assumed to be augmented according to current plans for UHV grid expansions in the period from 2016-2020. Beyond this timeframe, there are no firm plans to rely on, and therefore the model determines economic optimal investments to be added in the period 2021-2030.

Simulations performed to date did not find it economical to make significant additional investments in the very long distance transmission corridors from the far west of the country, that is from provinces such as Xinjiang, Gansu, Ningxia and Qinghai to the coastal provinces. There are several reasons for this:

- During the 12th and 13th FYP periods, significant transmission corridors with record-breaking capacities have already been established, thus, the power transport needs have been satisfied.
- Regional rebalancing: While renewable energy production is currently concentrated in very remote areas, many of these areas are

also where electricity consumption will grow the most.

- With the introduction of low-speed wind turbines, wind power potential assessments have increased in recent years, with the bulk of the additional potential being in less windy areas that are closer to load centres. These provinces are already attracting increased development, as investors are wary of the high curtailment rates in the "Three Norths" area.
- Distributed renewable energy development, particularly distributed solar PV generation, is projected to increase rapidly, primarily serving demand in the load centres it is deployed in.
- As China's power demand centres and coastal regions largely coincide, cost breakthroughs for offshore wind also lead to increased RE deployment closer to existing load centres.

Furthermore, by promoting that the transmission system is to be used effectively to transmit power according to the demands determined by the market, the existing grid infrastructure is used more effectively, which also reduces the need for additional grid investments.

Investments

The energy transition in both scenarios requires significant investments to be directed to the deployment of renewable energy. Looking at the RE power sector, the pace of RE investments is only slightly increased in real terms in the Stated Policies scenario. As deployment increases, reductions in RE investment costs provide an offset. Renewable energy investments are doubled in the High RE scenario by 2030.

Table 1: Investments in the RE power sector in the perspective of the broader energy system and overall economy.

	2015	Stated Policy	High RE Penetration
		2030	2030
RE investment(trillion RMB)	0.46	0.66	1.34
RE share of energy investment	30%	37%	45%
RE share of all investment	2%	1%	3%

While investments in renewable energy increase in both scenarios, in the Stated Polices scenario, the RE power sector's investment increase does not keep up with the development in the overall economy, where annual investment growth rate (7.4%) exceeds the average national economic growth rate (5.8%) over 2015-2030 periods.

Economic Impacts Of Re Development In The Power Sector

Investments in renewable power stimulates direct value added of 1.7 trillion RMB in the Stated Policies scenario and about 2.8 trillion RMB in the High RE Penetration scenario by 2030. In the High RE Penetration scenario, this constitutes approximately 2.2% of GDP. Additionally, about 50% (1.6 trillion RMB in High RE scenario) of additional value added is simulated in the supply chain.

As both scenarios entail an increasing role for natural gas through 2030, the contribution of the gas sector to economic output and value added grows roughly in proportion with this increase.

The coal power industry's total output and value added is increases slightly in the Stated Polices scenario from 2015-2030, while there is a slight decrease in High RE Penetration scenario. This implies that while the coal power sector's days of significant economic expansion may be in the past, at least until 2030 in these scenarios, a soft landing is projected and the coal power sector can be made whole for past investments, particularly if it conforms to the new reality where a premium will be put on flexibility over baseload efficiency.

It is noteworthy also, that in comparison with fossil fired generation, RE captures a bigger proportion of the value added within the primary sector; in contrast, a large proportion of output and value added in upstream sectors for coal power is captured in the resource extraction and supply stages.

Power generation companies, which span both RE and fossil technologies, will be able to increase their stake in the overall economy from increased RE focus based on kWh delivered.

It is noteworthy also, that in comparison with fossil fired generation, RE captures a bigger proportion of the value added within the primary sector; in contrast, a large proportion of output and value added in upstream sectors for coal power is captured in the resource extraction and supply stages.

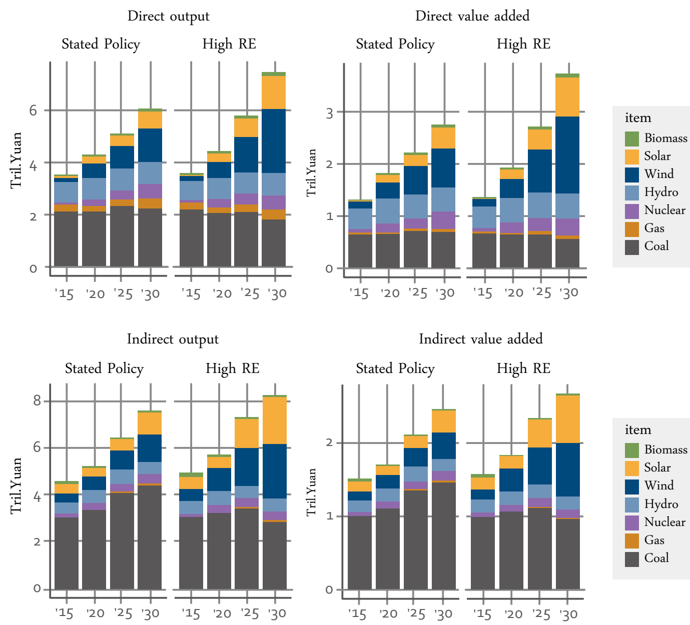


Figure 35: Direct output (A1), direct value added (A2), indirect output (B1), and indirect value added (B2), of power sectors up to 2030 (2010 prices)

Employment Effects

The distribution of job creation among different sectors shows a similar pattern to that seen in the results for outputs and value added. The employment is largely moved from conventional fossil fuel sector to machinery, services, and construction sectors, indicating negative impacts of renewable energy development particularly on the coal extraction and oil refinery sectors. However, this employment shift would last a relatively long period which provides enough time for the government to smooth the industrial transition.

In 2030 in the High RE Penetration scenario, developing renewable energy creates 15.5 million jobs in total, including direct jobs of 7.2 million jobs in the RE sectors and 8.3 million jobs in other sectors. Most jobs are from the following sectors:

- Service: 3.8 million jobs
- Machinery: 1.9 million jobs
- Metal: 1.9 million jobs
- Transport: 1.2 million jobs
- Electronic: 0.53 million jobs.

Hydro power, in the Stated Policy scenario, still takes the leading role of direct employment of RE sectors in 2030 and its share over total RE employment even increases. The employment share of the wind sector, however, declines from its 2020 peak to less than 20% of total. In the High RE Penetration scenario, employment in the wind sector overtakes that of the hydro sector and becomes the largest employer in the overall RE sector. For both scenarios, solar power ranks third for total RE employment.

By considering the negative effects on the other sectors related to conventional energy supply, the overall impacts on employment at the sectoral level are as follows:

In 2030 for the High RE Penetration scenario, the top five sectors with biggest employment losses are:

- Coal mining, Construction, Crude oil, Extraction of petroleum oil, and Forestry, with loss of -29.86, -0.88, -0.47, -0.47, -0.44%, respectively;

And the last five sectors with smallest employment losses or even gains are:

- Scientific research and education, Machinery, Electronic equipment, Nonferrous metals, and Metal products, with change of 0.92, 0.67, 0.65, 0.36, 0.34%, respectively.

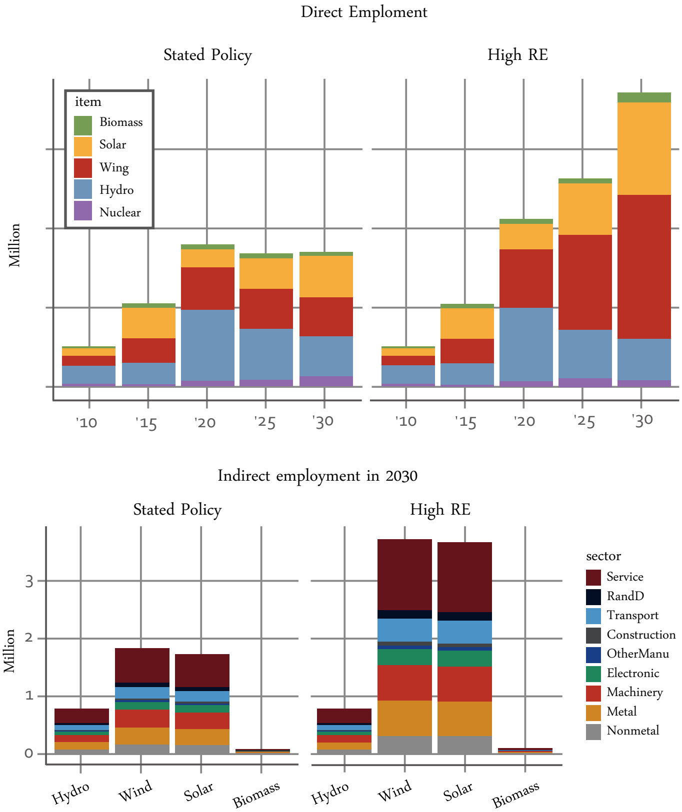


Figure 36: Direct employment of RE sectors until 2030 (top) and indirect employment in other sectors stimulated by non-fossil energy sectors by 2030.

Impact On GDP

While the positive impacts stimulated by the development of renewable energy are apparent in terms of direct and indirect stimulation of RE-related sectors, other sectors, especially those related to the conventional energy supply chain, may suffer negative impacts. The development of renewable energy on such a large scale has wide-ranging implications.

Naturally, the most negatively affected sector is coal mining. Significant negative impacts are observed in energy-intensive sectors such as construction, cement, iron and steel, mineral mining, and machinery, as investment flows are absorbed by the renewable energy sector. Investment toward the construction of fossil-fired power plants and other sectors which are stimulated by demand for products of the previously mentioned high-carbon sectors decreases. Meanwhile, benefits accrue in upstream sectors of RE investment, e.g., electronic machinery, and in the research and development sectors.

The net impacts in 2030 are as follows. On the supply side, the total outputs of all sectors are reduced by 0.03%, and the GDP increases by 0.27%. On the final demand side, household expenditures and government expenditures change by 0.36% and -0.15%, respectively, and export and import increase slightly by 0.21% and 0.22%. This implies that large investment in RE development will not cause significant shock to the macro economy. On the contrary, it will create a more sustainable and greener industry structure.

CHAPTER 4

Implementing A Sustainable Energy System

In the previous chapter we have demonstrated that renewable energy is part of the solution to the current problems for the Chinese energy system. We have also shown that an energy system with a high share of renewable energy is feasible and the system can be cost efficient, provided that the right regulatory and economic framework is in place.

Clearly, the current framework conditions are not sufficient. As shown in the first chapters, a number of urgent problems have not been solved and a strong effort is needed to ensure a steady transition towards sustainability.

In the next chapter we will examine the most important policy measures and institutional settings for promoting renewable energy in the Chinese energy system. The analyses are based on Chinese research combined with international experiences, mainly from Europe and USA. These experiences are harvested together with our international partners and makes the best available platform for using international experiences in a Chinese context, because the partner countries, US, Denmark and Germany are international frontrunners in renewable energy utilisation and integration as part of a more comprehensive energy system transition. In China CNREC has worked together with North China Electric Power University and Tsinghua University regarding the flexibility topics.

Creating Flexibility In The Chinese Power System

One of the most important power system features for an efficient integration of renewable energy is flexibility. In the past, demand for flexibility in the electric power system mainly arose as a result of load fluctuation and unexpected outages of thermal units. Today, an increasing share of variable renewable energy (VRE) production requires the power system to be able to quickly adapt to the production from the variable production as well as the variable load. The current power system is not set-up for such requirements, hence, planning and operation of electric power system must be profoundly reformed to improve the full electric power system's flexibility.

In the future, electric power system must give into full play to the "systematically flexible resources", including flexible resources at power generation side, demand side, power grid and for energy storage to unleash and improve cost-efficient flexibility in power system. It is necessary to look at the whole supply chain to create a flexible power system and to create strong incentives for the stakeholders to implement flexible solutions. The experiences from Europe and USA clearly shows that an efficient power market with time dynamic pricing is part of the solution. We will discuss this later in the report.

Generation Flexibility

International studies suggest that introduction of power markets and creating flexibility for the thermal power production are the most cost efficient flexibility measures and they should be implemented before turning to more expensive solutions like electric storage technologies. For China, the large 1000 GW coal power capacity is an obvious starting point for increased flexibility besides further development of pumped storage power plants.

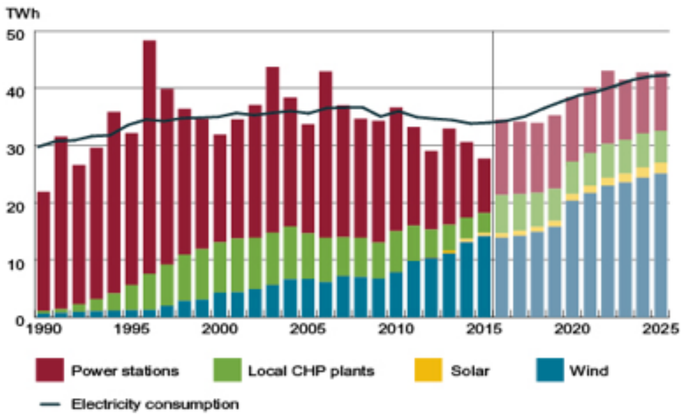
As example, in Denmark thermal power units are retrofitted to allow for faster ramping and low minimum stable production

(20% of rated capacity) and for significantly more flexible cogeneration by adding thermal storage systems, enabling the power plant to increase power production in condensing mode in periods where the electricity price is high, or to stop production in periods where the price is low (the heat storage takes care of the district heating supply).

In 2016, National Energy Administration (NEA) launched a demonstration program for thermal power generation flexibility to increase peak shaving capacity of existing thermal power generation units (CHP and condensing units). The aim is to demonstrate that Chinese power plants can reach an an internationally advanced level with minimum technical output of the units at lowest stable firing load without oil in condensing condition can reach 20%-25%. Presently, the program comprises units with a total installed capacity of around 18 GW. By referencing international advanced experiences, supporting policy and incentive mechanisms, China should be able to promote retrofiting and upgrading of thermal power with total capacity of 500 GW into flexible energy. Thermal power generation in areas of Three North Region (i.e. North-western, North-eastern and Northern China) with RE concentrated and part of power receiving areas in Central and Eastern China should reach the advanced level of Denmark.

Demand Side Flexibility

A large variety of flexible resources are present at demand side, ranging from energy-intensive industries, daily domestic power consumption service and intelligent furniture, electric vehicles, heat pumps and water heaters, etc. The whole society needs to jointly participate in demand response to allow demand response to reach 15% of maximum power load and even higher. In future, large industrial users with technical conditions available should normalize participation in demand side response by using intelligent control technology.



Changing role of thermal plants in a high renewable power system
The Danish energy transition affects thermal power plants:
• Increased amounts of wind and solar power reduce the market share of thermal plants.
• Closure of coal-fired power plants with no heat production
• Coal-fired CHP's are converted to biomass.

Figure 37: Electricity production development in Denmark (historic prior to 2015, and anticipated thereafter)

For thermal power plants to survive, they must adapt to a new situation and focus on flexibility and the provision of other services. Figure 38 illustrates a Danish CHP extraction plant with increased its operation area by reducing its minimum load.

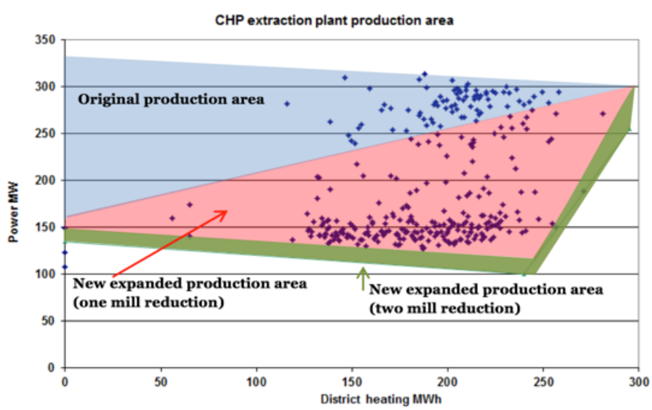


Figure 38: Change in production area due to investment in flexibility for a CHP extraction plant
Before the changes, the minimum load was 45%, and the result of the changes (which took roughly half a year), was that the operation area was doubled, and the minimum load reduced to 36%. The dots in the figure represent each hour of production during the first month of production with the enhanced production area.

Controllable electric appliances of business users and residents (e.g. dishwashers and washing machines), intelligent electric vehicles of transport sector will automatically adjust operating power or operation time, allowing for load adjustment or load shifting. In particular, tens of millions of electric vehicle charging stations will evolve into one of essential providers for flexible resources at demand side while energy storage could evolve into one of essential providers for ancillary service of frequency regulation.

Grid Flexibility

The power transmission and distribution network is the key vehicle for the power system's flexibility, allowing various flexible resources to be sharing and supplement each other in both space and time. Utilities, ISO and RTO of U.S. are now enhancing cooperation and merging, and also Denmark and Germany accommodate wind power and facilitate power balance in Nordic System and ENTSO-E. China needs to enhance and make best use of power interconnectors between provinces and regions to accommodate RE and facilitate power balance in regional and national power grid as well as the electricity market, which can not only increase available flexible resources but also improve efficient use of these resources.

Power Markets As Key Driver For Re Integration

The most decisive factor for increasing flexibility in the power system is to create economic incentives for the different stakeholders. Establishing of a transparent power market (wholesale and retail) is an efficient way to create dynamic pricing, where the price of electricity reflects the supply and demand for electricity on an hourly or sub-hourly basis.

Since the 1990s, countries as the United States, Germany and Denmark have gradually established the mature competitive modern electric power market including spot markets (day-ahead, intra-day and real-time) and medium and long term trade contracts to promote the cost efficient purchase of electric power and renewable energy. In recent years, more attention is paid to the improvement of the flexibility of the power system through the electric power market. For example, the promotion of more flexible five-minute spot market transaction and economic dispatch and more complete auxiliary services and products (such as unbalanced and ramping products), grid interconnection and balance area in a wider range, quicker short-term transaction settlement. Meanwhile, more attention is also paid to the comprehensive and fair utilization of all flexible resources and to promoting the power grid supervision with flexible performance and integrating the electric power and thermal systems. The electric power market and flexible dispatching become important measures to promote the integration of renewable energy.

China has not yet established a modern electric power market system and this hampers the efficient development and operation of the whole power system with conflicting interests between the thermal power generators and the developers of renewable power plants. As a consequence, traditional thermal power plants still continue to strive for base-load power production, the inter-provincial and inter-regional electric power transaction are not optimised, and demand side response resources do not have incentives to be activated. All-in-all, this seriously restricts the release of flexibility improvements in the electric power system in China. Today, it is widely recognized that the missing power market mechanism has become the key issue in influencing the consumption of renewable energy.

In March 2015, Chinese government issued the “Several Opinions on Further Promoting the Reform of Electric Power System” document (ZF [2015] No.9) which provides a new driving force for the market-oriented reform of electric power and the transformation of electric power into green and low carbon mode. In the future, China should pay more attention to improving the flexibility of electric power system in the electric market and leading various flexible resources in the system to actively participate in the market so as to release and improve their flexibility. Therefore, the market structure and market system with effective competition must be established. It is necessary to speed up the development of plan for power utilization, allow and encourage power generation enterprises to enter into the competitive power market, standardize the direct transaction between large users and speed up the establishment of power spot market and auxiliary service market to improve the efficiency of optimizing allocation of electric power resources. The trading period of spot market should be gradually shortened from 15 minutes to 5 minutes to reduce the demand for spare capacity of the market.

Implementation Pathway

From the perspective of implementation path, China should gradually enrich the transaction varieties in the market, expand the market scope and improve the market operation rules at the three stages: current market (2020), medium-term market (2025) and forward market (2025).

In the near future (before 2020), it is necessary to improve the incentive mechanism for peak-load regulation in regions without spot market, give rewards for compensation to thermal power generating unit providing deep peak-load regulation, include the renewable power generation and power rationing into the assessment and compensation of auxiliary service of peak-load regulation, establish the auxiliary service market and improve the enthusiasm of various power generation enterprises for participating in the auxiliary service of peak-load regulation. An electric energy market should be established with transparent pricing, auxiliary service market and retail market mechanism on the basis of spot market in pilot areas and carry out the transaction based on balance adjustment with a period of 15-30 minutes in the real time electric power balance mechanism to ensure the transition from plan management to market optimization.

In the medium and long term (after 2020), China should improve and promote the spot market, further perfect the auxiliary service market and gradually remove the electricity generated in priority on the generation side and the electricity purchased in priority of the planned quantity on the power consumption side. The modern electric power market should be established in 2025 and comprehensive competitive electric power market should be implemented before 2030.

With the establishment of modern electric power market and increase of the proportion of renewable energy, the electric power spot market based on the marginal cost competition will significantly promote the renewable energy power generation. Through the submission of the price to sell electricity based on the marginal cost in the day-ahead market and real-time market, the renewable energy power generating unit will be prioritised in the real-time economic dispatch and become one of main providers of electric energy in the electric power system. Thermal power plants will be exposed to the market and will be encouraged to operate more flexible according to the dynamic pricing on the spot market. The spot market and auxiliary service market provide a more effective platform for all generating units including thermal power generating unit. The flexible units including thermal power unit can adjust the pricing strategy in accordance with the historical or real-time electricity price in the market to maximize the profits.

Figure 37 illustrates a market-based dispatch of the power system in the JingJinJi region in the High RE Penetration Scenario in 2030. The thermal units are seen to ramp up when the price is high and down when the price is low, and of course the flexible coal units are able to ramp further down before they consider switching off entirely. Especially during the mid-week where there is a significant low price period for an extended period of time, it is more economical for many plants to shut-down entirely, thereby allowing for the integration of a larger amount of the potential wind and solar generation.

Particularly, in the High RE penetration scenario, due to the high penetration of solar power in the region, it is worth noting that the power price is generally lower in the middle of the day when the sun is shining and higher in the night and in the evening especially, where the sun setting coincides with the demand peaking. Pumped storages mitigate this by predominantly charging during the mid-day and discharging around the evening peak. Furthermore, in the High RE scenario smart charging of electric vehicles shift considerable charging away from the evening peak (depicted as generation, but is actually a reduction in consumption) and into the mid-day.

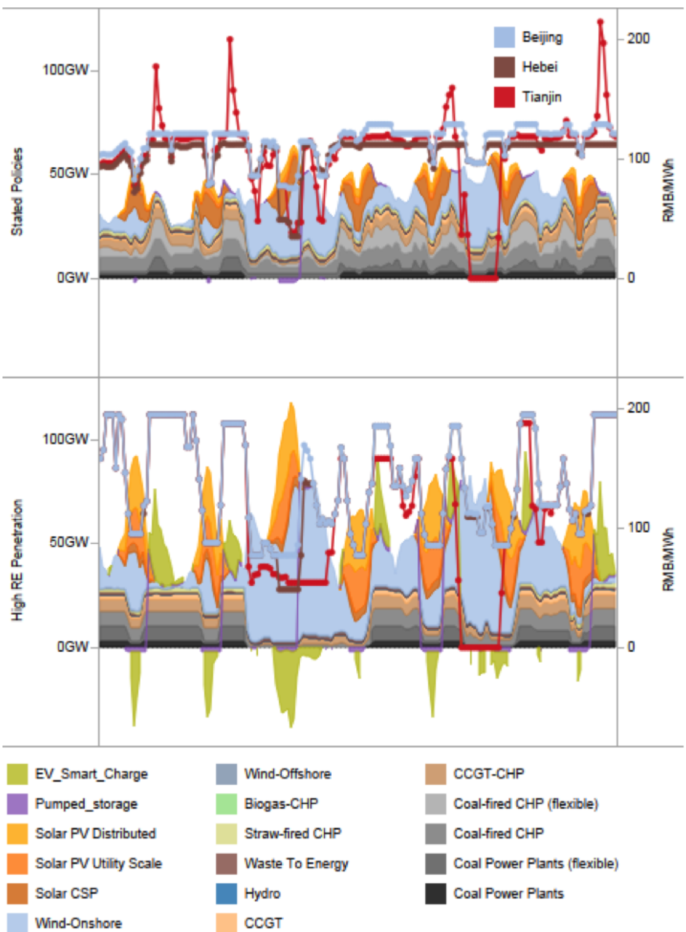


Figure 39: Operation of power generation, storage and demand-side response from electric vehicles as well as the simulated power price (energy only) in one week of 2030 in the two scenarios, in the JingJinJi region

In the aspect of retail market, with the continuous increase of market-oriented users and electricity selling package, more flexible resources on the demand side will be attracted and the regulating effect of more flexible retail electricity price on the demand will be more significant. The operator of distribution network and power trading company can make use of the real-time electricity price or control signal (for example, the marginal price signal of the distribution network or the dynamic/ time-of-use electricity price signal provided by the trading company and load integrator or the direct control signal) to adjust the operating power or operation time of the controllable electric appliance (such as dishwasher and washing machine).

New Policy Measures To Promote Renewable Energy

The current support mechanism for renewable energy in China consists of a feed-in tariff system, mainly financed by a surcharge on electricity prices, combined with national capacity targets for the different technologies as part of the five-year planning. This mechanism has been successful in deploying wind and solar capacity, but less successful in ensuring access to the grid and the priority of power generation from renewable energy.

Furthermore, the surcharge funding is limited in size and it will be difficult or impossible to continue with the current level of support, especially with the ambitions to continue or increase the annual deployment of RE technologies as expressed in the current five-year planning.

The general feed-in tariff system is not particularly good at encouraging a coordinated planning and deployment process, where deployment is matched with grid planning, and the system is not taking advantage of the possibilities for more market oriented dispatch, which will be the outcome of the ongoing power sector and power market reform.

Hence, it is necessary to rethink the support system to make it better suited for the future development in the framework conditions and to comply with the need for further large-scale deployment of renewable energy.

In the first half year of 2016, some new mechanisms were launched and implemented and it reflects the innovation in policies regarding 1) target setting and guidance, 2) strengthening the operational management of electric power system and 3) expansion of the financing sources for renewable energy subsidy. It is also the key system arrangement which decides the deployment of renewable energy in the future.

Target Guiding System For The Development And Use Of Renewable Energy

The principles of the target guiding system are as follows:

Each province (district or city) will have a target for the share of renewable energy (excluding hydro) in the total power consumption based on the targets for renewable energy in the power consumption of the whole society and in accordance with the status of renewable energy and power consumption level of each region. The local government is responsible for the set-up of the system, and the grid companies, trading companies and power generators will be the responsible for the practical fulfilment of the targets. For power generators, it is suggested that they shall have 9% of the total generation as RE power in 2020. The power generation enterprises shall be able to fulfil the requirement by trading of green certificates, hence the institutions for green certificates trading shall be established.

The detailed implementation has not yet been settled and several issues remain to be solved:

- Firstly, the detailed responsibilities shall be clarified and the overall targets shall be decomposed into annual indexes;
- Secondly, compliance measures for enforcing the targets shall be set-up to motivate the local stakeholders to meet the targets;
- Thirdly, comprehensive research regarding a green-certificate system (see below);
- Fourthly, it is necessary to solve conflicts and connection problems between the policy for development and utilization target and the existing price, subsidy and other relevant policies;

All-in-all, the target policy must be regarded as one part of a more comprehensive and coordinated support system, including pricing, trading mechanisms, power market design and guarantied production. It will be one of the main policy tasks the coming years to ensure clear, transparent and efficient support mechanisms, which enables ambitious deployment targets instead of creating barriers for continued RE development and deployment.

Research On Quota Systems And Green Certificate Trading Mechanism

An evaluation system for non-hydro renewable sources power generation quotas and a green certificate trading mechanism are direct reflections of the above described target guidance system.

A power generation quota and green certificate trading system will, once established and implemented, reduce the need for national funding of feed-in tariffs for renewable energy power generation and contribute to create a more level playing field between renewable energy and coal power. The revenue from a green certificate system will, together with a market pricing of electricity in general, constitute a main part of the revenue for renewable energy.

With green certificate trading mechanism put into effect, coal-fired power generation enterprises will have to pay fees. Such fee is, compared with external cost of coal-based power, low (estimated less than 10%); however, it is still contributing to reflecting the real cost of coal power and thereby to the energy system transformation.

Full Compensation System For Re Power

The main purpose of the full compensation system is to reduce the curtailment of variable generation from wind and solar power. Furthermore, it will split the RE power generation into two parts: a part, which the power grid companies must purchase need, and a part, which the RE power producer are encouraged to sell on market conditions.

During implementation, the system needs to be improved in the following aspects:

- It shall be coordinated with local wind-thermal power transaction
- Annual utilization hours shall be determined based on reasonable annual indexes
- It can be implemented as a policy to relieve curtailment and other adverse impacts as results of local policies which impede RE consumption amid economic downturn and demand surplus and slowdown in the electric power industry. However, the system in itself is insufficient to solve non-technical power curtailment and to relieve the increasingly serious problem with thermal power overcapacity.

New Pricing Mechanism For Re Power

As electricity market reform advances, market-based electric power pricing mechanism will be introduced and an objective, transparent and flexible electricity market scheduling mechanism will be established. Further, subsidy payment will change from the current feed-in tariff based on benchmark electricity price of renewable energy and coal power into a premium to a market based price. The following issues should be taken into consideration:

- Control on total amount of subsidy fund, namely ensuring sufficient and reasonable subsidy fund

- Improvement of subsidy fund usage efficiency and reasonable distribution as well as variable electric prices based on development stages and renewable energy technologies
- Innovation of subsidy methods, reinforced market guidance and coordination of multiple policies.

Specific suggestions include:

1) Match up with the power sector reform and change the pricing system from a feed-in tariff to a feed-in-premium.
2) Set differentiated subsidies for the different RE technologies corresponding to the development stages. For well-developed technologies such as on-shore wind power generation and large-scale solar PV power generation, the subsidy should be implemented for the early stage and the subsidy adjustment cycle shall be shortened; for renewable energy power generation in demonstration or generalization stage, stable economic policy shall be maintained, namely continuing benchmark electricity pricing mechanism and providing stable investment environment to improve its commercialized development.
3) Implement a tendering price policy step by step. For well-developed renewable energy technologies, cost and price of electricity could to be determined by project tendering in order to reduce the needed amount of subsidies.

Distributed Power Generation

The development of the distributed PV power generation market in China is far below the expectation. The newly-added installed capacity in 2015 is 1.39 GW which is only a tenth of that of the centralized PV power station.

New applications like PV curtain walls, agriculture-PV complementation project, fishing-PV complementation project and PV poverty relief constantly emerge, bringing about new business opportunity for the distributed development. The project financing channel is still singular and the security guarantee ability is weak; especially, the financing is difficult and the business model developed by third parties are still not mature. In recent two years, PV financing mode innovation is started rapidly and such new-type PV financing modes as crowd funding, financial leasing and YieldCo emerge in large numbers but there are only few pilot projects.

The Current Incentive System

There are two options for distributed PV on-grid price: one option is to use the fixed on-grid price for the local PV power station and the other option is that all the quantity of electricity enjoys feed-in premium (0.42yuan/kWh). In many areas, the government introduces the additional feed-in tariff policy, forming the situation of distributed PV with the multi-level subsidies of the state, province, city and county. For the distributed PV project, residents and enterprises in Yongjia County of Zhejiang Province can enjoy four-level feed-in tariff policy and the feed-in tariff respectively reaches up to 1.12 yuan/kWh and 1.02 yuan/kWh. The procedures for project management and grid connection management of distributed PV are greatly simplified and it is clear that they will not be restricted by annual PV construction scale.

Problems And Challenges

There are many uncertain factors for the distributed PV development: the distributed PV projects are decentralized and the operating framework for the owner, electricity consumption and electricity price differ greatly. Third-party financing has many risk factors such as the share of electricity used by the project itself, the collection of electricity fee of users, insolvency of the construction company or change of owner of property right and even potential building demolition, directly influencing the expected earnings of the project. Also, it is difficult for the distributed PV project to obtain the mortgage loan of the bank.

International Experiences

Distributed PV power generation is popular in Germany and the United States. Experience of Germany and the United States indicates:

Firstly, stable and favourable policy is the basis and guarantee including simplified grid connection and project management procedures and a favourable distributed PV feed-in tariff policy.

Secondly, it is necessary to combine traditional and new financing modes; German distributed PV enjoys favourable feed-in tariff and special loan and the project investment income is better, attracting the input of capital from commercial loan and social security funds; various types of multi-level incentive policies in the United States are promoted together including the federal government policy (investment tax credit policy and accelerated cost depreciation policy) and state government policy (solar energy quota system and net electric quantity measurement and etc.). To maximize the policy benefits, the innovative development of business model and investment and financing mode is important, promoting the rapid growth of the market.

Suggestions For Policy Measures

1) Ensure the practical implementation of the existing policies including the simplified project management and grid connection management procedures and ensure prompt payment of the RE feed-in tariff.
2) Complete the policy and management mechanism. Encourage the grid company to settle the electricity fee uniformly, detail and complete the classified feed-in tariff policy of the distributed PV and prepare the tripartite cooperative contract model for the distributed PV power generation project which can standardize the third-party investment.
3) Complete the investment and financing mechanism and innovate the business model. Guide the favorable credit policy; the bank shall provide long-term loan with low interest; establish the national level distributed financing guarantee fund; actively introduce the third-party risk sharing mechanism; allow the pledge of distributed PV assets; promote project financing.
4) Combine the electric power system reform and the distributed PV development. Allow the distributed PV generation to participate in the electric power trading and explore the direct electricity selling in the power supply area; establish the trading platform and trading mechanism for the distributed PV power generation, reduce the trading cost and solve problems like the difficulty in collection and payment of electricity fee and long period of settlement.

Re For Heating

Renewable energy for heat supply refers to supply of hot water, heating and refrigerating, thermodynamic and other heat supply services by using renewable energy resources such as solar, biomass energy, geothermal, electricity from RE and so on.

The use of RE for heating is stably increasing in China. In 2015, RE for heating amounted 60 Mtce. Solar heaters are the biggest contributors, followed by biomass energy and geothermal energy. Electricity from RE for heat supply is still at the stage of pilot demonstration. Despite the large contribution to China's energy supply, as non-commercial energy, use of RE for heating, (solar, biomass and geothermal energy, etc.), are not incorporated into the energy statistics of China and often neglected.

China is yet to formulate a supporting policy dedicated for RE for heat supply. Compared with conventional energy, the market of RE for heat supply is limited and dispersed. Compared with coal-fired heat supply projects, it is less cost-effective and thus in urgent need of a national support policy. Some local governments begin to explore paths to promoting development of RE heat utilization market, including mandatory installation policy for solar water heating system and concession agreement for central heat supply from biomass energy and intermediate deep geothermal energy, which, however, are still at the stage of pilot projects.

Problems And Opportunities

RE heating is often presented with great opportunities like acceleration of energy transformation as required by key development positioning strategies of national government, transformation of urban heat supply system in northern China regions and transformation of heat supply system into clean energy. However, RE for heat supply in China now is facing the problems of "electricity with higher priority over heat", less competitive cost-effectiveness, integration technology for heat supply yet to be improved and lack of incentive mechanisms.

Suggestions For Policy Measures

In order to effectively promote development of RE, it should be promoted at both consumer end and RE supply end, including promoting development of urban RE for heat supply, promoting application of various RE for heat supply technologies depending upon actual local circumstances, fully promoting RE for heat supply in buildings, actively promoting RE for heat supply in industrial and agricultural production, promoting large-scale application of RE for heat supply technologies and implementing pilot demonstration of new-type heat supply system, etc.

Support mechanisms should include a good national policy framework regarding control of total energy consumption, emission reduction of greenhouse gas, energy conservation, pollution control and investment & financing for RE to establish good external environment Set up prioritized development concepts to incorporate RE for heat supply into national RE development and urban development planning and make good heat supply planning Study and design heat supply pricing, subsidy and other incentive policies and mechanisms to improve cost-effectiveness of projects Make more efforts in taxation and financial support to incorporate support from RE development fund Refine and perfect regulation system and perfect standard system of RE for heat supply to enhance heat supply metering work and building of support system.

Abbreviations

APEC	Asia-Pacific Economic Cooperation
BMLR	Boiler maximum lower rating
Bnm^3	Billion normal m^3
CCGT	Combined Cycle Gas Turbine
CCS	Carbon capture and storage
CdTe	Cadmium telluride
CHP	Combined heat and power; the term co-generation is sometimes
CI(G)S	Copper indium gallium deselenide
CNREC	China National Renewable Energy Center
CO_2	Carbon dioxide
COP21	21^{st} of Conference of the Parties (UNFCCC)
CPC	Communist Party of China
EDO	China Renewable Energy Analysis Model- Electricity and District heating Optimization
CGE	China Renewable Energy Analysis Model-Computable General Equilibrium
END-USE	China Renewable Energy Analysis Model-end use
CREO	China Renewable Energy Outlook
CSP	Concentrating solar power
DENA	Deutsche Energie-Agentur (German Energy Agency)
EDO	Electricity and District heating Optimization
EJ	Exajoule
ENTSO-E	European network of transmission system operators for electricity
EPA	Environmental Protection Agency (United States)
EU	European Union
EV	Electric vehicles
FIP	Feed-in premium
FIT	Feed-in tariff
FYP	Five-Year-Plan
GDP	Gross domestic product
GHG	Greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (the German Federal Enterprise for International Cooperation)

GW	Gigawatt
GWh	Gigawatt hour
HG	Mercury
INDC	Intended National Determined Contribution
IRENA	The International Renewable Energy Agency
IRR	Internal rate of return
ISO	Independent System Operator
LEAP	The Long-range Energy Alternatives Planning System
LNG	Liquefied natural gas
MSW	Municipal solid waste
Mtce	Million tons of (standard) coal equivalent
Mtoe	Million tons of oil equivalents
Mton	Million ton
NDC	Nationally Determined Contribution
NDRC	National Development and Reform Commission People's Republic of China
NEA	National Energy Administration of China
NH_3	Nitrogen
NMVOC	Non-methane volatile organic compound
NO_x	Oxides of nitrogen
OECD	Organization for Economic Co-operation and Development
Development	Particulate matter less than 10 microns in diameter
PM10	Particulate matter less than 2.5 microns in diameter
PM2.5	Photovoltaics
PV	Research and development
R&D	Renewable energy
RE	Ren Min Bi (Chinese currency)
RMB	Regional transmission organisation
RTO	State Council
SC	Standard coal equivalent = one metric ton of coal = 0,7 toe = 890
SCE	m^3 natural gas = 29.39 GJ = 8.14 MWh
SO_2	Sulphur dioxide
SOE	State-owned enterprises, China
TFEC	Total final energy consumption
TWh	Terawatt hour
U.S.	United States
UHV AC	Ultra-high-voltage alternating current

UHV DC	Ultra-high-voltage direct current
UK	United Kingdom
USC	Ultra-supercritical Coal-fired
VRE	Variable renewable energy

Convert to:	TJ	Gcal	Mtoe	Mtce	GWh
From:	Multiply by:				
TJ	1	238.8	2.388×10^{-5}	34.1×10^{-6}	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	0.142823×10^{-6}	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	1.428	11 630
Mtce	29307.6	7001.7×10^{3}	0.7	1	8141
GWh	3.6	860	8.6×10^{-5}	122.835×10^{-6}	1

Unit representing energy generated by burning one metric ton (1000 kilograms or 2204.68 pounds) of coal, equivalent to the energy obtained from burning 5.2 barrels (700 kilograms) of oil or 890 cubic meters of natural gas that is, 29.39 gigajoules (GJ), 27.78 million Btu (MMBtu), or 8.14 megawatt hours (MWh)

Units

Area	m^2	Square metre
	Km^2	square kilometre
Coal	Mtce	million tonnes of coal equivalent (equals 0.7 Mtoe)
Emissions	ppm	parts per million (by volume)
	Gt CO2-eq	gigatonnes of carbon-dioxide equivalent
	kg CO2-eq	kilogrammes of carbon-dioxide equivalent
Energy	toe	tonne of oil equivalent
	ktoe	thousand tonnes of oil equivalent
	Mtoe	million tonnes of oil equivalent
	tce	tonne of coal equivalent
	ktce	thousand tonnes of oil equivalent
	Mtce	million tonnes of oil equivalent
	MJ	megajoule (1 joule x 106)
	GJ	gigajoule (1 joule x 109)
	TJ	terajoule (1 joule x 1012)
	PJ	petajoule (1 joule x 1015)
	EJ	exajoule (1 joule x 1018)
	kWh	kilowatt-hour
	MWh	megawatt-hour
	GWh	gigawatt-hour
	TWh	terawatt-hour
Mass	kg	kilogramme (1 000 kg = 1 tonne)
	kt	kilotonnes (1 tonne x 103)
	Mt	million tonnes (1 tonne x 106)
	Gt	gigatonnes (1 tonne x 109)
Power	W	watt (1 joule per second)
	kW	kilowatt (1 watt x 10^3)
	MW	megawatt (1 watt x 10^6)
	GW	gigawatt (1 watt x 10^9)
	TW	terawatt (1 watt x 10^{12})