A Star for China's Energy Transition

Five Golden Rules for an Efficient Transformation of China's Energy System

IMPULSE

Agora Energiewende

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Preface

Dear readers,

China has become one of the world's leading countries in the fight against climate change. It has taken a proactive stance in UN climate negotiations and now leads the world in renewable energy deployment. At the same time, China continues to struggle with its own air pollution and greenhouse gas emissions. While Chinese emissions declined in past years, they began to rise again in 2017.

One of China's largest clean-energy projects is the transformation of its power sector. The government aims to increase the share of non fossil-fuel based electricity in its power system to 50 per cent by 2030. According to our calculations (and those of others), this target is ambitious but feasible. Despite the achievements of recent years, significant challenges remain, especially with regard to the re-structuring of the power system.

This report addresses some of these challenges in detail. It builds on the lessons (positive as well as negative) that we have learned in Europe in recent decades. The key insight offered by the report is that a holistic perspective is necessary to ensure compatibility between policy instruments. We have summarized our findings in Five Golden Rules.

I hope you find this report stimulating, and that it helps to catalyse the policy changes necessary for a successful clean-energy transition in China.

Sincerely,

Dr Patrick Graichen
Executive Director of Agora Energiewende

Key findings at a glance:

1 **To achieve a 50 per cent share of clean electricity by 2030 at a minimum cost, China needs to add around 35 GW of wind energy and 65 GW of solar energy per year between 2020 and 2030.** This would be roughly in line with the quickest deployment levels seen in previous years. With a rapid decline in technology costs, wind and solar can serve as a substitute for new nuclear and hydro, which current plans foresee growing at an unrealistically high rate.

2 **"Flexibility" will need to become the new watchword in China's power system, as by 2030 roughly 25 per cent of the power supply comes from variable renewables.** Restructuring the power system will be essential in order to keep it reliable and cost-effective. Inflexible baseload technologies and non-merit-order-based, coarse-scale dispatch are incompatible with a system that is increasingly dominated by weather-dependent power generation technologies.

3 **China has initiated a number of important reforms already, but fundamental challenges still lie ahead.** Recent policy reforms have moved in the right direction, as China has started pilot projects for emissions trading, has reviewed its renewables remuneration scheme, and has acknowledged the need to create a power spot market. However, fundamental challenges remain to be addressed. These include overcapacity in coal-fired assets, an inflexible dispatch system, and a lack of data transparency and accessibility for market participants.

4 **Five Golden Rules will help build a consistent policy regime and guarantee system reliability and cost-effectiveness.** China has the opportunity to leapfrog to a renewables-led power system design that ensures cost-effectiveness and reliability. The Five Golden Rules we develop in this paper will help policy makers view the various policy instruments and emerging sectoral markets both pragmatically and coherently while taking into account interdependencies and avoiding inconsistencies:

Golden Rule 1: Use existing generation capacity efficiently by implementing short-term markets
Golden Rule 2: Incentivise flexibility to ensure system reliability and adequacy
Golden Rule 3: Provide stable revenues for new investment in renewables
Golden Rule 4: Manage the decline of coal and its structural consequences
Golden Rule 5: Acknowledge the pivotal role of transparency and data accessibility

Content

Introduction

Wind and solar energy have grown at a strong pace in recent years in China, and now it faces new challenges through the transition to clean energy. It is no longer enough to simply build additional capacity. China also needs to view the various elements of its energy system from a holistic perspective.

This sounds like an obvious statement, but adopting an integrated perspective is difficult, as experiences in Germany and elsewhere have shown. Consider for a moment the various policy instruments that have been enacted in Germany over the years, without giving serious thought to their mutual interaction. There might have been good reasons for each decision, but the overall outcome has been inefficient. To give just one example: despite the rapid growth of renewable energy in recent years, Germany's greenhouse gas emissions have not decreased. Inconsistent policy measures are the cause: specifically, the failure of the European emissions trading scheme and the lack of additional instruments to reduce carbon intensive energy production.

Accordingly, for some years we have been arguing that a pan-European perspective is essential. Clearly, we need a coherent set of policies on renewable energy funding, market design, and the reduction of high-carbon assets.[1]

Interestingly, both China and Europe deploy a similar mix of policy instruments, including:

→ renewable remuneration schemes (voluntary and obligatory instruments),
→ carbon markets, especially the emissions trading pilot programmes, and
→ a tailored power market design, which is still under development in China.

The challenges arising in China are similar to those encountered in Germany and Europe. We met with our Chinese partner CNREC and discussed how the Chinese power system can be transformed in an integrated manner. Obviously, many Chinese particularities need to be taken into account. But the need to consider different policy instruments in a coherent and integrated manner remains the same.

This report is the result of these discussions. It provides a high-level perspective on how different policy instruments and markets interact and can contribute to a more efficient and reliable future energy system in China. In doing so, we argue for a pragmatic perspective that does not stick to textbook economic theory but rather acknowledges real-world experience. This analysis intends to focus the debate on key questions and implications that policy makers need to keep in mind when designing future markets and regulations.

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[1] Agora Energiewende (2016a).

Background: Shedding Light on China’s Climate and Energy Targets

At the Paris Climate Conference in December 2015, China joined other nations in endorsing a global, legally-binding target for keeping global warming “well below 2 °C above pre-industrial levels” as well as for “efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.”[2]

Meeting the Paris agreement will require, among other things, that the global power sector be fully decarbonised by no later than 2050.[3] The power sector must necessarily lead decarbonisation efforts because we already have cost-effective technologies for making this sector carbon free. This stands in sharp contrast to other sectors, like agriculture and industry, where technological developments are not equally advanced and where emissions cuts cannot occur as rapidly. To achieve full decarbonisation of the power sector by 2050, about 50 per cent of the process would need to be completed by 2030. This intermediate goal requires large investments in zero-carbon technologies within the next 15 years to replace fossil-fuel assets and enable steep cuts in short-term emissions. This demands the collective effort of all countries – rich and poor – to realise a fundamental transformation of power sectors around the globe.

Given the size and emissions-intensity of China’s power sector, and the need for swift action by 2030, China needs to undertake significant domestic efforts, independent of any global emissions trading or regulation regimes that could emerge from international climate negotiations in coming years.

In its Nationally Determined Contribution (NDC), China pledged to:

- → peak carbon dioxide emissions by around 2030 and make the best efforts to peak earlier;
- → lower carbon dioxide emissions per unit of GDP by 60 to 65 per cent relative to 2005 levels;
- → increase the share of non-fossil energy sources (renewable and nuclear) in the energy mix to around 20 per cent by 2030; and
- → increase forest stock volume by around 4.5 billion cubic meters relative to 2005 levels.

Since issuing its NDC, China has made substantial progress in adopting and implementing new energy and environment policies. Coal consumption has remained relatively flat since 2013; in 2017, the government accelerated the phase-out of direct coal heating in the residential sector. Wind and solar energy deployment in China continue to lead the world in terms of both capacity and output. In 2017 alone, China added 53 GW of solar PV, almost five times as much as was added in the United States. Furthermore, this annual increase is larger than the 43 GW of total solar PV capacity in Germany.[4] While wind and solar curtailment remain high, both saw improvement in 2017 and early 2018.[5] The government has set a timeline to keep wind and solar curtailment below 5 per cent in all provinces by 2020, and has implemented a number of measures for ensuring this, including provincial renewable obligations, new power lines, and a monitoring system to limit new investment in regions with high curtailment.

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[2] See Paris Agreement, Article 2.1 a).

[3] IPCC (2018). Publication forthcoming.

[4] In June 2018, however, the Chinese government decided to freeze new subsidy-based PV installations and allow for around 20 GW of new capacity for this year.

[5] NEA (2018a). It should be noted that the way to calculate the curtailment rate might differ from country to country. In China, this is indexed to the theoretical generation potential of the renewable resource.

Additional impetus for a cleaner energy system has been triggered by public awareness of air pollution and its implications for public health and the environment. In 2018, China revised its national constitution, making the development of an "ecological civilization" and the protection of the environment a key national goal.[6] After President Xi Jinping's 2014 speech calling for a revolution in energy production and consumption, the government published its 2016 Energy Production and Consumption Revolution Strategy (2016–2030). The strategy calls for China to raise the share of non-fossil fuel power generation in total power generation to 50 per cent by 2030, versus around 28 per cent in 2016. This is a clear step beyond the NDC target of 20 per cent non-fossil energy by 2030.

The Chinese government understands that a transition to cleaner energy, including the electrification of transportation and industry, would help China to tackle its air pollution challenges and put the country's future growth on a less carbon-intensive pathway. It is clear that end-of-pipe emissions controls can achieve at best only half of the emissions reductions needed for China to cut urban ambient PM2.5 concentrations to 30 micrograms per cubic metre (µg/m^3) by 2030, which is the national target.[7] Changes on the structure of China's energy system are thus needed to meet air quality goals.

All of this has led to a fundamental debate about the transformation of the energy system in China. In some countries with functioning power markets and integrated transmission systems, wind and solar have replaced coal-fired electricity, often leading to early plant retirements. The falling cost and improved efficiency of wind and solar make this vision increasingly practical for both local and national policy makers.[8] Costs for wind and solar power have fallen to the extent that they have become cost-competitive with other forms of energy generation in many places around the world,[9] although in China relative costs for coal continue to be perceived as less expensive than other options in the short term. In the most likely scenario, which reflects the expectations of government and major industries, China's goal of generating at least 20 per cent of its energy from non-fossil fuel by 2030 translates into a 38 per cent share of clean electricity in the power sector.[10] According to official plans, hydro and to a lesser degree nuclear power would be the major contributors due to their planned new installations and large-volume legacy capacity.

The share of wind and solar generation – known as variable renewables (vRES) – in the total electricity generation mix are projected to increase from around 7 per cent in 2017 to 10 per cent by 2020 and to 15 per cent by 2030 (Figure 1). At this rate, China would meet its 20 per cent non-fossil fuel target with an average 5.3 per cent growth rate of GDP from 2015 to 2030 (Table 1). The carbon intensity reduction of the economy would exceed 65 per cent relative to 2005, which corresponds to the high-end target in the Climate NDC.

The 2030 non-fossil energy target of 20 per cent can be achieved with a 15 per cent share of wind and solar electricity generation

In this scenario, which is broadly consistent with the government's plan, wind capacity needs to grow by 19 GW and solar PV by 26 GW annually between 2020 and 2030. As recent deployment rates have exceeded these numbers (Table 2), meeting and eventually overshooting the 2030 NDC target should be achievable.

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[6] Xinhua Agency (2018).

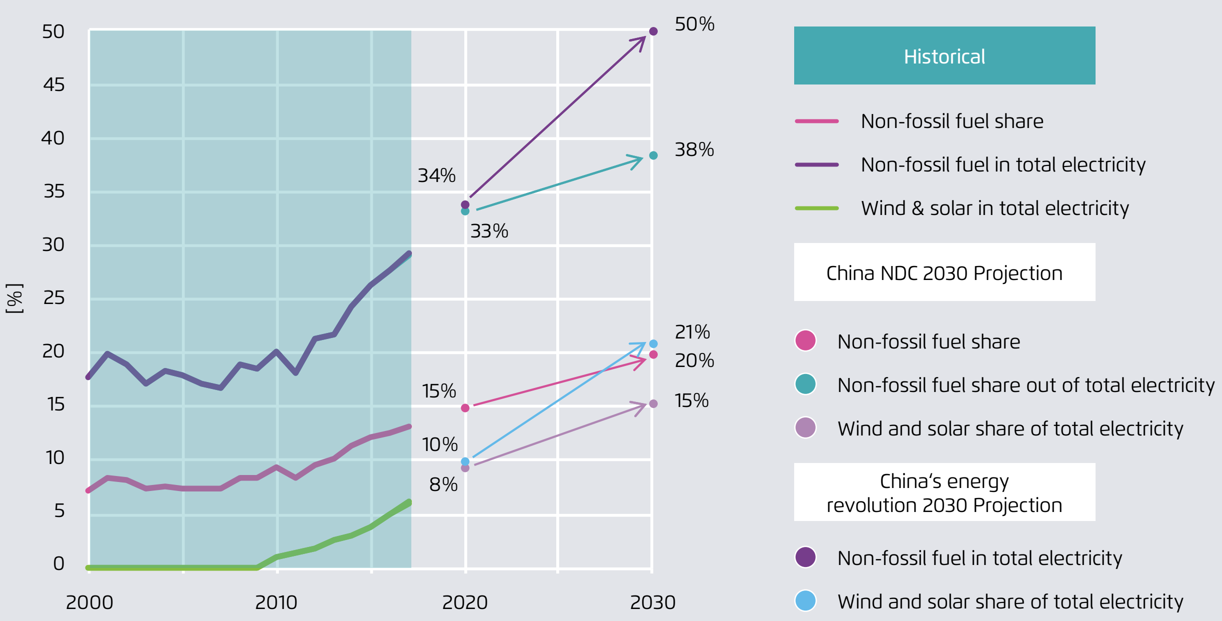
[7] Ma Jun (2017).

[8] Wang Zhongying (2018).

[9] Agora Energiewende (2017a); IRENA (2018)

[10] Zhang and Bauer (2014)

RES generation out of total electricity, aligning with climate NDC and domestic targets **Figure 1**



Data (2000–2017) from annual flash reports of China Electric Council (CEC) and China's official document Energy Revolution 2030. The projection period (2017–2030) represents the scenario for meeting the non-fossil fuel target (pink arrow) in China's NDC. It considers the most likely development pace of renewables, especially hydro and nuclear, whose lead time is over 5 years. Details can be found in Zhang and Bauer (2013) and Wang and Zhang (2017).

Key economy and energy settings for the scenarios **Table 1**

	2005	**2010**	**2015**	**2020**	**2030 projection**
GDP (2005 price, 100 million yuan)	185896	317682	463889	635568	1009477
Electricity demand (TWh)	2494	4194	5802	6830	8770
Total energy consumption (10000 tce)	261369	360648	429905	526347	555500
Non-fossil electricity share with targets according to NDC	18%	20%	26%	34%	38%
Wind & solar share with targets according to NDC	0%	1%	4%	10%	15%
Wind & solar share with targets according to 50% domestic target				10%	21%
Wind & solar share with targets facing slowing-down hydro & nuclear				10%	25%

Note: Adapted and further analysis based on Zhang and Bauer (2014)

Historic non-fossil fuel power generation capacities and projections for 2020 and 2030

Table 2

	2016 (GW)	2017 (GW)	2020* (GW)	2030 (GW)
Hydro	332	341	350	420–450
Nuclear	33	36	58	80–120
Wind	148	164	220	400-600
Solar PV	78	130	200	450–850
Solar Heating	–	–	10	~30
Biomass	12	12	15	15–100

* Various government plans and industrial projections (2020–2030); estimates from the government-affiliated think tanks the Electric Power Planning & Engineering Institute (EPPEI) and the Renewable Energy Engineering Institute (CREEI); and personal communication with China National Renewable Energy Center (CNREC).

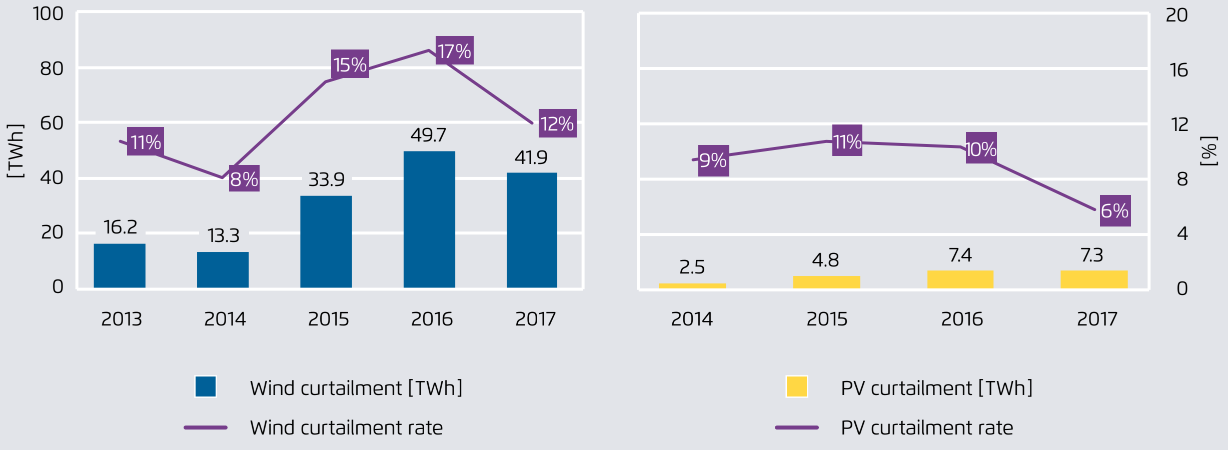
Note: Biomass utilization in China is persistently limited and lag behind other countries. The upper end of hydro and nuclear corresponds to Chinese government plans. In our view, hydro and nuclear are likely to halt completely after 2020 for projects that have yet to start.

The Chinese government therefore decided to pursue a more ambitious path. The official Energy Production and Consumption Revolution Strategy (2016–2030) aims at 50 per cent non-fossil electricity in 2030. This new target significantly outpaces the NDC, and it indicates an accelerated development of renewable energy.

The 50 per cent non-fossil fuel electricity target translates into a 21 per cent share of wind and solar if nuclear and hydro increase according to official plans (the high-end of the numbers in Table 1), curtailment rates of wind and solar PV can be reduced and the energy intensity of the Chinese economy decreases.

Wind and solar PV curtailment (2011–2017)

Figure 2



NEA of China; quoted in GIZ (2018)

But what happens if some of the government's key assumptions do not hold true? Specifically, what if:

- → hydro and nuclear do not live up to expectations, and growth slows down, or
- → curtailment of wind and solar continues to occur at current levels, or
- → efficiency efforts remain insufficient and the economy stays as energy-intensive as before?

According to previous expectations, hydro and nuclear power capacity increase to 420 GW and 120 GW, respectively, by 2030, up from around 340 GW and 36 GW as of 2017.

But the pace of hydro and nuclear power development in China has been slowing down due to declining economic feasibility and many other hurdles. For hydro, this includes the low market value of new power assets in geographically remote regions, and the problems associated with ecological damage and migration. As for nuclear, rising costs due to more stringent safety requirements and public resistance make it increasingly unrealistic that China will meet its 120 GW target.

Curtailment is another severe problem in China (Figure 2), especially in non-coastal areas, which curtail up to 50 per cent of wind (without compensation). Comparisons with the US illustrate this point. Although China's installed wind capacity was greater than that of the US in 2015 (145 versus 75 GW), it generated less electricity (186 versus 191 TWh).[11] In 2017, China had almost two times more installed capacity than the US (164 versus 89 GW), but it surpassed US production by a much smaller margin (306 versus 254 TWh), which represents a gap of 50 per cent in terms of utilization.[12]

Energy intensity is another concern. The NDC scenario assumes a limited growth of energy use from 2020 to 2030 due to efficiency measures. But if energy elasticity continues to hover around 0.5, as it

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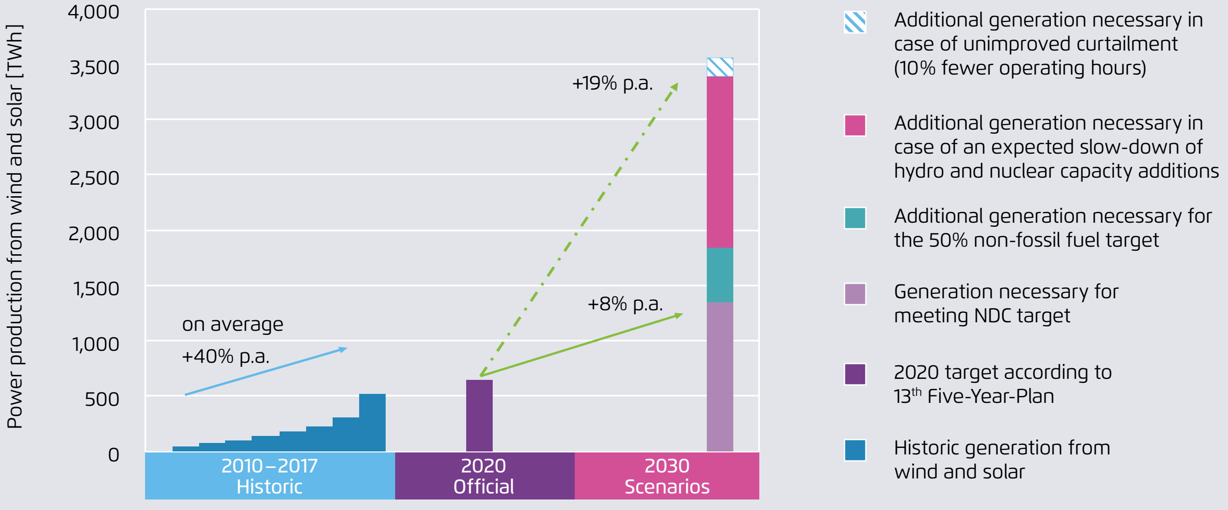
[11] Lu, et al. (2016).

[12] Huenteler et al. (2018).

2020–2030 wind and solar generation for robust targets in the face of multiple uncertainties Figure 3



For historic data, CEC data and projection is scenario-based sensitivity analysis.
In the 2030 scenarios, the utilization rate of wind and solar is assumed to be 2,000 hours and 1,200 hours as the benchmark.

has for the past 30 years, total energy use would rise significantly. Under such a case, the efforts to expand non fossil-fuel based electricity, especially that from wind and solar, need to increase to offset the larger energy use.

Each of these issues could have an impact on the required installation rates for renewable energy – all the more so, if they come to bear on China's power system all at once.

In a more dramatic scenario where the growth of added hydro and nuclear capacity slows fundamentally, wind and solar growth would need to be more than double the rate indicated in the benchmark case (Figure 3). In such a case, reaching the 50 per cent non fossil-fuel based electricity target would require an annual installation of wind and solar PV beyond 35 GW and 65 GW between 2020 and 2030.

Clearly, wind and solar are cheap enough and have proven their ability to grow rapidly. Among all variables, they are the most reliable and predictable. To be on the safe side, it would be advisable to increase the share of wind and solar in order to compensate for a potential failure to deliver in other areas (i.e. lower hydro or nuclear capacity expansion or higher than expected energy demand). We estimate that a share of wind and solar of around 25 per cent of total electricity generation by 2030 would ensure robust achievement of local and global pledges, despite remaining uncertainties.

1. Renewables-led Energy Transitions: Perfect Theory and Imperfect Practice

In Europe, proponents of a harmonised approach to EU climate and energy policy have argued that the European energy transition should be based on two major elements: a strengthened Energy-Only Market (EOM)[13] and a strengthened EU Emissions Trading scheme (ETS). It is claimed that these two instruments offer the most cost-effective route for reliably transitioning to a low-carbon energy system, and that additional instruments should be avoided or phased out because they distort the effective functioning of the EOM and ETS markets.

In North America, the situation is similar and some economists support the idea of a carbon tax to decarbonise the energy system. According to a recent survey by New York University,[14] 81 per cent of economists consider a market-based system – a combination of carbon pricing plus workable power markets – to be most efficient, while 13 per cent prefer performance standards and other regulated programmes that prioritise cleaner fuels and energy efficiency.

What about China? China has no experience with short-term power markets,[15] and it is only starting to experiment with emissions trading schemes. But China is talking about how to best design markets and regulations in order to facilitate the energy transition cost-effectively. Like Europe and the US, viewpoints vary significantly. Some scholars praise the spot market as an all-powerful instrument; others tend to prioritise long-term bilateral trading. Some have placed great hopes in the emerging emissions trading scheme; others point to the inherent mistakes that would lead to the failure of the instrument and explore alternatives such as supply-side polices for renewable energy and coal.[16]

In this section we first discuss the theoretical underpinnings of such views. Later we argue why pure textbook economics only partially hold true in the real world[17], and China's context only complicates the matter. A holistic approach is especially needed when it comes to renewable integration, stimulating new investment, a working power market, and a reliable power system to enable a smooth transition to a renewables-based power system.

1.1 Simplified Perfect Theory of EOM and ETS

There has been of wealth of studies on the workings of energy-only based power markets (EOM) and the proper design of emission trading schemes. In theory, the two instruments are a perfect match. The EOM brings about scarcity prices that allow market participants to recover the capital costs of generation assets and to ensure long-term system adequacy. An emissions trading scheme disproportionally increases the cost of carbon-intensive generation technologies, which results in a competitive advantage for low-carbon assets and hence an internalization of external (environmental) costs.

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[13] See a detailed explanation on this terminology at www.europarl.europa.eu/RegData/etudes/BRIE/…/EPRS_BRI(2017)603949_EN.pdf

[14] Howard and Derek (2015).

[15] In China, "spot market" is often used to refer to the wholesale market from day-ahead to real time. This may vary from market design in North America and Europe.

[16] See, for instance, Jaccord (2017) and Mendelevitch (2017).

[17] These views assume perfect foresight, price-elastic demand, perfect competition and the complete internalization of the external costs of carbon emissions.

In the real world, however, inadequate policies can distort the system and disrupt the theory.[18] Thus far, the combination of deregulated power sectors and carbon pricing, i.e. EOM plus ETS, has neither delivered effective carbon reductions nor stimulated investment in a diversified, zero-carbon power system of the future. To understand the reasons for this, we must first lay out the assumptions of the underlying theory.

Claim 1: If left undistorted, energy-only markets provide sufficient revenues and incentives for new investment in all types of power generation and demand-response technologies

The assumption that EOMs provide sufficient revenues for new investments only holds true under certain conditions. First, the demand side has to be price-elastic, i.e. power consumers must reduce their consumption when prices on the power market increase. A price-elastic demand curve facilitates market clearing (the process of matching supply and demand) when supply is saturated, leading to so-called scarcity prices (Figure 4). Consumers unwilling to pay the market clearing price reduce electricity consumption during these hours, which avoids involuntary load shedding (brownouts, rolling blackouts). Prices during these hours reach high levels, thus facilitating total cost recovery for all technologies. In addition to price-elastic demand, the conditions of perfect foresight and perfect competition must be met if an EOM is to deliver efficient outcomes.[19] If these conditions are met, boom & bust cycles (repeated periods of over- and underinvestment) can be avoided.

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[18] Agora Energiewende (2016a).

[19] De Vries (2013).

Scarcity pricing in theoretical EOM environments facilitates cost recovery for all power plants Figure 4

Agora Energiewende (2016a)

In the theoretical case, investment in so-called peaking plants is critical. This is because such plants operate only for a few hours each day, at times when consumption is high and renewables production is low. Peaking plants require high scarcity prices during these operating hours to enable total cost recovery (including the initial investment).[20]

Power systems with high shares of wind and solar energy pose an additional challenge because wind and solar PV have relatively high investment costs and very low operational costs. Known as zero-marginal-cost technologies, they are typically in operation when wholesale power prices are low, and benefit only infrequently from high prices. As a result, they are more vulnerable than conventional capacity to stochastic scarcity prices.

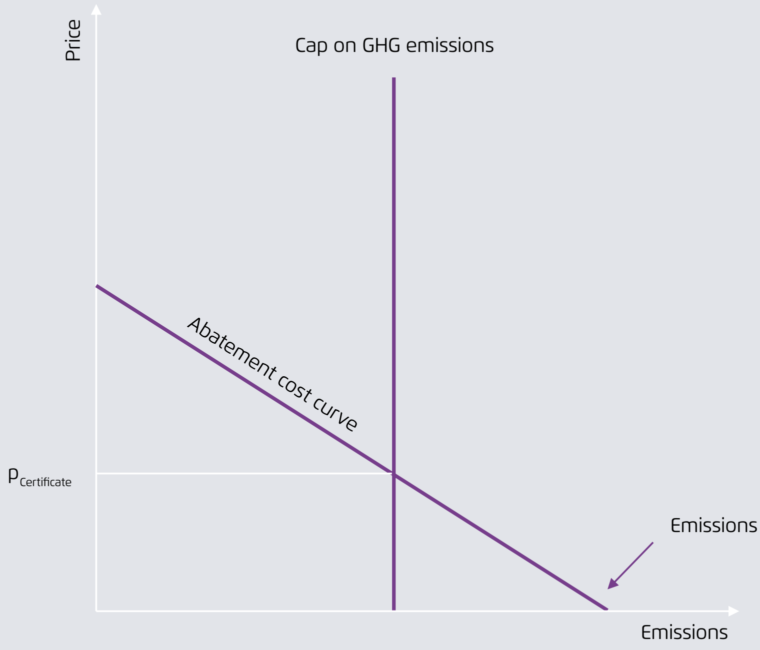
In theory, undistorted power markets should ensure total cost recovery for renewable technologies, for low-carbon residual load-serving technologies and for demand-side adaptations, provided that the ETS sets a sufficiently high price on carbon emissions to reflect the needed emission cuts.

Claim 2: Emissions trading schemes can incentivise a cost-effective decarbonisation of the power system by setting a binding and declining cap on emissions.

The EOM is agnostic about whether to use high- or low-carbon technologies. But when combined with an ETS, it is designed to steer investment to low- and zero-carbon options, provided the previously exter-

A binding cap on emissions triggers emission abatement measures. The cost of the "marginal abatement" required to meet the cap sets the ETS certificate price.

Figure 5



Agora Energiewende (2016a)

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[20] It should be noted that in this case such plants may be able to strongly manipulate the market. Accordingly, EOM always has a market force problem. For more, see Cramton & Ockenfels (2012).

nalised costs of carbon emissions are internalised.[21] The amount of this extra cost reflects the "socially responsible" level of carbon emissions that may be emitted by economic sectors that fall under the emissions trading scheme. Ideally, this cap is consistent with long-term emission reductions required to meet long-term climate change targets.

The emissions cap triggers a shortage of emission allowances, which sets the price for emission certificates and incentivises abatement measures (Figure 5). The certificate price pushes the market to favour low-carbon over high-carbon technologies and, theoretically, facilitates a cost-efficient reduction of CO_2 emissions, since investments occurs where marginal abatement costs for reducing a given amount of emissions are the lowest.

The certificate price steers the dispatch of existing resources, favouring the increased use of low-carbon plants while incentivising investment in new low-carbon technologies as well as the closure of high-carbon assets. At the same time, it can reduce demand by passing on the carbon cost through the electricity price. In effect, the ETS should enable fuel-switching from high-carbon to low-carbon assets and from carbon assets to carbon-free renewables for a more efficient achievement of emission targets.

Like the EOM, the theoretical ETS case relies on certainty for market actors. They must have confidence in the stability of the regulatory framework and in the progressive and reliable reduction of the emissions cap over a period lasting several years to several decades.

1.2 Shortcomings of Real World EOM and ETS

In our view, relying on solutions derived from simple textbook economics would almost certainly cause decarbonisation efforts to fall short, not only in China, but all over the world. There are at least four reasons why:

→ **ETS allowance prices high enough to incentivise investment in zero-carbon technologies are unrealistic and would be unacceptable to many stakeholders.**

→ **Uncertainties and risks hinder the right types of future investments.**

→ **Regulatory risk:** Politicians do not want to take responsibility for the risk of outages by implementing safety nets

→ **Costs of renewables:** The market value of renewable energy tends to decline as the share of renewable power in the mix rises (cannibalisation effect).[22]

Below we look at these four elements in more detail.

ETS allowance prices high enough to incentivise investment in zero-carbon technologies are unrealistic and would be unacceptable to many stakeholders

For many observers, the political negotiations surrounding the European ETS during the past 20 years have been sobering to follow. While everyone seems to like the theoretical purity of the instrument, real-life practice has presented a very different picture. Politicians have shied away from setting strong emission caps, fearing abrupt changes and the impact on European industry. From the beginning, the generous allocation of emission allowances and various loopholes have paralysed the instrument and led to negligible price levels.

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[21] This pricing can result from an emissions trading scheme or a carbon tax. In the following, we refer solely to ETS. For the sake of simplicity, we have assumed a uniform carbon price for all sectors.

[22] Hirth (2016).

Experience in North America (e.g. RGGI) and South Korea has not been much different from that in Europe or in China's pilot projects. Frustrated with this political failure in many places, decision-makers have given up on an "ETS only" solution and have introduced additional instruments such as the minimum carbon price levels employed in California, Quebec/Canada and others.[23]

In Europe, most recent reforms seem to have had an effect on the price. In September 2018, the EU ETS price reached a 10-year high at about 25 EUR per ton. This is still far from the socially optimal level, which lies in the range of 60 to 80 EUR in short term and higher afterward. It remains to be seen whether this development will endure in the long term.

Uncertainty and risks hinder the right types of future investments

EOM- and ETS-driven investment neglects one important characteristic of real-life markets: uncertainty. A degree of uncertainty is a given in any market. Depending on its nature, uncertainty can be a hindrance in markets that are supposed to help meet political targets – as is the case in the energy and carbon markets in liberalised systems. Uncertainty translates into risk insofar as the economic impact of uncertain events can be calculated. Risk management is a basic economic activity. From the perspective of market participants there are risks that can be hedged against *within* the existing market framework and others that cannot be hedged against (e.g. future changes to market rules) or only at prohibitively high cost.

For conventional technologies, uncertainties and risks related to wholesale market prices are of key importance. The stochastic nature of scarcity events is arguably the most critical source of investment risk.

The fact that scarcity events are stochastic (occurring occasionally when demand is high and feed-in from v-RES is low) implies that the total cost of an investment in conventional capacity may not be fully recovered during the operational lifetime of the plant, if the number of actual scarcity events (and price spikes) is smaller than expected.

The risk of partial cost recovery becomes higher the lower the expected number of operational hours is. (Peaking plants are a typical case.) Once an investment decision has been taken, several years can pass until it goes operational, and market conditions may change in the meantime. As a result, investors in mid-merit and peaking plants apply "top-ups" – i.e. risk premiums – to their investment assessment valuation as a hedge against lower wholesale prices and diminished capacity. Accordingly, funding costs rise as uncertainty increases.

Fuel price developments and the evolution of future ETS certificate prices constitute another source of risk, yet they are already an intrinsic part of the power price risk, because fossil-fuel power plants typically set prices in the wholesale market and the operators of conventional plants can thus employ risk management activities (such as buying primary energy derivatives and forward contracts for CO_2 allowances and selling derivatives of forward contracts for electricity).

Though hedging instruments (futures, forwards, options) are available for reducing market risks, they cannot fully alleviate all uncertainty. For example, the available long-term markets for hedging are typically incomplete.[24] Accordingly, a simple theoretical

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[23] Worldbank and Ecofys (2018)

[24] Market completeness is the extent to which the full set of forward and spot markets and risk management tools are available for each product. Incomplete markets do not maximize efficiency (Stiglitz, 2001).

energy-only market cannot always ensure sufficient capacity, as market risk cannot be optimally allocated among market participants. Less than optimal capacities cause high prices, increasing the likelihood of overshooting investment – this is known as boom and bust cycles – and cannot fully facilitate a shift to a more flexible and less-carbon intense power mix.

Uncertainty with regard to future price levels and scarcity price situations are also affected by a broader set of political and regulatory risks. Political risks may take many forms. One risk is the implementation of price caps to protect consumers from excessively high and volatile prices, and to mitigate the market power of key actors. Another is that investors cannot anticipate future market design adjustments that affect price distribution. Similarly, the active removal of inflexible, baseload capacity affects investment in efficient and flexible technologies.

Capital intensive technologies like solar PV and wind are more vulnerable to risk and uncertainty than investment in fossil-fuel fired capacity, and thus more likely to suffer from high risk-premiums when market conditions are the same. High-capital cost technologies depend on stable revenue streams from selling electricity on the market. Even small increases in the risk premiums of RES projects may increase capital costs and thus lead to a significant rise in project costs. The important point here is that other, less capital-intensive investments are much less exposed in their cost and financing structure to risk. This puts RES projects at a major competitive disadvantage when compared with conventional generation technologies.

Regulatory risk: Politicians do not want to take responsibility for the risk of outages by implementing safety nets

A reliable and secure power system is important for any economy, and power system reliability is often considered a public good. Even if an energy-only market incentivises new investments and delivers system reliability, many politicians and regulators seem to doubt the effectiveness of the energy-only market. In practice, declining reserve margins in the power systems have triggered debates about the need to incentivise additional investments to "keep the lights on", be it full-blown capacity markets or "safety net approaches" such as capacity reserves or strategic reserves.[25] The introduction of such instruments and the public discussion surrounding them have increased uncertainty among market participants, making market-based investments in new capacity less likely.

Realistically, therefore, the question is not *whether* interventions that increase system reliability can be avoided but how to make sure that they are economically feasible with a power system with high-level of variable renewables.

The situation in China is a good example. There, "supply security" is not just a constraint on system operation; it is also the ultimate goal, more important than economic efficiency itself.

Cost of renewables: the market value of renewable energy tends to decline as the share of renewable power in the mix rises

There is an ongoing and important academic debate concerning the electricity market prices achieved by RES installations during the hours they produce when the power system has a high share of vRES.[26]

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[25] Capacity reserves, also known or strategic reserves, address the political concern that the EOM might not build sufficient capacities. They do not reduce risks for the remaining capacities inside the EOM. Hence, they may create a "slippery slope effect", where the size of the reserves becomes larger and larger due to the lack of market-driven investment.

[26] See, for instance, Agora Energiewende (2015), Hirth (2013) and Hartner et al. (2015).

There is some evidence that a higher share of vRES is associated with falling market revenues for each kWh of vRES electricity produced. Some questions remain, however. For instance, does the reduction in market revenue decline slower or faster than the LCOE of newly built RES capacity? Do more flexibility options in the power system result in a bottoming out of the market price? Does the market value of wind and PV decline as a function of the speed of their deployment? Does their market value increase relative to the speed by which the overall power system becomes more flexible?

If the market revenues from wind and PV were to fall faster than LCOEs, this would support the argument that wholesale market revenues from wind and PV cannot fully recoup investment in these technologies when their share is high.

Furthermore, when the share of RES is high, the marginal price in the wholesale market is set by RES and nuclear, not by fossil fuel-fired plants regulated by the ETS. During these hours, the ETS does not add to the market price obtained by RES producers. As soon as the last fossil-fired power plant ceases its dispatching, the market price could drop to the marginal cost of nuclear and/or the marginal cost of RES installations – i.e. zero for wind and PV.[27] In a system with a large share of renewables, RES investors would anticipate such developments and not invest in new RES capacities unless there were some mechanism for generating stable market revenues, even in presence of large shares of zero-carbon capacity.

Again, the general theory of the EOM does not address the financing challenge that occurs when there is a high share of zero-marginal-cost capacity in the market. It also fails to reconcile the key role played by wholesale power markets with the political imperative of creating a zero-carbon power system within two decades.

1.3 Additional Complexity in the Chinese System

China has begun discussions about the best regime for its power market, along with a process of reform launched in 2015[28]. Like their counterparts in the EU and USA, scholars and practitioners in China have talked about the value of economic theory and how to apply it in practice. Two China-specific elements further complicate this debate: the specific Chinese dispatch regime, and the overcapacity of coal-fired power plants. Seeing how many studies already shed light on the second aspect,[29] we have decided to focus on the dispatch paradigm.

While these factors have profound economic, policy and political implications, China has the opportunity to leapfrog some of the difficult learning phases experienced by the EU and the USA and to develop a coherent and effective power market regime right from the beginning.

The conventional dispatch paradigm is inflexible and conflicts with the nature of vRES

The dispatch principle in the current Chinese power system is not merit-order based, and thus not cost effective. Its system is characterized by horizontally split baseload preferences, low granularity scheduling, and plan-based transmission volumes as the boundary for provincial balances. Such a dispatch model strongly conflicts with the nature of variable renewable energy that requires an increasingly flexible power system. Figure 6 illustrates this relation: the more variable renewables are added to the system, the less baseload and mid-merit electricity is needed. Such changes are not reflected in the Chinese

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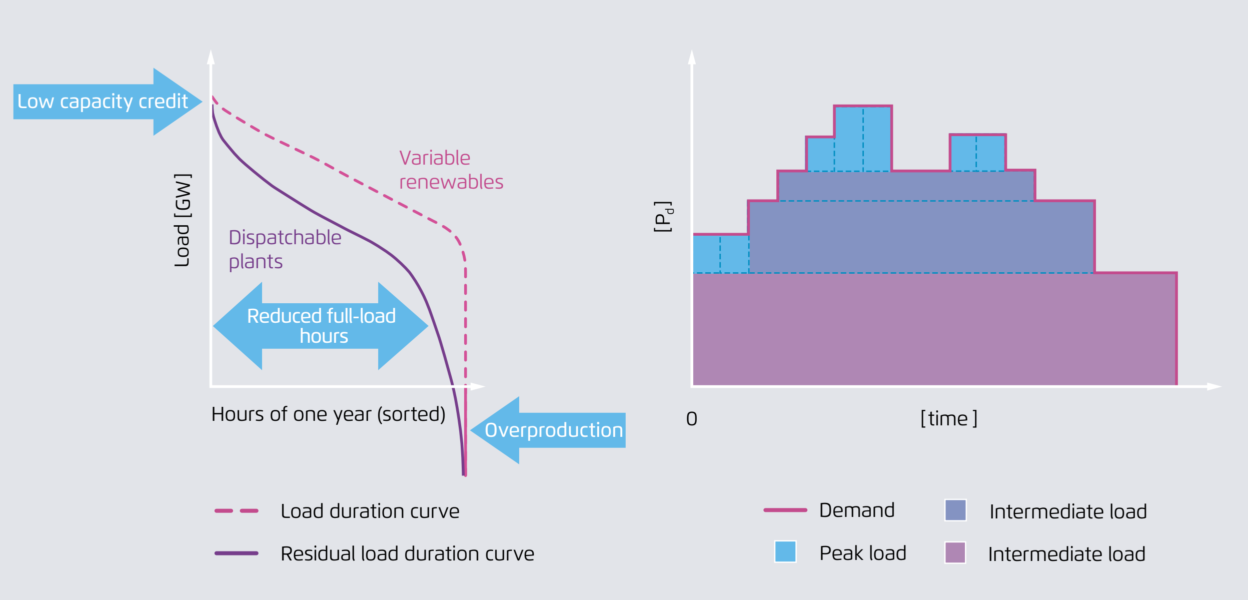
[27] It depends on whether the supply side or the demand side sets the price.

[28] On the review on the current progress, see Davidson et al. (2017), Pollitt (2018), and RAP (2018).

[29] See, for instance, Kahrl et al (2011) and Jiang et al. (2018)

The dispatch paradigm conflicting with the profile of (residual) load curve with high level renewable

Figure 6



Note: Renewables would reduce the residual load duration until the base load disappears; coarse-scale scheduling (right) still prevails in China's power system operation.
Personal communication with Professor Chen Haoyong, Sept. 2017; Ueckerdt et al. (2013)

dispatch pattern, which leads to inefficiency and increasing costs.

The shortcomings of the current Chinese system include:

1. The annual generation plan guarantees minimum full-load hours for coal-fired power plants (production quota) in every province.
2. Due to technological and institutional limitations, thermal power plants are unable to vary their output. (See Figure 7 for an example of system operation in a typical day.) Minimum output is usually set at 50 per cent of technical capacity.[30]
3. Finally, CHP plants are usually heat led and often not equipped with the technical parameters to decouple heat and power output. As they have a social obligation to satisfy heat demand in winter, CHP plants must adhere to increased minimum heat production. This takes priority over downward regulation in order to accommodate wind or solar power. This market framework is not conducive for developing alternative heat generation or storage, which might alleviate the problem. In the regions heavily relying on CHP (e.g. Northeast China), the minimum load is normally as high as 60 per cent or more, which leaves little room for other options.
4. Transmission lines across provinces and regions are operated in a very inflexible manner. This limits the "smoothing effect" of the variability of wind and solar plants that the grid infrastructure can provide.

Changing from "average dispatch" to "economic dispatch" is inevitable as the growth of variable renewable energy fundamentally challenges the current regime. The absence of price information (e.g. when power plants do not submit bid data at each time

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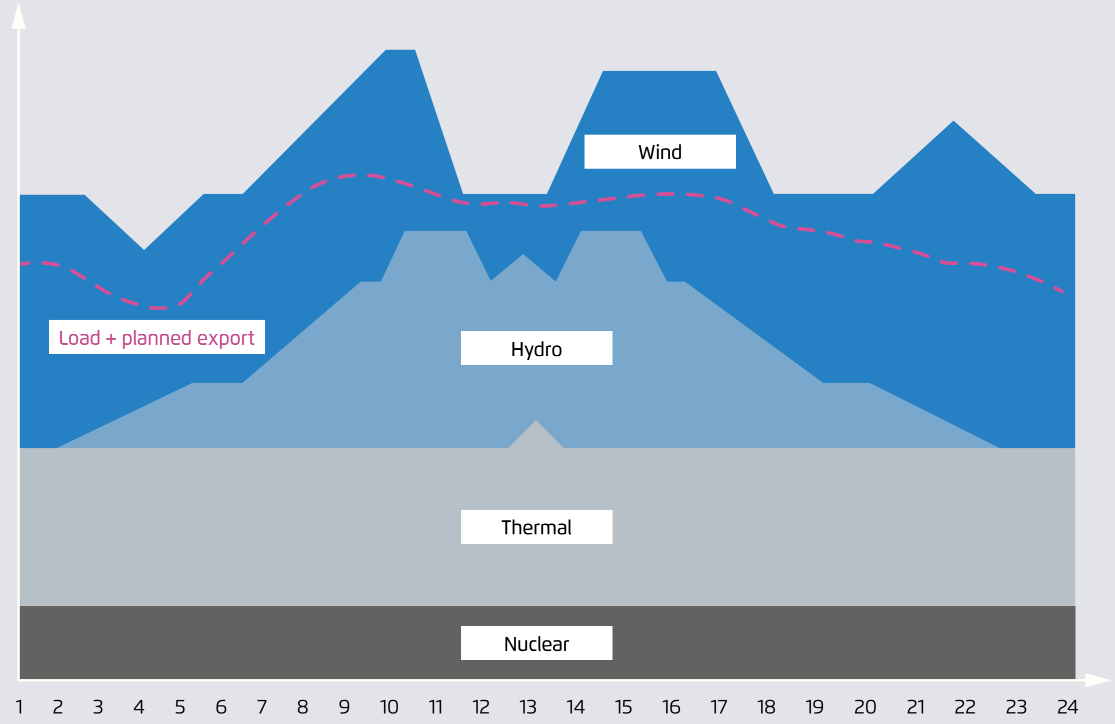
[30] Davidson et al. (2017). By comparison, German and Danish coal-fired power plants are operated flexibly and can reduce their minimum load up to 10 per cent of gross capacity. See Agora Energiewende (2017b).

Typical operation in the power system of China

Figure 7



Luo Zhiqiang (2017). Power market in SGCC: review and outlook. Presentation at the 9th Clean Energy Ministerial (CEM9), Copenhagen, Denmark, May 2018.

scale) and the coarse scale of balance scheduling leads to low system operation granularity.

Furthermore, larger dispatch areas, which would benefit the whole system, are simply not practical in the current regime. The top (centralised) dispatch operators are superior to provincial level operators and usually stick to planned transmission schedules, regardless of variable electricity production and residual load.

A recent study confirms the positive effects of an economic dispatch regime: the reduction of curtailment and the number of coal plant operating hours and significant social cost savings such as lower rates for consumers and less air pollution.[31] But the study also found that changes in the dispatch regime would bring about strong redistributional effects. Inefficient coal power plants would go out of business, leading to job losses and affecting local and regional economies.

A further challenge is the growing overcapacity of coal-fired generation, which has intensified since the addition of 50 GW of new coal capacity in 2015. Another 200 GW are currently under construction or planned. In 2017, coal still contributed 60 per cent to the capacity mix and over 70 per cent to the generation mix despite the booming development of renewable energy. If the current trend continues, China would largely have a coal capacity of 1,100 GW or more by 2020 (Figure 8).

Because demand is not growing at the same pace as capacity, the projected share of coal power in 2020 significantly overshoots the economical optimum.

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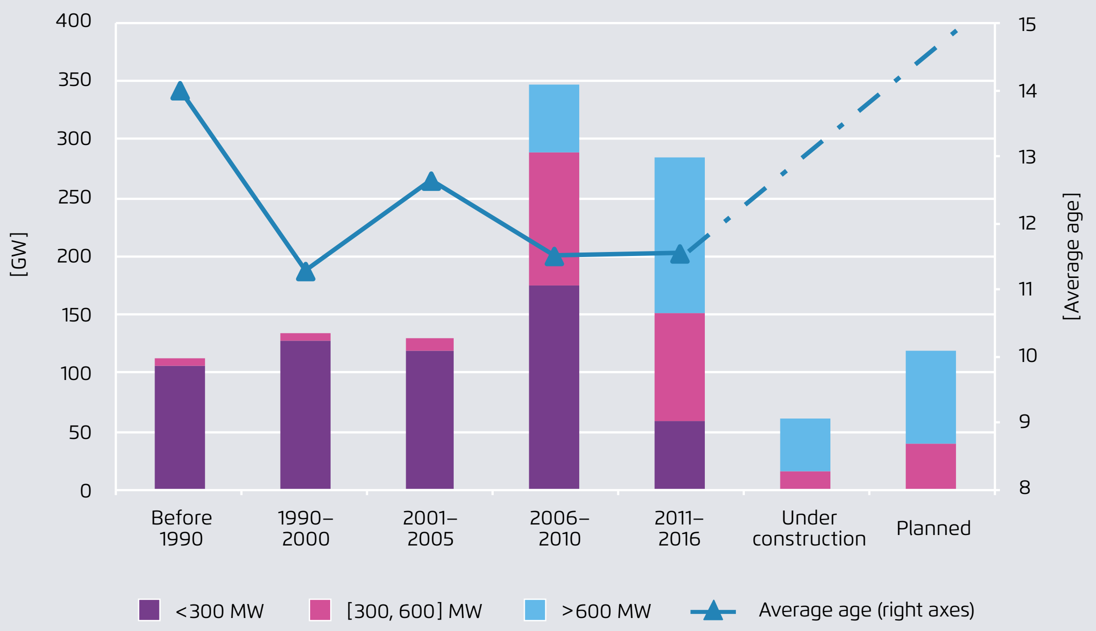
[31] According to Wei (2018), coal consumption would be reduced by six per cent.

Baseload coal power units built within the past 15 years dominate the power system in China

Figure 8



Own compilation based on official data from NEA and CEC (2011).

In a competitive market, operational hours would decrease significantly, shrinking revenues accordingly. It is easy to imagine that the owners of coal plants are not the most enthusiastic proponents of the economic dispatch model. Local governments, whose coal assets tend to be smaller and less efficient, are particularly afraid of such a change.

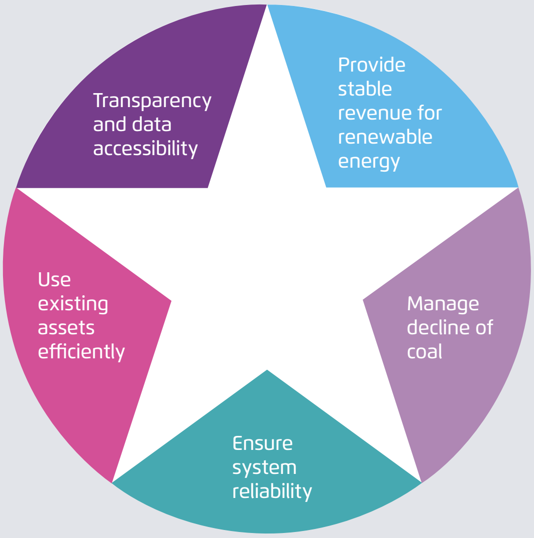
2. Five Golden Rules for the Chinese Power Market Transition

China aims to achieve a 50 per cent share of non fossil-fuel based electricity in its power mix by 2030. This is an ambitious goal, but doable. First and foremost, it requires a stringent and coordinated package of policies. To this end, we have identified Five Golden Rules for future power system design. Following these rules will help to fulfil expansion targets while also keeping reliability high and costs low:

- → 1. Use existing generation capacity efficiently by implementing short-term markets
- → 2. Incentivise flexibility to ensure system reliability and adequacy
- → 3. Provide stable revenues for new investment in renewables
- → 4. Manage the decline of coal and its structural consequences
- → 5. Acknowledge the pivotal role of transparency and data accessibility

These five golden rules apply to the power market and its interaction with other energy sectors. An energy transition in the wider sense obviously requires attention to other aspects as well – including in particular grid design and energy efficiency – but these issues are addressed in other publications.

The China Star: five rules for renewable integration and new investment in China. Figure 9



Own illustration

Golden Rule 1 | Use Existing Generation Capacity Efficiently By Implementing Short-Term Markets

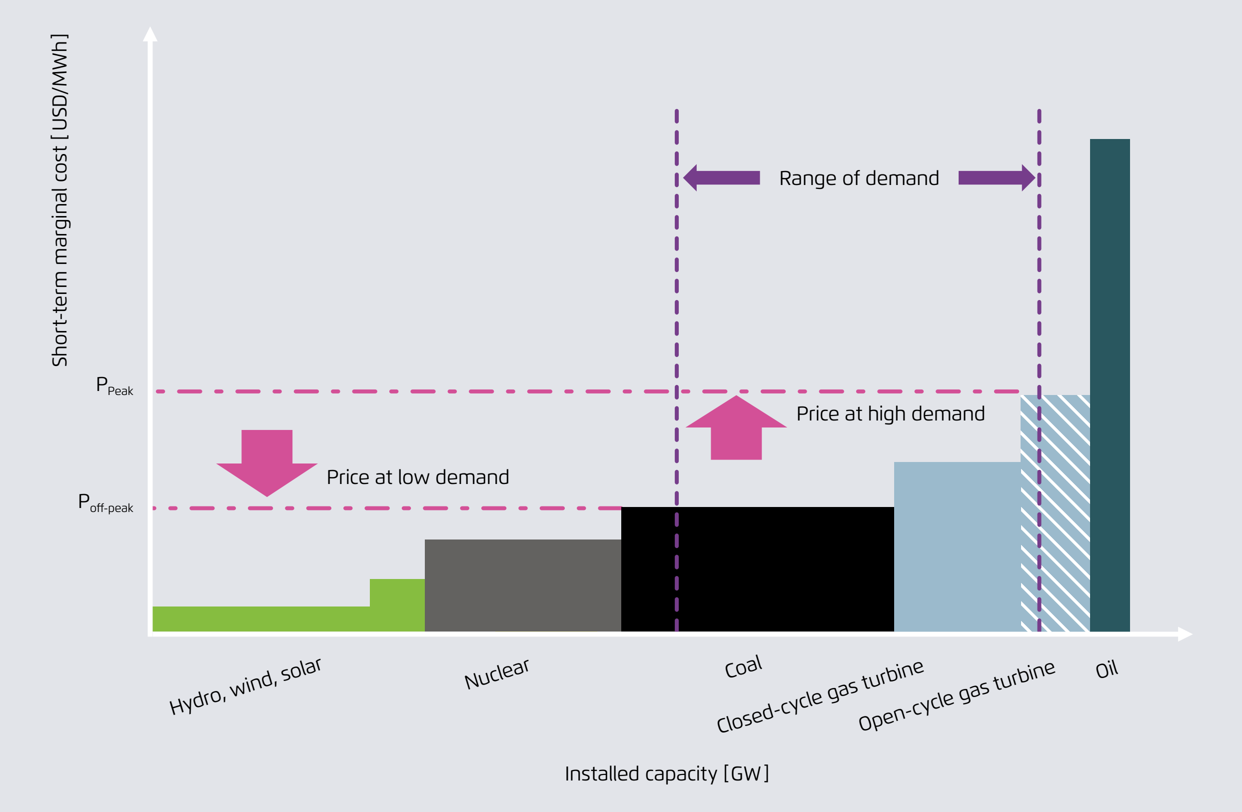
Since the power sector was liberalised in the 1990s, short-term markets have become common place in Europe and parts of the US. The main tenet of the short-term market is the merit order principle. The merit order is a way of ranking available sources of electricity generation capacity, based on ascending price (reflecting the short-run marginal costs of production) together with the amount of energy that will be generated. Provided there is no distortion, generation units with the lowest marginal costs are the first ones to be brought online to meet demand, and the plants with the highest marginal costs are the last to start operating.

In the rest of the world, merit-order based dispatch was common practice even before liberalisation of the power section took place. This is fundamentally rooted in the fact that merit-order is a cost-minimised system.[32] Merit-order dispatch leads to various effects that are relevant to the present discussion.

One is a merit-order effect by renewables. Here, the integration of renewable generation on the wholesale market right-shifts the merit-order generation curve, which noticeably reduces the clearing price

Illustration on how merit-order based dispatch ensure short term efficiency

Figure 10



Adapted from CNREC (2017)

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[32] Neoclassical economics says that an efficient market follows three distinct theoretical principles when pooling resources: a marginal pricing principle; an opportunity cost pricing principle; a no-arbitrage principle. Pricing based on merit-order aligns with these principles. See details at CNREC (2017).

while slightly increasing the amount of traded energy (which is an almost inelastic demand curve). This has strong implications for the funding of renewables discussed under Golden Rule 3.

Another effect is the huge price fluctuations due to variation in demand and output (Figure 10) by the second, minute, hour, day, season and year. Take German price data as an example. The range of electricity prices is 1000 per cent of the mean electricity price, and prices varied by a factor of at least two during a normal day. The price of other energy carriers fluctuated much less: natural gas prices varied by 70 per cent of the mean price and crude oil prices by 36 per cent of their mean. Neither commodity demonstrated within-day price variation.[33] Chinese government and society have been working to accommodate massive price variations like these.

China has tested short-term markets in some areas already. The aim is to have them fully operational in eight provinces by early 2019. Based on the above principles, our recommendations are as follows for the Chinese context:

→ **Make trading and system operations as open and transparent as possible.** A well-functioning market should be open to all actors and follow a set of well-defined, non-discriminatory rules. Issues of generator size should not prevent market participation; anyone capable of providing services (such as flexibility) should be able to participate. In this context, access to data is often key. It is therefore recommended that the market pilots establish a data hub that is open to all market participants and the public.

→ **Establish pilot trading systems that allow trading with short-interval electricity products and shorter lead-times (e.g. hourly settlement with day-ahead lead times) and strengthen capabilities for relevant hardware and software development.** The coarse scale of the preceding system is no longer valid. Automated technology allows us to trade close to real time, and shorten the time intervals to less than an hourly scale. This is very positive, because hourly or even quarter-hourly products better reflect variations in demand and renewable energy production.

→ **Strictly adhere to China's renewable energy law and compensate renewable asset owners for curtailed energy.** The curtailment of renewable energy is strongly driven by the available grid infrastructure and therefore occurs in market-based systems as well as in non-market-based systems. Renewable energy generators have not yet received payments for the curtailed hours. This has a detrimental effect on cost (it is energy already paid for) and climate (it would have been carbon-free energy). Moreover, it is a strong disincentive for companies to invest in new renewable assets. A consistent merit-order approach would shift the risk of curtailment to those market participants who produce when costs are higher and demand is lower.[34]

→ **Gradually expand system operation and actual balancing areas from individual provinces to larger regions.** In the current dispatch paradigm, the balance area is restricted to individual provinces, with local demand and long-distance trading separated into two different markets. Coupling regional markets would allow a better deployment of existing resources for balancing and therefore lower costs. But the establishment of a single national short-term market is a medium- to long-term project. A gradual coupling of provincial or regional spot markets will nevertheless create positive effects, and should eventually lead to a uniform national market.

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[33] Hirth et al. (2013)

[34] See RAP (2015b), Hove and Mo (2017) and Dupuy and Wang (2016).

Golden Rule 2 | Incentivise Flexibility to Ensure System Reliability and Adequacy

The greatest concern for policy makers and system operators is keeping electricity systems secure, which means preventing black-outs and brown-outs. System security has two aspects: system reliability, i.e. the short-term ability of the system to balance demand and supply; and system adequacy, i.e. the long-term ability of generation assets to cover peak load.

Amid growing shares of renewable energy, power systems are changing. Power is no longer produced only by centralised stations; the increasing number of variable sources such as solar and wind has led to more distributed production. The power system thus needs to coordinate a fast-growing number of actors, while the volatile nature of renewable sources requires systemic changes in technology. In short, flexibility must become the new paradigm of power markets. Flexible services can be delivered by both supply and demand sides. The most important flexibility options are: grid design, dispatchable firm capacity (fossil and non-fossil), demand response, storage, and the interaction of the electricity system with other sectors (such as transport and heating & cooling).

Safeguarding system adequacy and system reliability has become a dynamic issue: it is not only about "how much" capacity is needed but also about "what kind" of capacity. When it comes to short-term system reliability, markets are usually considered the best way to satisfy needs. Experience from Europe and the US shows that flexible services can be incentivised in every market segment, although long-term forward markets usually do not fall into this category. Figure 11 illustrates the process.

When it comes to long-term system adequacy, the situation becomes more complicated. In fact, there is an ongoing argument amongst experts as to whether energy-only markets are able to incentivise optimal investment in new generation capacity. Theoretically, this might be possible. But the predictions of theory are not always reliable.[35]

At this point, we are not ready to argue for one side or the other. But it remains a fact that many policymakers have opted for an additional instrument to safeguard system adequacy – namely, capacity remuneration mechanisms (CRMs). We can roughly distinguish three different variations of CRMs:

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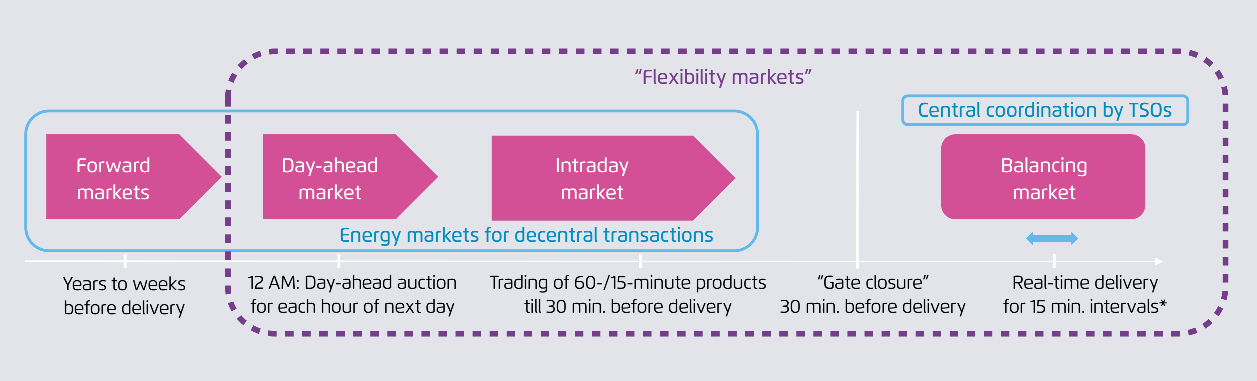
[35] For a short overview of this discussion, see Agora Energiewende (2013).

Sequence of market-based transactions in a typical deregulated power system — Figure 11



* Imbalance penalties incentivise market actors to obey physically to their market trades
CE Delft and Microeconomix (2016).

- Strategic reserves, as used in the Scandinavian market[36]
- CRMs outside the energy market in some American markets, e.g. capacity auctions in PJM, NYISO and MISO[37]
- CRMs within the energy market, e.g. Operating Reserve Demand Curve (ORDC) in the Texas ERCOT market[38]

Whatever instrument is chosen, its design is crucial in order to deliver the needed additional flexible resources and limit distortions to the energy-only market. Therefore, the instrument should reflect the difference in value between resources with different capabilities. Efficient energy and balancing markets remunerate flexible technologies more than inflexible ones. The same can be said of capacity/capability remuneration instruments.

The question of how to incentivise flexibility resources is becoming ever more important in China. Our recommendations are as follows:

- **Establish a short-term market, as discussed in Golden Rule 1.** This would be the best way to incentivise flexibility on the supply side, and – if designed well – on the demand side as well. As the development of such a functioning short-term market takes time, we recommend that interim steps be taken (see below). It is important that these interim mechanisms are reversible and compatible with short-term markets in the long run.
- **Make existing coal-plants more flexible to save costs, reduce emissions and provide more flexibility in the power system.** From a technical point of view, most Chinese coal plants would need retrofits to be operated in a load-following mode. Experience from Germany and Denmark could provide important insights here.[39]
- **Change the "benchmark tariff system" for coal-fired power plants.** This is an important step for disincentivising coal assets.[40] Currently the price mechanism does not differentiate between capacity payments and energy revenues.[41] Instead, power plants enjoy the generous "benchmark price" set by the government.[42]
- If China, as has been proposed, adopts a capacity remuneration mechanism (CRM), it is crucial that it be designed in such a way that it
  - (a) **does not severely distort future energy-only markets**, and
  - (b) rewards flexibility, e.g. ramping capacity, instead of baseload capacity.

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[36] See http://ec.europa.eu/competition/sectors/energy/strategic_reserve_en.pdf

[37] See Sprees et al. (2013).

[38] See www.ercot.com/content/wcm/training_courses/107/ordc_workshop.pdf

[39] See Agora (2017b).

[40] See Hu (2016); RAP (2016).

[41] It should be noted that the system is evolving. In 2017, bilateral trading counted for roughly 20 per cent of the total electricity market.

[42] The benchmark price is indexed to the coal price and therefore differs across provinces. For details, see Jiao et al. (2010).

Golden Rule 3 | Provide Stable Revenues for New Investments in Renewables

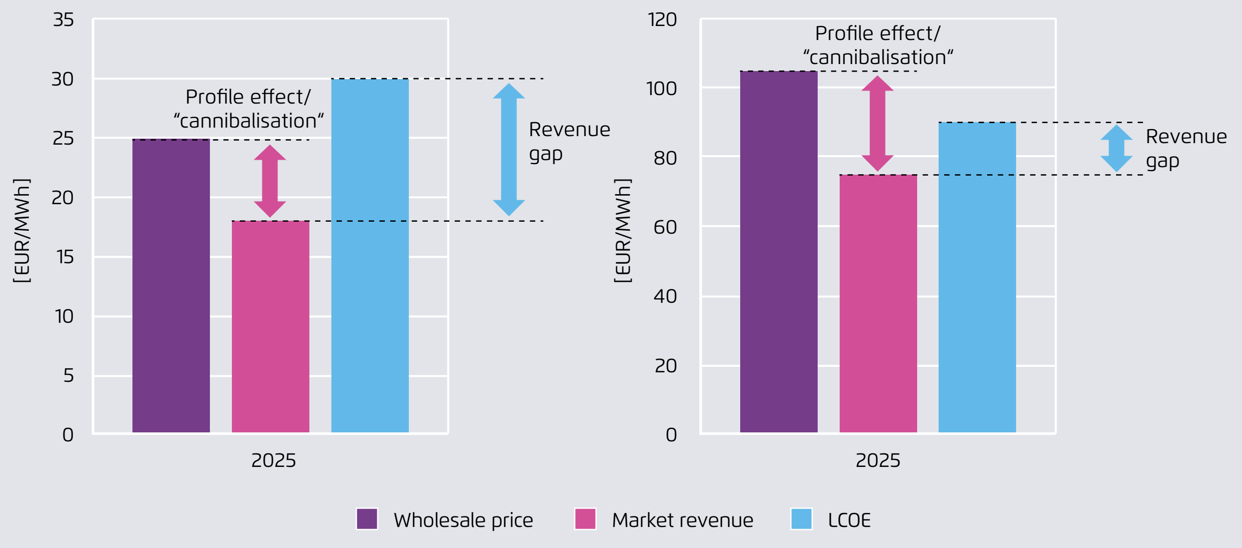
The rapid decline in vRES generation costs constitutes an ongoing trend worldwide, not least of all in China. The latest auction for solar PV projects in Baicheng, Jilin, cleared at around 5 euro cents, close to the local benchmark price of coal-fired generation.[43] This development is in line with the expectations of the Chinese government, which anticipates cost parity between wind/solar PV and coal by 2020.

Roughly ten years ago, China adopted a Feed-in Tariff (FIT) to support wind energy; soon after, it introduced one for solar PV. The system established a reference price for the regulated benchmark price of coal power, but it does not give priority access for renewable energy in the grid. Therefore, curtailment of wind and solar energy is high. Although the renewables law calls for the compensation of curtailed energy, the reality often looks different. Nevertheless, FIT levels were sufficiently attractive for investors to create a veritable renewables boom in China in recent years.

The renewables surcharge on consumers has reached 1.9 RMB cents/kWh, or 3 per cent of the end-use tariff. This amount is considered the politically acceptable maximum. Because the government does not plan to exceed this limit,[44] it has started to search for alternative mechanisms with lower direct costs. In May 2018, the Chinese government abruptly cut subsidies for solar PV, resulting in 20 GW less installed capacity than previously envisaged. The government also issued a guideline document that requires auction-based pricing for post-2018 utility-level wind and solar projects.[45] However, it has yet to make the details of the transition from FIT to auctions public.

The costs of renewables and their market value with and without carbon pricing

Figure 12



Redl (2018)

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[43] See https://m.jiemian.com/article/1976259.html

[44] This information is based on informal sources in the NEA.

[45] See NEA (2018b).

With technology costs for wind and solar reaching competitive prices with coal, more and more people are calling for a halt to any kind of financial support for renewable energy. Typically, they argue that wind and solar should be able to compete with other generation sources, especially when wholesale power markets are in place. They believe that support should be phased out once the emissions trading scheme pilot projects are introduced throughout all of China.

These claims are built on false assumptions about the nature of renewable technologies. Even if distorting effects like full-load hour guarantees for coal plants are dismantled (which has yet to occur in China), renewable energy would be unable to recoup its investment in a competitive market. This is due to the specific market value of zero-marginal cost technologies. The better the conditions for wind and solar, the more electricity they produce, driving down the price. Thus, at times when wind and solar produce a lot of electricity, they hardly earn money, because prices are low. At the same time, when they are not producing, prices are high, but they cannot take advantage of this revenue opportunity. This so-called cannibalisation effect (solar and wind cannibalise their own market value) becomes increasingly relevant as the share of wind and solar capacity grows and more and more hours of low or even zero prices occur. This may sound like a future issue for China, but it is in fact a huge concern now for investors who need to calculate their revenues for periods of up to 25 years. Figure 12 illustrates this dilemma.

To provide certainty for investors in renewable energy, therefore, a long-term mechanism needs to be in place that ensures constant and fair revenue flows. Our recommendations for China in the short term are as follows:

- **Fully implement and enforce the renewable energy law**, especially the principles of priority grid access and priority dispatch. The law constitutes the logical foundation for the compensation of renewable curtailment.
- **The renewable obligation policy now under consideration in China should respect the principle of a unified power market.** When designing market mechanisms, such as renewable obligations (as well, carbon ETS markets), policy-makers should avoid creating separate markets that distort, rather than strengthen, the price signals of the united electricity market. By mixing the "green power" and "green certificate" in current design, and a separate market for cross-regional power transmission, China risks bifurcating power markets and distorting price signals.
- **The auction design** should reflect risk alleviation concerns. The lower the risks, the lower the cost of capital, the lower the costs for new renewable installations. Ensuring low investor risks is an efficient way to further expand renewables while driving costs down.

Golden Rule 4 | Manage the Decline of Coal and Its Structural Consequences

In the Chinese energy mix, coal is king. China is the world's largest producer, consumer and importer of coal. By 2017, coal accounted for about 60 per cent of China's energy consumption and around 65 per cent of its electricity consumption. However, this situation is changing:

- → Due to improved efficiency, use is declining and economic activities are changing[46]
- → Coal resources in some regions are depleted
- → Air pollution from coal emissions is a growing concern
- → Signs of climate change are becoming more and more obvious

Having acknowledged these factors, the Chinese government is now seeking to manage the transformation of the power sector. In the 11th Five-Year Plan (2005–2010), the central government began to force provinces to close over 80 GW of small and inefficient coal plants, leading to social disruptions in many regions. Furthermore, it launched a programme to replace small and old plants with new and larger ones.[47]

More recently, China has started testing an emissions trading scheme in certain pilot regions. According to observers, it will take at least a decade until China concludes these pilot programmes. It remains to be seen whether China will be able to avoid the traps of other emissions trading schemes such as the over-allocation of certificates. We believe it would be a great mistake to try to cut carbon use using an emissions trading scheme alone. Instead, it seems wise to implement additional instruments that help actively manage the decline of the current coal fleet.

The smart management of the coal fleet phase-out will enhance the overall efficiency of the transition towards a clean energy system while mitigating its negative consequences on workers and regions. Our recommendations are therefore as follows:

- → **Immediately ban new coal:** Overcapacity is already an issue today. Adding more coal capacity – with an envisaged lifetime of 40 to 50 years – will severely aggravate the situation. The risk of stranded assets is high, and the costs will be borne by the workforce and to a certain extent by society as a whole. An immediate cessation of coal plant construction is thus a first and important step.
- → **Fully exploit the potential of the emissions trading scheme:** Though there are serious doubts that the ETS will suffice, it is important to make it as effective a tool as possible. Learning from the mistakes in Europe is a good idea. This means acknowledging the interdependencies between ETS and other policy instruments. The cap in the ETS should not be fixed; rather, it should be a function of the outcomes of other instruments such as feed-in tariffs, energy efficiency measures and smart retirement instruments. Thus, any CO_2 reductions that go beyond their projected baseline must be deducted in order to preserve the cap's economic efficiency and environmental integrity.
- → **Supplement the ETS with additional instruments** that actively retire existing coal-fired power plants, as we have seen it in other parts of the world. In principle, the following options exist: a) an emissions performance standard that requires power plants to keep emissions below a certain threshold, b) a fiscal instrument such as a tax on carbon or c) a distinct phase-out plan that determines the life-time of every single coal unit, as is currently being discussed in Germany.
- → **Anticipate socio-economic impacts on affected regions and facilitate structural change.** As a managed decline of coal will lead to changes in social and economic systems of regions that rely on coal today, it is crucial to consider an active management of the structural changes in these vulnerable regions; especially with regards to the financial implications.

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[46] Spencer et al. (2018).

[47] Zhang and Qin (2016).

Golden Rule 5 | Acknowledge the Pivotal Role of Transparency and Data Accessibility

The Chinese power system is transitioning from a highly regulated system to more market-based one. The government is committed to the use of market forces in the allocation of resources, though it will continue to employ regulatory instruments as well. Whatever system emerges, the transformation process will take time and will require policy makers to devote attention to numerous processes occurring in parallel. Many tasks still lie ahead in practically every area: improving infrastructure, designing efficient market-based mechanisms, and managing the social effects of the transition, to name but a few.

An area that needs special attention is the availability and transparency of data. A power system that is increasingly based on thousands and millions of small, medium-size and large-scale generation units, and that involves growing numbers of market participants on the supply and demand sides, requires intelligent steering mechanisms. A centralised authority is no longer capable of acting as an "all-powerful operator" to manage such a system. Rather, the information conveyed by prices within the scope of a market system is essential. China's decision to implement a spot-market is, therefore, the right one.

But a market can deliver adequate results only when market participants have access to information. Investors need ample information to make decisions on future investment, be it in generation, grids or flexible services. Similarly, consumers need information to make deliberate decisions and negotiate with suppliers. And system operators need information on plant availability, on weather conditions, and on grid congestion. The same is true for generators, who need this kind of information to ramp up or ramp down a specific unit or to take it offline entirely. If transparency is lacking, markets tend to develop informal structures dominated by certain players who abuse their market power.

Luckily, nowadays, digital technologies allow for the easy and cost-effective collection, treatment and publication of relevant data. Weather forecasts, for instance, have improved significantly and allow us to project electricity generation of wind and solar installations. Transmission lines can be observed with digital devices, allowing system operators to detect congestion or even break-downs in just seconds. Likewise, system operators can track production and consumption at a very granular scale in real time, even in a large country like China. Making all this (and other) data accessible to market participants will promote the smooth operation of the market while also contributing to the efficiency and reliability of the power system.

Our recommendations are therefore as follows:

→ Require system operators to publish data and allow public access. Such public reporting requirements need explicit guidelines that stipulate report formats, frequency, time resolution, etc.[48]
→ Initiate impact assessments and public debates, which can prevent negative and distortive effects with regards to market unification and policy efficiency.
→ Promote the visualization of data and strengthen the development of software and other related tools in China through, say, R&D subsidies. This will ease access and data interpretation by market participants, prevent misinterpretations and improve use of data and system efficiency.

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[48] The EU Transparency Regulation N °543/2013 could provide interesting insights regarding the granularity of such a regulation.

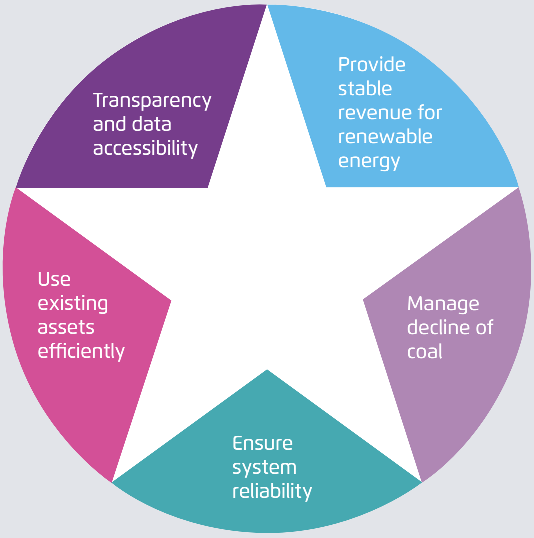
Conclusions

China's power system has initiated a transition towards a renewables-based, market-oriented system. Much has been achieved already, and many reforms have been launched. The government has started to liberalise retail markets and distribution grids for new owners and market players; short-term wholesale markets are scheduled to start operating as pilot projects soon; emissions trading schemes have been established in several provinces; and the government is working on a new, auction-based renewable remuneration scheme. Much work remains to be done, however.

In light of the sector's dynamism – including in particular the rapid growth of wind and solar energy – China must stay committed to reform efforts. The strong growth in renewables witnessed in recent years has encouraged the Chinese government to adopt a more ambitious target for 2030. Instead of the implied 38 per cent share of renewable electricity set forth by the NDC, the government now aims to achieve 50 per cent share of non fossil-fuel based electricity by 2030. Assuming realistic growth in other technologies – including nuclear and hydro in particular – we estimate that wind and solar energy will need to account for around 25 percentage points of the 2030 target.

To achieve these targets in a cost-effective way, reforms to the power system must not be halfhearted. The risk is that renewables curtailment, market distortions and other inadequacies will significantly increase the costs for the Chinese consumer. It is important to consider various policy instruments and sectoral markets in a coherent manner, to take into account their interdependencies and short-comings and to develop a pragmatic and consistent set of policies that will eventually ensure a cost-effective, clean and reliable power system.

The China Star: five rules for renewable integration and new investment in China. Figure 13



Own illustration

To these ends, we have proposed Five Golden Rules for reforming the Chinese power market. These five golden rules are:

- → **Golden Rule 1:** Use existing generation capacity efficiently by implementing short-term markets
- → **Golden Rule 2:** Incentivise flexibility to ensure system reliability and adequacy
- → **Golden Rule 3:** Provide stable revenues for new investment in renewables
- → **Golden Rule 4:** Manage the decline of coal and its structural consequences
- → **Golden Rule 5:** Acknowledge the pivotal role of transparency and data accessibility

These five aspects are interconnected and need to be addressed holistically. If China keeps them all in mind, it will have a chance to leapfrog to a power market design that accommodates very high shares of renewables –while also keeping costs down and ensuring system reliability.

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