TOWARDS A WATER & ENERGY SECURE CHINA

TOUGH CHOICES AHEAD IN POWER EXPANSION WITH LIMITED WATER RESOURCES

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CHINAWATER RISK

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Tough choices ahead in power expansion with limited water resources

This report is published by China Water Risk to explore strategies towards water & energy security in China as well as to provide an overview of water risk exposure across China's power landscape.

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About China Water Risk

China Water Risk (CWR) is a nonprofit initiative dedicated to addressing business & environmental risk arising from China's urgent water crisis. We aim to foster efficient and responsible use of China's water resources by engaging the global business and investment communities. As such, we facilitate discussion amongst industry leaders, investors, experts & scientists on understanding & managing water risk across six industry sectors: Agriculture, Power, Mining, Food & Beverage, Textiles and Electronics. CWR also has been commissioned by financial institutions to conduct research analyzing the impact of water risks on the Power, Mining, Agricultural and Textile sectors. These reports have been considered groundbreaking and instrumental in understanding China's water-energy-food nexus.

Join the discussion at www.chinawaterrisk.org.

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The views expressed in this report are those of China Water Risk and not those of our supporters.

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CHINAWATER RISK

OVERVIEW

China's waterscape is changing. Water risks in China, be they physical, economic or regulatory, have great social-economic impact and are well recognized. China Water Risk (CWR) has encouraged a comprehensive view of such water risks since our launch in October 2011 with the aim of increasing the understanding and thereby the mitigation of such risks. We believe that water cannot be considered alone, that an unsiloed approach to the challenges China faces relative to water is critical. Thus water and energy has of necessity been a key area of focus. We can no longer ignore that rapid industrialization and rising affluence, along with an increasingly complex water-energy nexus, has put mounting pressure on the supply of water.

Today, power generation is the largest user of industrial water. In fact, 93% of power generation in China is water-reliant. In short, no water = no power and vice versa as we require power to clean, transport and distribute water. Moreover, China's water resources, arable land and energy reserves are mismatched: many of the nation's large coal mines lie next to the North China Plain, the country's agricultural heartland. Many of these areas also have limited water. In China, water scarce provinces (with water resources similar to the Middle East) generate nearly half of China's GDP, almost 40% of total agricultural output value and hold over half of China's ensured coal reserves. Rampant pollution has also exacerbated water scarcity and brought about concerns over soil pollution and food safety. It is inevitable that there will be conflicting needs for limited water in the future.

China is still hungry for thirsty power. At 0.87kW, China's per capita power generation installed capacity is still far below that of the G20 average. By 2050, China could add 2TW of installed capacity – this is more than the current total installed capacity of the US, UK, France, Germany, Russia and Japan combined. Despite this staggering expansion, China's per capita installed capacity will only rise to 2.6kW by 2050 which although in line with Japan's 2.3kW/capita in 2012, is far below that of the US of 3.4kW/capita for the same year. Can China manage this magnitude of power expansion with limited water resources?

The power sector's water risk exposure is great. Coal is currently China's vanguard fuel yet public concern over air pollution has led to official commitments to reduce reliance on coal. However, despite the fact that coal's share of total installed capacity is forecasted to fall below 50% by 2050, China is still looking at a significant expansion in its coal-fired fleet in absolute terms. Already water used in coal extraction and production as well as coal-related industries including coal-fired power generation is estimated to account for over half of industrial water use in China. Concerns over whether China has the water to extract and produce coal to meet these ambitious targets have been raised. The Ministry of Water Resources has even issued a Water-for-Coal Plan limiting the development of large coal bases subject to regional water availability.

We seek to address these water risks in this report by building on our two previous groundbreaking report collaborations with HSBC and CLSA on power generation and coal mining respectively. In addition, we have included water risk exposure profiles for coal-fired power generation, hydropower and nuclear power. Hidden and little talked about water risks brought on by aggressive wind and solar power expansion as well as other renewables are also detailed.

Water in China also increasingly is interlinked with climate issues. The rise of extreme weather events exacerbates water scarcity and divergent trends in water use and resources indicate a thirstier future. With around three-quarters of China's electricity generated by coal, electricity generation in China is affecting water resources not just through direct water use but indirectly through climate change impact as a result of carbon emissions. Getting the power mix right by balancing water use, carbon emissions and their electricity generation capabilities is imperative.

Achieving economic growth, social stability and ecosystem integrity is a fine balancing act for the government. Unfortunately, climate solutions in energy such as carbon capture and storage may not be available to China due to their large water requirements and carbon-friendly, hydropower, bioenergy and concentrated solar power all require water to generate power. Meanwhile some water supply solutions such as desalination and water diversion are power intensive. There are no one-size-fits-all solutions to China's water-energy-climate nexus. More importantly, China's energy choices do not only impact global climate change but affect water availability for Asia: more coal could accelerate glacial melt and more hydropower could lead to water wars given the region's transboundary water resources including the Brahmaputra, the Mekong, the Salween and the Indus rivers.

Trade-offs between electricity generation, climate and water need to be examined holistically. Given these challenges as well as the rise in competition for water resources between energy and food, this report explores strategies towards water and energy security in China with climate and food security in mind.

No country can afford a water supply crisis let alone a food and energy crisis. China will do whatever it takes to ensure water security, because only with this comes energy and food security. Multiple strategies will have to be adopted simultaneously across a broad spectrum of sectors. Already there are many such policies in place. In this report, we have grouped these strategies into a broad three-prong approach to facilitate understanding. They are (1) balancing power mix by considering trade-offs among water, energy and climate; (2) controlling water use in the agriculture, coal mining and coal-related sectors to ensure food and energy security; and (3) curbing energy demand as saving power means saving water. Each of these “strategy-prongs” are detailed in a separate chapter.

It is important to note here that these strategies will not just impact the power sector. Industrial exposure is also significant with Chinese industry driving 85% of China’s electricity consumption. Direct exposure of China’s industrial backbone to water scarcity and pollution coupled with indirect exposure through water-reliant electricity consumption means a double whammy for multiple industries. Steel and cement sectors which are power intensive and require coking coal as input should pay particular attention. Consequently, there are serious implications for business continuity. Investors and providers of long-term capital to industry are particularly exposed to such risks.

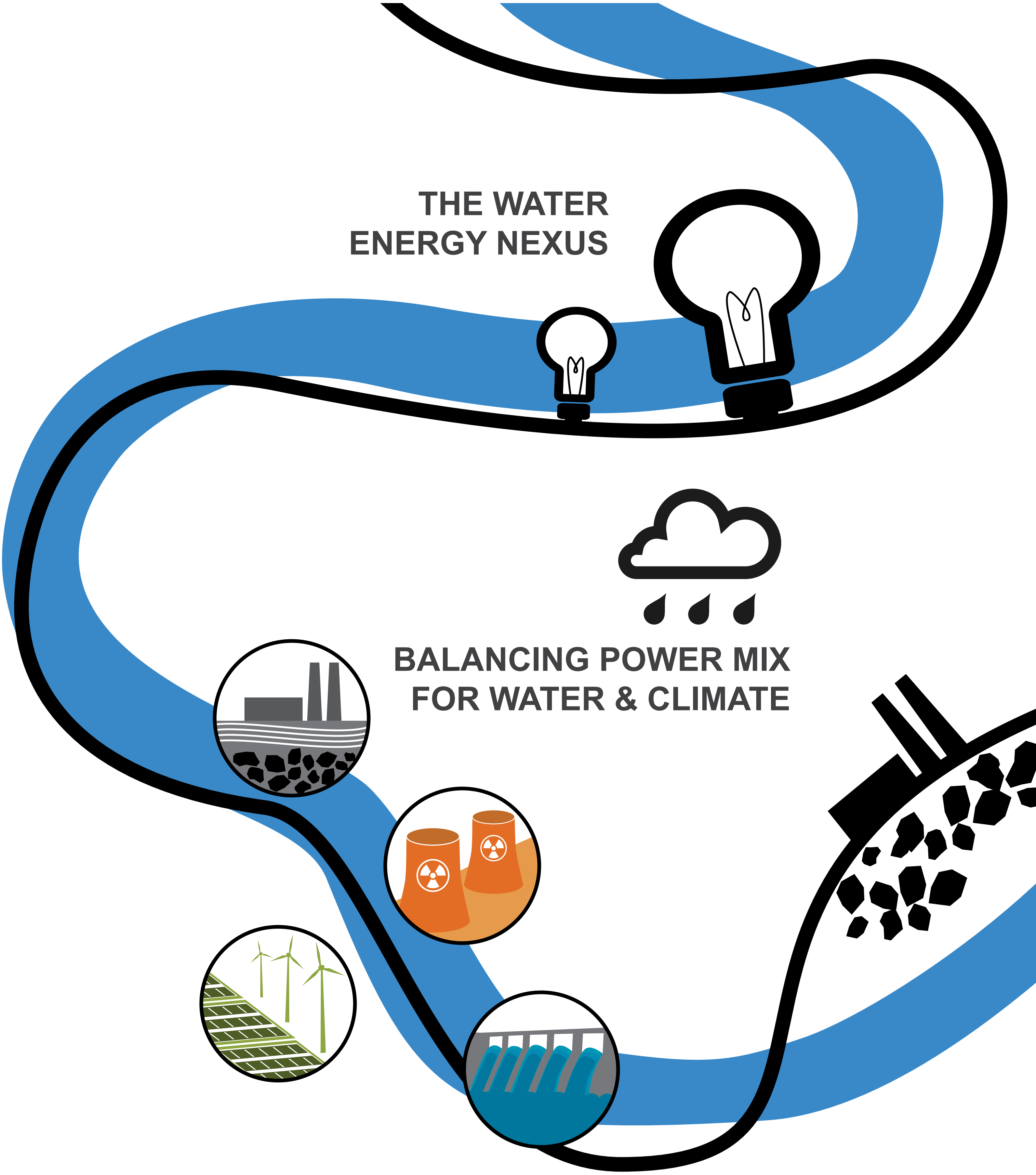
China’s energy mix is evolving. Already China has plans to shift its energy sources away from coal and hydropower towards less water-reliant power such as wind and solar. Water-reliant power is projected to fall from 93% to 72% by 2050. However, the magnitude of China’s power expansion still means +1.2TW of water-reliant power, equivalent to 4x the total installed capacity of Japan.

Nevertheless, an energy secure future in China includes the ability to supply electricity without having to rely on other countries for fuel. As such, coal will remain the vanguard due to the country’s vast coal reserves, pointing to the need to prioritise improvement and investment in water use along the whole coal chain. Also, mixed views on the availability of water for coal in China indicate the need for more disclosure and transparency in large coal bases. On the other hand, nuclear, although carbon-friendly, is at a crossroad due to water contamination fears brought on by inland nuclear power expansion in densely populated areas such as the Yangtze River basin. Hydropower’s dual role of power generation and water flow management means it’s here to stay, but the increasing role of dams in assuaging droughts and providing flood relief, worry downstream neighbours. Finally, wind and solar will dominate renewable growth but improper treatment and illegal discharge of toxic wastewater and radioactive waste from rare earths required in their manufacture bring hidden water risks for important watersheds in China. The Yellow River which feeds the North and the Dongjiang River, which supplies water to important cities such as Guangzhou, Shenzhen and Hong Kong are particularly exposed to such threats.

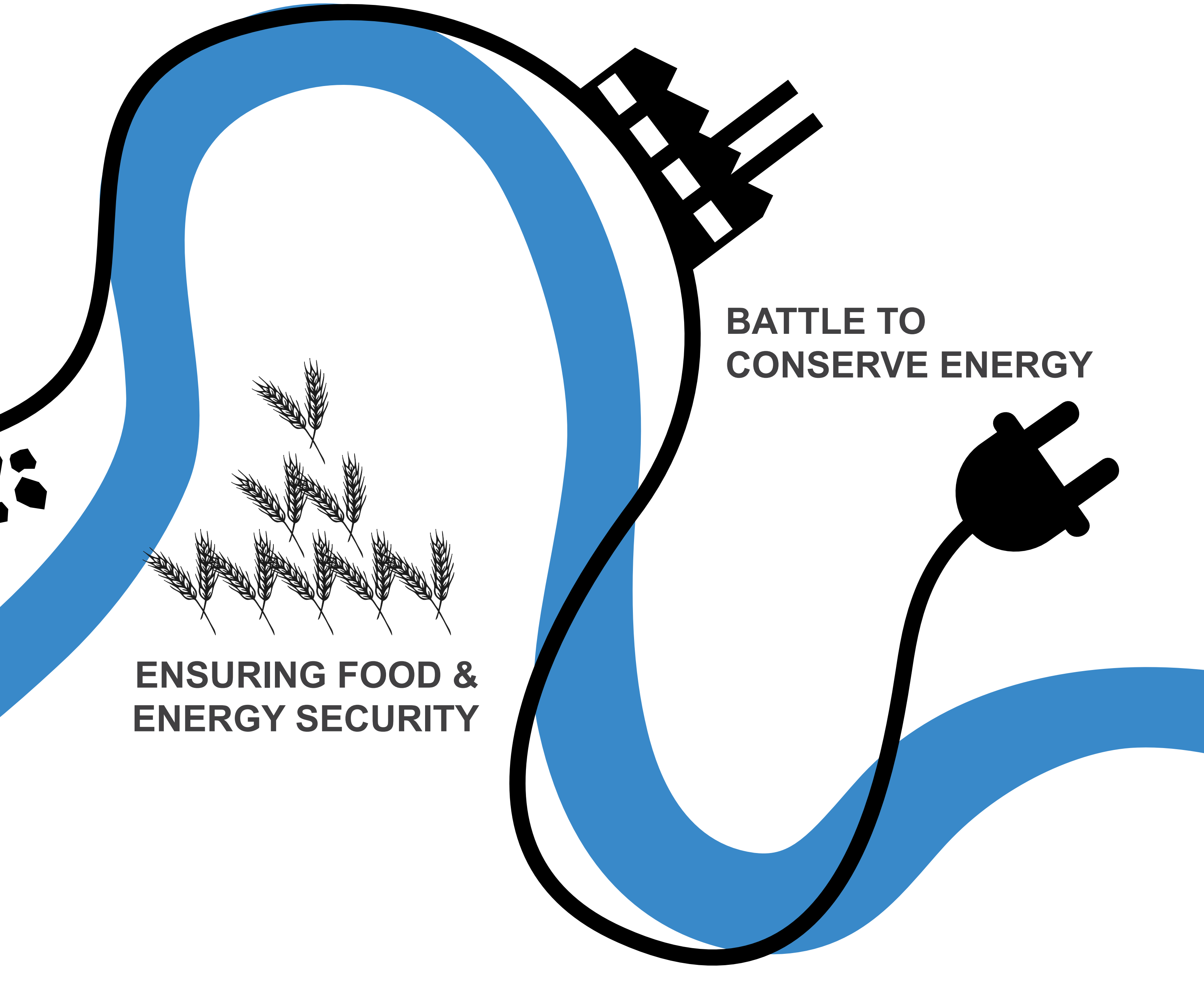
Clearly current mining practices in rare earth ores as well as rare earths production need to be addressed, but this is not just China’s problem as “made in China” supplies the global movement for a renewable future. In 2012, China accounted for 90% of global rare earths production; thus reliance on China is unavoidable. Japan and the US are China’s largest trading partners. The global rare earths and renewable industries need to reinvent themselves. China’s trading partners should bear some responsibility and work with China to find ways to minimise potentially disastrous impacts on China’s key watersheds. In the most aggressive expansion scenario of wind capacity for China alone, the accumulative wastewater generated by the increased demand in rare earths is 20x.

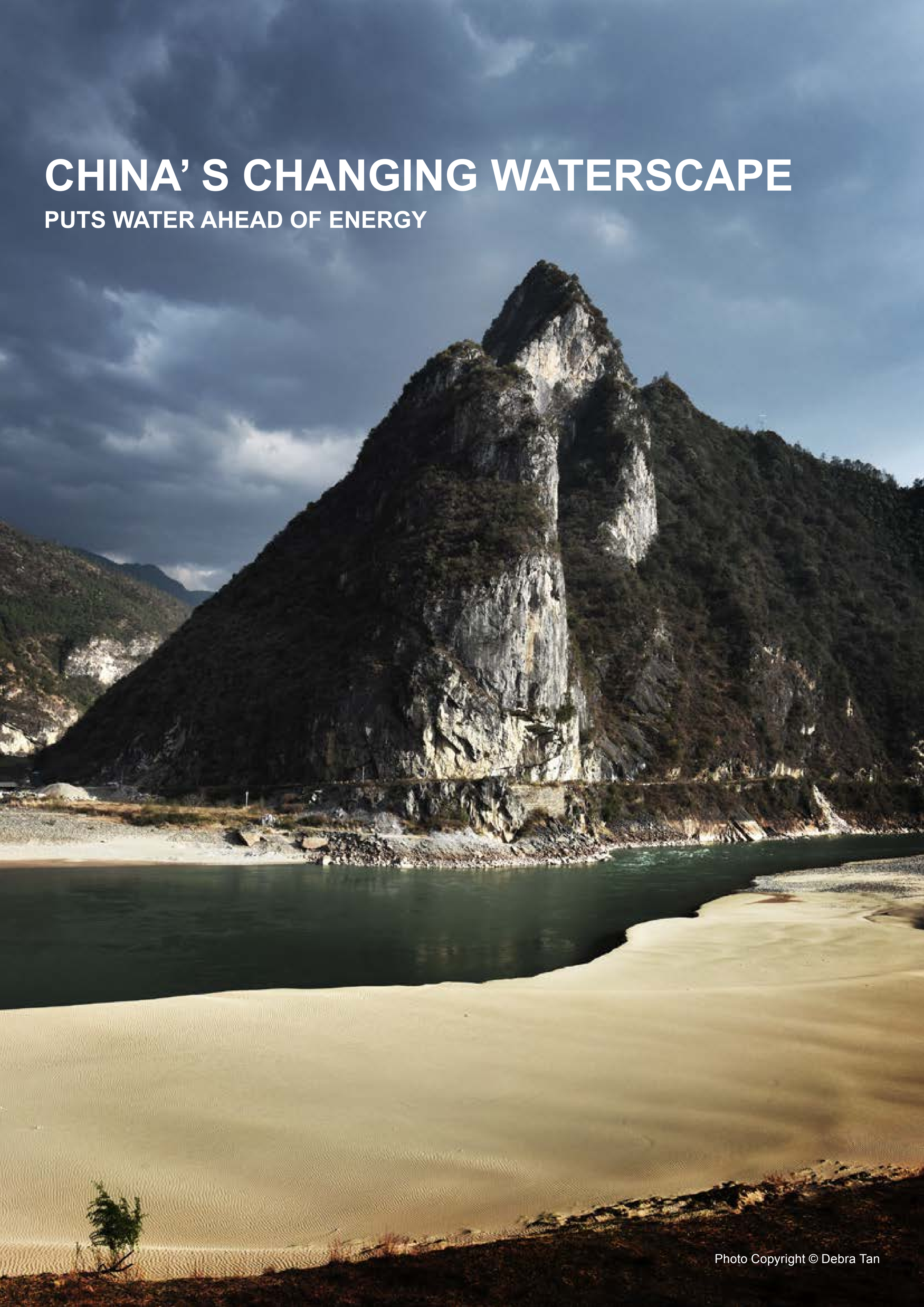
There are clear water risks for China and by extension for all of us. Tough choices lie ahead on the road towards a water and energy secure China. In reality, dispersed authority and overlapping responsibilities may hamper the right choices for water, energy and climate. Navigating China’s water energy nexus is complex and implementing strategies to address it, a long uphill battle. We hope this report helps facilitate understanding of these challenges and their global consequences. With glaciers in the Qinghai-Tibetan Plateau shrinking 15% over the last three decades, the stakes are high. The future of China’s energy mix doesn’t just impact China; it has regional watershed implications and global climate ramifications. It is time to start productive conversations to find solutions for Asia’s water-energy-climate nexus. As the upstream riparian, China will no doubt play the central role in regional water security. Can it ensure water & energy security whilst keeping climate change in check and at the same time side-step transboundary conflict? It’s time to take a closer look.

CHINA' S CHANGING WATERSCAPE



CHINA'S WATER & ENERGY ROADMAP





CHINA' S CHANGING WATERSCAPE

PUTS WATER AHEAD OF ENERGY

- A water supply crisis is one of the top 5 risks by impact for the last three consecutive years according to the annual Global Risks Reports issued by the World Economic Forum. For 2015, it ranks as the No. 1 Risk ahead of infectious disease and weapons of mass destruction.

- In China, a water supply crisis is imminent. Rising urbanization is putting pressure on water infrastructure and the government has said it will spend RMB4 trillion between 2011 and 2020 to ensure water supply. Experts say if business continues as usual demand will exceed supply of water by 2030.

- 11 regions in China ("Dry 11") are water scarce with similar water resources to the Middle East. The Dry 11 include economic powerhouses Jiangsu and Shandong and the municipalities of Beijing, Shanghai and Tianjin. Nearly half of China's GDP comes from the Dry 11. Currently, seven of these provinces' water use exceeds their renewable water resources. Central government recognises water could impact society and constrain economic growth and is acting with top down policies.

- China's State Council introduced the Three Red Lines water policy in 2011 to (1) control water use; (2) improve water efficiency; and (3) prevent and control pollution. National water use quotas were set for 2015, 2020 and 2030; with water efficiency ratio targets for irrigation savings as well as industrial water savings. New water pollution reduction targets and stricter industrial discharge standards were also issued. These new targets vary from province to province rendering some more vulnerable than others – location matters.

- These reforms and targets are necessary as China faces energy and food security issues with 93% of power generation requiring water to generate on a daily basis and close to 40% of agricultural output value derived from water scarce regions. This puts water ahead of energy in ensuring both energy and food security.

- Geographical mismatches in natural resource distribution, such as farmland, coal reserves and water between the North and South add to the complexity of water management. The North only has 25% of China's total renewable water resources but 63% of China's farmland and 86% of ensured coal reserves. The North is also reliant on groundwater yet severe groundwater pollution in China's agricultural heartland, the North China Plain, has brought about concerns over food safety. Previously state-secret soil pollution survey revealed that close to 20% of China's arable land is polluted.

- While China is on track to meet the 2015 water use targets, agricultural water use is still rising faster than planned. Managing water use across agriculture, industry and municipal is key in ensuring water security. Competition for water between industry and agriculture may be unavoidable going forward, with industry potentially losing out both to food security and energy security. Power generation, as the largest use of industrial water in China, is particularly vulnerable.

- With climate change and the rise of extreme weather events exacerbating water scarcity, divergent trends in water use and resources indicate a thirstier future. Achieving economic growth, social stability and ecosystem integrity is a fine balancing act for the government. Climate solutions in energy such as carbon capture and storage may not be available to China due to their large water requirements and carbon-friendly hydropower, bioenergy and concentrated solar power all require water to generate power.

- The changing waterscape not only puts water ahead of energy but shapes China's energy choices in the future. This has serious implications for business continuity: investors and providers of long-term capital to industry are particularly exposed to such risks. China's energy choices will also impact global climate change and affect water availability for Asia: more coal could accelerate glacial melt while more hydropower could lead to water wars over the region's transboundary water resources. China's changing waterscape matters.

CHAPTER 1:
CHINA' S CHANGING WATERSCAPE – PUTS WATER AHEAD OF ENERGY

WATER HAS NO SUBSTITUTE: WATER RISK TOPS INFECTIOUS DISEASES & CONFLICT

Water crisis is amongst the top 5 global risks by impact over the last three years

Water crisis is a prominent and rising risk. A water supply crisis has been amongst the Top Five Risks by Impact according to the World Economic Forum over the last three years. It's Global Risks Report 2015, ranks it as the #1 risk with the greatest impact if left unchecked. This puts it ahead of the spread of infectious diseases and weapons of mass destruction across all three years. Yet corporates, investors, media and governments spend more time focused on the latter.

2013-2015 Top 5 Global Risks by Impact

	2013	2014	2015
1	Major systemic financial failure	Fiscal crises	Water crises
2	Water supply crises	Climate change	Spread of infectious diseases
3	Chronic fiscal imbalance	Water crises	Weapons of mass destruction
4	Diffusions of mass weapons of destruction	Unemployment and underemployment	Interstate conflict with regional consequences
5	Failure of climate change and adaptation	Critical information infrastructure breakdown	Failure of climate change adaptation

Source: Global Risks Report 2015, The World Economic Forum

Clear shift away from economic to environment risks

The Global Risk Report defines a global risk as "*an uncertain event or condition that, if it occurs, can cause significant negative impact for several countries or industries within the next 10 years*". There has been a clear shift over the past ten years away from economic risks in general to environmental risks[1]. These include failure to adapt to climate change, floods & droughts as well as water crises. However, the report warns that while there has been "*recognition of the importance of these slow-burning issues, strikingly little progress has been made to address them in light of their far-reaching and detrimental consequences for this and future generations*".

Water has no substitute; our entire civilisation runs on it

We have taken water for granted and forgotten the old adage *"we created everything from a drop of water"*. There is no substitute for water: it is essential for our survival, it is essential to food and energy production and operations across multiple industries from fashion to electronics. Basically our entire civilisation runs on water.

WATER LINKS FOOD, POWER, GROWTH & CLIMATE

BAU means there could be a 40% water supply gap by 2030

Global water demand will only rise as population grows. At the same time, climate change and increasingly frequent droughts and floods will only serve to exacerbate water scarcity. In a "Business-as-Usual" (BAU) scenario, The 2030 Water Resources Group forecasts annual global water demand to grow by 53%, to 6,900 billion m^3 per year; a significant 40% above current accessible and reliable water supply levels.

Increase demand in food of 70% and 2°C rise add more pressure to agriculture, the largest global water user

Globally, agriculture is the largest user of water accounting for around 70% of water withdrawals according to the FAO. More food will need to be grown to feed the rising population and there is also changing dietary requirements, which will add more pressure on food production. The UN predicts an increase in food demand of 70% by 2050 to meet these needs[2]. A 2°C rise in global average temperature will also adversely impact food production. Mitigating risks brought about by climate change is therefore crucial for both food and water.

THE WATER ENERGY NEXUS (WEN)

"Energy production depends on water. It is used in power generation, primarily for cooling thermal power plants; in the extraction, transport and processing of fuels; and, increasingly, in irrigation to grow biomass feedstock crops. Energy is also vital to providing freshwater, needed to power systems that collect, transport, distribute and treat it."

Source: The International Energy Agency

1.4bn people still remain in the dark; water consumption in power generation is expected to rise by 85%

Unfortunately, the number of people without access to electricity in 2009 was 1.4 billion or 20% of the world's population according to the International Energy Agency (IEA 2010). Electricity requires water to generate and in the US, power generation is the largest user of water, using more water than agriculture. By 2035, the IEA expects water consumption to generate energy to rise by 85% (IEA 2012). In turn, electricity is also required for water & wastewater treatment as well as the delivery of water to where it is needed.

Another issue is that many of the solutions to mitigate climate change are water intensive and solutions to increase water supply are power intensive. Climate and water solutions may therefore not be available in countries that need to add a lot of power with limited water resources.

WATER MATTERS IN CHINA: DOMESTIC POLICIES HAVE GLOBAL RAMIFICATIONS

Water risks are most pronounced in India and China, which have limited water resources but have to add a lot of power

Water risks are most pronounced in India and China, home to over a third of the world's population. China and India (let alone the rest of South & South East Asia) are on the brink of adding significant installed capacity to generate more power but have limited water resources. Since climate and choice of fuel type will impact water availability, there are trade-offs to consider between energy and water policy choices. What is good for water may not be good for power and vice versa; either way decisions impact climate.

Water rich Brazil is also suffering water shortages...

Word of caution: it's not just countries with limited water resources at risk. As Brazil is finding out, a combination of poor water resource management and extreme weather has brought about severe water shortages in Sao Paolo. Residents in the capital could face water rationing or cuts for five out of seven days. Water shortages and lack of sanitation form a breeding ground for health risks and rising societal tensions. There could also be food shortages and power cuts as the majority of the country's power is hydropower, which whilst green will be affected by water shortages. There is a real likelihood that residents may have to move as solutions such as building reservoirs and tapping non-revenue water take time. A water crisis is a crisis that no country can afford.

...in China the water crisis is urgent. Energy and crop choices matter

In a world where extreme weather events are increasingly frequent, a water crisis is more likely to happen than not. Managing water supply, food security, energy security alongside economic growth and social stability is a fine balancing for any government. In China, the water crisis is urgent: energy and crop choices matter; and strict water management is essential to avoid water shortages. The question to ask when assessing China's water risk exposure is therefore not *"what is the likelihood of an all-out water shortage"* but *"what are the implications of the policies China will put in place to avoid it"*.

Recent official signals that water comes first in China have global ramifications

In China, policies implemented for water will shape China's food and energy choices in the future which in turn have global trade and climate ramifications. Food, energy and water are all crucial resources but there are recent official signals that water comes first. It is time to rethink power through a water lens – there are deep implications not just for the power industry but for other industries as China moves to protect its water resources and ensure allocation of water for food & energy security.

5 REASONS WHY WATER COMES FIRST

Water No.1 on China's political agenda...

Historically, agricultural self-sufficiency has been a top priority for China. However, with the inevitable rise in demand for food, and constraints in farmland and water resources, China has been looking "upstream" towards water security. In 2011, water rose to the top of the political agenda when it was the first and only year the No. 1 Document did not focus on agriculture (see box).

Historic No.1 Documents "Themes"

1982 – 1986 Focus on Agriculture
1986 – 2003 Not publically available

Focus returns to Agriculture in 2004

2004 Boost farmers income
2005 Strengthen rural work & production capacity
2006 Construct a new socialist countryside
2007 Develop modern agriculture
2008 Fortify the foundation of agriculture
2009 Achieve steady agricultural development
2010 Coordinate urban & rural development areas

2011 **"Three Red Lines" for water conservancy**
- Control total water use, efficiency & water pollution
- Improve water infrastructure
- Water tariff reform including punishing water-intensive users

2012 **Scientific & technological innovation to boost yields**
- Accelerate water conservancy & increase irrigated area
- Promote safe & highly effective fertilisers; low-toxic & low residue pesticides

2013 **Modernise agriculture & strengthen rural economy**
- Water savings & more crop-per-drop in NE China
- Accelerate land reform & rural subsidies to develop large-scale farming

2014 **Maintain food security by improving rural environment & resolving environmental constraints**
- Minimum farmland at 120 million hectares to ensure grain security
- Pursue "basic grain self-sufficiency" whilst increasing the use of overseas markets

2015 **Rural reforms, modern agriculture & food security**
- Designation of permanent farmland with high-quality development
- Innovation in agricultural investment & financing mechanisms
- Facilitate key water transfer projects & water source conservation projects

Source: China Water Risk, various government ministries

..."Three Red Lines" approach to water management introduced in 2011

The No. 1 Document in 2011 introduced the "Three Red Line" approach to water management: (1) control total water use; (2) improve water use efficiencies and (3) prevent & control pollution. This top down approach meant that national water use caps were introduced in 2011. Since then various policies, laws and regulations have been issued and implemented to ensure the "most stringent" management of water.

Official "war" declared on water, air and soil pollution

An official war has also been declared on water, air and soil pollution by Premier Li Keqiang in 2014. All these have short-term, mostly negative, implications across all industries but will ensure long-term sustainable growth in China. These are discussed later in this section, but first, here are five reasons why it is imperative to safeguard China's water resources:

1. China is drier than you think

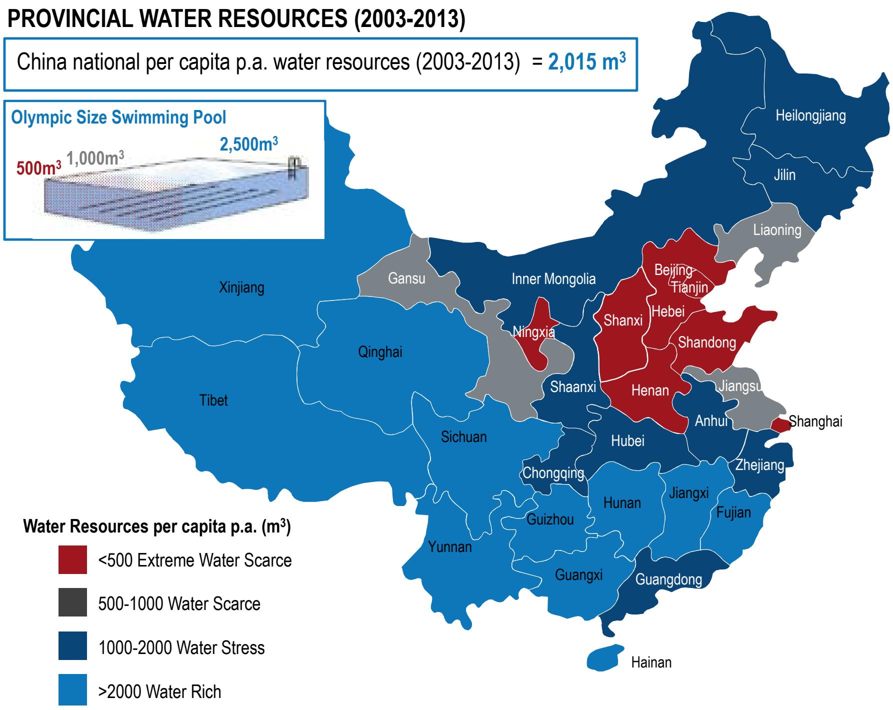
11 provinces in China fall below World Bank water poverty mark with similar water resources as the Middle East

In China, the water crisis is urgent. It is estimated that four of the world's ten most populated river basins are in China. These ten river basins' share of global GDP is forecast to rise from 10% today to 25% by 2050 and half are already experiencing unsustainable levels of water withdrawals[3]. According to Chinese government data, the historic (2003-2013) average national annual renewable water resource per capita is 2,015m^3, only just above the UN water stress level of 1,700m^3.

It is clear from a glance at the map below that water resources are not evenly distributed throughout China's 31 provinces, regions and municipalities:

- A total of 11 provinces in China ("Dry 11") fall below the World Bank Water Poverty Mark of 1,000m^3 including economic powerhouses Jiangsu & Shandong and the municipalities of Beijing, Shanghai and Tianjin;
- Eight provinces are defined as suffering from extreme scarcity with annual water resources below 500m^3, putting them on a par with Middle Eastern countries like Jordan and Oman; and
- Seven of the Dry 11 are now running water deficits: their water withdrawals exceed their renewable water resources. These are Beijing, Hebei, Henan, Jiangsu, Ningxia, Shanghai and Tianjin.

8 provinces suffer from extreme water scarcity; they are as dry as Jordan and Oman (red colour in map)



Source: China Water Risk (based on China Statistical Year Book, historical average water resources & trends by province 2003-2013). Dry 11 denoted by red and grey shaded provinces.

2. China's economy, food & industry: Exposed to water risks

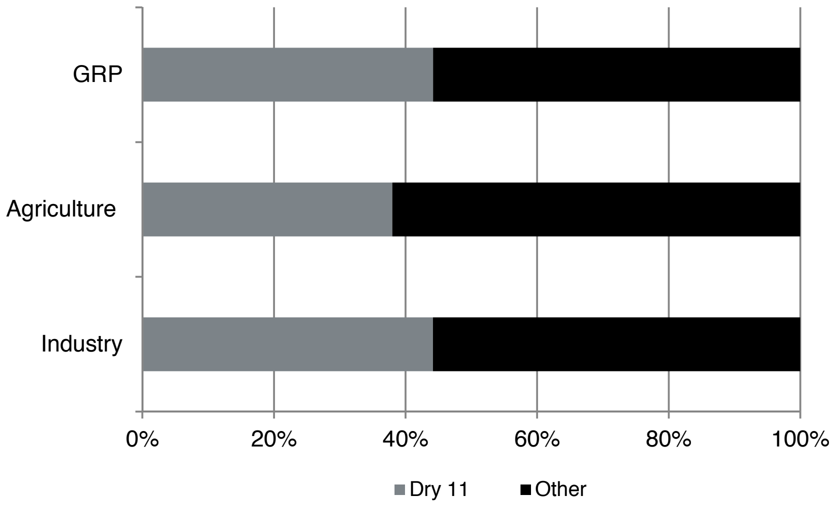
Water is a must for economic growth

When the annual water resource per capita of a country or region falls below the water poverty mark of 1,000m³ per capita, the lack of water becomes a severe constraint on food production, economic development and protection of natural systems. As mentioned before, water is a must for economic growth – there is no substitute; it is required to power the economy. In China, economic exposure to physical water scarcity in the Dry 11 is significant (see chart below):

- 44% of China's National GDP is generated by the Dry 11; five amongst the Top 10 Provinces with the highest contribution to GDP are water scarce;
- 38% of China's total agricultural output value; and
- 45% of China's total industrial contribution to Gross Regional Product (GRP).

...the Dry 11 account for 44% of China's GDP and close to 40% of agricultural output value

2013 Economic Exposure to Dry 11 Water Scarce Regions



Source: China Water Risk, NBSC 2014

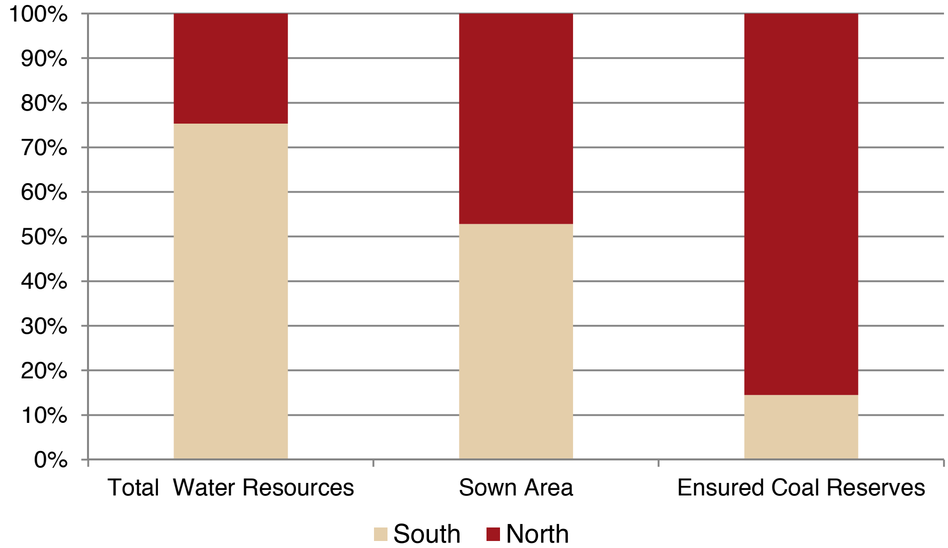
China will face tough decisions in balancing the economy, food and industry with limited water resources. A mismatch in the geographical location of China's natural resources such as farmland, coal & gas reserves as well as water resources adds further complexity.

3. Geographical mismatches in natural resources & rampant pollution adds complexity

Unfortunately not all of China's natural resources are distributed evenly. China's water resources, farmlands and coal reserves do not lie in the same region. The South has more water than the North with 75% of China's total renewable water resources. However, 47% of China's sown area and 86% of coal reserves lie in the North (see chart on below).

The North is drier with more farmland and coal reserves than the South...

2013 North-South Distribution of Key Natural Resources



Source: China Water Risk, NBSC 2014

... and is more reliant on groundwater

Moreover, the North is more reliant on groundwater than the South and severe groundwater pollution and over-extraction in the North China Plain (China's agricultural heartland) has brought about concerns over food security and food safety (see box below).

GROUNDWATER WOES PLAGUE THE NORTH

Depletion of groundwater

The North is generally 5x more reliant on groundwater than the South of China resulting in over-extraction of groundwater. The Dry 11 (majority of which are in the North) use over half of their total groundwater resources compared to the national groundwater supply rate of 15%. Depletion of groundwater has far-reaching consequences. It not only contributes to the drying up of lakes and wetlands but increases salinity of groundwater supplies. Furthermore, over-extraction gives rise to subsidence, which causes damage to infrastructure as well as reduces aquifer storage capacity. In 2012, the Chinese Academy of Geological Sciences warned of excessive annual withdrawal of 4 billion m^3 of groundwater in Northern China resulting in subsidence threat to 170,000 km^2 of land. This is equivalent to the land area of Korea, Denmark and Taiwan.

Severe groundwater pollution

Official statistics show that groundwater pollution has continued to deteriorate over three consecutive years with 60% of groundwater falling in the 'bad' and 'very bad' categories compared to 55% in 2011.

In February 2013, a Ministry of Land & Resources groundwater survey showed that the North China Plain, China's most important agricultural region (producing corn, sorghum, winter wheat, vegetables and cotton) suffers from severe groundwater pollution with over 70% of overall groundwater quality classified as Grade IV+, in other words, unfit for human touch. This was the most comprehensive survey conducted to date and it found that groundwater pollution is more serious for shallow groundwater in the North China Plain compared to deep groundwater. There was almost no shallow groundwater of Grade I quality and only sporadic existence of groundwater at Grade II-III quality, putting the amount of groundwater at unfit for human touch at 78%. Deep groundwater fared only slightly better at 74%.

In recognition of the critical state of groundwater, State Council issued its first-ever National Plan on Groundwater Pollution Control in 2011. Subsequent policies restricting groundwater use in coal mining have also been issued – please refer to the Chapter on "Coal & Coal-fired Power".

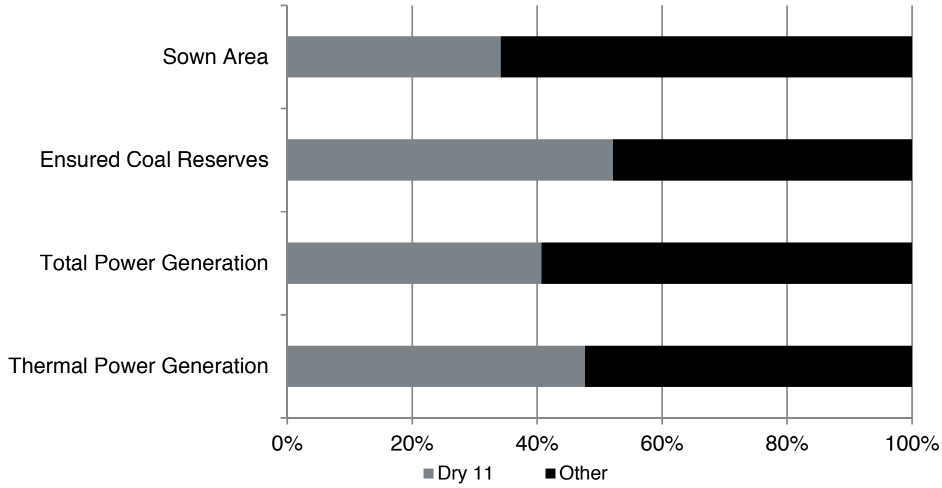
Source: China Water Risk: Big Picture: Groundwater Depletion, "2013 State of Environment Report Review", "New Guard: New Hope for Pollution?", "Groundwater Crackdown – Hope Springs"

Considerable exposure to water scarcity across agriculture, energy reserves and electricity generation

Exposure of China's natural resources to water scarcity is equally worrying (see chart below):

- 34% of China's total sown area lie in the Dry 11; most of China's large farming provinces lie in the North China Plain: Hebei, Henan, Shandong, Jiangsu and parts of Anhui – except for Anhui, the rest are water scarce;
- 52% of China's coal reserves lie in the Dry 11; Shanxi with 38% of China's coal reserves is as water scarce as Oman; and
- 48% of China's thermal power generation capacity is in the Dry 11.

2013 Resource Exposure to Dry 11 Water Scarce Regions



Source: China Water Risk , NBSC 2014

China is investing in mega diversion projects to move water from the South to the North

Given the geographical mismatch in natural resources and their exposure to water risk, it is not difficult to see why China has invested in mega diversion projects to transfer water from the South to the North. Mao Zedong himself said *"southern water is plentiful, northern water scarce. If at all possible, borrowing some water would be good"*. Decades later, the Eastern Route of the South-to-North Water Diversion Project was completed, in late 2013; the Central Route's Phase I has been in operation since December 2014; whilst the Western Route is still yet to be constructed.

There has been much criticism over the Eastern & Central routes. Construction of the Eastern Route started in 2002 and the Central Route in 2003, and was expected to cost the nation around USD62billion[4] but delays meant that the project is now estimated to cost RMB500 billion[5] (USD82 billion). Given the high social and financial costs as well as environmental impacts, many have questioned whether water re-use or improving non-revenue water would have been better choices (see Chapter 2: "China's Water Energy Nexus").

Furthermore, rampant surface and groundwater pollution have affected China's soil & farmland, raising concerns over food safety (see box below).

LIMITED FARMLAND AFFECTED AS WATER POLLUTION SEEPS INTO SOIL

China has limited farmland but pollution from wastewater discharge from agriculture and industry has resulted in soil pollution.

Only 14% of China's land area or 135 million hectares is classified as "farmland" according to the 2nd National Land Use Survey by the Ministry of Land & Resources and the National Bureau of Statistics released in December 2013. However, China's "total sown area for farm crops" defined as area of land sown or transplanted with crops regardless of being in cultivated or non-cultivated area is much larger 163 million hectares. Not all this land is however irrigated, total irrigated land stands at around 63 million hectares in 2013. Already, Wang Shi Yuan, Vice Minister of the Ministry of Land & Resources recently lamented that 3.33 million hectares are too polluted to grow crops and have been withdrawn from agriculture.

There has been rising concerns over food safety and increased social media chatter, in particular over cadmium & chromium rice. In February 2013, the Ministry of Environmental Protection ahead of the change in new guard, officially linked heavy metal discharge from industry to cancer villages. By 2014, previously state secret soil statistics were revealed by the Ministry of Land Resources. The First Nationwide Soil Pollution Survey covered 6.3 million km^2 (two-thirds of China's total land area) and revealed that 16.1% of the soil was polluted. Furthermore, it showed that 19.4% of arable land was polluted with 82.8% of contaminated soil samples found with toxic inorganic pollutants including cadmium, mercury, arsenic, chromium and lead.

Source: China Water Risk: "The State of China's Agriculture", "New Guard: New Hope for Pollution?", "Pollution: 5 Reasons to Remain Optimistic"

Government will act to protect farmland from pollution

Government action to protect farmland from pollution will have implications for farmers and water-intensive and polluting industries alike, including the power sector. Indeed the 14 priority provinces identified for heavy metal pollution control not only has 60% of China's sown land[6] but include six of China's Top 10 coal producing provinces such as Inner Mongolia, Shaanxi, Henan, Shandong, Sichuan and Yunnan (more on top coal producing provinces exposure to water risks in the chapter on "Coal & Coal-fired Power").

Competition for water between industry and agriculture may be unavoidable

Competition for water between industry and agriculture may be unavoidable going forward, with industry potentially facing a double whammy by losing out to food security and energy security. This is particularly true for provinces along the upper and middle reaches of the Yellow River where China's coal & energy bases lie.

The planned Western Route should alleviate water stress along the upper reaches of the Yellow River providing water to the coal bases but is this necessary? Or would diverting rivers to feed the Western Route upset the delicate balance of the upper Yangtze watershed? The fate of the Western Route will very much depend on the ability of the various provincial governments to manage agricultural and coal base water use. Future water requirements for coal & coal-fired power as well as savings from irrigation & water use efficiency improvements in coal bases are explored in Chapter 4: "Ensuring Food & Energy Security".

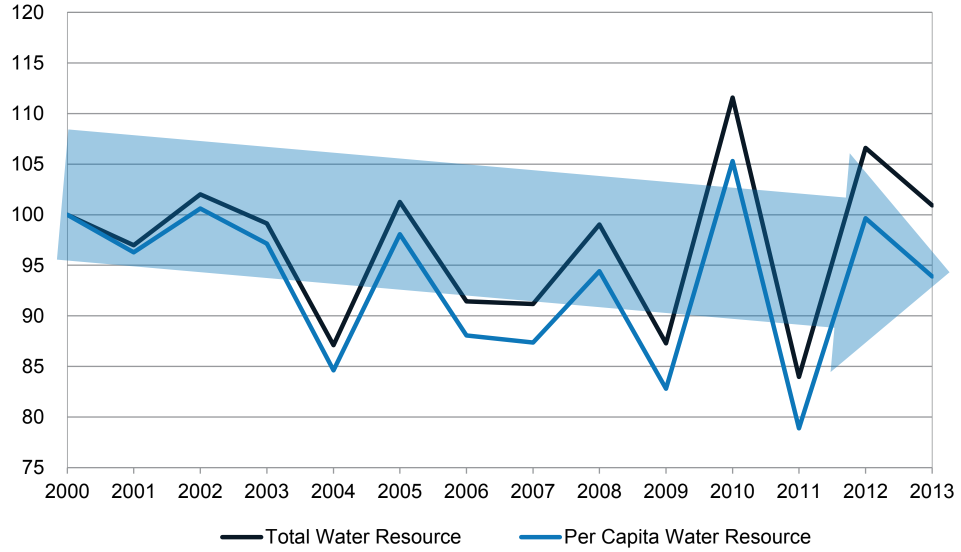
4. Divergent water trends & loss of glaciers indicate a thirsty future

Downward trend in total and per capita water resources

Although China's total water resources vary from year to year, they have been following an overall downward trend over the last decade (as seen in the chart below). A population rise of 7.4% during the same period actually means that in reality per capita resources are falling at a much faster rate, putting further stress on already stretched water resources. Increasing frequency and extremity of floods and droughts (as shown by the peaks and troughs in the chart below) have also made it difficult for groundwater to recharge.

2000-2013: Falling Water Resources

Indexed to 100



Source: China Water Risk analysis based on National Statistics Bureau of China various years

Climate change exacerbates water scarcity; glaciers equivalent to the area of a 5th of Switzerland have melted

With climate change exacerbating water scarcity, the problem is here to stay. A United Nations Environment Programme (UNEP) 2009 study warned of freshwater supplies falling with reserves such as polar ice caps and glaciers melting at a high rate. In China, glaciers have already shrunk 15% from 53,000km^2 to 45,000km^2 over the last three decades according to the Chinese Academy of Sciences (CAS). This means that the Qinghai-Tibetan Plateau has 'lost' 8,000km^2 of glaciers. This is equivalent to the land area of 8 Hong Kongs or a fifth of Switzerland.

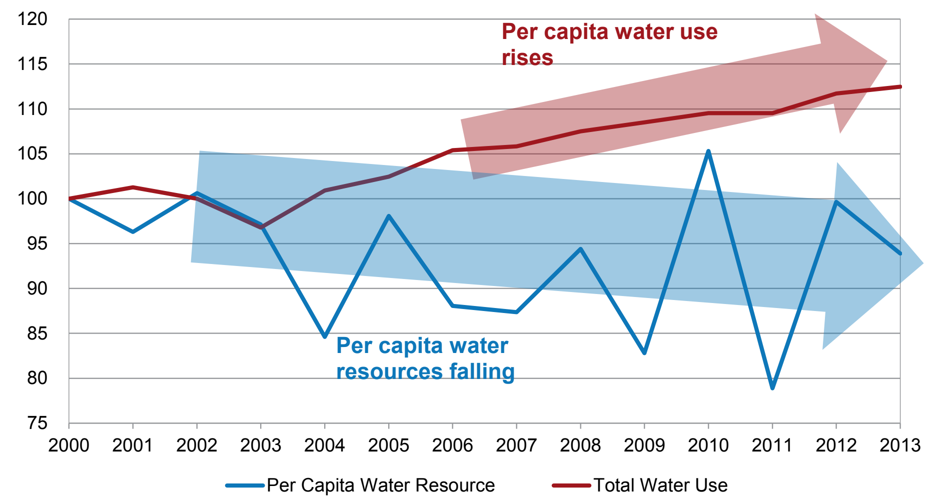
China expected to urbanise from 53% to 62% by 2030

Meanwhile, as water resources fall, water demand is expected to rise as migration to cities continues. As China urbanises, the more affluent population will not only use more water, they will use more electricity, eat more meat, buy more clothes & electronics; all of which require more water to produce. China's urbanisation ratio is currently at 53.7% in 2013 compared to only 36.2% in 2000; the UN forecasts this to rise to 62% by 2030, putting additional stress on water supply. These divergent trends shown in the chart below indicate a thirsty future.

Divergent water trends indicate a thirsty future

2000-2013: Falling Water Resources & Rising Water Use Per Capita

Indexed to 100



Source: China Water Risk analysis based on National Statistics Bureau of China various years

CLIMATE & WATER SOLUTIONS ARE LOCKED IN A VICIOUS CYCLE

Water supply solutions such as desalination and water diversion projects are power intensive. Since China's primary fuel source is coal, they are therefore carbon-intensive. Lower carbon emissions targets could restrict the adoption of carbon-intensive freshwater solutions such as desalination and water diversion projects.

On the other hand, climate change could bring about changes in the intensity and variability of rainfall with more frequent and severe weather events, raising the risk of water shortages, flooding and drought. This exacerbates water scarcity in the long term. Climate solutions such as carbon-capture technology are water intensive and may not be viable for China due to limited water resources.

Given China's limited water resources and carbon emission targets, the choices of water supply & climate solutions are less obvious – there are clear trade-offs which need to be examined. The amount of power used in desalination and diversion of water is discussed in Chapter 2: "China's Water Energy Nexus" and the comparison of water use with and with carbon-capture technology is set out in further detail in Chapter 3: "Balancing Power Mix for Water & Climate".

Some 'clean & renewable' climate solutions may also trigger "unintended consequences":

- Biofuel: 1st generation biofuel is clearly not an option given China's limited farmland and current water landscape. However, waste to energy options have potential;
- Hydropower may result in rising geopolitical tensions in the region due to the tapping of transboundary rivers for hydropower; and
- Rapid build out of wind and solar as well as a massive drive in energy efficiency could accelerate rare earth ore extraction which in turn will pollute China's water sources.

There are no one-size-fits-all solutions to this water-energy-climate nexus. China's energy choices not only impact global climate change but affect water availability for Asia: more coal could accelerate glacial melt and more hydro could lead to water wars given the region's transboundary water resources. As the upper riparian, China may "own" these glaciers, but their meltwaters feed Asia's major rivers such as the Brahmaputra, the Salween, the Mekong, the Yellow, the Yangtze and the Indus.

It is important to understand the impact of alternative energy choices on Asia's water sources before forming an everything-but-coal stance in an effort to mitigate climate risks. Transboundary risks are discussed in the chapter on "Hydropower" whilst water risks related to rare earth ore extraction are discussed in in the chapter on "Other Renewables".

5. Business cannot continue as usual otherwise demand will exceed supply

President Xi says the environment is reaching the upper limit of carrying capacity

"Our environment has reached or is reaching the upper limit of its carrying capacity", said President Xi Jinping at the year-end Central Economic Work Conference on 9 December 2014. This constraint not only refers to the worrying condition of water quality, but also relates to the sub-optimum allocation of water resources and inefficient use of water in agriculture and industrial production.

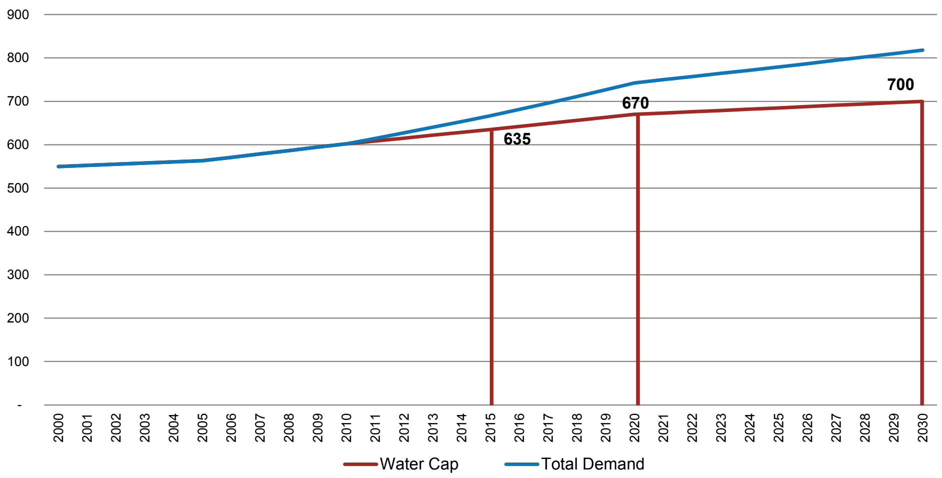
Indeed a BAU scenario estimated by The 2030 Water Resources Group under an average economic growth scenario where no efficiency gains are assumed forecasts China's demand for water to be 818 billion m^3 compared to water supply at 619 billion m^3. This shortage of 199 billion m^3 in 2030 is greater than the total amount of industrial water use of 140 billion m^3 in 2013.

RMB4 trn budgeted to increase water supply

To meet the rising demand in water, State Council has set aside RMB4 trillion to increase water supply to 635 billion m^3 by 2015 and 670 billion m^3 by 2020. The government has placed a further national water use quota at 700 billion m^3 by 2030. As can be seen from the chart below, China's national water use quotas are well below the BAU projections. Clearly, a "business as usual" scenario is not viable. Water allocation and management needs to be optimised.

National water use quotas are well below BAU projections; clearly BAU is no longer viable

China Business-as-Usual Water Use vs. National Water Use Quotas (bn m^3)



Source: NSBC, Ministry of Water Resources, 2030 Water Resources Group

TOUGH CHOICES AHEAD AS BEIJING MOVES TO ENSURE WATER SECURITY

Water, food, energy and climate are all interlinked...

It is clear from the above that water, food, energy and climate are all interlinked. Decisions to mitigate risks in one aspect could trigger unintended consequences in another. The government has to balance all these facets from a water perspective. As such, ensuring that the nation stays within the Three Red Lines is key. However, as mentioned in *"5 Trends for 2015"* published on our website in February 2015, staying within the Three Red Lines means rough terrain ahead.

...trade-offs are unavoidable if China is to stay within the 'Three Red Lines'

Tough choices need to be made to grow the economy with limited water. There will be trade-offs amongst industries, agriculture & energy, fuel mix, crop mix and water use & carbon emissions. Comprehensive reform across sectors and cross-ministry collaboration are also necessary. Already, a series of fundamental reforms have been implemented including amendments to the Environmental Protection Law to allow for higher penalties and litigation, merging of some of the functions of different ministries or possibly consolidating some ministries.

Policies set to shift from "economy vs environment" to "economy & environment" indicate that water comes first

The shift from 'economy vs environment' to 'economy & environment' has started. Beijing will shepherd China towards water security and an "ecological civilization". Policies, regulations, laws & standards introduced and implemented have laid the groundwork for change. From the game-changing policy paths set out in the next page, it is clear that in this long march towards an "ecological civilization", water comes first.

As many of the above policies come into effect this year, we expect to see a marked change in China's waterscape.

8 GAME CHANGING POLICY PATHS

1. New Amendments to Environmental Protection Law: More power to the environment & people: This is the first legislative change in the Environmental Protection Law since it was enacted in 1989. The amendments gave more teeth and tools for the Ministry of Environmental Protection (MEP) to wield over polluting enterprises. Loopholes were also closed providing a strong base for other environment related policies and standards. The new law also gives more power to the people in trying to make civil ligation easier. But most importantly, the new amendments enshrine environmental protection as the country's basic policy stating that economic and social development should be coordinated with environmental protection. This is a fundamental shift in planning China's future growth.

2. Financing to Play a Dual Role: Relaxed for development of the environmental services sector & tightened for polluting companies: Relaxing investments into the environmental service sector is part of the government's continuing efforts to push the growth of its Strategic Emerging Industry #1 (Energy Saving & Environmental Protection). This is expected to grow to around RMB4.5 trillion. On the water front, more than RMB6 trillion of investment is expected; RMB4 trillion on water infrastructure and RMB2 trillion to tackle water pollution. China is also turning to private capital to help reduce provincial debt burdens.

3. Industrial Standards: New and/or 'more stringent': The government plans to spend RMB211 million to amend and consolidate 600 existing environmental standards into about 300 by 2015. The government is also targeting heavy polluting industries by introducing new industrial standards and tightening existing ones across sectors. Prior to the above stricter standards, conflicting wastewater discharge and raw water quality standards plus inadequate pricing have led to low water prices and high untreated wastewater discharge. They have also failed to encourage companies to adopt water-saving technologies in their production facilities. These combined with an inefficient wastewater fee collection system have meant that it is cheaper to pollute than to clean up. The new standards bypass the vicious cycle for direct discharge into bodies of water by setting more stringent industry standards with discharge limits that are not dependent on the quality of water bodies the wastewater is being discharged into. The approach has been carried out on an industry-by-industry basis; tackling issues be it pollutant or location specific for that industry.

4. Water Pollution Prevention & Control Action Plan: Key in holding one of the Three Red Lines: In 2014, the government declared war on pollution on air, water and soil. An action plan is expected to be in place for each of these elements. The Air Pollution Prevention & Control Plan was released in 2014. As for the Water Pollution Prevention & Control Action Plan, we expected this to be released just before/ during the National People's Congress meetings in March 2015 but it has yet to be released at the date of writing. Rumours say it has passed State Council's internal review and they are now deciding its release date. The plan is expected to clearly define stringent pollution control targets, aiming to significantly reduce industrial pollution, manage municipal pollution and recover rural rivers. It will also likely set targets to improve overall water quality by 30% to 50% and single out key polluting sectors as well as encourage private investments in technologies such as wastewater treatment, recycling and membrane technology. It is also expected to strengthen water pollution management on rivers, lakes and oceans; prevent and control water pollution from agricultural non-point source pollution; and implement "source to tap" supervision process.

5. Provincial Report Cards: GDP is 'out' & Water is 'in': The environment has suffered as a result of the ruthless pursuit of GDP growth in the past. Lowering the importance of GDP as an indicator and the addition of water management in performance reviews demonstrate to provincial government officials that China's priorities are shifting and they need to rebalance the economy & environment in order to march towards an "ecological civilisation". Moreover, reporting on achieving environmental targets is now mandatory for all officials under the new environmental law. Those who fail to meet the targets need to report to the State Council setting out corrective measures in writing within one month of the failed assessment. The combination of these changes will also help enforce the Three Red Lines set out in the "Most Stringent Water Management System". Shanghai's removal of GDP growth target in 2015 signals more changes to come.

6. Water-for-Coal Plan: Water limits the development of China's energy bases: On 17 December 2013, the MWR introduced the "Water Allocation Plan for the Development of Coal Bases". This Water-for-Coal Plan is a prime example of the un-siloing of sectors. It is a key policy to address a part of China's water-energy nexus and it indicates that regional water availability in China will dictate plans for future coal development. In short, it is saying water security is more important than energy security. This view is echoed by Li Junfeng (Director General of the National Center of Climate Change Strategy Research at the National Development and Reform Commission) – please see below.

7. Water Resource Allocation: Trading water use & wastewater discharge permits: No corporate can operate without water. Two water permit trading systems are being put in place to enforce the Red Lines: Wastewater Discharge Permits: to control the total amount of wastewater discharge; and Water Use Permits: to manage the total water use. These have a dual purpose, acting as both carrot and stick. Companies that operate in more water- efficient and cleaner ways will accumulate water savings within their Water Use Permits and/or Wastewater Discharge Permits, which can then be sold; other companies that want to expand their production, may fall short of permits and can buy these. We see these two types of permits as another way for government to control total water use and total wastewater discharged within an industry. By allowing companies to trade these two types of permits, a price reflecting the level of water scarcity & cost of pollution can be formed. This will allow government to fine-tune water allocation among different sectors – from agriculture to industry and also within industries.

8. March Towards a Circular Economy: A must-do not a nice-to-have: The State Council's 'Circular Economy Development Strategies and Action Plan' issued on 5 February 2013, pushes for circular economies across ten industries and China's industrial parks. A circular economy means less water, less energy, less resource waste and more recycling -all crucial for China if it is to ensure growth with its limited resources. The ten industries are: Coal, Power, Steel, Nonferrous Metals, Petroleum & Petrochemicals, Chemical, Building Materials, Paper, Food & Textile. China needs to shift these ten sectors and its industrial parks towards a circular economy to insulate them from 'shocks' of intensifying competition for water in the future. As such, detailed strategies and action for each industry have been set out. The focus is on a complete "close loop" for each industry – the 'recycling' indicated from raw materials input all the way through the manufacture of the product including end-use disposal. Water, power, coal and agriculture (where necessary) inputs are also highlighted in each industry clearly giving weight and recognition to the underlying water risk. More on the circular economy in Chapter 5:"Battle to Conserve Energy".

Source: Excerpts from a China Water Risk article: "8 Game Changing Policy Paths", February,2015

HOLDING THE THREE RED LINES IS NOT EASY

To stay within the Three Red Lines, China will have to:

- not use more water than the national/provincial caps set in 2015, 2020 and 2030;
- improve water use efficiencies across sectors; and
- prevent, control & reduce water pollution.

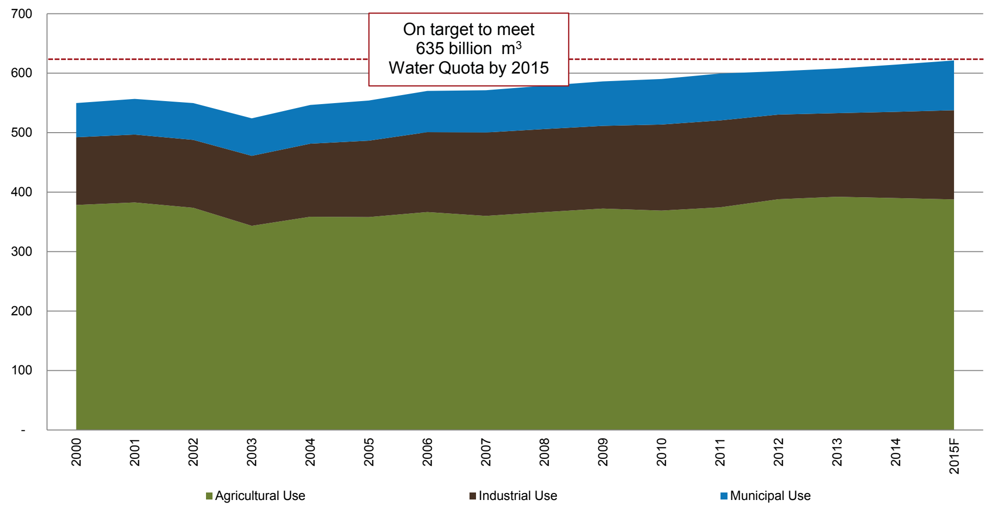
Is China on track?

China is on track to stay within 2015 national water use quota

Total water use: According to Chinese government statistics, the total amount of water use in 2013 was 618 billion m^3. Previously, we have held the view that demand may exceed supply as early as 2015. However, although actual agricultural water use has been rising at a faster rate than we originally projected, this has been offset by much lower water demand growth rates in industrial water use due to the economic slowdown in recent years. We therefore believe that China is well on track to stay within the 2015 national water use quota set by central government at 635 billion m^3. Going forward, controlling water use in water intensive sectors is key in order to adhere to the 2020 & 2030 quota.

Agriculture and industry account for 86% of water use

China: Actual & Projected Government Water Withdrawals by Sector (bn m^3)



Source: China Water Risk estimates, NBSC

Water solutions to increase water supply may also be limited, reined in by China's water-energy nexus – this is discussed in further detail in Chapter 2: "China's Water Energy Nexus".

Controlling water use in agriculture and power generation, the second largest user of water, is key

Improve water use efficiencies: Today, agriculture and industry account for 86% of total water use. Since agriculture is the largest user of water, it should generate the largest water savings. That said, agricultural water has risen from 369 billion m^3 in 2010 to 392 billion m^3 in 2013. Indeed State Council would like agricultural water to fall to 360 billion m^3 by 2025. The Ministry of Agriculture (MOA) thinks otherwise and forecasts water use to stay at 390 billion m^3 by 2025[7]. Power generation is the next largest user of water in China. Given that China has significant power expansion plans, can the nation stay within the Three Red Lines? Controlling water use in its two most water intensive industries is therefore of paramount importance. Finally, since farmland and coal bases lie next to each other, improving irrigation and water use in agriculture is essential in securing water for China's coal & energy bases to cater for the future. China's power expansion plans and water required for power generation are explored in

Chapter 2: "China's Water Energy Nexus" whereas water savings scenarios in agriculture and coal to ensure energy security are discussed in Chapter 4: "Ensuring Food & Energy Security" and energy efficiency improvements & energy savings are detailed in Chapter 5: "Battle to Conserve Energy".

China has no choice but to tackle pollution...

Prevent, control & reduce water pollution: China is serious about cleaning up. It has to - environmental degradation has reached a tipping point. Last year, Premier Li Keqiang officially declared war on pollution.

> *"The government will take strong measures to prevent and control pollution with the focus on mega cities and regions with frequent occurrence of smog. The government will also implement a clean water action plan, strengthen the protection of drinking water sources, prevent and control water pollution in key river basins, and carry out land restoration. We will resolutely declare war against pollution as we declared war against poverty.*
>
> *We will ... apply the strictest possible oversight, punishment and accountability to prevent and control food contamination and ensure that every bite of food we eat is safe."*
>
> *Premier Li Keqiang in his address at the 12th National People's Congress, 2014*

...8/10 Chinese are "deeply concerned" about environmental conditions

When eight out of every ten Chinese surveyed in the first-ever 'National Ecological Civilization Awareness Survey' conducted by the MEP express they are 'deeply concerned' about overall environmental conditions, China cannot afford not to tackle water pollution. With mainstream and social media news abound with drinking water scares and food safety fears since the start of 2012: almost nine out of ten surveyed are now 'highly concerned' over these issues. A declaration of war on pollution is inevitable in order to 'satisfy the masses'. This year, during the 12th National People's Congress, Premier Li vowed to get tough admitting that pollution is a "*blight on people's quality of life*".

In addition, the government also hopes to improve urban and rural access to safe drinking water. By 2015, 95% of all Chinese cities are to access public water supply whilst 80% of rural Chinese will access collective water[8]. However, water & wastewater treatment all require more power – this is discussed in more detail in Chapter 2: "China's Water Energy Nexus".

Chinese think tanks say that stricter limitations on power generation and coal-to-chemicals are musts

Holding the Three Red Lines is not easy. As warned by the China Institute for Water Resources and Hydropower Research (IWHR) in their recent report "The Strictest Water Resources Red Lines Ask for Coal Production and Use Control", even under "water conservation scenarios" which "*have notably lower water consumption levels compared to reference scenarios*" … "*in the near term, water conservation alone will still fail to meet water consumption red lines; only with stricter limitations on water-intensive industries such as power generation and coal-to-chemicals can the red lines be satisfied*".

Last year, at the Eco Forum Global Annual Conference held in Guiyang, Li Junfeng, one of China's most prominent advocates of renewable energy, delivered a strong argument saying that "*water security is more important than energy security*". This was widely quoted by Chinese media. Since he is currently the Director General of the National Center of Climate Change Strategy Research at the National Development and Reform Commission (NDRC) but was previously the former Deputy Director of NDRC's Energy Research Institute, he is in a unique position to look at China's energy mix from a broader context. In an interview with us, he clearly reiterated his view: water security is more important, more complex and needs more attention (see box below).

Water security is more complex and needs more attention than energy

WATER OVER ENERGY SECURITY
CHINA WATER RISK INTERVIEW WITH LI JUNFENG

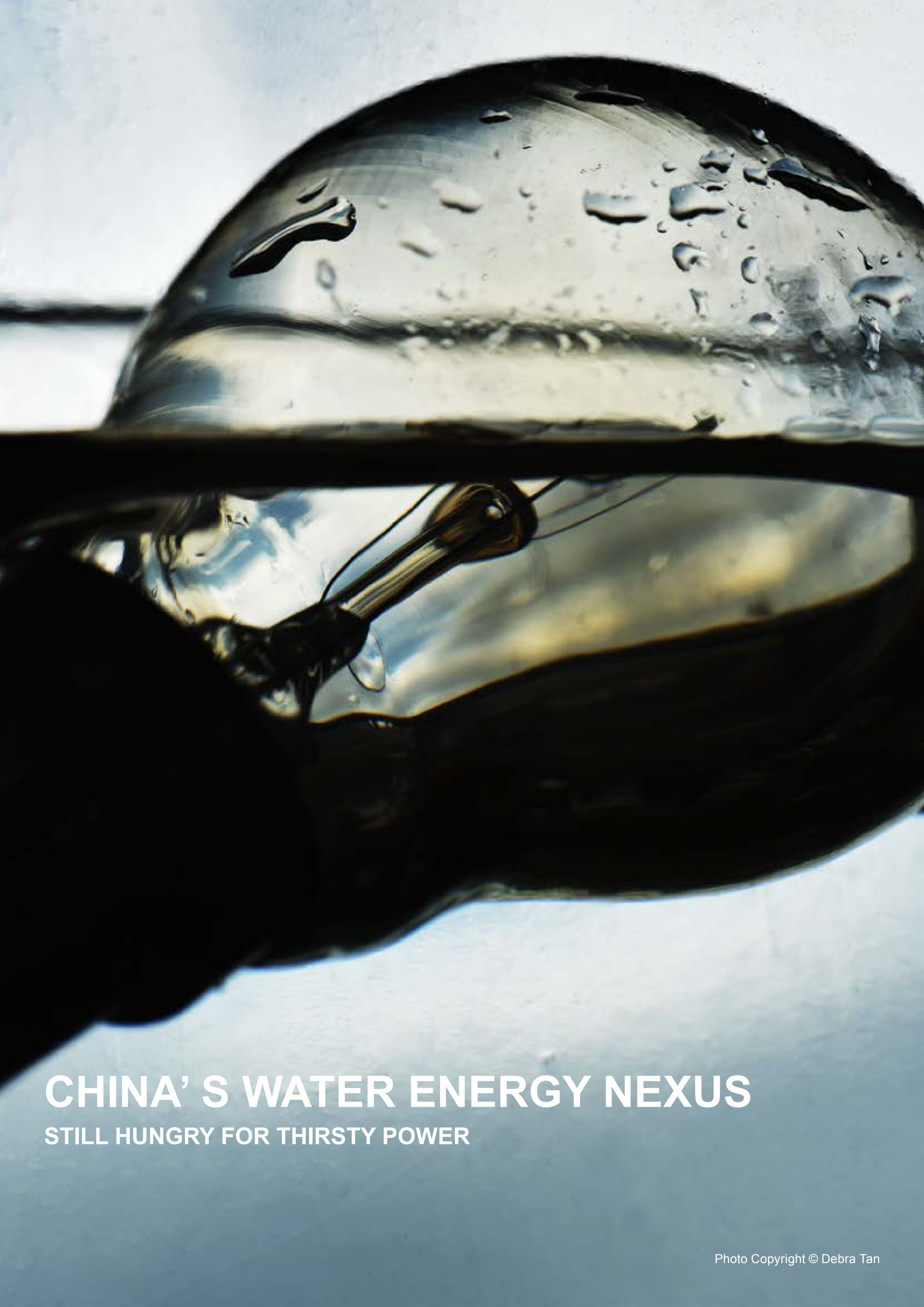
"CWR: You have been actively addressing the importance of water security with regards to energy security. What makes you think "water security is more important than energy security"?

Li Junfeng: China has been suffering from nationwide shortage of energy and water resources. Water security and energy security are both important and closely related. However, water security is more important. It's more complex, and needs more attention. China's oil demand can be met by importing 60% of its oil from other countries; but it wouldn't be possible to ensure freshwater supply in this way – it would be unsustainable if a highly populated, global manufacturing country like China imported 10% of its water demand."

Source: The above is an excerpt from a China Water Risk interview on our website titled "Water Over Energy Security", with Li Junfeng Director General of the National Center of Climate Change Strategy Research, October 2014

The situation is sobering and critical... it is time to rethink power through a water lens

The situation is sobering and critical. It's all interlinked and it comes down to water. It's time to rethink power through a limited water lens. Stricter allocation of water between agriculture, extractives, power, and other industries is imperative and investment needs to be made into strategies to lower water use within each industry. These are discussed in the ensuing chapters of this report.



CHINA' S WATER ENERGY NEXUS

STILL HUNGRY FOR THIRSTY POWER

- Power generation is heavily reliant on water for cooling purposes as well as driving steam turbines. Water is also required by hydropower stations. China's power is thirsty: 93% of its installed capacity needs water to generate electricity on a daily basis in 2013. The power sector is the 2nd largest user of water in China after agriculture, making it the No.1 industrial user of water.

- In turn, water is reliant on power for treatment, transport and distribution, thus forming the water energy nexus. Electricity used to provide clean access to water in China can power the whole of Denmark. Power is also needed to treat wastewater discharge which is similarly on the rise; already China's total wastewater discharge volume is comparable to the annual flow of the Yellow River.

- While water tariff reforms are afoot to make water solutions such as water reuse/recycling, water transfer and desalination economically viable, these solutions are power intensive. Desalination can consume over 4x more electricity than local surface or groundwater water production. Clearly, in some cases what is 'good for water' is neither energy efficient nor carbon-friendly. Choices matter in selecting the right water solution; the wrong choice could add to China's already pressing power needs.

- Electricity consumption in China has almost quadrupled over the past decade from 1,347TWh in 2000 to 4,976TWh in 2012. Industry drives the nation's hunger for power, with 85% share of electricity consumption. Direct exposure of China's industrial backbone to water scarcity and pollution coupled with indirect exposure through water-reliant electricity generation form a double whammy exposure for Chinese industry.

- China is still hungry for thirsty power and could add 2TW by 2050. This is more than the current total installed capacity of the US, UK, France, Germany, Russia and Japan combined. China's per capita installed capacity is still below that of the G20 average. As such, we expect China's per capita installed capacity to rise to 1.7kW by 2030 and 2.6kW by 2050. While this in line with Japan's 2.3kW/capita in 2012, it is far below that of the US's 3.4kW/capita for the same year.

- Concerns over China's power expansion are not whether the build out can be achieved but whether China has enough water resources to fuel this expansion. The power sector's water risk exposure is great. Already, China has plans to shift its energy mix away from coal and hydropower towards less water-reliant power such as wind and solar. Water-reliant power is projected to fall from 93% to 72% by 2050. However, the magnitude of China's power expansion means that it is still +1.2TW of water-reliant power; equivalent to 4x the total installed capacity of Japan.

- Water and energy are clearly interlinked; decisions in one area impact the other. To achieve energy security with limited water, multiple strategies will have to be adopted simultaneously across a broad spectrum of sectors. Such strategies can be grouped into a broad three-prong approach: (1) balancing power mix by considering trade-offs among water, energy and climate; (2) controlling water use in the agriculture and coal and coal-related sectors to ensure food and energy security; and (3) curbing energy demand as saving power means saving water.

- Energy conservation goes beyond increasing the operational efficiency of China's power fleet. Since industry is the largest user of electricity, optimising industry mix is key; this includes shifting towards tertiary or less power-intensive industries. Such strategies will not just have implications for the water and power sectors but impact many related industries including steel, cement, coal-to-chemicals and rare earth industries.

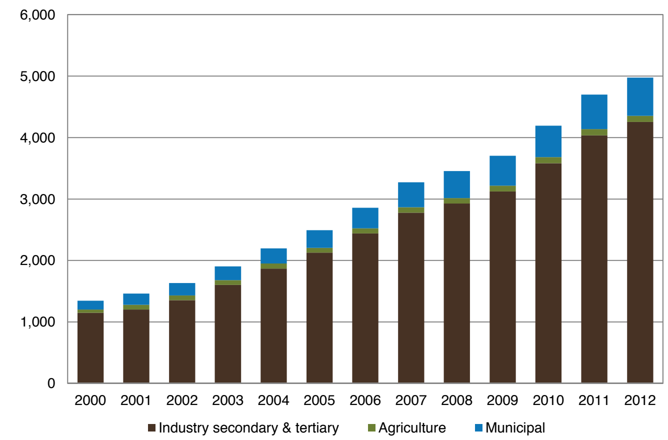
CHAPTER 2:
CHINA' S WATER ENERGY NEXUS – STILL HUNGRY FOR THIRSTY POWER

CHINESE INDUSTRY DRIVES THE NATION'S HUNGER FOR POWER WITH 85% SHARE

Energy consumption has risen dramatically over last decade

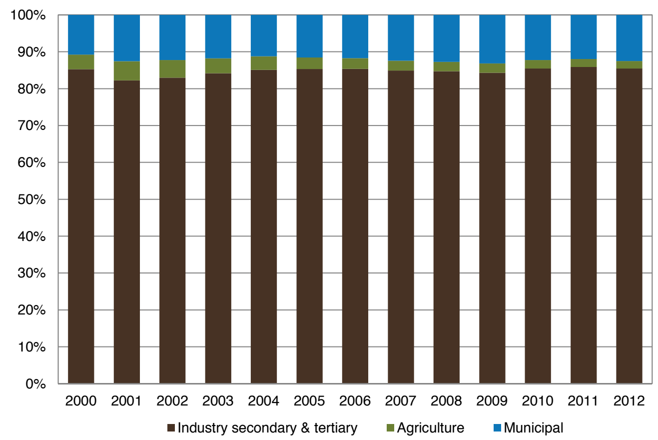
China's electricity consumption has risen dramatically over the past decade rising from 1,347TWh in 2000 to 4,976TWh in 2012. It is clear from the chart below left that although municipal consumption of electricity has risen, it is industry that has driven electricity growth. Electricity consumption by secondary & tertiary industries stands at 4,253TWh in 2012. However, the share of electricity consumption has stayed remarkably flat with industrial electricity consumption historically accounting for around 85% of electricity used in China (see chart below right).

2000-2012 China's Electricity Consumption By Sector (TWh)



Source: China Water Risk, NBSC various years

2000-2012 China's Electricity Consumption By Sector (%)



Source: China Water Risk, NBSC various years

China's electricity consumption mix is changing - shifting away from power intensive industries to accommodate increasing municipal demand

Going forward, as China urbanises, municipal electricity consumption is expected to continue to rise. Therefore any significant energy savings would have to come from Chinese industry. Indeed there have been significant ongoing efforts to address this.

Aside from energy efficiency improvements, a change in industry mix such as a shift towards tertiary industries or away from power-intensive industries would also dramatically alter the nation's electricity consumption profile.

Both energy efficiency efforts and reducing electricity consumption by changing industry mix are addressed in Chapter 3: "Balancing Power Mix for Water & Climate".

POWER IS THIRSTY: 93% OF INSTALLED CAPACITY REQUIRES WATER TO GENERATE POWER

93% of China's power generation is water-reliant

The power sector is heavily reliant on water for cooling purposes as well as driving steam turbines. Water is also required by hydropower stations. In 2013, hydropower and thermal power represented 22.3% and 70.4% of the installed capacity of the nation respectively. This means that 92.7% of China's power generation is reliant on water.

Power sector is the #2 user of China's water and more than half of China's industrial water use is by coal related industries

Today, the power sector is the second largest user of water in China after agriculture. In 2012, China's power sector used approximately 10% of the nation's water, which is relatively low compared to the UK's 34% and 49% in the US[9]. Power generation is however the largest user of industrial water in China and is currently dominated by coal-fired power. It is estimated that more than half of China's industrial water usage is by coal related industries – from coal mining to preparation, coal-fired power generation, coke production and the coal-to-chemical industry[10].

WATER ALSO NEEDS POWER

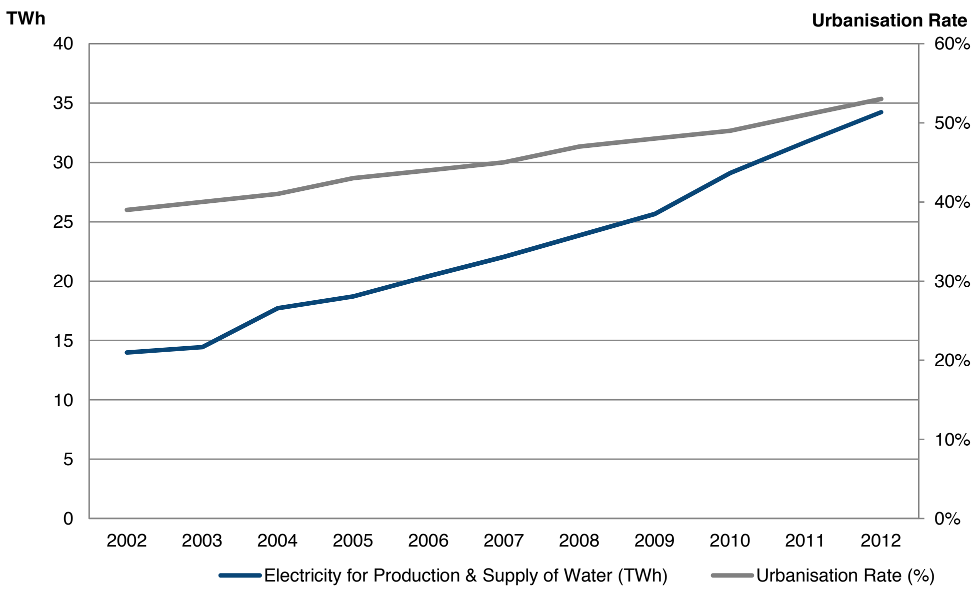
In turn, power is also required to treat, transport and distribute water. The power required to treat water varies depending on whether the water is surface water or groundwater and the distance it has to be piped for treatment. Water supply solutions such as recycling/reclaiming water and desalination are even more energy intensive.

Electricity used to provide access to clean water in China can power Denmark

Electricity consumed in production and supply of water can power Denmark but it is only 0.7% of electricity consumption in China

As China urbanises, water demand is expected to rise and therefore as is electricity consumed in the production and supply of water (see chart below). Electricity consumed in the production and supply of water has more than doubled from 15TWh in 2002 to 34TWh in 2012. This is almost enough to power Denmark which in 2013 consumed 34TWh[11]. That said, power to provide access to clean water is only a mere 0.7% of total electricity consumption of China, indicating the magnitude of China's power needs.

Electricity Consumed in the Production & Supply of Water in China



Source: China Water Risk, NBSC various years

Wastewater treatment also requires power

China is the No. 1 global wastewater producer; its wastewater discharge volumes are comparable to the annual flow of the Yellow River

With the largest population in the world, China is easily the top ranked country by the amount of wastewater produced. In 2012, the total discharge of wastewater in the country amounted to 68.4 billion tonnes which is in volume terms comparable to the annual flow of the Yellow River[12].

Wastewater discharge is expected to rise due to clamp down on illegal discharge

Whilst domestic wastewater discharged has risen in line with the urbanisation rate over the last decade, industrial wastewater has been falling since 2008 despite rising contribution by industry to China's GDP which points towards the fact that industrial water is likely under-reported. Wastewater discharge has risen marginally in 2013 but going forward, we expect this to rise at a faster rate due to the war on pollution and the clampdown on illegal discharge thanks to harsher punishments in the newly amended environmental law which came into effect in 2015. Power consumption by the wastewater treatment sector will therefore rise accordingly. That said, the Chinese government is promoting circular economies in ten industries and industrial parks; waste and wastewater from these industries are expected to be re-used in the industry to produce energy – see how waste can be used to generate energy in the chapter on "Other Renewables".

RECOVERING ENERGY FROM WASTEWATER

Our wastewater is full of energy and many treatment plants are already recovering part of it. Yet, this has proved challenging sometimes, either technologically or economically. New developments are expected to alleviate these challenges.

Much fat, oil, grease and other energy-rich organic contents can be found in domestic wastewater. Accordingly, wastewater could be considered as a resource rather than as a waste. Indeed, after being separated from the effluent stream, the sludge can be digested anaerobically to produce biogas, which in turn can be used to generate heat and electricity. Some treatment plants in Germany even produced more electricity than they required.

While traditional systems may lack flexibility in terms of water input or temperature, or simply prove too expensive, new processes are being developed, such as the anaerobic membrane bioreactor systems, which could alleviate some of the existing impediments and help tapping into this significant potential.

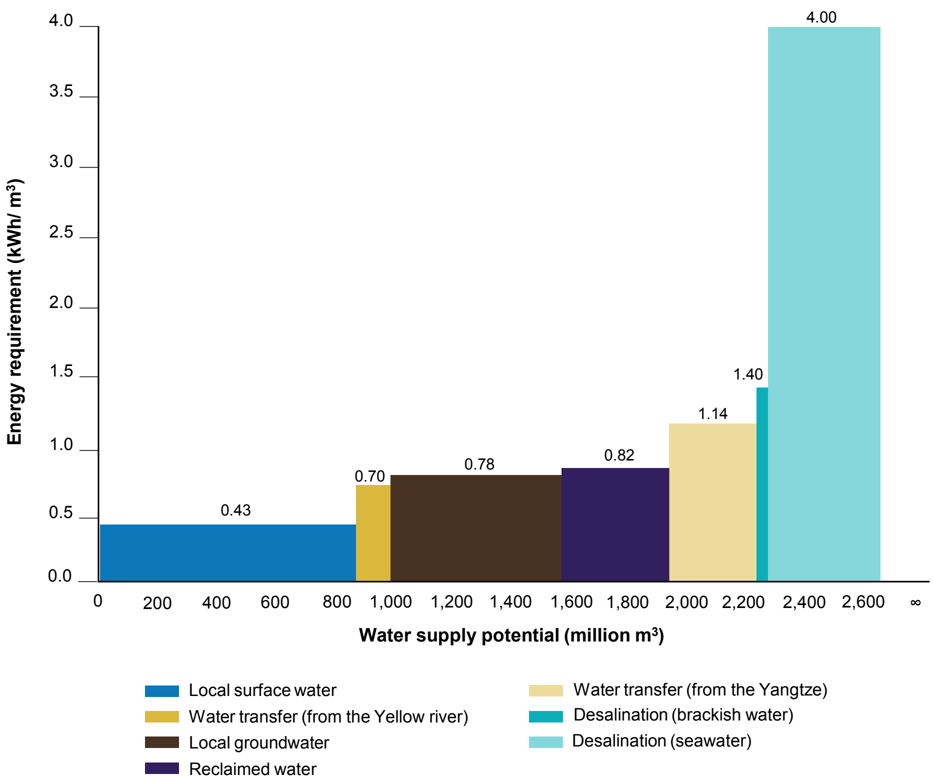
Source: China Water Risk, The Energy Autonomous Sewage Treatment Plant – Vision or Illusion? 16th International Symposium on Sustainable Water Management, 2012.

Desalination, water diversion and water recycling are power intensive

Desalination can consume over 4x more electricity than local surface or groundwater production

Water supply solutions such as recycling/reclaiming water and desalination are power hungry. The energy requirement can vary widely. A World Resources Institute (WRI) analysis in Qingdao[13], China shows that energy consumption can vary from 0.43kWh/m^3 of local surface water production to 0.78kWh/m^3 for local groundwater, whilst desalination plants can consume 4kWh/m^3 of freshwater produced from seawater (see chart below):

Energy Requirements for Water Production for Qingdao



***Notes:** Water supply potential from various water sources are estimated based on Qingdao Water Resources Bulletin (Qingdao Water Resources Bureau, 2012) and Qingdao Desalination Development Plan (Qingdao Development and Reform Commission, 2005). Energy requirements for unit water production from various water sources are estimated based on WRI's field interviews and literature (such as Cohen et al., 2004; Singapore Public utility Board, 2012).*

Source: WRI, 2014

Clearly in some cases, what is 'good for water' is neither energy efficient nor carbon-friendly.

Sometimes what is 'good for water' is neither energy efficient nor carbon-friendly

For Qingdao (which is in Shandong, a water scarce province), perhaps the better solution to increase water supply is to reclaim wastewater which is more energy efficient than both water transfers from the Yellow River and converting seawater into freshwater. As reclaiming wastewater uses less power, it would be cheaper than desalination due to the higher cost of power. WRI recommends that to help alleviate water stress in China, lower cost options from more environmentally sustainable water sources – such as water efficiency investments and wastewater re-use – should be thoroughly investigated first and prioritized instead (see box below).

DESALINATION: TOO MUCH POWER FOR WATER

China's desalination strategy would consume an enormous amount of energy, causing other problems such as increased greenhouse gas emission and air pollution, and would cost more than most cities can afford. Until desalination technology becomes more energy efficient, it should only be used as a backup source of water in China.

Source: The above is an excerpt from an article on posted on our website titled "Desal: Too Much Water For Power", by Zhong et al, WRI Beijing, January 2015

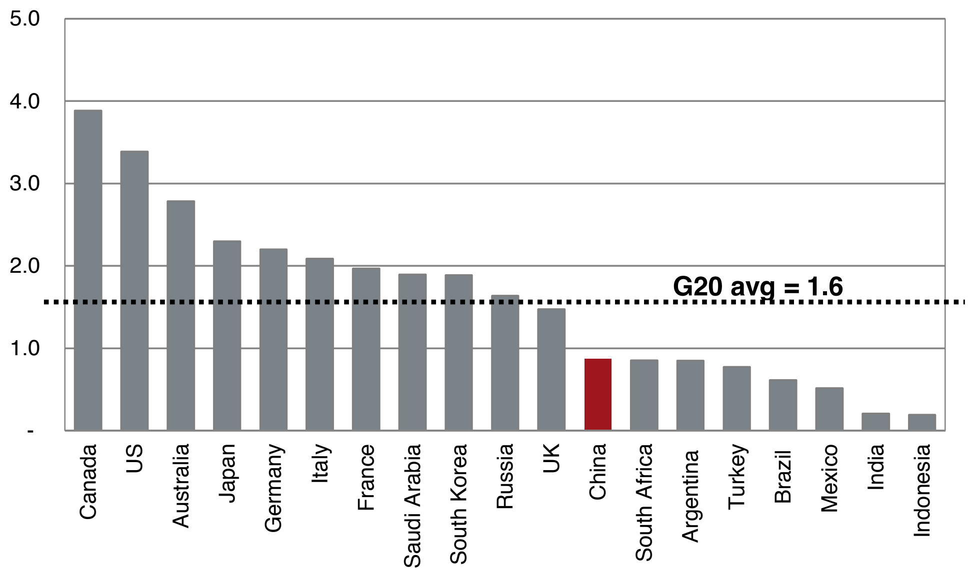
The water energy nexus issues described above are particularly pertinent given the amount of power generation capacity China is planning to add over the next three decades. Both power and water need to be managed effectively in order to ensure both water and energy security. Strategies to execute this are explored in the next three chapters - Chapter 3: "Balancing Power Mix for Water & Climate", Chapter 4: "Ensuring Food & Energy Security" and Chapter 5: "Battle to Conserve Energy".

CHINA'S INSTALLED CAPACITY IS STILL BELOW G20 AVERAGE

China's per capita installed capacity is far behind G20 nations

Currently, China's per capita installed capacity is still far behind that of the G20 nations. In 2012, China's installed capacity per capita is 0.87kW compared to the G20 average of 1.6kW. It is far below that of the UK and US at 1.5kW and 3.4kW respectively. Based on China's current power expansion plans and the UN projected population growth for China by 2030 of 1.4 billion, China's installed capacity per capita will rise to 1.7kW by 2030, bringing it on par with the current G20 average.

2012 G20 Installed Capacity Per Capita (kW/ pax)



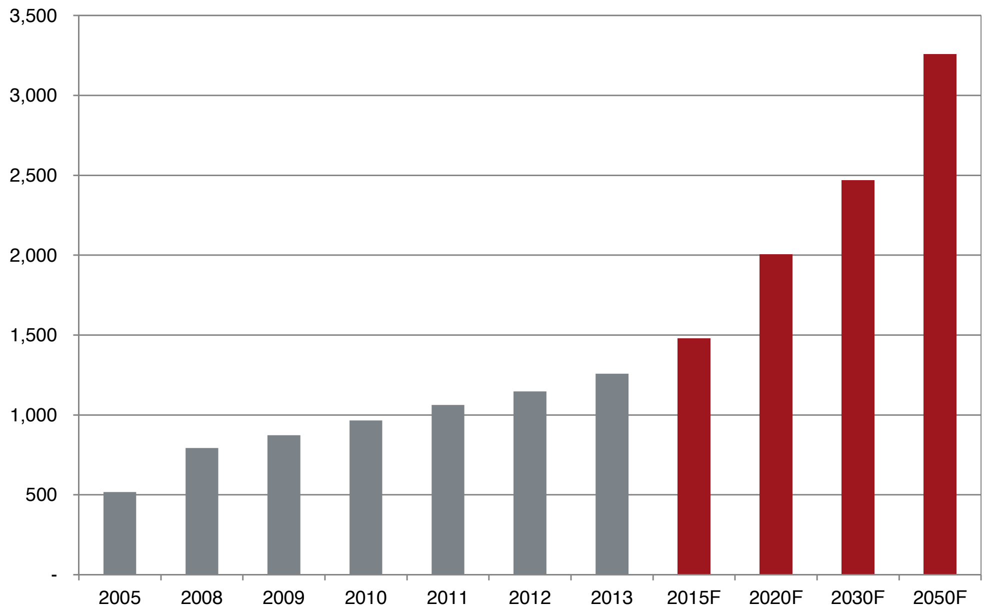
Source: China Water Risk, US EIA, World Bank
Note: EU is not included

+2TW BY 2050 IS MORE THAN THE TOTAL INSTALLED POWER CAPACITY OF US, UK, FRANCE, GERMANY, RUSSIA & JAPAN

China's installed capacity to be 3.26TW by 2050...

According to official forecasts, China plans to increase its installed power generation capacity from 1.26TW in 2013 to 3.26TW by 2050. This additional generation capacity of 2TW by 2050 is equivalent to the current entire generation capacity of the US, UK, France, Germany, Russia and Japan put together.

2005-2050F China's Actual & Planned Total Installed Capacity (GW)



Source: China Water Risk estimates, CEC, NBSC, 12FYP, State Council, NEA Research Affiliate

... concerns not over build out capability but if there is enough water for the expansion

This aggressive build-out takes China to a projected installed capacity per capita of 2.6kW, in line with Japan's current 2.3kW per capita but still far behind US per capita installed capacity today. The concern lies not in capability of China to achieve such an expansion as its track record shows a penchant for mega-projects, but in whether China has enough water resources based on the current mix of power generation to bring the nation up to par with developed countries.

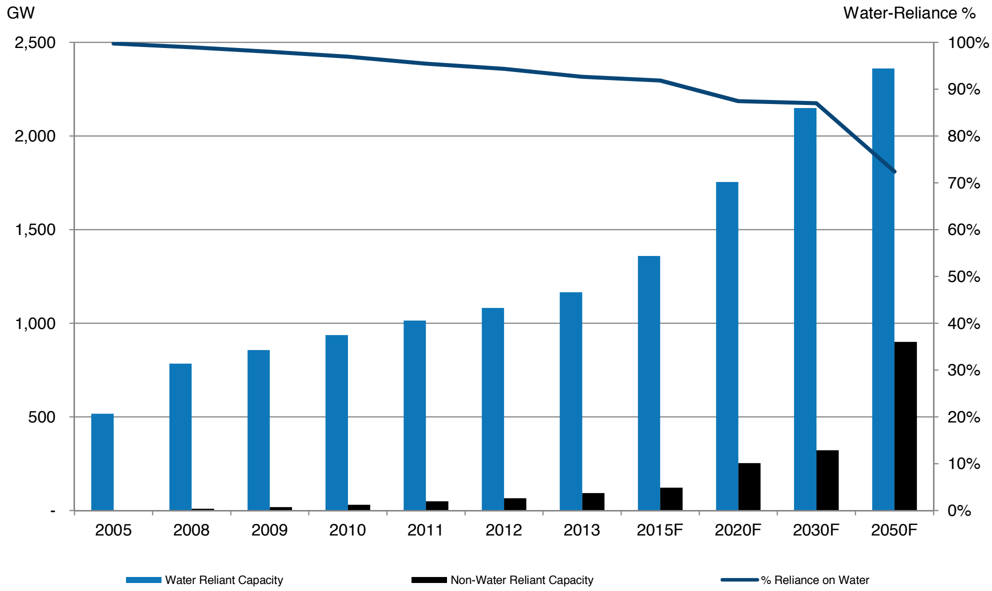
WATER-RELIANT INSTALLED CAPACITY FALLS TO 72% BY 2050

Energy mix is changing but water-reliant power generation remains high at 72% in 2050

Currently, 92.7% of China's installed capacity requires water to generate electricity. China has been changing its mix of energy for power generation away from coal towards less water-reliant power such as wind and solar.

It is clear from the chart below that there is a fall in the share of water-reliant power capacity. By 2050, due to an aggressive planned build out of non-hydro renewables between 2030 and 2050 of almost 580GW, the proportion of China's installed capacity that relies on water falls to 72.4% (see chart below). China power generation capacity's reliance on water therefore although falling, remains high.

2005-2050F Planned Installed Capacity - Reliance on Water



Source: China Water Risk estimates, CEC, NBSC, 12FYP, State Council, NEA Research Affiliate

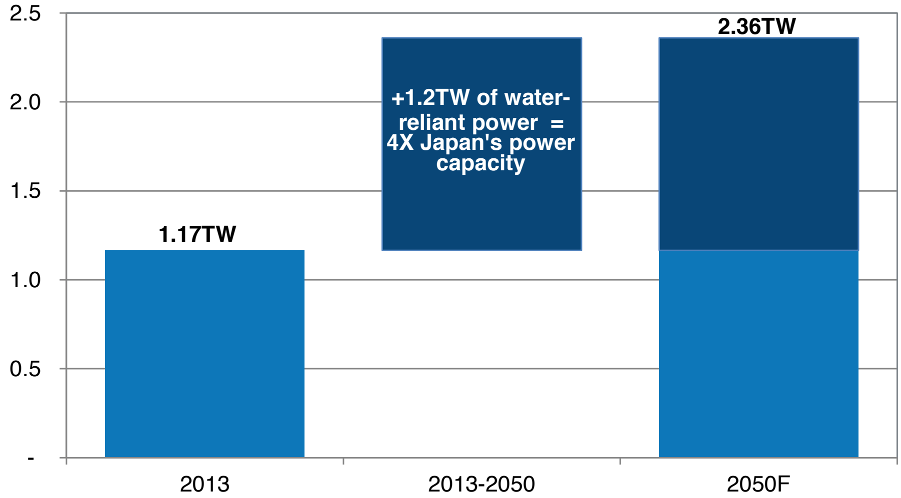
CHINA'S WATER-RELIANT ADD OF +1.2TW IS 4X JAPAN'S CAPACITY

+1.2TW of water-reliant power will be added by 2050...

Despite a fall in mix of water-reliant capacity, China is still adding 1.2TW of water-reliant installed capacity. To put this growth into perspective, this add is more than 4x than the current installed capacity of Japan. In fact, 1.2TW is greater than the combined installed capacity of UK and the US as at 2012. Can China add more power with limited water?

...can China add more power with limited water?

China Addition of Water Reliant Installed Capacity (TW)



Source: China Water Risk, NBSC, NEA Research Affiliate, CIA Factbook

THREE-PRONG APPROACH TO ENSURE ENERGY SECURITY WITH LIMITED WATER

To achieve energy security with limited water, multiple strategies will have to be adopted simultaneously. These strategies will not just have implications for the water and power sectors but straddle multiple industries. To facilitate understanding, of these interlinked and complex issues, we have grouped these strategies and respective policies into a three-prong approach:

Tough choices ahead in balancing power mix for both water and climate...

1. **Balancing Power Mix for Water & Climate:** Different types of power have different impacts on water and the climate. Getting the right mix of power between thermal power (coal, gas & nuclear) as well as hydropower and other renewables such as wind and solar is important. Trade-offs between energy efficiency and water use will have to be considered. Power generating solutions that might work for climate may bring about water risks. For example, hydropower expansion on transboundary rivers may trigger geopolitical risks, whereas wind and solar might bring hidden risks due to the currently polluting practices in rare earth mining. There are tough choices ahead.

   We have set out the trade-offs between water, energy and the climate in Chapter 3: "Balancing Power Mix for Water & Climate" whilst water risk exposure of each power type are analysed and detailed in separate chapters on "Coal & Coal-fired Power", "Hydropower", "Nuclear Power" and "Other Renewables".

...lowering water use in agriculture and coal bases is key

2. **Ensuring Food & Energy Security:** Coal will remain the vanguard fuel in China. Unfortunately, due to the geographical mismatch of resources, China's large-scale coal bases lie in the parched North, next to its agricultural heartlands. Ensuring enough water for both coal bases and agriculture is of paramount importance in China's pursuit of energy and food security. Given the inevitable competition for water resources in the future, lowering water use in both agriculture and coal bases is key. In Chapter 4: "Ensuring Food & Energy Security", we explore potential agricultural water savings for transfer to coal bases. Water use scenarios to meet 2020 coal output and coal-fired power generation are also detailed to gauge their exposure to water risks. Last resort options such as water diversions from the South to the North are also examined in the chapter.

...cutting energy demand and optimizing industry mix are necessary strategies in moving towards a circular economy

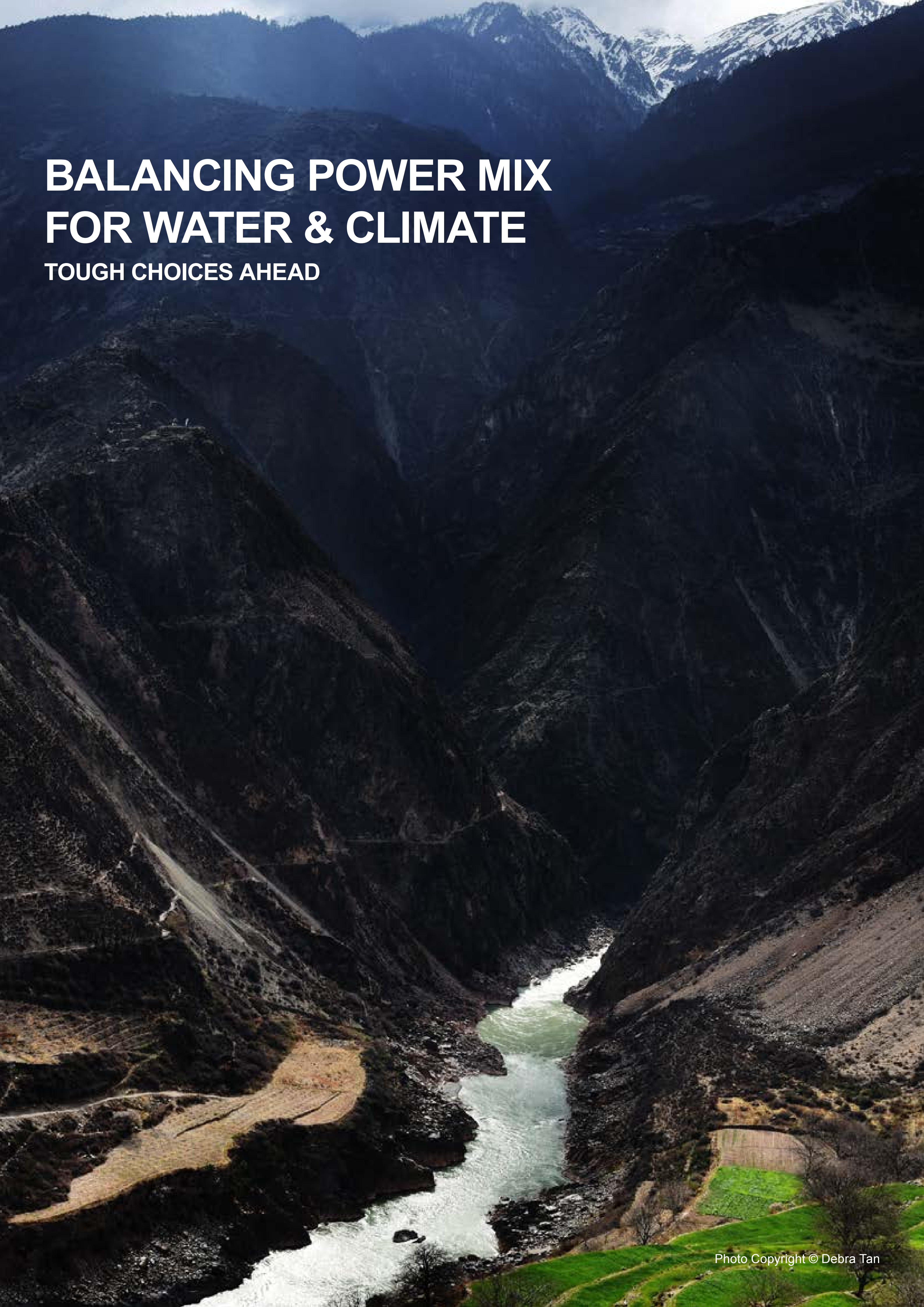
3. **Battle to Conserve Energy:** Since power requires water to generate, saving electricity is a 'double saving' because the water required to generate that power is also saved. Curbing energy demand is essential to slow the rate of growth in power consumption. It is also the best option for water, air and climate. Upgrading China's coal fleet is not enough; cutting energy demand and optimizing industry mix are also necessary strategies. With industry accounting for 85% of China's electricity consumption, energy savings reaped can be significant. Ultimately, China wants to create circular economies in its important industries that are both water and power intensive. Potential energy savings and water savings from upgrading China's coal fleet as well as scenarios for industrial efficiency improvements in the power intensive sectors like steel and cement are analysed and explained in Chapter 5: "Battle to Conserve Energy". China's circular economy plans for the coal, power and steel sectors are also discussed.

There are unintended consequences; choices need to be holistic

Word of caution: strategies within each of the approaches have unintended consequences. Choices need to be holistic. Current systemic issues in managing energy and water do not facilitate this. Navigating China's water energy nexus is complex and an uphill battle. We hope the three-prong approach set out in the next three chapters help frame this critical discussion.

BALANCING POWER MIX FOR WATER & CLIMATE

TOUGH CHOICES AHEAD



- In 2014, President Xi and President Obama jointly announced their intention to cut carbon emissions. In 2012, 74% of China's electricity generated was coal-fired. Therefore, electricity generation is affecting water resources not just through direct water use but indirectly through climate change impact as a result of carbon emissions. Getting the power mix right by balancing water use, carbon emissions and their electricity generation capabilities is imperative.

- Some types of power require more water to generate electricity than others. Life-cycle analysis shows that water consumption can range from 0.56m^3/MWh for wind to 24.5m^3/MWh for biomass; coal and nuclear are around 3.2m^3/MWh whilst hydropower is at 17.8 m^3/MWh. Clearly, power type choices will impact China's water resources.

- Water trade-offs with carbon emissions also need to be considered because if climate is at risk, water resources are at risk. While wind, solar PV and nuclear may be carbon-friendly choices; there are issues with each, for example contamination fears of drinking water sources with inland nuclear expansion in densely populated areas pervade. Hydropower, on the other hand, whilst carbon-friendly obviously requires water. In addition, its role in water flow management may trigger geopolitical tensions if transboundary rivers are dammed.

- Some power types are better than others at generating electricity. 1MW of installed capacity for hydropower, solar and wind will generate less electricity than 1 MW of nuclear or coal-fired installed capacity. However, higher capacity factors do not indicate a superior power type as their actual capacity factor is largely influenced by the role they play in electricity generation.

- Currently in China, nuclear is solely used as a base-load generator operating close to its maximum capacity factor at 85%; whereas natural gas mostly serves as a peak generator, operating at an average capacity factor of 37%, far below its maximum of 87%. China's coal fleet is used for base load and peak generation as well as smoothing power generated by intermittent sources such as hydropower, wind and solar. As a result, China's coal fleet has a capacity factor of 54%. Finally, coal's dominant role in smoothing means that renewables in China are not "100% green".

- China needs to choose wisely when replacing one energy source with another. There are no "silver bullets" in the water-climate-energy nexus. Future power expansion will see coal and gas capacity share fall from 69% in 2013 to 47% in 2050, while nuclear share rises from 1% to 10%. Hydropower will shrink from 22% to 15% in favour of wind and solar, which is set to rise from 7% to 28% for the same period. That said, expansion across all power types between 2013 and 2050 is aggressive: +650GW in coal and gas, +325GW in nuclear, +220GW in hydropower and +808GW in wind and solar. To provide perspective, the 2012 total installed capacity of Japan and India was only 293GW and 255GW respectively.

- Choosing the right type of technology within coal, nuclear, hydropower and other renewables is equally important for both climate and water. Combinations of power generation technologies and cooling systems need to be considered and tailored depending on water availability. Indeed, the MWR's Water-for-Coal Plan already recommends dry cooling in water scarce regions for coal-fired plants.

- China's energy mix is evolving. An energy secure future in China includes the ability to supply electricity without having to rely on other countries for fuel. As such, coal will remain the vanguard whilst nuclear, although carbon-friendly, is at a crossroad due to water concerns. Hydropower's dual role of power generation and water flow management means it's here to stay. Wind and solar will dominate renewable growth but rare earths required in their manufacture bring hidden water risks for important watersheds in the North and the South.

- Tough choices lie ahead. In reality, dispersed authority and overlapping responsibilities may hamper the right choices for water, energy and climate. There are currently nine government departments managing water and 25 managing energy. Complex interlinked issues in the water-energy-climate nexus cannot be resolved without holistic management and government reform. Indeed, President Xi has indicated that China's energy revolution includes reforming its supply, consumption, technology and the system.

CHAPTER 3:
BALANCING POWER MIX FOR WATER & CLIMATE – TOUGH CHOICES AHEAD

WATER-ENERGY-CLIMATE NEXUS: GETTING THE POWER MIX RIGHT

China committed to peak carbon emissions around 2030

In November 2014, President Xi Jinping and President Barack Obama jointly announced pledges to cut carbon emissions. The China-US Climate Change Agreement saw China promising to reach peak carbon emissions around 2030 and the US to cut its emissions by 26% to 28 % of its 2005 levels by 2025. As part of the agreement, the presidents also launched a USD50 million water-energy nexus program under the US-China Clean Energy Research Centre.

There are clear trade-offs between water, energy & climate

As discussed earlier, there are clear trade-offs between water, energy & climate. Electricity generation is not just water reliant, it is also a major contributor to carbon emissions in China. In 2012, 74% of electricity generated was from coal and as such, it could be argued that electricity generation is affecting water scarcity not just through direct water use but indirectly from climate change impact through its carbon emissions.

No one-size-fits-all solution in the climate-water-energy nexus

Given that China has to add significant power over the next few decades with limited water resources and climate change in mind, balancing choices between fuel types is imperative. Which fuels can generate the most power with less water and have the least impact on climate? What is good for the climate and power may not work due to limited water; and what is good for water, may not generate that much power. Some water solutions may also be bad for the climate.

Bearing in mind that many climate solutions may not be available given limited water, there are no “silver bullets” and no one-size-fits-all solution in the climate-water-energy nexus. This section examines the choice of power type from perspectives of water use, carbon emissions and their electricity generation capabilities.

SOME TYPES OF POWER NEED MORE WATER THAN OTHERS TO GENERATE 1MWh

Confusing terminology has led to many varying numbers of water required for coal production & coal-fired power generation

Some types of power require more water to generate electricity than others. But before we discuss water use across different types of power, it is helpful to clarify some terminology which can be confusing (see box below). This has led to many varying numbers in the amount of water required for coal production to coal-fired power generation. As the Wilson Center and Greenovation Hub said in their recent report "China's Water Energy Food Roadmap"[14], "*terminology about water can be a bit 'slippery'*".

WATER TERMINOLOGY CAN BE MUDDY

Water Withdrawal/ Water Use

Water withdrawal refers to the amount of water removed from a surface or groundwater source, whether it is ultimately returned to its original catchment or not. We have used this interchangeably with 'Water Use' in this report.

Water Consumption

- **Water consumption** refers to the amount of water withdrawn which is not returned to its original catchment. The water is mainly consumed through evaporation and/or incorporation into a product.
- **Life-cycle water consumption** refers to the water consumed throughout the whole life-cycle of a product. For energy, this includes the water consumed for extracting, processing, and transporting the fuel, as well as building, operating and decommissioning the power conversion facilities.

Water Impact

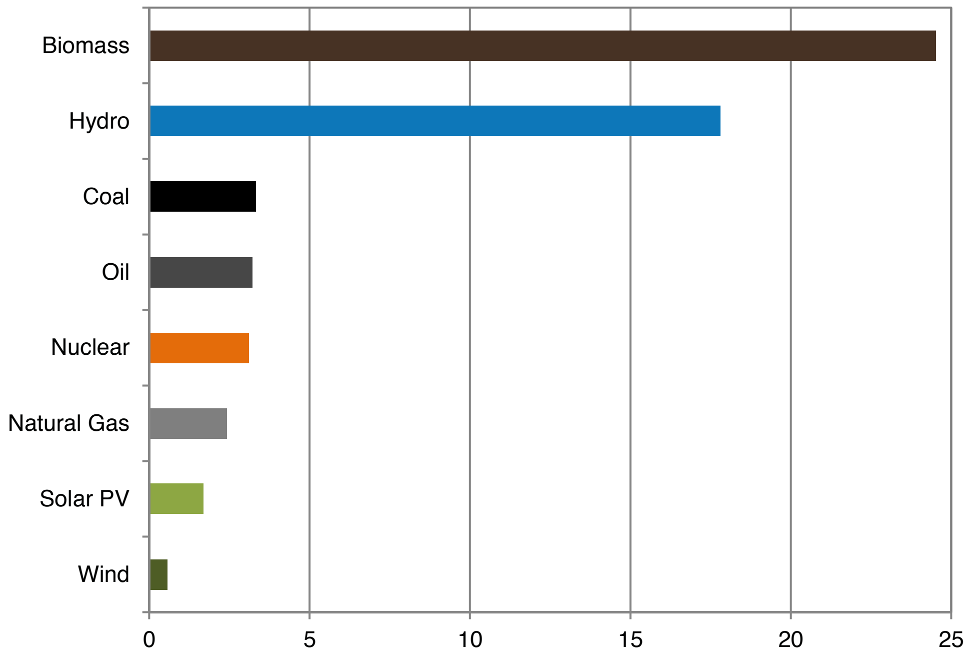
Water impact refers to the amount of water whose quality has been significantly affected by a process. This is a rather broad notion and the value will depend on the thresholds adopted to consider the damage.

There are many reports & papers on the future projections of China's energy needs. There is also research on water requirements in the energy sector, albeit less prolific. Previously, in a report for CLSA U® titled "Water for coal: Thirsty miners will share the pain", we used Pan et al. (2012) to calculate water withdrawals for the coal industry. Water use and water impact and for coal extraction and production as well as targets under the Water-for-Coal plan are discussed in the chapter on "Coal & Coal-fired Power".

Life-cycle perspective for water and carbon illustrates trade-offs

However, for the purpose of comparing different types of power generation, we have opted to use a more recent paper by Feng, Hubacek, Siu & Li (2014) on life-cycle water consumption in Chinese electricity production. In selecting the right type of power we must look at the entire life-cycle: from coal/uranium mining to the construction of the plant to electricity generation. In addition, Feng et al., assessed both life-cycle water consumption and carbon emissions by power making it easier to illustrate "comparable" trade-offs between water consumption and carbon emissions. The chart below shows the amount of water consumed to generate one 1MWh using life cycle analysis[15].

Water to Generate 1MWh - Life Cycle Analysis (m^3)



Source: Feng et al., Renewable & Sustainable Energy Reviews (2014)

Water consumption can vary widely from 0.56m³ for wind to 24.5m³ for biomass

As can be seen, the amount of water consumed in generating 1MWh varies widely from $0.56m^3$ for wind to a significant $24.5m^3$ for biomass. 95% of water consumption in biomass is due to water consumed in crop production. Given China's limited arable land and water constrains, first generation biofuel is not an option. However, there is potential for the development of bioenergy with agricultural and municipal waste material. This could potentially replace up to 10% of total coal consumption[16]. Generation of bioenergy from waste is discussed further in the chapter on "Other Renewables".

Hydropower is a large consumer of water but new tech can reduce evaporation from reservoirs

Generation of electricity using hydropower is next largest consumer of water at $17.8m^3$ per MWh. This is largely due to evaporation in reservoirs. Recent technologies could help reduce this evaporation by up to 70%[17], through the installation of floating solar panels on the reservoir itself. Japan has already announced the installation of more than 20MW of floating solar panels[18]. Other countries such as Australia, Great Britain, France, India, Israel, and Italy are experimenting similar technologies as well. So far, we know of no such pilot in China at the moment to reduce reservoir evaporation. However, in Qinghai there is a pilot where solar PV is used to complement hydropower. Please see the chapter on "Other Renewables".

For water: solar PV and wind are clear winners

Coal, oil and nuclear have similar life-cycle water consumption at 3.32m^3, 3.22m^3 and 3.1m^3 respectively to generate 1MWh. Solar PV and wind are clear winners from a water perspective. However, it is important to note here that not all solar technology is water friendly. Concentrated Solar Power (CSP) with wet cooling can consume around 3.5m^3/MWh[19], which is more than coal and gas; and this does not even take into account its life-cycle impact – more on this in the chapter on "Other Renewables".

... but climate risks must also be considered

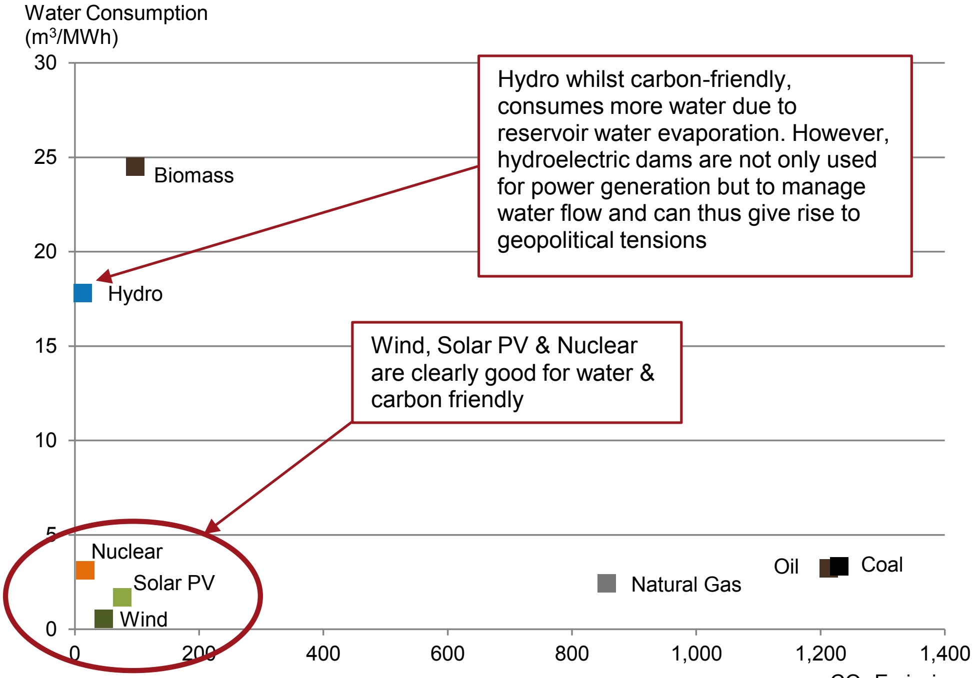
It is clear from the above that water can be managed by changing China's power generation mix. What is also clear is that some power types that are "green" and climate friendly can be thirsty compared to coal and gas which consume less water. However, it would be wrong to select power type from a water perspective only. This is short-sighted. Climate risks need to be taken into consideration as climate change only exacerbates water scarcity in the long run (see Chapter 1: "China's Changing Waterscape")

CHOOSE WISELY: CLIMATE AT RISK = WATER RESOURCES AT RISK

For water and carbon: wind, solar PV and nuclear are clear winners

Considering only both life-cycle water consumption and emissions across power types, the choices are obvious. Per the chart below, wind, solar PV and nuclear are the clear winners. Meanwhile, tackling evaporation issues in reservoirs and bioenergy generation from waste will bring hydro & biomass back to the table as real options for both water and climate.

Water vs. CO_2 per MWh by Power Type



Source: Feng et al., Renewable & Sustainable Energy Reviews (2014)

Hydropower is also used to manage water flow and can give rise to geopolitical tensions

That said, a word of caution on hydropower: it is not just used for power generation but also to manage water flow. Growing hydropower capacity on transboundary rivers raises concerns amongst China's neighbouring countries. Moreover, there are environmental issues and seismic risks to be considered. Finally, given potentially diminished capacity in the future due to extreme weather, we believe that alternatives should be examined before tapping transboundary rivers with large-scale hydropower. Water risks and other issues surrounding China's hydro expansion and generation are discussed in detail in the chapter on "Hydropower".

NUCLEAR MUST HAVE WATER & MANY FEAR CONTAMINATION OF DRINKING WATER SOURCES

Nuclear power plants require substantial amount of cooling water while operating in order to generate electricity (almost twice the amount for coal in terms of water withdrawal). In addition, even after a reactor is shut down, water is required to cool down the reactor to prevent damage to the core. Therefore, water shortage could be a major threat in terms of nuclear safety. As such, nuclear expansion after the Fukushima incident was halted and put under review. There were valid concerns over the build-out of inland nuclear power plants especially since river water flow, which is required for cooling and therefore safety purposes, might not be permanently available.

The moratorium has since been lifted. The new nuclear power plant model (Westinghouse AP-1000) used for inland nuclear expansion in China is equipped with a passive cooling system. In this configuration, a large water tank is situated above the reactor, and if required, could pour enough water to keep the reactor cool enough.

However, other risks remain such as the radioactive contamination of the main drinking water sources of highly populated areas. Water risks and nuclear power expansion are set out in the chapter on "Nuclear Power".

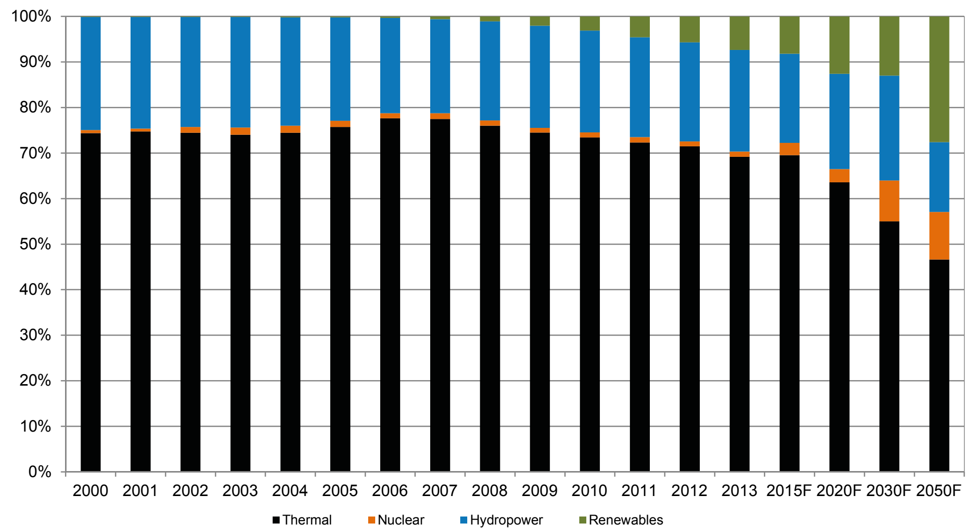
Composition of China's power generation mix clearly matters from a water perspective. Given the above, do China's current power expansion plans by power type make sense?

INSTALLED CAPACITY ADD FAVOURS CLEANER & LESS THIRSTY POWER

Significant plans to add less thirsty wind and solar, as well as carbon-friendly nuclear

At the time of writing, China plans to add 2TW of installed capacity by 2050. It appears that China is on the right track and its actual and planned installed capacity mix by power type is set out in the chart below. At a glance, there are significant plans to add nuclear, wind and solar by 2050. Nuclear power expansion is greatest between 2020 and 2030 whilst significant wind and solar capacity add is later between 2030 and 2050. Hydropower's portion of installed capacity is clearly shrinking from a 22% share in 2013 to 15% in 2050. Thermal (non-nuclear) share of the installed capacity mix falls from 69% in 2013 to 47% in 2050. All this makes sense from water and climate perspectives.

2000-2050F China's Total Installed Capacity (%)



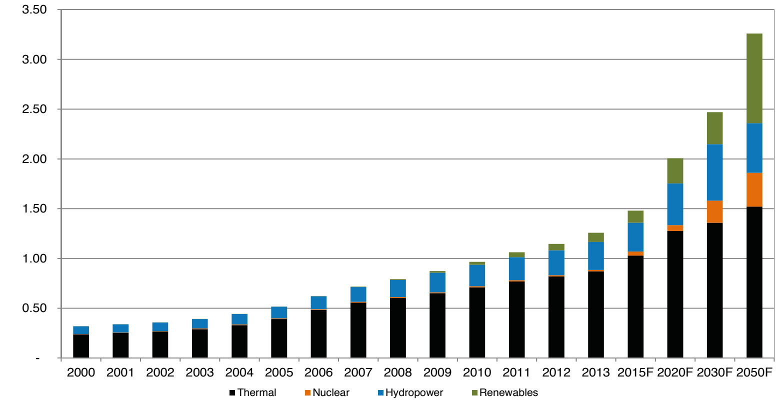
Source: China Water Risk , CEC, NBSC, 12FYP, State Council, NEA Research Affiliate

BUT COAL-FIRED CAPACITY STILL RISES

Coal and hydropower expansion plans are still significant

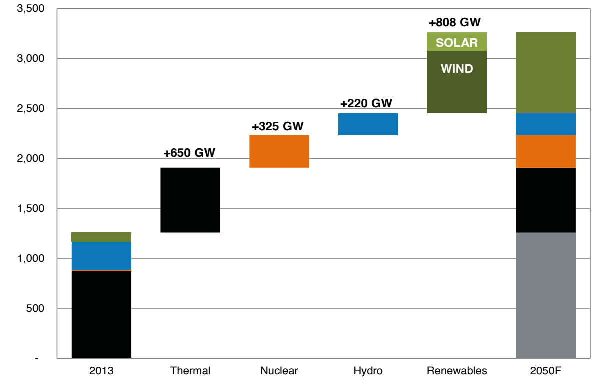
However, it is important to note here that despite a fall in the mix, planned coal-fired capacity and hydropower expansion is still significant in absolute terms. In fact, there are plans to add power across all power types between 2013 and 2050: +650GW in coal & gas-fired capacity; +325GW in nuclear; +220GW in hydropower and +808GW in wind & solar as shown in the charts below.

2000-2050F China's Total Installed Capacity (TW)



Source: China Water Risk , CEC, NBSC, 12FYP, State Council, NEA Research Affiliate

Breakdown of China's Installed Capacity Addition 2013-2050F (GW)



Source: China Water Risk estimates, CEC, 12FYP, State Council, NEA Research Affiliate, NBSC

Additional nuclear capacity of +325GW is more than the installed capacity of Japan

The scale of capacity expansion in each type of power is massive. To put this into perspective, the add of +650GW of coal & gas is greater than the 2012 total installed capacity of the UK, France, Germany and Russia. The additional nuclear capacity of 325GW is much greater than the entire installed capacity of Japan; and the additional 220GW of hydropower is almost equivalent to the total installed capacity to India of 255GW in 2012. Let alone the enormous add of wind and solar.

2050 forecasts are not set in stone; uncertainties remain in the long-term

It is important to note here that the 2050F forecasts are not set in stone. For example, we have forecasted nuclear installed capacity to grow to 340GW in 2050 whereas the Chinese Energy Research Society released 2050 projections of 400GW-500GW in October 2014.

Finally, it should be noted that not all power types are 'equal' in the generation of electricity; some energy sources are better than others. The installed capacities of different types of power generation are therefore not comparable when it comes to generating power due to their varying capacity factors.

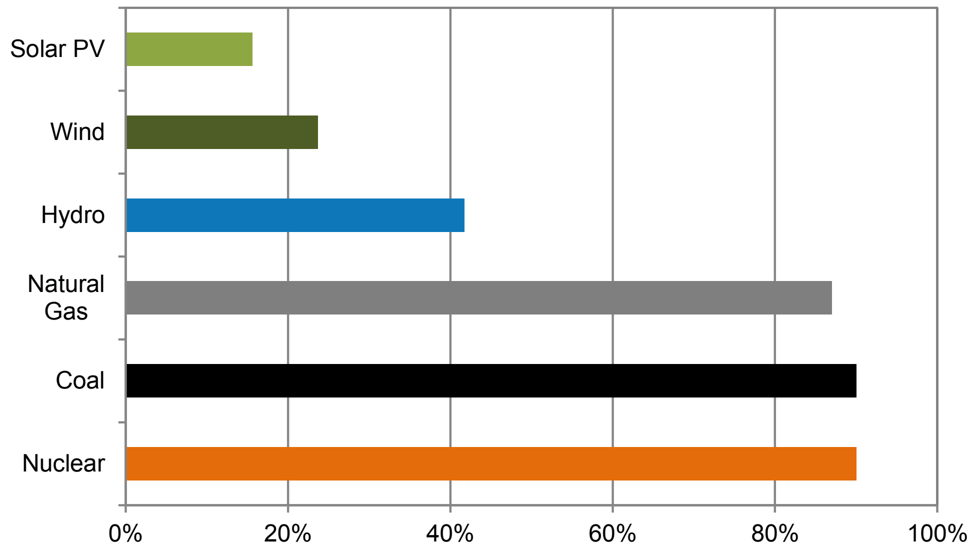
SOME POWER TYPES ARE BETTER THAN OTHERS AT GENERATING ELECTRICITY

Not all power types are equal: 1MW of hydro, solar and wind generate less MWh than 1MW of nuclear, gas or coal

Capacity factor indicates how much electricity is generated compared to what could have been produced if the generator had been operating at full capacity during the same period. Because of the inherent intermittency of the resource, hydropower, wind, and solar installations have a lower capacity factor than fossil fuel power plants using nuclear, coal and gas. As a result, 1MW of installed capacity for hydropower, solar, and wind will generate less MWh than 1MW of installed capacity for nuclear or coal-fired power plants. The chart below illustrates the maximum capacity factors across different power types in China:

China's maximum capacity factors range from 16% for solar to 90% for nuclear

China Maximum Capacity Factor by Power Type



Source: China Water Risk Estimates based on CEC, NEA, State Grid Corporation of China, EIA Annual Energy Outlook 2014

MAXIMUM CAPACITY FACTORS - ESTIMATION RATIONALE

For coal, nuclear and natural gas combined cycle, we consider the maximum capacity factors to be 90%, 90% and 87% respectively. Indeed, China has achieved this level for nuclear in 2013 according to the NEA. As for coal, although the CEC benchmark shows that some small coal-fired power plants have reached capacity factors above 94%, we estimate a lower value of 90%. This is more in line with international Best-Available-Technology (BAT) levels. Given the lack of data for natural gas in China, we have also used BAT levels as the yardstick for China at 87%.

In the case of hydropower and solar power, we consider that the existing fleet is already used at its maximum capacity, and therefore equates the maximum capacity factor with the actual value, which are 42% and 16% respectively. However, for wind, a portion of the electricity potentially generated annually is not admitted to the grid for different reasons (e.g. economic preference for other sources, stability of the grid). According to the NEA, this so-called curtailment rate decreased from 10.7% in 2013 to 8% in 2014. Recently, NEA committed to eliminate this so-called curtailment rate by 2015. In our estimation of maximum capacity factor for wind, we therefore consider the total amount of power that could have been generated. The maximum capacity factor is therefore considered to be 23.7% (out of 21.8% in the actual situation).

Some power generators are not operating at maximum capacity for several reasons

However, not all power generators are operating at maximum capacity. Although, China may achieve capacity factors 90% for coal & nuclear and internationally, gas can achieve 87%, China's thermal power fleet is only operating at actual average capacity factors of 54% (coal), 85% (nuclear) and 37% (gas) in 2014. At first glance, it may appear that coal and gas are "inefficient" compared to nuclear but the low capacity factor shouldn't be mistaken for efficiency. By comparison, the US coal fleet's actual average capacity factor was 64% (2009) and in the UK actual average capacity factor for coal-fired power stood at 57% (2012).

Several factors can contribute to the reduced capacity factors:

- Maintenance operations;
- Disruption of fuel supply (for fuel based powers);
- Inherent fluctuation of the energy source (e.g. wind, solar, hydro);
- Role of the power generator (e.g. base load vs. peaking generator);
- Grid limitations;
- Imbalances in power supply and demand; and
- Economic rationale.

Indeed, the different roles played by power generators might prevent efficient generators from reaching high capacity factors.

DIFFERENT TYPES OF POWER HAVE DIFFERENT ROLES – BASE LOAD, PEAK LOAD & SMOOTHING

Power generation roles matter...

Some of the large discrepancies between actual and maximum capacity factor values for coal and gas are due to the way each of the power types are currently being used in China:

...gas-fired power has low actual capacity factor because of its peaking role

Natural gas has a maximum capacity factor of 87% but a very low actual capacity factor of 37%. This is because it mostly serves as a peak generator and is used only to supply power occasionally, when demand is high or when other intermittent sources are not producing enough power. However, if they were operated as base load generators like nuclear, natural gas power plants' actual capacity factors would be far closer to their maximum;

...nuclear is solely used as a base load generator

Nuclear is the only type of power that is solely used a base load generator in China. In other words, it is almost continuously operating in order to meet the minimal electricity demand, the base load. Therefore the actual capacity value of 85% is closer to the maximum capacity factor at 90%;

...coal-fired power fleet is used for multiple purposes: base load, peaking and smoothing

Coal appears to be doing better than gas but worse than nuclear. So why add new coal-fired power plants if the existing fleet is only used at 54%? This is because China's coal fleet is currently used for multiple purposes: base load generation, peak generation and for smoothing the power generated by intermittent sources. Although the average efficiency of Chinese coal power plants have been continuously improving these last years (see chapter on "Coal & Coal-fired Power"), there are wide-ranging efficiencies in the existing coal fleet.

The newly-built large and efficient coal power plants are likely to operate continuously and serve as base load generators whilst the small and less efficient coal power plants which have not been phased out through the "build big, close small" policy will be maintained to serve only as back-up or peaking generators. Using them to permanently increase coal power generation would curtail the efficiency gains China has been striving to achieve these last years. Coal's use in smoothing power generated by intermittent sources is also clear when comparing the year-on-year evolution trends of hydropower and coal power respective capacity factors – please see the chapter on "Hydropower" for this analysis. Therefore despite the improved efficiency of the coal fleet, coal's actual capacity factor remains relatively low and has even decreased from 57% to 54% between 2013 and 2014.

Hydro, wind and solar PV are intermittent sources of power, requiring non-nuclear thermal power to smooth

Hydro, wind and solar PV have low capacity factors due to the fact that they provide intermittent power and thus require non-nuclear thermal power to smooth. Since this is dominated by coal, these renewable options are not technically "100% green". Word of caution on hydropower: as mentioned previously, it is not only used to generate power but also for water flow management. With the increasing frequency and magnitude of floods and droughts this role becomes more important. Water held by reservoirs to assuage floods and relieve droughts will mean further diminished capacity in hydropower generation – this is discussed in detail in the chapter on "Hydropower" whilst issues in wind and solar are set out in "Other Renewables".

The comparison of capacities is not straightforward: adding 1GW of coal is not the same as adding 1GW of wind, solar or hydro

Therefore, when it comes to creating alternative scenarios (e.g. replacing a power source with another), it might be misleading to compare capacities using only actual capacity factors. The role of the power generator as well as its capability in fulfilling the different roles should also be considered. Adding 1GW of coal is not the same as adding 1GW of wind, solar or hydro; and although nuclear is carbon-friendly compared to coal and gas, it currently does not have the flexibility of fulfilling various roles like coal and gas. In the future, there is talk of using nuclear for smoothing. Modern nuclear plants although not having the full flexibility of coal and gas plants for daily smoothing and peak generation, can execute variable loads with one or two large power changes per day and operate in load-following mode. Expansion plans for the China's nuclear fleet are discussed in the chapter on "Nuclear Power".

Constraints on natural gas expansion, include water concerns over the extraction of China's shale gas reserves

Costs and availability of the energy source are also considerations. These constraints currently limit the ability of China to increase its gas fleet. According to the China Electricity Council (CEC), China's gas-fired installed capacity stood at 37GW or a mere 3% of China's total installed capacity as at 2012. By 2050, China's gas-fired capacity forecasts will almost triple to 120GW but this is only still 4% of China's total installed capacity. However, more gas would mean less air pollution than coal - so should China be giving it more consideration? Whilst China has the largest shale gas reserves, it may be unable to tap these due to water risk & seismic exposure. See "**Lots of Gas but Access Remains Elusive**" in the following page.

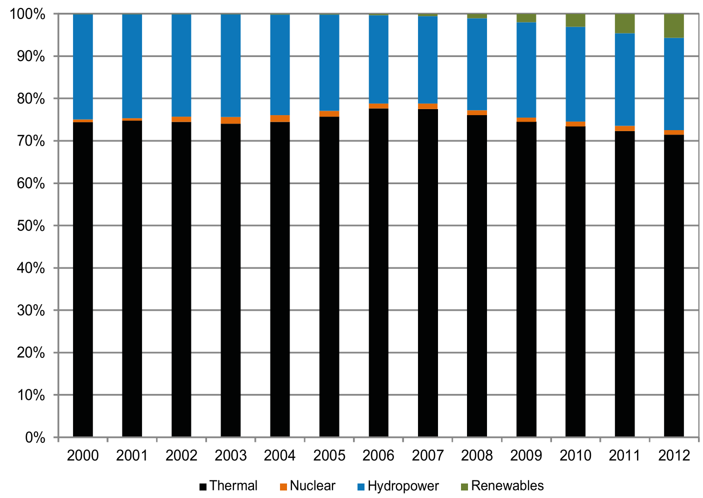
Even if China was able to access its shale gas reserves safely, Chinese experts believe that China is still not ready to move away from coal as the vanguard. Examples given are:

- The US post 'shale gas revolution' still relies on coal for 30% of its primary energy consumption;
- In Europe, coal consumption in Poland, France and Germany has actually been increasing; and
- In 2013, BP's analysis of global energy mix shows that coal's share has been actually been increasing from 27% in 2004 to 31% in 2013. In comparison, oil's share in global energy mix has dropped whilst natural gas remained flat.[20]

While non-nuclear thermal power capacity has fallen to 71% in 2012, its share of electricity generation remained at 78%

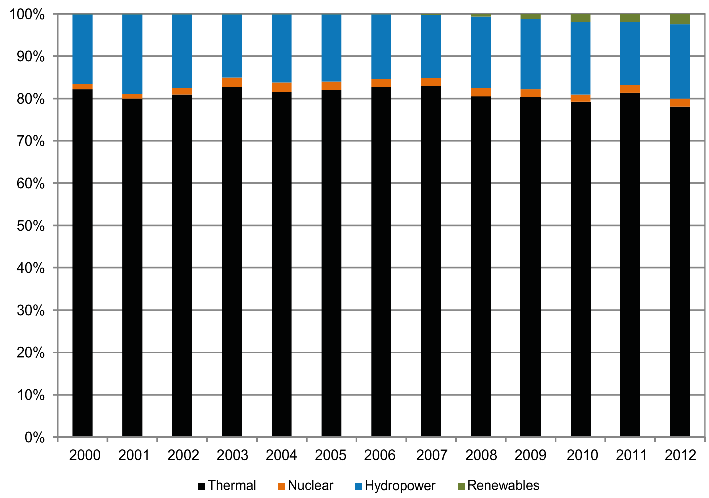
Finally, because of the different capacity factors of the various types of power as well as the different roles they are playing in the provision of electricity, the installed capacity mix and electricity generation mix of different power types will not match as can be seen form the charts below. The chart below left shows that non-nuclear thermal share of installed capacity has fallen to 71% in 2012. The chart below right shows electricity generation and due to the various capacity factors and roles played by different types of power, non-nuclear thermal share of electricity generation still remains at 78%; of which coal is around 95%.

2000-2012 Breakdown of China's Installed Capacity (TW) (%)



Source: China Water Risk, CEC, NBSC, 12FYP, State Council, NEA Research Affiliate

2000-2012 Breakdown of China's Power Generation (TWh) (%)



Source: China Water Risk, CEC, NBSC, 12FYP, State Council, NEA Research Affiliate

LOTS OF GAS BUT ACCESS REMAINS ELUSIVE

China has significant reserves of various types of gas: natural, liquefied natural and unconventional (shale & coal bed methane). However, for domestic gas reserve extraction there are water scarcity & pollution issues.

Natural Gas: 4,643 billion m³ of ensured natural gas reserves

Natural gas is an odourless, colourless gas, largely formed over millions of years underground. It's made of a variety of compounds but methane is by far the most significant.[21]

China had the 11th largest natural gas reserve globally in 2013[22] of this, 7% of China's natural gas is located in its oceans. Of the remaining 93% the majority is located in the Safe 11 provinces, then the At Risk 9 provinces and only 4% in the Dry 11 provinces (see chart below right). China's Top 5 natural gas provinces account for 87% of gas reserves not including that in the ocean (see table below left). China also imports natural gas.

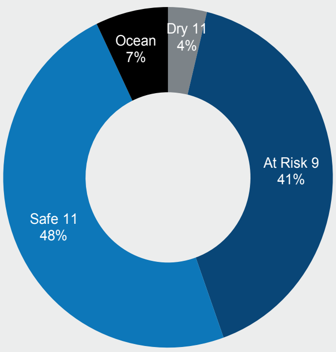
Rank	Province	% share of China's ensured natural gas
1	Sichuan	28%
2	Xinjiang	21%
3	Inner Mongolia	19%
4	Shaanxi	14%
5	Chongqing	6%

Source: China Water Risk, NBSC

Extraction concerns

A concern with gas extraction in Sichuan is the province's high level of seismic activity. As for Xinjiang, Inner Mongolia and Shaanxi, they also have 31% of China's ensured coal reserves. Should water be used for gas or coal?

2013 China Ensured Natural Gas Reserves Exposure to Water



Source: China Water Risk, NBSC

COAL OR GAS: IS GAS A BETTER CHOICE FOR WATER SCARCE CHINA?

China has plans to reduce its coal reliance from around 70% in 2010 to less than 60% by 2030 according to the National Energy Association. But with water constraints surfacing for coal and cities now choked in smog should the switch to gas come earlier? Natural gas emits 45% less carbon per energy unit, while natural gas combined- cycle power plants are more efficient than coal-fired plants. More efficient plants use less water, which is also a key consideration in water-scarce China.

Looking at the success of shale gas in the USA, Beijing has introduced new policies aimed at encouraging increased investment in fracking research and development. Last year, China issued its shale and other unconventional gas strategy for the same period as the 12th Five Year Plan, which establishes four ambitious milestones, including completion of a nationwide shale-gas survey and appraisal; production output to reach 6.5 billion m³ by 2015, reaching an annual production of 60 billion to 100 billion m³ by the end of 2020; development of suitable methods, technologies and equipment for China's shale gas survey, appraisal, exploration and production; establishment of technical standards, rules and policies regulating China's shale-gas development, including reserve survey, appraisal and certification, test and analysis, exploration and production, and environmental measurements.

China has 62 shale gas wells in trial development zones, 24 of which have generated natural gas qualified for industrial use. In September 2012, the Ministry of Land and Resources announced that foreign joint ventures would be invited to bid for a second round of shale gas exploration rights in China. This is the second tender process but China limited last year's to domestic companies and did not receive the expected response. This most recent tender, covers 20 blocks across eight provinces for 20,000 square kilometers.

Historically, China has not particularly welcomed foreign energy developers and investors, so clearly it is looking out of necessity to develop hydraulic fracturing technology appropriate for its geology.

Source: The above is an excerpt from China Water Risk analysis and review: "Is Fracking the Answer for Water Scarce China", October 2012

Liquefied natural gas - reliant on imports

Liquefied Natural gas (LNG) is created by cooling natural gas to -160°C, creating a clear, colourless and non-toxic liquid, 600 times smaller than natural gas. Its liquid state makes it easier for transportation.[23]

By December 2014, China has seven LNG projects in operation, though this is planned to increase to 24 in the future.[24] China struck a deal with Russia in 2014 to secure LNG imports of up to 38 billion m^3 per annum post 2018 and are in talks to secure a further 30 billion m^3 of LNG.[25]

Shale gas & coal bed methane – large reserves but no easy access

Unconventional natural gas is trapped in deep underground rocks that are hard to reach, such as shale rock or coal beds. Shale gas is extracted from shale rock using fracking, or hydraulic fracturing, of the rock. Shale rock is very common; the British Geological Survey estimates it makes up 35% of the world's surface rocks. Coal bed methane (CBM) is a type of unconventional gas. Methane occurs naturally underground within coal reserves. It can be extracted using a variety of techniques. In comparison to shale gas, the amount of gas from CBM is relatively small.[26]

China has the largest shale gas reserve globally. In 2013 China had 32 trillion m^3 of technically recoverable shale gas, the largest global reserve.[27] That said, shale gas is difficult to access for various reasons from water availability to water pollution as well as seismic risks – see box below. Indeed, the NEA "Energy Development Strategic Action Plan (2014-2020)" issued in June 2014 halved China's 2020 shale gas target to 30 billion m^3 from an earlier target of 60-80 billion m^3. "*The previous targets were more of a vague prospect, a hope. 30 billion m^3 is a more realistic goal*," said a government source commenting on the new target.[28]

As for CBM, the extraction target is 20 billion m^3 by 2015 as per the 12FYP Energy Development Plan. The new 2020 target is double this: China plans to extract 40 billion m^3 of coal bed methane by 2020 according to the NEA issued the "*Action Plan for Coal Bed Methane Survey and Development*" issued in February 2015. The plan to achieve this includes establishing three or four CBM industrialized bases in key coal bases by 2020.

WATER & FRACKING

Unconventional gas drilling process is not without significant controversy. In the U.S., the oil and gas industry argues hydraulic fracturing is a safe and environmentally sound way to produce clean energy and reduce dependence on foreign oil. Critics, however, say that it contaminates water and releases large amounts of methane into the atmosphere. These concerns have led many countries to look at additional regulation. France last year became the first nation to ban hydraulic fracturing as a method of natural gas extraction.

In China, there are additional challenges related to water usage, although hydraulic fracturing does appear to compare well with other sources of energy generation. The fact is that most of China's power relies on water, whether it is water for cooling nuclear power stations, solar panel factories or coal-washing steam turbines – and fracking is no exception.

A further problem, however, is that some of China's largest untapped shale gas deposits are in the Western regions where water is scarce. Drillers could find themselves competing with consumers for water (see table above). Additionally, the potential for contamination of existing water supplies – both aquifers and above ground sources – is certainly a factor China must consider in the context of already excessively polluted water. In many places where hydraulic fracturing is in heavy use, there has been controversy surrounding contamination of both water and agricultural land from improperly discharged toxic wastewater.

And then there are other factors to consider including China's geology. The country's reserves are believed to be twice as deep as those in the U.S. and are located far below mountainous terrain. It is unclear whether there will be sufficient investment to develop the appropriate drilling technology.

Finally, infrastructure is another challenge for China. By all accounts, the current pipeline network, processing and storage facilities, not to mention the roadways and bridges, are in no way adequate to handle the potential windfall in natural gas that would be released if fracking were substantially developed. So for now, although China might be keen to develop its massive shale gas reserves, it is clear that it may be some time before the technology and infrastructure make hydraulic fracturing a real way forward for the country.

Source: The above is an excerpt from China Water Risk analysis & review: "Is Fracking the Answer for Water Scarce China", October 2012

BALANCING WATER, CLIMATE & POWER GENERATION CAPABILITIES: TECHNOLOGY CHOICES MATTER

The right power mix is important for climate and water...

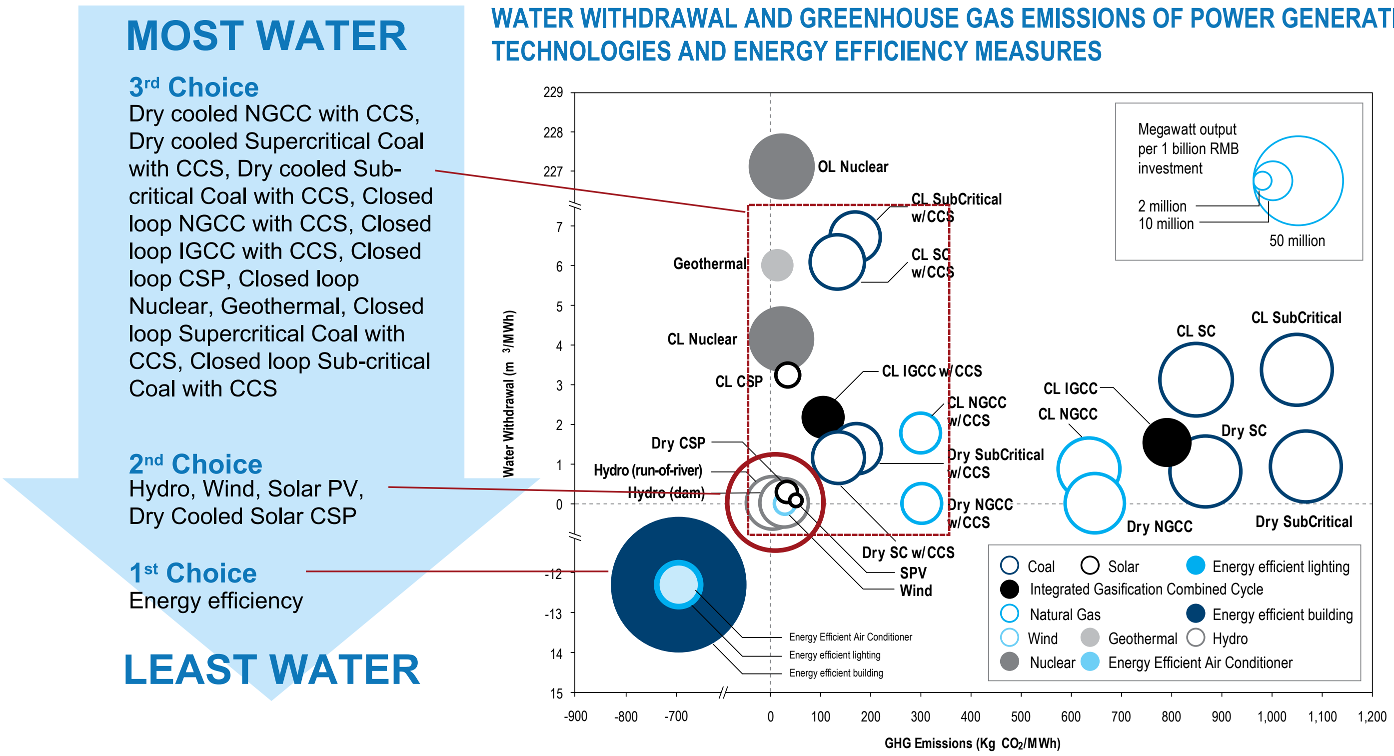
It is clear from the above that the right type of balance between fuel types will impact the climate as well as water resources in China. Each type of power impacts water, climate and power differently. The fact that they play different roles in power generation to provide base-load, peak-load or transmission smoothing lends complexity in balancing power mix.

...technology choices also matter

In a limited water scenario, not only is it important to get the mix of power type right but choosing the right type of technology within coal, nuclear, hydro and renewables is equally important. There are implications for water and climate across different technologies for each power type. Trade-offs between mitigating water and climate risks and electricity generation should be considered all together.

In this regard, WRI evaluated the climate and water implications of over 20 combinations of power generation technologies and cooling-systems used or proposed in China and other countries[29]. The result of this was represented in a Water-Climate Impacts Bubble Chart shown below. In addition, we have overlaid selection of power generation technologies ranked first by lowest to largest water withdrawals, taking in account only water & carbon but not construction costs:

SELECTION OF POWER GENERATION TECHNOLOGIES
(LOWEST WATER WITHDRAWALS)



Source: China Water Risk based on World Resources Institute's Water-Climate Impacts Bubble Chart published January 2015

Points to note from the above diagram are:

Best option: energy efficiency

- The first choice is energy efficiency gains, which give the best trifecta win in water, energy & climate. This concurs with our earlier conclusion in this chapter; energy efficiency is explored in detail in Chapter 5: "Battle to Conserve Energy";

Second choice: hydro, wind and solar

- The second choice is hydropower, wind and Solar PV and Dry Cool Solar CSP. It should be noted here that whilst hydropower requires zero water withdrawal, a hydropower dam can consume up to 68m^3/MWh; whilst run-of-river hydropower has zero water consumption. Nevertheless, as discussed before, all these are intermittent sources and require either power from coal or gas for smoothing. Water risks and challenges surrounding renewable power are analysed in chapter on "Hydropower" and "Other Renewables"; and

Third choice: gas, coal, nuclear with CCS and water-savings features

- The third choice includes technologies within gas, coal and nuclear with carbon-saving features such as carbon capture storage (CCS) and water-savings features such as dry cooling and closed loop. As discussed previously, although all three fuels can be used for base load generation, limited nuclear capacity as well as difficulties sourcing gas will mean that coal will remain the vanguard. However as can be seen, dry cooled supercritical coal with CCS, dry cooled sub-critical coal with CCS and closed loop supercritical coal with CCS and closed loop sub-critical coal with CCS are possible options to lower carbon emissions. Water savings from switching between dry and wet cooling in coal-fired power are explored in the chapter on "Coal & Coal-fired Power".

Warning: CCS significantly increases water use

It is important to note here that CCS increases water use and may also impact water sources – please see box below.

QUICK VIEWS ON CARBON CAPTURE STORAGE & WATER

"Carbon capture and storage (CCS) can cut emissions but at a water cost.... as the carbon capture process itself requires additional cooling, even for the most efficient ultra-supercritical plant, associated water withdrawal and consumption would increase by about 90 percent. Another concern is that injected CO_2 might affect groundwater quality, releasing toxic inorganic compounds that could jeopardize human health."

"Opportunities to Reduce Water Use and Greenhouse Gas Emissions in the Chinese Power Sector", WRI

"In some developed countries like the US, CO_2 emissions from thermal power plants should be captured through CCS (Carbon Capture & Storage). However, the current CCS technology is not yet mature and requires lots of investment. Given the current technology, adding CCS equipment will result in a 4-7% drop in energy generation efficiency of the power plant, so CCS is not yet globally mainstream."

Professor Xie Kechang, Vice President of the Chinese Academy of Engineering

Substantial geothermal potential remains untapped

The range of power in the 'third choice' category also includes geothermal. With one sixth of global geothermal reserves, China's geothermal potential is high but its share of China's primary energy consumption is very small and by 2030 is only forecasted to grow to 2%. More on geothermal expansion plans in the chapter on "Other Renewables".

Government promotes: energy efficiency, renewables, cleaner coal

The above preferences of power types are in line with the government's direction on energy development:

1. Promoting energy efficiency by creating a new Strategic Emerging Industry: Energy Savings & Environmental Protection;

2. Promoting significant renewables (ex-hydro) add +808GW by 2050; and

3. Promoting clean coal & gas utilization by increasing water efficiency in energy generation and limiting water use in energy generation, especially in large coal-fired energy bases.

Indeed the MWR's Water-for-Coal Plan recommends dry cooling in water scarce regions. That said, to execute this "energy revolution plan" requires holistic management and collaboration across multiple government ministries.

ENERGY REVOLUTION NEEDS: HOLISTIC MANAGEMENT & GOVERNMENT REFORM

Reforms are necessary...

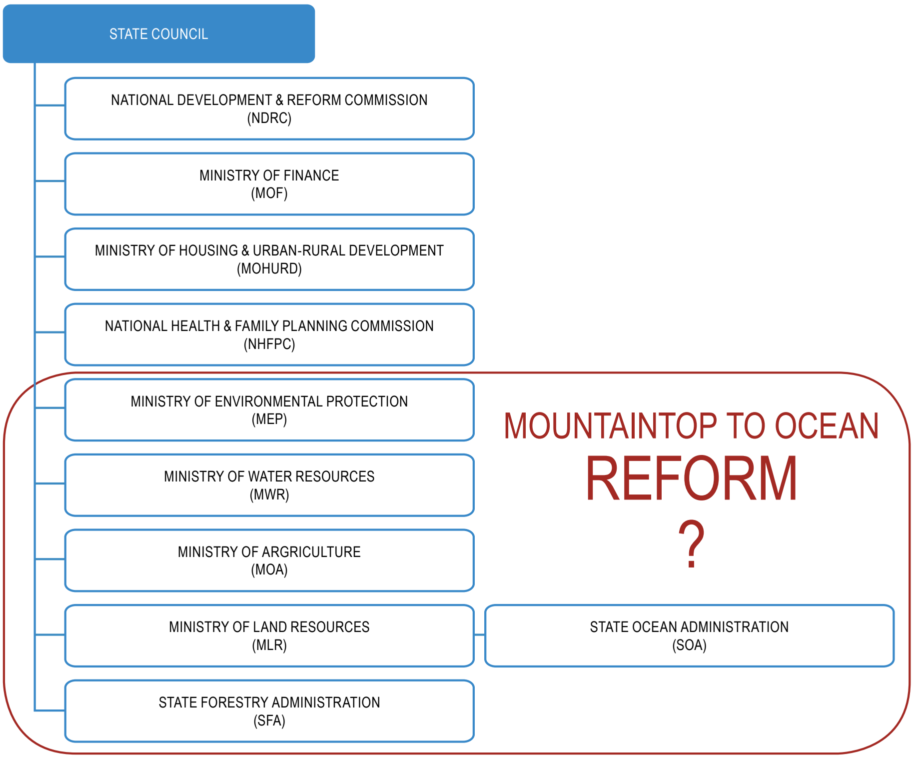
In order to achieve the above whilst staying within the Three Red Lines, we see changes to the environmental law and ministerial oversight as necessary reforms, especially if the government intends to optimize the management of the water-energy-climate nexus. Indeed, President Xi has indicated that China's energy revolution includes looking into reforming its supply, consumption, technology and the system.

In the 2014 Central Government Work Report, the word "reform" appeared 77 times. One expected reform is the reforming of the MEP by merging it with various authorities in charge of glaciers, rivers, lands, forests and oceans[30]. An official war on pollution provides Beijing with bigger impetus to push through structural reform to streamline the ministries that manage various aspects of water resources.

...dispersed authority and overlapping responsibilities hamper action

Under the current structure, the administrative authorities of environmental issues are dispersed among different ministries and administrations. Administrative departments usually have to spend great efforts in coordination before finally reaching an agreement to solve real problems. The dispersed authority and overlapping responsibilities with other ministries has resulted in 'same-but-different' functions resulting in inconsistent and inefficient data collection. It also hampers pollution monitoring, resource management (farmland, groundwater, surface water and the ocean) and environmental protection. Monitoring each resource is already a difficult task let alone monitoring and protecting the ecosystem as a whole.

There is no doubt that the dispersed authority has weakened the MEP's effectiveness in protecting the environment resulting in inefficient use of public resources. As President Xi said in his government report on 15 November 2013, "*Mountains, water, forest, farmland and lakes are all parts of a common living circle... the administration of their use and ecological rehabilitation must be in accordance with the law of nature*". The much talked about 'From-the-Mountaintop-Down-to-the-Ocean' reform is expected to give more power to the MEP to protect the environment, effectively by merging it with various other ministries & authorities in charge of the glaciers, rivers, lands, forests and oceans (see diagram below). The fact that MLR and MOA are part of the envisioned reform signals Beijing's view that water scarcity & pollution, soil pollution, management of farmlands and food security issues are all interlinked.



Source: China Water Risk, China government media
Note: Ministry of Health was issued in 2012 by the Ministry of Health which has since been integrated into the National Health & Family Planning Commission in 2013

There is movement towards the un-siloing of water, energy and food

Ministries, officials and academics are recently becoming increasingly vociferous in the media against plans which don't make sense across 'silos' of water, energy & agriculture. Increasingly cohesive and comprehensive plans are required to address water scarcity, pollution and related food & energy security issues. For example, in the energy sector:

Coal is under heavy scrutiny, with small mines being shut down and stricter water requirements

- 17 December 2013: MWR issued the Water-for-Coal Plan[31] which pertains to the development of large scale coal bases in China. Now construction of coal mines must complete water feasibility reports to be submitted to MWR & NEA for approval;
- 12 May 2014: 12 central government bodies including the MEP, NDRC, MLR, MoF & NEA jointly issued a Circular on Stepping Up Efforts to Shut Down Small Backward Coal Mines[32], aiming to close down 2,000 small & "backward" coal mines across the country by the end of 2015; and
- 17 July 2014: MEP issued a notice, requiring water resources capacity assessments based on water resources demand and allocation among all the main industries in coal-fired energy bases.

9 government departments manage water while 25 manage energy

As can be seen, efforts have focused on coal at the moment. This is a good start but there is a long way to go - there are nine government departments managing water and 25 managing energy.

THE FUTURE MIX OF CHINA'S POWER GENERATION

China is not ready to move away from coal

China's energy mix is evolving. The road is long. China is not ready to move away from coal (see box below). Whilst the mix may be evolving, what is clear is that China's installed capacity will rise. What is also certain is that new projects will have to be subject to more stringent Environmental Impact Assessments (EIA) in the future, be they hydropower, wind or solar; or powered by coal, gas or nuclear.

All power types have implications for water....

For new capacity, choices between power types need to be considered with water, climate and electricity generation technologies in mind. The current roles different power types as base load, peak load or smoothing should also be revisited. Costs and availability of fuel source should also be considered. In some cases, fuel source may be plentiful but extraction of it may come at the cost of water resources if not managed properly. Decisions have to be weighed holistically and by power type:

...it is imperative to save water in both coal production and coal-fired power generation

Coal is still the vanguard: Coal will still account for a significant portion of electricity generation by 2020/2050 and is currently the fuel used to smooth intermittent hydro, wind and solar power. Given that coal is here to stay, it is therefore imperative to ensure maximum water savings in both coal production and coal-fired power generation. This is especially important if China wants to hold the Three Red Lines on water as coal and coal-related industries account for more than 50% of industrial water use. Water-saving strategies in coal and coal-fired power including open, closed loop to air cooling; water rights trading between coal bases & agriculture as well as water diversion are explored in the next chapter whilst projections in coal consumption, production and whether there is enough water for coal are detailed in chapter on "Coal & Coal-fired Power".

CONVERSATIONS ON COAL: CHINA NOT READY TO CUT COAL CHINA WATER RISK INTERVIEW WITH PROFESSOR XIE KECHANG

CWR: Some people are calling for a more aggressive target of renewable energy to ensure "peaking of CO2 emissions" by 2030. What is your opinion?

XIE KECHANG: Clean high-efficient and sustainable utilization of coal is as important as the development of renewable energies. China should have a diversified energy mix. To adjust the current energy mix, we should balance these two strategies.

The development of both strategies will require investment of thousands of billions RMB. It'll be up to the decision makers to decide whether the money goes towards renewable energy or clean high-efficient coal utilization. My opinion is that both are equally important.

However, such decisions are difficult due to conflicts of interests within government. There are 25 government departments in charge of energy. President Xi said that China's energy revolution should cover four aspects: supply, consumption, technology and the management system. Reforming the management system will be a big challenge.

Source: The above is an excerpt from a China Water Risk interview with Professor Xie Kechang, Vice President of the Chinese Academy of Engineering, titled "China: Not Read to Move Away from Coal", April 2015

Inland nuclear expansion raises substantial water contamination fears in densely populated areas

Nuclear is carbon-friendly but safety and water concerns slow expansion: Nuclear is a carbon-friendly base-load fuel and at present, China appears intent on expanding capacity over the next three decades to reach either 340GW or 500GW of nuclear installed capacity at 2050. This will most likely make it the largest generator of nuclear power globally but despite this, it will still only account for 19%-28% of power generation. However, safety concerns post the Fukushima accident and water issues might slowdown the planned expansion. Indeed, water availability is a key constraint - a disruption in water availability for cooling is not disastrous in coal/gas-fired plants; but in nuclear power plants, it could cause severe damage to the core reactor.

Currently, all nuclear power plants are located along China's coast but there is limited coastal area for expansion. Already, construction of the 26 planned inland nuclear power plants were suspended and under review post the incident at Fukushima. Nuclear power plant expansion and related water issues are set out in the chapter on "Nuclear Power".

Hydropower expansion could raise geopolitical tensions if more transboundary rivers are tapped

Hydro's dual purpose of 'green' power and water flow management could raise geopolitical tensions: China's hydropower development will continue for the dual purpose of electricity generation and water flow management. China will continue to dam rivers as reservoirs have various purposes like flood control, providing irrigation water and safety nets in times of droughts. Given the possibility of drier weather ahead for Southern China, it is imperative for China to play a more central role in transboundary issues and international water law as this will ease regional anxieties on existing dams. Expansion should also take into account seismic exposure and other environmental concerns. Watershed and ecosystems are at risk and coastal cities by major river deltas could be exposed to increased subsidence risks due to the reduction in silt flow by dams. Moreover, there is still a question of more extreme weather ahead diminishing operational capacity and increasing reliance on coal-fired power to smooth this seasonal variability.

Hidden water risks in rare earth mining for wind and solar could threaten China's key watersheds

Other renewables although not water reliant, might bring hidden water risks: in manufacture due to rare earth mining. China has been aggressively developing renewables in recent years. Large wind energy bases are being built in northern China alongside large coal bases and energy bases. Distributed solar will also see a further boom. Both provide potential to substitute thermal power and mitigate water risks in dry regions. However, concentrated solar power plant, as another solar energy option, raises concern in water use. Other alternatives such as biomass, geothermal and ocean energies will still remain small in China's total energy pie. In order to increase renewables' share in primary energy consumption up to 15% by 2020, China will continue to be a global leader in renewables in terms of investment, installed capacity and power generation. As Chinese manufacturers expand to the global market, the cost of renewables has dropped significantly. However, scale-up of renewables is still limited by grid connectivity as well as their intermittent nature. Moreover, manufacturing of wind turbines and solar panels could bring hidden water risks due to destruction of watersheds from rare earth mining. Therefore, although renewables generally do not require much water, they are not necessary "clean" from the lifecycle perspective.

These water risks need to be addressed for a water & energy secure future

Clearly, there are complex interlinked issues with each of the above types of power. The current status and expansion plans as well as water use and water limitations (naturally or regulatory) for each power type are discussed in detail in their respective sections later in this report.

In reality, balancing the mix of power generation capacity is not enough to resolve issues at the water-energy-climate nexus. As discussed in Chapter 1: "China's Changing Waterscape" with limited water, there is also the water-food-energy nexus to consider. Aggressive water savings in both agriculture and coal are required to ensure sufficient water for China's coal bases, especially if coal is to continue to be the vanguard in China's power expansion strategy. This is discussed in detail in the next chapter on "Ensuring Food & Energy Security".

ENSURING FOOD & ENERGY SECURITY

CONTROL WATER USE IN AGRICULTURE & COAL

- The rise in demand for food and electricity coupled with the nation's geographical constraints adds further importance to managing water. China's agricultural heartland, the North China Plain, as well as many of the large coal and energy bases in the North rely on the Yellow River.

- China's 14 large coal bases, spread over 12 Coal Base Provinces are expected to represent 95% of China's coal output by 2020. Half of these Coal Base Provinces are water-scarce whilst three are water-stressed. Moreover, they have 49% of China's total sown land. Food and energy will compete for water in the North. China needs to balance and control water use between agriculture and its large coal bases to ensure food and energy security

- Coal and coal-fired power are growing faster than total water use allowed by the national water use red line quotas. In order to stay with the water use red line by 2030, China needs to save agricultural water to allow for industrial and municipal water to both grow at faster rates than the national quota. Indeed, the practice of transferring agricultural water savings to coal base projects has been experimented in Water Use Permit trading pilots along the upper reaches of the Yellow River.

- At 63% of China's total water use, managing agricultural water is key to the national management of China's water resources. There are clear agricultural water saving directives. Agricultural water use stood at 392 billion m^3 in 2013 but State Council has indicated this should be 360 billion m^3 by 2025. However, detailed analysis of irrigation savings for two Coal Base Provinces in accordance with irrigation efficiency targets, illustrates the difficulty in achieving this; especially in the face of climate change and extreme weather.

- Coal also faces a double whammy in times of droughts: (1) more water and power are required for irrigation and therefore less agricultural water is transferred to coal bases; and (2) hydropower generation capacity is diminished as water is held back in reservoirs, thereby drawing on more coal-fired power to smooth lower hydroelectric output. Lowering water use along the whole coal-value chain is therefore a must to secure water for coal. With around 95% of China's coal mined underground, it is also vital to protect groundwater resources by minimising mining's impact on water to contain groundwater and soil pollution.

- Over half of industrial water is used by coal and coal-related industries but water use benchmarks in coal mining and processing fluctuate widely. The lack of disclosure from coal bases and coal mining corporates as well as discrepancies in water use benchmarks published by Chinese academia and think tanks mean that it is difficult to estimate water savings. Assuming coal production of 4.2 billion tonnes by 2020, water use can range from 0.7 billion m^3 to 16 billion m^3.

- In power generation, scenario analyses across various benchmarks and technologies show that coal-fired plants must have access to 109-157 billion m^3 of water to generate electricity in 2020. Lowering water use in coal mining and coal-fired power generation result in significantly higher gains than irrigation savings. Without these, it may be difficult to ensure sufficient water in Coal Base Provinces for both energy and food security.

- There is no doubt that China will do whatever it takes to guarantee water for coal, including diverting more water from the South. There are already plans in place to transfer 17 billion m^3 along the Western Route of the South-North Water Diversion Project. The project, which is yet to start, will divert water from three main rivers: the Yalong, Dadu and Tongtian to the Yellow River.

- Controversy over the diversion of these three rivers looms as it may upset the delicate balance of the upper watershed of the Yangtze with long-ranging impacts on the environment. Moreover, water diversion requires material additional power. Given these concerns, aggressive water savings in coal and agriculture should first be exhausted; water diversion should be a last resort.

CHAPTER 4:
ENSURING FOOD & ENERGY SECURITY– CONTROL WATER USE IN AGRICULTURE & COAL

FOOD AND ENERGY COMPETE FOR WATER IN THE NORTH

As shown in previous sections of this report, decisions between energy types will have to be made in finding the right balance within the water-energy-climate nexus. However, for the foreseeable future to 2050, coal is still the vanguard. Therefore to ensure China's energy security, China must (1) secure water for coal and (2) implement strategies to save water along the whole coal value chain. Also, coal is currently blamed for the smog shrouding the capital, so ensuring cleaner coal and water-for-coal are top priorities.

China's coal bases lie next to the nation's farming heartland in the parched North

As mentioned before in Chapter 2: "China's Water Energy Nexus", the power sector is the largest user of industrial water. In fact, coal and coal-related products account for more than half of industrial water use. Moreover, as discussed in Chapter 1: "China's Changing Waterscape", a geographical mismatch in the allocation of resources between the North and South mean that coal bases lie next to the nation's farming heartland in the parched North. Going forward, competition for water between food and energy is inevitable.

The government has been experimenting with water trading schemes between agriculture and industry along the Yellow River

Various policies have been set at a provincial and national level to ensure that the water supply-demand gap can be met and these have implications for managing both coal bases and agriculture nationally and provincially. Provinces with large coal bases will also feel added pressure as we expect government to also give food security top priority. Agricultural self-sufficiency has been a top priority for China and will continue to do so (see box on Historic No.1 Documents in Chapter 1: "China's Changing Waterscape"). That said, the government has been experimenting with water trading schemes between agriculture and industry, in particular in provinces along the Yellow River.

With the inevitable rise in demand for food and electricity and geographical constraints, China needs to tread lightly in within this water-food-energy in balancing the nation's agricultural needs against the ability of large coal & energy bases to continue to provide power for the social and economic development of China over the next three decades. This section explores the tightness in managing water for both food and energy security. Is there enough water for coal bases in the China to expand production to meet the coal cap at 4.2 billion tonnes and ensure sufficient water for agriculture at the same time? Lowering water use along the coal chain, agricultural water savings as well as water diversion from the South are all analysed and set out below.

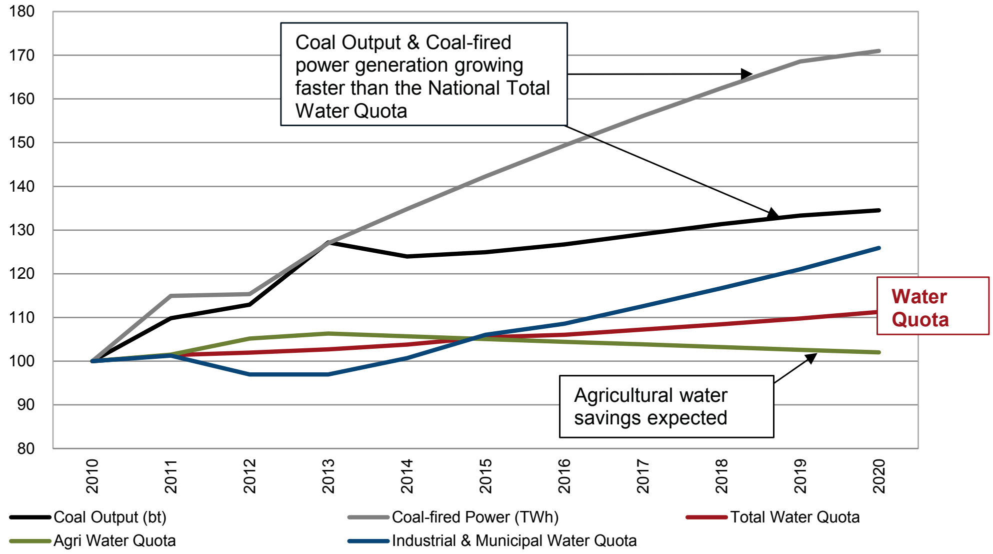
COAL CLEARLY GROWING FASTER THAN NATIONAL RED LINE WATER USE QUOTAS

Coal output & coal-fired power generation are growing faster than the total water use allowed by the 'Three Red Lines'

Currently total water use is at 618 billion m^3 and as discussed in earlier Chapter 1: "China's Changing Waterscape" we are on target to stay within the 2015 national water cap of 635 billion m^3. According to the Three Red Lines, the national water use quota at 2020 is set at 670 billion m^3 allowing for a 2015-2020 CAGR of 1.08%, followed by a 2020-2030 CAGR of 0.44% to bring national water use to 700 billion m^3 by 2030. This implies aggressive water savings across agriculture and industrial sectors as municipal water is set to grow due to rising urbanization. The chart below compares coal output and coal-fired power generation growth to the national water quota:

Coal Output & Coal-fired Power Growing Faster than the National Water Quota

INDEXED TO 100



Source: China Water Risk Estimates based on CEC, State Council

Aggressive agriculture water savings are needed to stay within the 'Three Red Lines'

Key points to note from the chart above are:

- Agricultural water is falling, allowing industrial and municipal water to grow at a faster rate than the total water quota (the red line);
- Although China is now following a 'new normal' with slower growth levels than in the last decades, the red line growth remains far below that of both coal growth and coal-fired power generation growth fueling higher competition for water resources; and
- Coal-fired power generation is growing at a faster rate than coal output due to a planned increase in coal consumption by power generation and (2) increase in efficiency - generating more power with less coal. Both our coal and coal-fired power projections to 2020 and their water use are set out in detail in in the chapter on "Coal & Coal-fired Power", whilst energy efficiency is discussed in Chapter 5: "Battle to Conserve Energy".

Obviously, lower water use along the whole coal-value chain is a must if the national water quota is to be met. It is also clear from the chart that agricultural savings are expected and that central government intends to transfer these savings to industry. Indeed, the practice of transferring agricultural water savings to the coal bases so that they have sufficient water for their expansion has been experimented in Water Use Permit trading pilots along the upper reaches of the Yellow River (discussed later in this chapter).

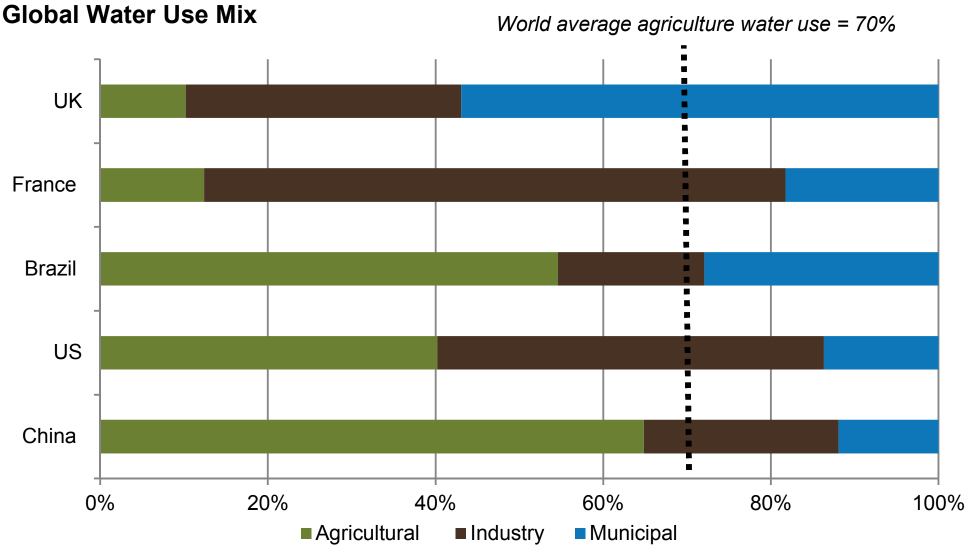
In recent years, we have seen the government issue a number of measures and targets aimed at constraining water use in the agricultural sector, coal consumption and production as well as introduce policies limiting water use in large coal bases. Topics discussed below may provide some insight into the rationale behind the direction of such policies.

AGRICULTURE IS #1 WATER USER IN CHINA: ITS WATER SAVINGS ARE USED TO GROW COAL

Agriculture accounts for 63% of total water use in China...

Agriculture is a large user of water. Globally, agriculture accounts for 70%[33] of total freshwater withdrawals. In China, agriculture is the largest consumer of water but accounts for less than the global average at 63%, despite being an agri-giant. However when compared to developed countries such as the US, UK & France, agriculture in China accounts for a larger portion of water use (see chart below).

Global Water Use Mix



Source: CIEC, AQUASTAT, China Water Risk

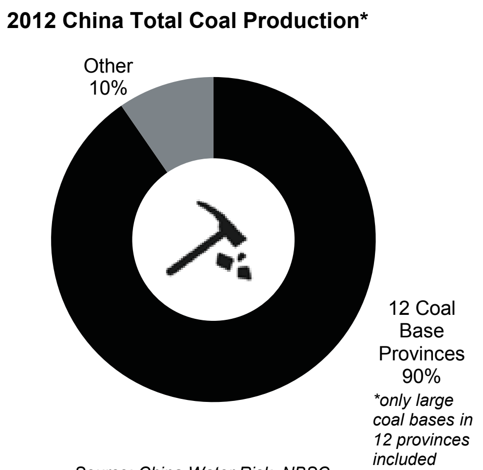
Water is not only a key input in agriculture but at 63% of water use, managing water in agriculture is also key to the total water resources management of China. Saving water from the largest water user to ensure energy security makes sense in theory especially since some coal bases lie near farmland. However, given the mismatched allocation of natural resources together with more frequent droughts and floods, this may prove to be more difficult in practice.

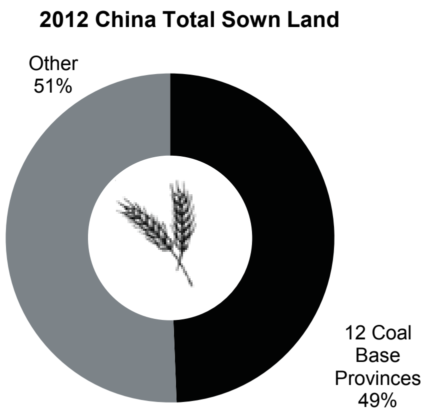
ALMOST HALF OF CHINA'S TOTAL SOWN LAND LIES IN THE SAME 12 PROVINCES AS CHINA'S COAL BASES

China coal is primarily supplied by 14 large coal base provinces. In a bid to close down small mines and ban coal production in Beijing, Tianjin, Shanghai, Guangdong and Zhejiang, China plans to consolidate coal production efforts into these 14 coal bases. By 2020, these are expected to provide up to 95% of China's coal production compared to 87% in 2010. These 14 coal bases are spread over 12 provinces and autonomous regions of Shanxi, Inner Mongolia, Shaanxi, Shandong, Hebei, Henan, Gansu, Xinjiang, Ningxia, Anhui, Yunnan and Guizhou ("Coal Base Provinces"). Six of these are water scarce, three are water stressed whilst three are water rich.

Coal Base Provinces are home to 81mn hectares of sown land; 120mn hectares are needed to ensure basic grain sufficiency

Three of these Coal Base Provinces: Henan, Shandong & Hebei are also amongst China's top farming provinces and are extremely water scarce. With 33.9 million hectares or 21% of China's sown land, coal bases in these provinces will compete with agriculture for water. The situation worsens when all 12 Coal Base Provinces are taken into account – the Coal Base Provinces are also home to 81 million hectares of sown land, close to half of China's total sown land which stood at 163 million hectares in 2012 (see charts below). State Council confirmed in No.1 Document in 2014 that farmland must be maintained at a minimum of 120 million hectares to ensure grain sufficiency.





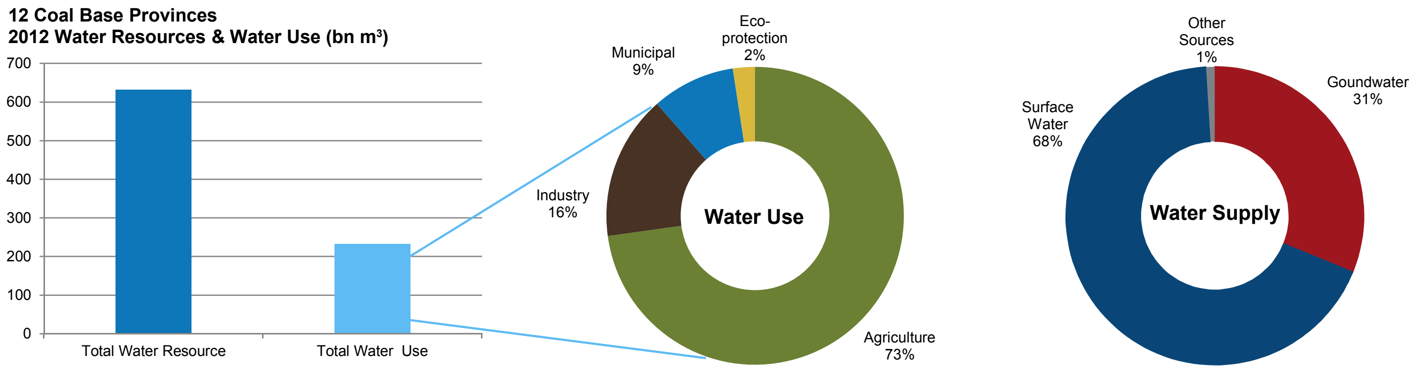
Source: China Water Risk, NBSC

There is no doubt that farmlands and coal bases will be competing for water in the future. There is not much room to maneuver in ensuring minimum farmland for food security. China has no choice but to strive to lower water use in both agriculture and coal in tandem.

12 COAL BASE PROVINCES USE 73% OF THEIR WATER FOR AGRICULTURE

Coal Base Provinces have a fifth of China's water resources

Water resources, water supply and water use in these 12 Coal Base Provinces matter. Coal Base Provinces' total water resources account for a fifth of the nation's water resources. In 2012, the total water used by the Coal Base Provinces was 233 billion m^3 or 37% of their total water resources. Of the 233 billion m^3 used agricultural water accounted for 73%, which is 10% more than the national percentage of 63% (see chart below). Agricultural water savings is therefore imperative to control water use in the Coal Base Provinces. In addition, reliance on groundwater is high with 31% of total water supplied by groundwater compared the national water supply mix average of 18%.



Source: China Water Risk, NBSC

Heavy reliance on groundwater as 95% of China's coal is mined underground

Finally, Coal Base Province are also drawing more heavily on their groundwater resources. The national average for groundwater supply as a percentage of groundwater resources was 13% in 2012. This is more than double in Coal Base Provinces where groundwater supply represents 27% of their groundwater resources. This is likely as 95% of China's coal is mined underground[34]. Therefore in order to protect groundwater resources (from over extraction and pollution which in turn helps ensure food safety) it is imperative minimise mining's water impact. Please see chapter on "Coal & Coal-fired Power" for more on details on the reliance on groundwater by Coal Base Provinces and their impacts from mining.

AGRICULTURAL WATER SAVINGS

Mixed views – can agricultural water use fall by 32 billion m³ to meet 2025 target?

State Council want to cap agricultural water use at 360 bn m³ by 2025

MOA says this cap should be at 390 bn m³, close to 2013 levels

Traditionally, China has irrigated to mitigate droughts rather than to reap agricultural water savings. Given this, central government has set an aggressive target to cap agricultural water at 360 billion m³ by 2025. State Council wants this to be achieved by improving irrigation efficiency with target irrigation efficiency coefficients[35] set at 0.53 (2015), 0.55 (2020) and 0.60 (2030). However, at the same time, State Council also wants to increase irrigated land which will require more water use. The Ministry of Agriculture (MOA) through its 'Opinions on Promoting Water-efficient Agriculture Development' said that an additional 30 billion m³ is required for irrigation[36] implying that water resources required by agriculture should be 390 billion m³ and not 360 billion m³. Can China close this gap?

Whilst China will meet the national water cap as discussed in the earlier chapter, agricultural water use has been rising from 369 billion m³ in 2010 to 392 billion m³ in 2013. Clearly agricultural water savings have not reaped at a national level. This increase could be attributed to the fact that irrigated farmland has increased by 3.2million hectares (2010-2013) in line with the 2011 No. 1 Document. In the meantime, it appears that not enough has been done to improve irrigation efficiency. Reasons for this are discussed later in this chapter.

Market-based mechanisms have been set up to help the nation stay within the 'Three Red Lines'

So is agricultural water savings a real possibility? The Chinese government thinks so and has come up with market-based mechanisms to help the nation stay within the Three Red Lines. One such mechanism is the trading of water use permits and wastewater discharge permits. The former has been piloted in provinces along the Yellow River.

Innovative water trading pilots to transfer water from agriculture to coal

Seven pilot provinces have been identified for water rights trading

In July 2014, the MWR announced seven provinces: Gansu, Guangdong, Henan, Hubei, Inner Mongolia, Jiangxi and Ningxia will host pilot markets for water rights trading. Four of these are amongst the Coal Base Provinces. After two-years of planning, led by the MWR, the basic framework of a national-level water trade market has been confirmed and will be submitted to the State Council for approval; relevant management measures and regulations will be set by the end of 2015[37]. Please see box below for a summary of these water use trading rights.

WATER RIGHTS TRADING MECHANISMS TO ENFORCE THE RED LINES

Two new market mechanisms are being reinforced and strengthened to manage the Red Lines in 2014:

- Wastewater Discharge Permits: to control the total amount of wastewater discharge; and
- Water Use Permits: to manage the total water use.

These have a dual purpose, acting as both carrot and stick. Companies that operate in more water-efficient and cleaner ways, will accumulate water savings within their Water Use Permits and/or Wastewater Discharge Permits, which can then be sold; other companies that want to expand their production, may fall short of permits and buy these.

By allowing companies to trade these two types of permits, the government needs to strictly control the overall permitted quantity of water use and the quality of discharged water. Accordingly, a price reflecting the level of water scarcity can be formed. The government can then use permit trading to fine-tune water allocation across industries, which could limit production capacity and push for more efficient and responsible utilization of water resources. It can also be used to rein in pollution in specific industry.

Whilst the pollution discharge permits are now traded on Taobao in pilot provinces, Water Use Permit trading lags and is still mainly government-led. The MWR only selected 7 pilot provinces in July 2014, aiming to establish provincial trading markets of Water Use Permits. These are Ningxia, Jiangxi, Hubei, Henan, Gansu, Guangdong and Inner Mongolia. Water Use Permit can be traded between different regions, different watersheds, upstream and downstream of rivers, different sectors or different individual water users. Each Water Use Permit, which clearly defines the amount of water assigned to the user, will be registered in a system. This could help to manage total water use provincially and nationally but needs reform before it can be traded like the Wastewater Discharge Permit.

Source: The above is an excerpt from a China Water Risk article titled "New Trading Markets to Enforce Red Lines" by Feng Hu, February 2015

Agricultural water savings can be sold to industrial users in coal bases

According to Professor Jia Shaofeng, Deputy Director of the Center for Water Resources Research of the Chinese Academy of Sciences, water right transfers between agriculture and industry have been in practice along the Yellow River, mainly in Ningxia and Inner Mongolia since 2003. These water right transfers have been used to finance agricultural water saving projects.

Industrial users require a Water Use Permit from the local government to access water but industrial water quotas in these provinces had almost reached their limits. Since the remaining quotas were not sufficient for new industrial projects, especially in those in the energy bases. "Buying" water savings from agriculture supplemented the industrial water quota and allowed for projects such as coal-to-chemical expansion in the coal bases. Hence a water rights trading market was born. This has since been "vigorously promoted" by the MWR so that irrigation projects could be financed to ensure food security whilst simultaneously ensuring enough water for coal-related projects.

The MWR promotes water rights trading to ensure food security and water for coal

So how much water can be saved by improving irrigation efficiency for transfer from agriculture to coal bases? Is this sufficient? Since these transfers are pilots led by government at a local level, provincial level statistics are hard to find. We have therefore estimated water savings by improving irrigation efficiency in accordance to the 12FYP to show the irrigation water savings potential below.

Agriculture water savings potential

Irrigation technologies have been evolving. Although China traditionally irrigated with the main aim of drought relief, some irrigated areas have been using water saving measures and even highly-efficient ones such as drip irrigation, sprinkler irrigation and pipe irrigation and so on. It is possible to improve irrigation savings and the government set targets tailored by province. To estimate agricultural water savings potential, we have picked two provinces:

- **Henan:** is one of China's Top 4 farming provinces and Top 4 coal producers. 42% of its water supply comes from surface water and the other 58% comes from groundwater; the percentage of water consumption/water resources is 113%. In other words, it is running a water deficit; and

- **Ningxia:** is one of the two provinces where water trading pilots were experimented. It has a high agricultural water use at almost 90% and is also running the largest water deficit with water use at nearly 7x its total water resources.

Given their water risk exposure, maximising agricultural water savings matters in these provinces:

Potential water savings in meeting 2015 irrigation efficiency target is 1 bn m^3 for Henan & Ningxia

Henan Irrigation Water Savings Scenario = 0.64 billion m^3 of potential savings

In 2013, Henan's agriculture water use is 14.2 billion m^3 representing 59% of total water use. According to a study from Henan Water Resources Department[38], 90% of agriculture water use is used in irrigation. Thus the irrigation water use in 2013 is 12.7 billion m^3. The irrigation efficiency coefficient of Henan was 0.57 in 2010, and is expected to increase to 0.60 by 2015 according to the Three Red Lines policy. Assuming that the irrigation efficiency coefficient at the start of 2013 remains the same as that in 2010 at 0.57 and was to improve to 0.60 within the year, the potential water saving by increasing the irrigation efficiency coefficient will be 0.64 billion m^3.

Ningxia Irrigation Water Savings Scenario = 0.36 billion m^3 of potential savings

In 2013, Ningxia's agriculture water use is 6.3 billion m^3, representing 88% of total water use. Assuming 90% of agriculture water use is used in irrigation, the irrigation water use in 2013 is 5.7 billion m^3. The irrigation efficiency coefficient of Ningxia was 0.45 in 2012, and is expected to increase to 0.48, 0.53 and 0.55 by 2015, 2020 and 2030 respectively. Assuming that the irrigation efficiency coefficient at the start of 2013 remain at 0.45 and was to improve to 0.48 within the year, the potential water saving by increasing the irrigation efficiency coefficient will be 0.36 billion m^3.

Aggressive irrigation coefficient targets could be hampered by small plot size and available financing

As seen above, irrigation savings in accordance with the 12FYP targets are limited given the small change in irrigation efficiency. Large saving potentials cannot be achieved without upgrading irrigation infrastructure and adopting more advanced irrigation methods. In 2010, only 30% of irrigated areas in Henan adopted water saving irrigation measures, and 26% of irrigated areas used highly-efficient water saving irrigation measures. For Ningxia, 22% of irrigated areas have been using highly-efficient water saving irrigation measures in 2013. Government could set more aggressive irrigation coefficient targets, but this could be hampered by (1) small average farm plot size and (2) available financing.

LARGE IRRIGATION WATER SAVINGS REQUIRE INFRASTRUCTURE UPGRADING

The irrigation water could be lost during transport through the canals and in the fields, and also during field application due to surface runoff and deep percolation to soil layers below the root zone of the crops. The irrigation efficiency is mainly combination of the below two sub-categories:

- **Conveyance efficiency:** the efficiency of water transport in canals. Depending on the canal type, canal length and soil type, it could range from 0.60 for long earthen canals with sand soil to 0.95 for lined canals; and
- **Field application efficiency:** the efficiency of water application in the field. It mainly depends on the irrigation method and the level of farmer discipline. Some indicative values of the average field application efficiency are provided by FAO:
  - Surface irrigation (border, furrow, basin): 0.60
  - Sprinkler irrigation: 0.75
  - Drip irrigation: 0.90

Overall, the average irrigation efficiency is around 56%, which however ranges widely amongst countries from 23% in water-rich Central America to 72% in water-scarce Northern Africa.

Source: FAO. Training Manual "Irrigation Water Management: Irrigation Scheduling", Facts and figures about Irrigation areas, irrigated crops,environment

If lined canals and sprinkler method are adopted in irrigation, the efficiency could be raised to around 0.70 (see in the above box). Assuming that both the irrigation efficiency coefficient in Henan and Ningxia could be increased to 0.70 in 2013, the relevant water savings could amount to 2.4 billion m^3 and 2.0 billion m^3 respectively.

Increasing irrigation efficiency by adopting modern practices could significantly up water savings

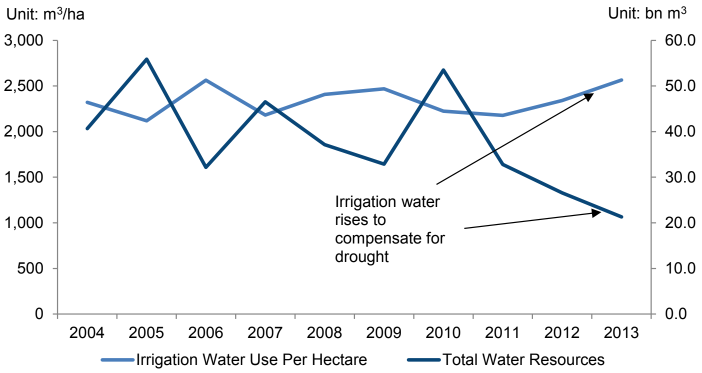
It should be noted that increasing irrigated land would negate any savings made through irrigation efficiency gains. In reality, the allocation of 360 billion m^3 to agriculture by 2025 is "nice to have" but may require more than just tackling irrigation. Optimising crop mix away from water intensive crops, pushing agritech to yield more crop-per-drop, promoting large-scale modernized farming as well as consolidating large-livestock breeding are all options to consider. Incidentally, central government also seems to be taking extra measures to 'control' the growth in meat consumed by optimizing the Chinese diet[39] and is also promoting modernized agriculture through large-scale farming in Northeastern China.

Beware of droughts and floods! Less agricultural water savings

Droughts in Henan increased irrigation water demand, negating efficiency gains

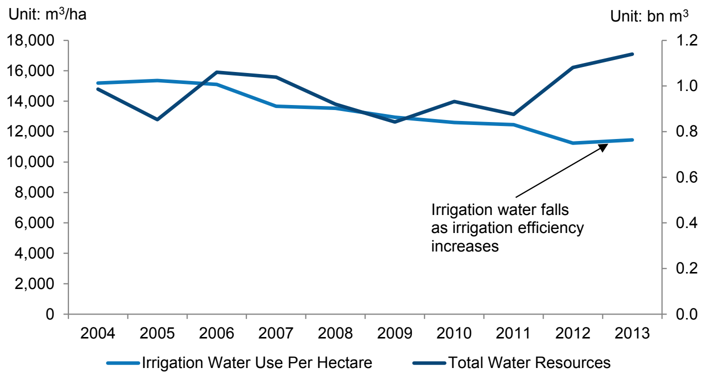
Improving irrigation efficiency is more difficult in practice as droughts and floods wreak havoc. As seen from the two charts below, there is a downward trend of unit irrigation water use in Ningxia from 2004 to 2013 in line with improving irrigation efficiency (see chart below right). However in Henan, which has a higher irrigation efficiency coefficient than Ningxia, irrigation water has been rising in recent years. This can be explained by the droughts suffered by Henan in recent years, resulting in increasing irrigation water demand to ensure food security.

2004-2013 Henan Irrigation Water Use Per Hectare



Source: China Water Risk, NBSC

2004-2013 Ningxia Irrigation Water Use Per Hectare



Source: China Water Risk, NBSC

Coal double whammy: receives less water from agri-savings & more demand from hydropower

Double whammy in times of droughts: more water and power required for irrigation means less water for hydropower and coal bases

Coal faces a double whammy with water in times of droughts. Not only is more water required for irrigation, but more power is also required for irrigation. Moreover, there will be less water for coal bases and less water to generate hydropower, which in turn will draw on more coal-fired power to smooth lower hydroelectric output.

A perfect storm could cause serious issues in power supply, like the severe power blackouts in India in 2012

A perfect storm could cause serious issues in power supply. For example in July 2012, India faced two severe power blackouts in most of northern and eastern India affecting over 300 million people. The extreme heat during that summer was already causing record highs in power use across cities in the North such as Delhi. On top of this, the late monsoon caused farmers in the North to rely heavily on their irrigation pumps thereby increasing power requirements from the grid. This put further pressure on power demand and the grid but at the same time, less water meant that hydroelectric capacity was also diminished and generating less than their usual load.

Regardless of the instruments opted for by local authorities, the strategic importance of water resource for the coal sector will dramatically increase as it might prove a bottleneck. Ensuring that coal and coal-fired power generation is insulated from these "shocks" by ensuring optimum water use within the coal bases is therefore key. Polices in place indicate that the government has understood these linkages.

WATER-FOR-COAL PLAN TO ENSURE WATER USE IN COAL STAYS WITHIN THE RED LINES

Regional water availability will dictate future coal development

We were commissioned by HSBC to investigate water and power issues this in "No Water, No Power – Is there enough water to fuel China's power expansion?" (September 2012). We subsequently highlighted upstream exposure to water risks in coal mining and worked with CLSA to write "Water for Coal – Thirsty miners will share the pain" (May 2013). Since then China has issued a Water-for-Coal plan where development of China's large coal bases are dependent on regional water availability.

Targets set out in the Water-for-Coal Plan must be met if the Three Red Lines are to be held

The plan is part of the 'Most Stringent Water Management System' released in January 2013, which set provincial water use quotas in order to meet the Three Red Lines. In short, targets set out in the Water-for-Coal must be met if the Three Red Lines are to be held. The Water-for-Coal Plan details out water use, water efficiencies and water pollution in mining including mine drainage as well as cooling technology recommendations for coal-fired power generation – please see chapter on "Coal & Coal-fired Power" for the implications of this plan for coal mines and coal-fired power.

New coal mining and power projects will face harsher scrutiny

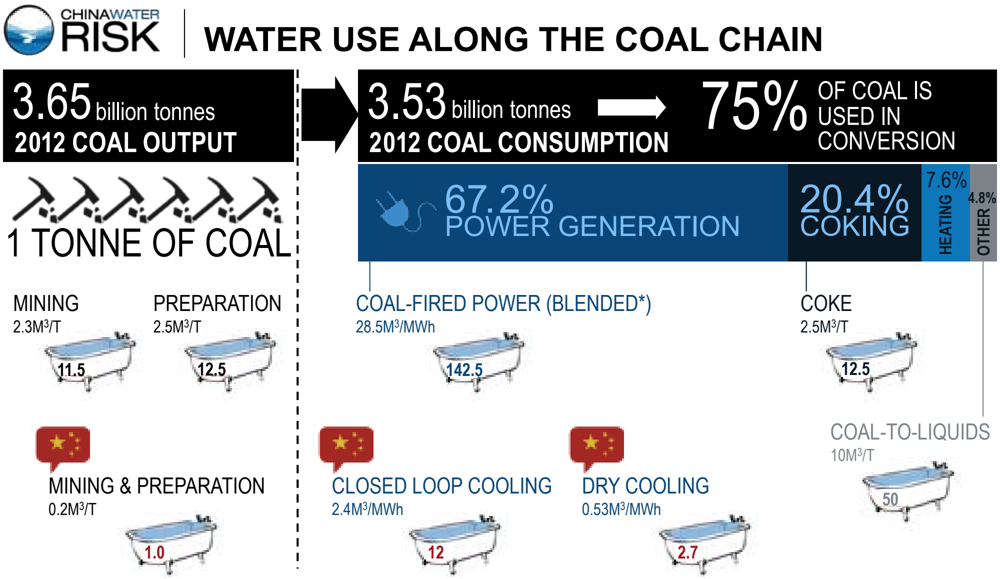
Primarily, the plan indicates that regional water availability in China will dictate coal development plans for the future. It also states that future coal base development plans should not be made independently but to be carried out simultaneously with relevant bodies responsible for water administration in the relevant provinces. A "Water Resources Capacity Assessment" should be conducted for new large scale coal mines. With the step up in environmental reform, we also expect to see Environmental Impact Assessment play a larger role in new projects or expansions within the coal and energy bases. In short, new mining projects, power plants and coal-related projects will face harsher scrutiny. Existing mines, power plants and coal projects will also have to improve on their water use. Lower water use across the entire coal chain is a 'must' to ensure sufficient water for coal and coal-fired power generation - we explore options below.

LOWERING WATER USE ALONG THE COAL CHAIN

Water use & coal consumption along the coal chain

Both water use and coal consumption to be considered to extract maximum water savings

Water is used in almost every step of coal production – extraction, preparation/washing, processing/conversion, transport, storage and disposal of pollutants, emissions and waste. In every step, water is withdrawn from the surface or from the ground, or recycled from the other stages and reused. Both water use and amount of coal consumed by coal mining and preparation, coal-fired power generation, coke production and coal to chemicals should be taken into account when trying to extract maximum water savings along the coal chain. We have set out below ranges of water use along the coal chain together with their share of coal use in conversion.



Source: China Water Risk, NBSC, Pan et al. 2012, MEP Clean Coal Production Standard, CNIS
Note: One Bathtub of water = 200 litres
**Blended coal-fired power includes once-through, closed loop and dry cooling*

Coal-fired power is the thirstiest but water use vary greatly subject to technology

As can be seen above, the range of water use by different process along the coal chain is wide with coal- fired power as the thirstiest. It should be noted here that even the ranges within power generation or coal mining and preparation can be wide due to various technologies employed and whether it is surface or underground mining. In power generation the range can fluctuate widely, the numbers in the graphic above are water withdrawals for closed loop cooling but for open loop cooling this can go up to 86m^3/MWh. It is also clear from the infographic above that the official targets are ambitious.

It should be noted here that many when referring to "water use" in mining are referring to water withdrawal but for power generation we are referring to water consumption (which is lower than water withdrawal) adding to the confusion. As a result, there are not surprisingly wide ranging estimates of water use in the coal and coal-fired power industries. The range of various estimates is set out in the chapter on "Coal & Coal-fired Power".

In this section, we will focus on water withdrawals in power generation in order to assess the sector's water risk exposure.

Coal and coal related industries account for more than a half of industrial water use

Coal & coal-related industries account for over half of China's industrial water use

Regardless of the wide-range of estimates, what is agreed is that coal and coal related industries account for more than half of industrial water use. We estimated this in the report we wrote for CLSA U® "Water for coal – Thirsty miners will share the pain" back in May 2013.

THE DOWN & DIRTY ON COAL & WATER

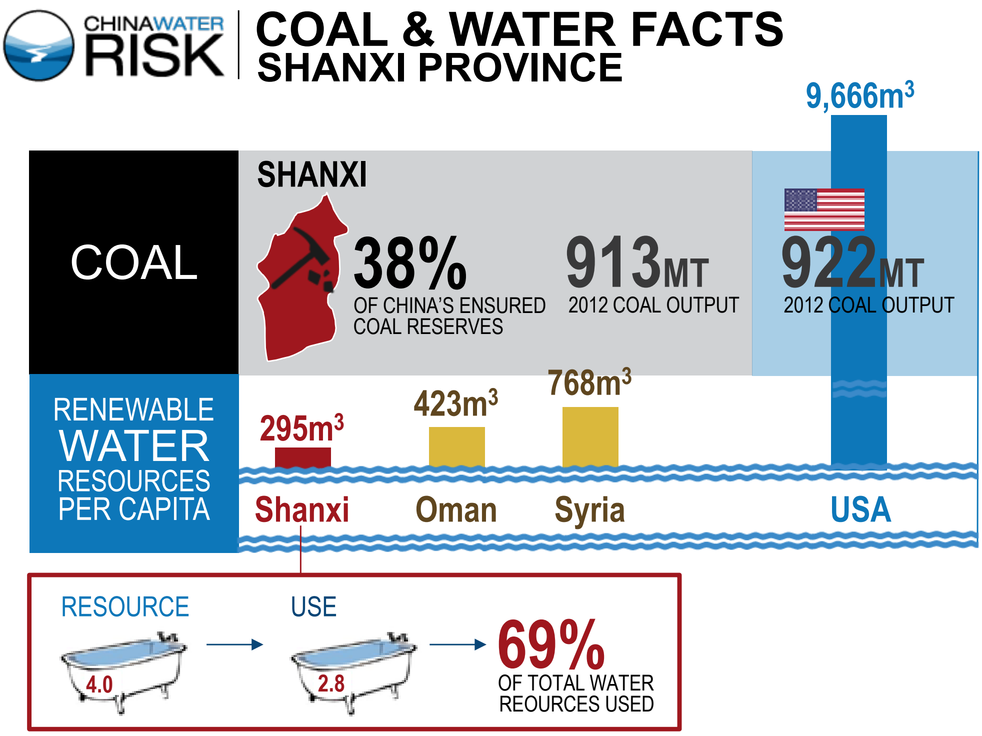
"The whole coal-chain could be at risk. More than half of China's industrial water usage is use in coal related industries—from coal mining to preperation, coal-fired power generation, coke production and the coal-to-chemical industry."

CLSA U ® "Water for coal —Thirsty miners will share the pain", May 2013

Latest Chinese study estimated water use in the entire coal chain to be 86 bn m³

"The Strictest Water Resources Red Lines Ask for Coal Production and Use Control" released in December 2014 by the China Institute of Water Resources and Hydropower Research (IWHR) estimated that water used in the entire coal chain in their base case scenario to be around 86 billion m^3; this is around 61% of total industrial water use of 141 billion m^3 in 2013.

What is also clear is that controlling water use in coal mining and preparation and coal-fired power generation will bring about the biggest gains in "water savings". Indeed these are what the MWR has targeted in their Water-for-Coal Plan. A glance at the Shanxi infographic below gives perspective on the magnitude of the coal production and stretched water resources.



Source: China Water Risk, NBSC, FAOAQUASTAT (2012)

China's investments in water-in-mining are low compared to global counterparts

For the CLSA U® report in 2013, to illustrate potential water risk exposure, we estimated that without any technological advances, water for extraction (without washing) of 4.1 billion tonnes of coal (the then 2015 estimate) to be 9 billion m^3 by 2015. This would be represent over 25% of the industrial water use at the Coal Base Provinces, a sizeable amount especially since this doesn't even include washing coal or water used in coal-fired power generation. We also highlighted in the same report that water savings from technological progress could lower this to 4 billion m^3 of water. Strategies can be employed to improve mining technology but China's investments in water-in-mining are low compared to global counterparts.

SCENARIOS TO LOWER WATER USE IN COAL & COAL-RELATED INDUSTRIES

Given that power generation is by far the largest consumer of coal and is also the most water intensive, we investigated scenarios to lower water use in both coal mining and processing as well was coal-fired power generation:

Water in coal mining & processing – water use fluctuates widely from 0.7 - 16 billion m^3?

Existing benchmarks for water use in coal mining differ widely, making it difficult to gauge water savings

To assess the water use in coal mining and processing in order to gauge potential water savings, we assumed that China would produce 100% of the 4.2 billion tonnes of coal by 2020. Existing benchmarks for water use in coal mining differ widely; moreover these differ significantly when compared to the "Cleaner Production Standard-Coal Mining & Processing Industry" (HJ446-2008) (Clean Coal Production Standard) introduced by the MEP in 2008. The standard gives three grades of water use quota in both underground and open mining:

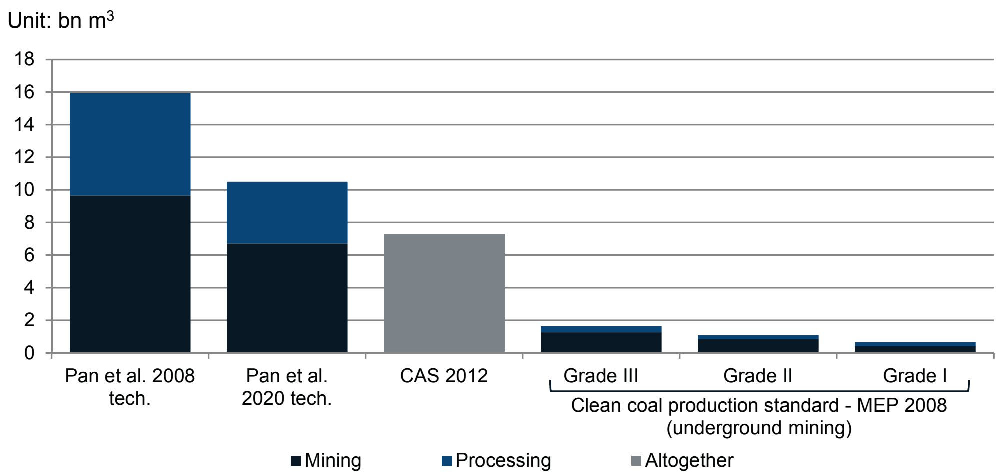
MEP standard provides three grades of water use in coal mining and processing

- Grade I: international advanced level
- Grade II domestic advanced level
- Grade III: domestic base level

Assuming coal production of 4.2 bn tonnes in 2020, water use can range from 0.7 bn m^3 to 16 bn m^3

These benchmarks therefore result in a range of total water use in coal mining and processing of 0.7 billion m^3 to 16 billion m^3 as shown in the chart below:

2020F Water Use to Produce 4.2 bn tonnes



Source: CWR estimates based on Pan et al. 2012, CAS, MEP

The various scenarios are as follows:

- Pan et al. – Assuming a coal wash rate of 60%, using old 2008 technology would result in 16 billion m^3 of water use compared to 10.5 billion m^3 if investments were made in technological improvements by 2020;

- Chinese Academy of Sciences (CAS) – Using the CAS benchmark we arrive at a lower water use in mining of 7.3 billion m^3. However, CAS does not provide a breakdown of water use in mining and processing nor does disclose the percentage of coal washed; and

- Clean Coal Production Standard (MEP 2008) – Water per tonne for extraction and processing are much lower across Grades I – III. Assuming a coal wash rate of 60%, the amount of water varies from 0.7 billion m^3 to 1.6 billion m^3.

Although most of China's coal washing are using closed loop systems, important saving potential still lies in coal mining

It should be noted that these numbers are not strictly comparable as the wash rate used by CAS is not known. We have used a wash rate of 60% as this is the 2015 target as per State Council's 2013 'Circular Economy Development Strategies and Action Plan'. Indeed China has been promoting the build out of large-scale coal-washing plants, thereby increasing the percentage of coal washed. There may be more pressure to increase washing rates further to improve air quality as it could help reduce sulpher and ash content in the raw coal. Given the lack of water, most of China's coal-preparation plants are using closed loop water systems. However, due to the lack of disclosure, actual water use figures are difficult to obtain as evidenced by the wide ranges above.

Despite the lack of disclosure and discrepancies over actual water used in coal mining, we have included this analysis to illustrate the potential range in water savings. Regardless of the uncertainty surrounding the actual water use for coal mining, there is little doubt that important water saving potential lies in the improvement of the coal mining and processing.

The various water per tonne of coal mined and processed benchmarks and standards at a national and provincial level are discussed in further detail in the chapter on "Coal & Coal-fired Power".

2020F Coal-fired power must have access to 109-157 billion m^3 of water to generate electricity

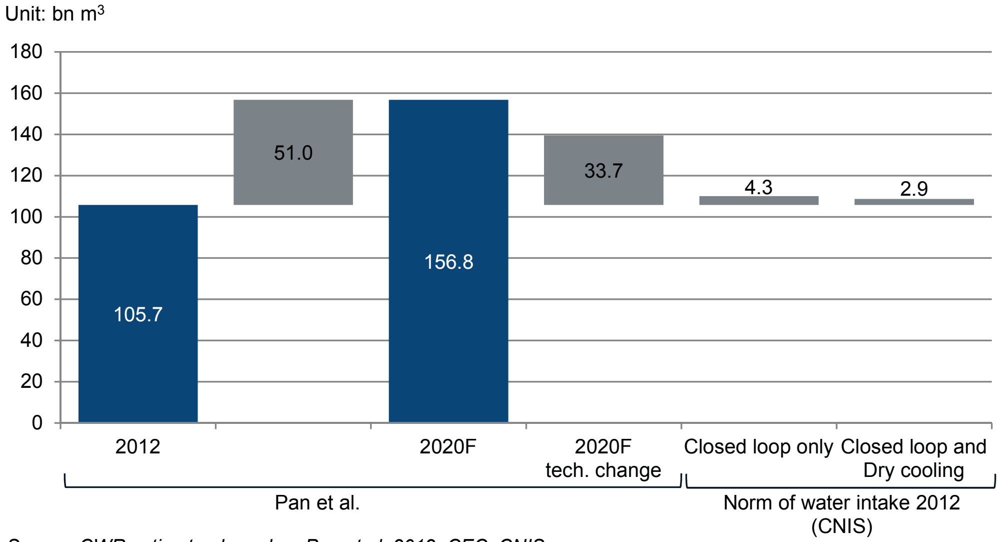
Technologies adopted by new power plants matter...

In 2012, China's coal-fired power plants generated 3,710TWh of electricity. According to our CWR Base Case Scenario, China's coal-fired power fleet is expected to generate 5,500TWh in 2020. The associated water use will largely be affected by the choice of technologies adopted for the newly installed power plants. The CWR Base Case Scenario as well as explanation of the different cooling types are discussed in detail in the chapter on "Coal & Coal-fired Power".

To estimate the amount of water required to generate this 5,500TWh, we used Pan et al. water withdrawal levels and estimated the water use for coal power generation without any improvement or modification in the choice of cooling technologies to provide a 2012 water withdrawal of 105.7 billion m^3. We then analysed several scenarios for the additional power required between 2012 and 2020 using different benchmarks and technologies from Pan et al and the China National Institute of Standardization (CNIS) as shown in the chart below:

... depending on the benchmarks and tech, coal-fired power plants must have access to 109-157 bn m³ of water

2012-2020F Water Withdrawal for Coal Power Generation



Source: CWR estimates based on Pan et al. 2012, CEC, CNIS

The scenarios above can be explained as follows:

- Pan et al. – assuming the additional coal-fired fleet adopts the current mix of cooling technologies (i.e. once-through, closed loop, and dry cooling) with no technological improvements, the coal power generation by 2020 would require an additional 51 billion m³ of water use bringing total water use in 2020 to 156.8 billion m³;

- Pan et al. with technological improvement – However, if investments were made in technological improvements, based on the values provided in the study, we estimate that only 33.7 billion m³ would be required thereby making a "water saving" of around 17 billion m³. In comparison, planned irrigation water savings calculated previously for Henan and Ningxia amounted to less than one billion m³ per province.

- CNIS – based on the standard values set out in "Norm of water intake for fossil fuel power plants" (2012), we estimate the additional water withdrawal in two cases:

  ○ Closed loop only – assuming that closed loop technologies are adopted for all the additional power plants between 2012-2020, this would require an additional 4.3 billion m³ a year from 2012; and

  ○ Closed loop & dry cooling – assuming we follow the Water-for-Coal plan injunction to adopt dry cooling technologies in water scarce areas, the additional water requirement from 2012 is further reduced to 2.9 billion m³.

Whilst dry cooling can save water, it requires more coal to produce the same amount of electricity

It should be noted here that whilst dry cooling appears to be the best option from a water perspective, it is more inefficient than wet cooling and more coal will have to be burned to achieve the same kWh. Water and carbon emissions trade-offs are discussed in more detail in the chapter on "Coal & Coal-fired Power".

It is important to note here that the above are calculations of water use/ water withdrawals in power generation. This is not to be confused with water consumption. Whilst the adoption of closed loop drastically reduces the amount of withdrawn water for power generation, it however increases the amount of water consumed through evaporation. We have used water withdrawals in power generation to illustrate water risk exposure and so that it is comparable to the other values of water use along the coal chain. However in the chapter on "Coal & Coal-fired Power", we have used water consumption to assess water savings in power generation using various cooling technology scenarios.

Lowering water use in coal mining and coal-fired power is necessary to ensure both energy and food security

Lowering water use in coal mining and coal-fired power generation can be significant. Without these, it may be difficult to ensure sufficient water in the Coal Base Provinces for both energy and food security. It is very clear from the above that lowering water use in the coal chain results in significantly larger gains than improving irrigation efficiencies. Moreover, these strategies will be less prone to floods and droughts. Given that the Top 5 provinces with the highest Gross Regional Product contribution to China's GDP are highly reliant on coal-fired power (see the chapter on "Coal & Coal-fired Power"), it is imperative that China ensures enough water for coal.

DO WHATEVER IT TAKES TO GUARANTEE WATER FOR COAL: DIVERT MORE WATER FROM THE SOUTH

Western Route of the South-North Water Diversion will transfer 17 bn m^3 of water, which is more than sufficient to ensure energy security

There is no doubt that China will do whatever it takes to guarantee water for coal including diverting water from the South to the North. Currently, there is a plan in place to transfer 17 billion m^3 of water along the Western Route of the South-to-North Water Diversion Project. The Western Route yet to be built and is comprised of several water transfer projects from three main rivers the Yalong, Dadu and Tongtian to the Yellow River. The planned amount of 17 billion m^3 to be transferred should be more than sufficient to ensure energy security as it is equivalent to around half the total industrial water use of the Coal Base Provinces.

The first phase of this is on the Dadu River and is expected to provide the North with 3-5 billion m^3 of water or around 8% to 14% of the total industrial use in the Coal Base Provinces. Perhaps this is enough and the Tongtian and Yalong Rivers can be spared of diversion? For more please see box below.

WATER DIVERSION ECONOMICALLY VIABLE & POSSIBLE

If agricultural water savings cannot meet the rising demand in industrial and municipal water use, building the Western Route of the South-North Water Transfer Project (Western Route) can be considered.

The key to the success of inter-basin water transfer projects is whether there are water users that could afford the relatively higher cost of 'transferred water'. The reason why some water diversion projects haven't commenced as planned is mainly because high project costs result in high water prices and there are currently not enough users who can afford to pay the price. For the Western Route, the energy industry will be the main user and these users can afford to pay the higher water prices.

Moreover, the Western Route actually comprises several smaller-scale water transfer projects which can be implemented through several phases. The water sources of the Western Route include three rivers with total annual runoff of 22.1 billion m^3: the Dadu River at an altitude of 2,900m, and the Yalong River & Tongtian River at 3,500-3,600m. According to the preliminary plan, the annual average transferable water from these three rivers is 12-17 billion m^3: 3-5 billion m^3 from Dadu, 3.5-4 billion m^3 from Yalong and 5.5-8 billion m^3 from Tongtian.

The first phase of the project can be implemented in the three tributaries of the Dadu River, namely Ake River, Ma'er River and Duke River as these lie closer to the Yellow River; about 3-5 billion m^3 can be transferred. If the development of the energy bases is really suffering from water shortage, water transfer from the Dadu River of around 4 billion m^3 to the Yellow River can be implemented first. Once implemented, it will not only meet water demand from energy bases, but also supply water for industrial and municipal use.

Source: The above is an excerpt from an opinion on China Water Risk titled "Will China's Energy Bases Drain the Yellow River" by Professor Jia Shaofeng, Deputy Director of the Center for Water Resources Research of the Chinese Academy of Sciences and Vice Chair of the Special Committee for Water Resources of China Hydraulic Engineering Society, February 2015

WATER DIVERSION SHOULD BE A LAST RESORT

Water diversion might upset the delicate balance of upper watersheds; it also needs more power

Whilst economically feasible, surely we should try to avoid this, especially since these three rivers originating in Qinghai are the main headwaters of the Yangtze River. Controversy over their diversion looms as it may upset the delicate balance of the upper watershed of the Yangtze with long-ranging impacts on the environment. In addition, diversion needs more power bringing us back to the water-energy nexus loop. Moreover, lowering water demand from both coal and agriculture may be enough to stop these diversions. Diversions should be used as last resort. This is also the view held by some experts - see box below:

WATER DIVERSION NOT NECESSARY IF DETERMINED TO SAVE WATER

"If we determined to save water and improve water-efficiency, I believe we are not going to launch new diverting projects. According to former Premier Wen Jiabao, China's economic growth has been uncoordinated and unsustainable in the past. To achieve economy development goals, we have wasted lots of energy, land and water resources.

In the past, diverting water is a common solution to meet water demand, but diverting is very limited. We had once diverted water from Luan River to Jin River, and then later Luan River run out of flow; we then launched diverting project from the Yellow River to Jin River, and the Yellow River suffers year-around no flow. What we are doing now is diverting water from Danjiangkou reservoir to the Yellow River. In 2014, the reservoir experienced terrible drawdown itself.

Water diversion is not a once-for-all solution to solve water shortage. It's actually a shattering way. To solve the problem in long term, we must improve water-efficiency, clean the polluted water and restore aquatic ecosystem."

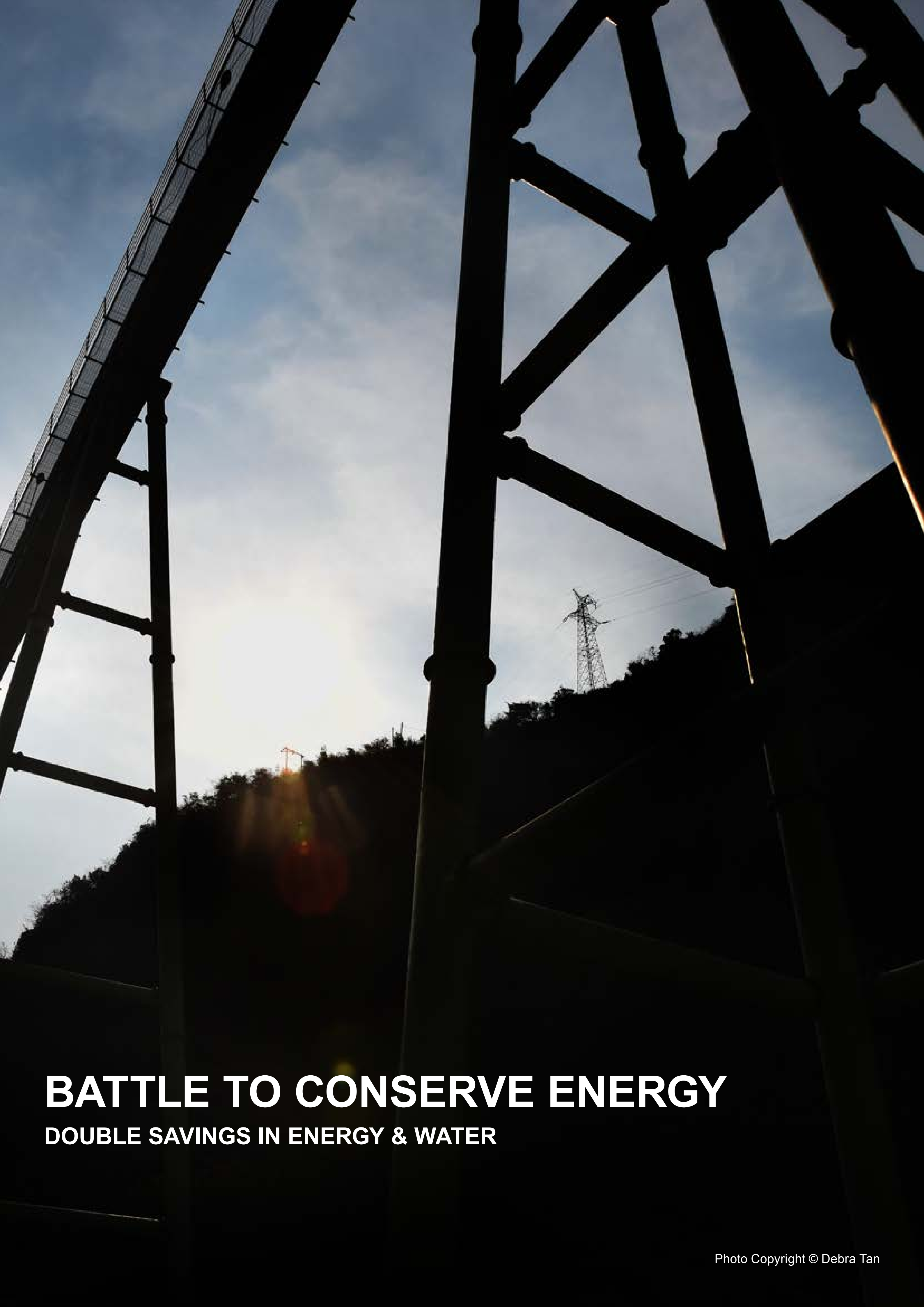
Li Junfeng, Director General of the National Center of Climate Change Strategy Research and Deputy Director of the Energy Research Institute at the National Development and Reform Commission

The Western Route should be a last resort

Diverting water along the yet-to-be-built Western Route could be an answer to the water woes of the parched North but we are of the view that this should be a last resort. Aggressive water savings in coal and agriculture should be first exhausted before considering water diversion.

Water and energy policies set in China can shape global coal and agricultural trade

Given these, we maintain our stance that it is time to adopt non-BAU thinking by viewing agriculture & food given limited water resources. It is also time to adopt an aggressive stance on energy savings as there are double savings in energy and water. Energy savings and policies to cut electricity consumption including changing industry mix and circular economies in coal and power are discussed in the next chapter. What China does matters globally beyond climate change; water and energy policies set in China can shape and shift both the global coal and agricultural trade.



BATTLE TO CONSERVE ENERGY

DOUBLE SAVINGS IN ENERGY & WATER

- The only trifecta win for energy, water and climate is the pursuit of energy savings; saving power saves water. China has made tremendous improvements in this direction: over half the world's entire energy savings in the past twenty years came from China. However, much potential still remains to be tapped in industry, which accounts for 85% of electricity consumption.

- Central government is already lending support towards this with the Energy Saving & Environmental Protection Industry, which is expected to grow to RMB4.5 trillion (USD734 billion) by 2015. This is the first of seven Strategic Emerging Industries announced at the start 2011. The 12FYP also set a target to save 17% of total primary energy consumption by 2015, with investment for key energy saving projects expected to be RMB982 billion.

- The battle to conserve energy is being led on several fronts simultaneously: (1) increase efficiency in power generation; (2) energy conservation across industries, buildings, agriculture and rural and urban households; and (3) cutting energy demand by optimising industry mix.

- Efforts to increase efficiency in power generation are mainly focused on aggressive upgrade of China's coal-fired fleet. Big gains have been made over the last 15 years and China's fleet is now on par with that of the US. In 2014, the NEA announced plans to improve further the coal-fired power fleet by 2020. CWR's Base Case scenario estimates that this could save up to 85 million tonnes of coal and consequently reduce the water demand for coal extraction by 147 million m^3.

- Electricity conservation efforts are estimated to save up to 805TWh by 2020, mainly through the adoption of efficient electrical appliances, efficient machinery, frequency converters and efficient lighting. Assuming this 805TWh was generated by coal-fired power plants, this would reduce the water consumed for cooling power plants by around 1 billion m^3 a year. Energy conservation can clearly bring about significant water savings.

- With industry representing 85% of the total electricity consumption, optimising the industry mix can bring about massive energy and water savings. Given the war on pollution, the government will look to curb energy demand in power intensive and polluting sectors. Analysis shows that tackling the cement and steel sector will provide win-win outcomes on these two fronts. Moreover, these sectors rely on coking coal as raw material input. Cutting excess capacity in these sectors will help control coal demand.

- These multi-prong efforts to save energy, together with the development of seven SEIs, will eventually change China's industrial mix towards high-end manufacturing, away from low-tech more water-polluting and intensive as well as energy intensive industries.

- However, although energy efficiency is improving, production is still rising. In 2014, the comprehensive energy consumption per tonne of crude copper, steel and cement decreased by 3.76%, 1.65% and 1.12% respectively. Despite these efforts, total industrial output outpaced efficiency gains and total energy consumption rose by 2.2% and electricity consumption increased by 3.8%.

- Ultimately, in the longer term to balance the economy and the environment, China has no choice but to create circular economies across its key industries. A circular economy means less water, less energy, less resource waste and more recycling. Ten industrial sectors have been identified; coal, power, steel and building materials are amongst the ten.

CHAPTER 5:
BATTLE TO CONSERVE ENERGY – DOUBLE SAVINGS IN ENERGY & WATER

ENERGY SAVINGS: MUCH POTENTIAL STILL TO BE TAPPED

Energy savings: the only trifecta win for energy, water and climate

From the previous chapters, it is clear that adding new power generation regardless of type have either negative impacts on water or on climate. The only trifecta win for energy, water and climate is the pursuing of energy savings. The message from the central government is loud and clear. "*We will fight to win the battle of conserving energy, reducing emissions and improving the environment*", urged Premier Li at a National People's Congress meeting on 5 March 2015[40].

> *"We will set a ceiling on total energy consumption and strengthen energy conservation in key areas such as manufacturing, transportation, and construction. We will work hard to develop a circular economy and promote the recovery of resources from industrial and household waste. There is enormous potential in China's market for energy conservation and environmental protection; we will develop the energy conservation and environmental protection industry into a new pillar of the economy."*
>
> *Premier Li Keqiang, report on the work of the Government delivered at the 3rd session of the 12th National People's Congress on 5 March 2015*

Industry is targeted as it consumes 97% of coal and 85% of electricity

It is not hard to understand why Chinese government is promoting energy conservation. If we look from the sector perspective, industry uses most of the coal and electricity. In 2012, industry (secondary and tertiary) consumed about 3.4 billion tonnes of coal, which is 97% of total coal consumption; meanwhile, industry also accounted 85% of total electricity consumption. In short, the upside form controlling electricity consumption in industry is great.

Over half of the world's energy savings in the past 20 years came from China

Already, China has made tremendous improvements in energy savings. Over half of the world's entire energy savings in the past twenty years came from China[41]. However, much potential still remains to be tapped in both power generation and energy consumption by industry.

In this section, we analyse the efficiency of China's energy generation and set out the government's efforts in promoting energy savings. We will also discuss the rationale behind the strategy employed and explore several energy saving scenarios including improving energy efficiency in accordance with 12FYP as well as changing industry mix by cutting backward/excess production capacity in the power intensive sectors such as cement and steel sectors. Finally, we will look into how China plans to transform the selected sectors including coal and power to a circular economy, as China marches towards an "ecological civilization".

CENTRAL GOVERNMENT SUPPORTS ENERGY SAVINGS: SEI#1 = USD734 BILLION

From "Economy vs Environment" to "Economy & Environment", with SEI#1 to grow to RMB4.5 trillion

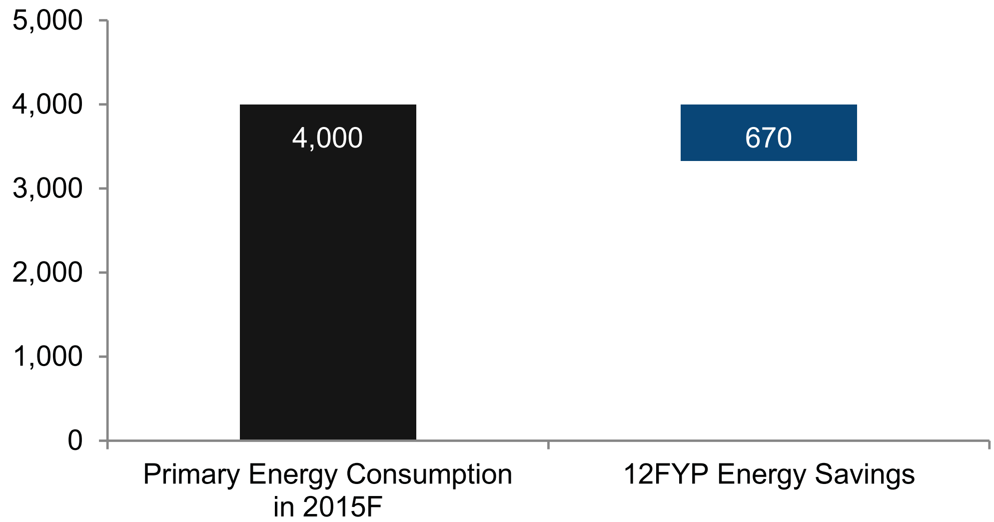
At the start of 12FYP, China announced plans to develop seven Strategic Emerging Industries, and the first one is Energy Saving & Environmental Protection (SEI#1). The State Council planned to grow SEI#1 to RMB4.5 trillion (USD734bn) by 2015. This, together with enforcement under the amended Environmental Protection Law in 2015, clearly indicates a shift of mindset moving away from 'Economy vs Environment' to "Economy & Environment" – the success of SEI #1 will demonstrate that one can make money from protecting the environment. SEI#1 also promotes double savings, meaning that the focus is not just on 'using less water' but also 'saving energy' which can in turn saves water. Moreover, this signals a mind shift in "moving out of silos" that encourages holistic policy making which is beneficial for air, water, energy and the climate in the long term. As mentioned previously, an energy revolution would need to cover four aspects from supply, consumption, technology and management system. See more in Chapter 3: "Balancing Power Mix for Water & Climate".

12FYP target: 17% of primary energy to be saved

According to the '12FYP of Energy Saving and Emission Reductions'[42] issued by the State Council on 6 August 2012, total energy savings during the 12FYP are expected to be 670 million tce, which is about the 17% of the total primary energy consumption by 2015 as shown in the chart below:

12FYP China's Energy Savings

Unit: mn tce



Source: China Water Risk, State Council

There are plans to improve efficiency in power generation, and to cut demand through energy conservation & optimisation of industry mix

The plan sets two main strategies to achieve the 2015 target:

1. Increase efficiency in power generation; and

2. Cut energy demand, which comprises:
   - Energy conservation in industries, buildings, transportation, agriculture, rural and urban households as well as public services; and
   - Optimisation of industry mix by:
     - Promoting strategic emerging industries;
     - Controlling the growth of energy-intensive and highly polluting industries;
     - Shutting down backward production capacity;
     - Upgrading traditional industries; and
     - Adjusting energy consumption mix.

INCREASE EFFICIENCY IN POWER GENERATION: AGGRESSIVE UPGRADE OF THE COAL FLEET

With a focus on water and energy, we will first explore energy savings in power generation, followed by water savings embedded in the energy saved. As we mentioned in Chapter 3: "Balancing Power Mix for Water & Climate", coal remains the vanguard in China's energy mix and coal demand is primarily driven by power generation (in the chapter on "Coal & Coal-fired Power"). In order to cut coal demand, it is important to increase energy efficiency in coal-fired power generation. Moreover, since the average lifespan of a coal power plant is about 40 years, it is essential not to get locked in with inefficient capacities. Indeed we have already seen improvements in China's coal-fired fleet.

Big gains in power generation efficiency over the last 15 years

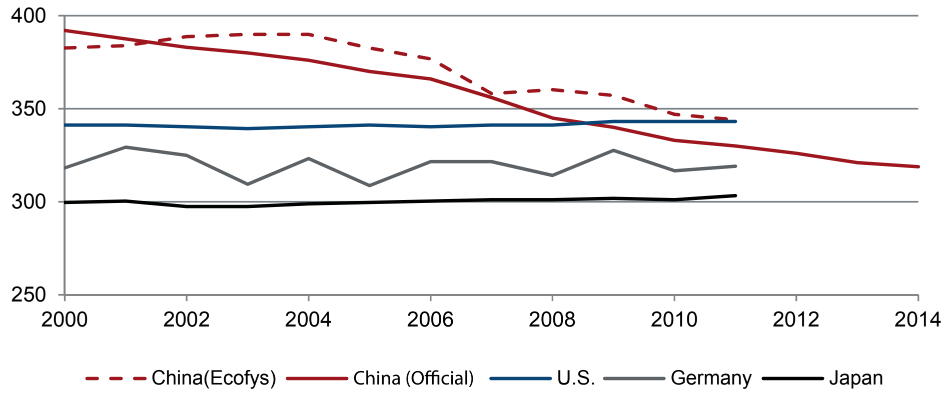
China achieved impressive efficiency gains in coal-fired power generation

China has achieved impressive efficiency gains in the last decade. In 2000, the average efficiency of existing coal-fired power generation fleet in China was 392 gramme of standard coal equivalent (gce) per kWh; in 2014, it has been improved to 319gce/kWh, dropping by 0.67% from the 2013 level of 321gce/kWh. The national average efficiency is now on par with the U.S. and maybe not far from Germany's levels (see below chart).

China's coal fleet efficiency is now on par with the US

Coal Power Plant Efficiency in China and Abroad

Unit: gce / kWh



Source: NEA, NBSC, Ecofys

The NEA's 'Action Plan for the Transformation and Upgrading of Coal Power Energy Conservation and Emission Reduction' (2014-2020) issued in September 2014, provides more details of the current efficiencies of coal-fired power plants by type of power generation unit (1GW, 600MW and 300MW; ultra- supercritical, supercritical and subcritical) and cooling type (wet and dry):

- For existing plants, the efficiency at the average level ranges from 290gce/kWh to 347gce/kWh, and at the advanced level it ranges from 285gce/kWh to 337gce/kWh;
- For new plants, the efficiency ranges from 282gce/kWh to 327gce/kWh; and
- The most efficient is 1GW ultra-supercritical with wet cooling, and the least efficient is 300MW subcritical with dry cooling.

Thus, much potential lies in improving efficiency in coal-fired power generation.

China: marching towards the most efficient power generation but with diminishing returns

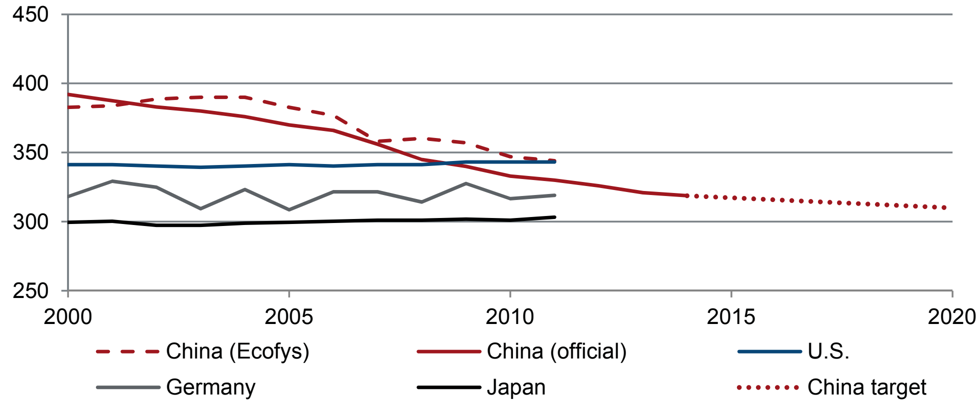
Efficiency gains remain to be tapped, albeit harder to reap

The NEA's action plan sets out the following targets by 2020 to further reduce specific coal consumption of power plants (see chart below):

- The average efficiency of existing coal-fired power generation fleet should be improved to be less than 310gce/kWh; and
- For new plants as well as retrofitted plants with capacity over 600MW, the average efficiency should be improved to be less than 300gce/kWh.

Coal Power Plant Efficiency in China and Abroad

Unit: gce / kWh



Source: NEA, NBSC, Ecofys

Considering the expected coal-fired power generation to be 5,500TWh by 2020, the potential coal saving is estimated to be almost 61 million tce (or 85.4 million tonnes in absolute term[43]) per year (see our scenario analysis below).

The improvement of the coal power generation efficiency has been made easier by the closure of small and inefficient capacity. However, as this inefficient capacity is decreasing, the additional efficiency gains will progressively prove harder to reap.

Scenario analysis: aggressive efficiency improvement in coal fleet = 679 million m^3 in water savings

Improving efficiency means coal savings...

We assess the coal savings related to the improvement of the coal-fired power plants' efficiency until 2020, as set up in the previously mentioned action plan from the NEA. Using 2013 as a base year, the average efficiency was 321gce/kWh and the total coal-fired power generation was 4,003TWh. Thus, coal consumption in power generation in 2013 is 1,285 billion tce.

By 2020, the coal-fired power generation will reach 5,500TWh according to our CWR Base Case Scenario. As shown below, we estimated the coal savings from efficiency improvement in power generation according to the targets set out by the NEA's action plan and also by assuming the most aggressive technological improvement:

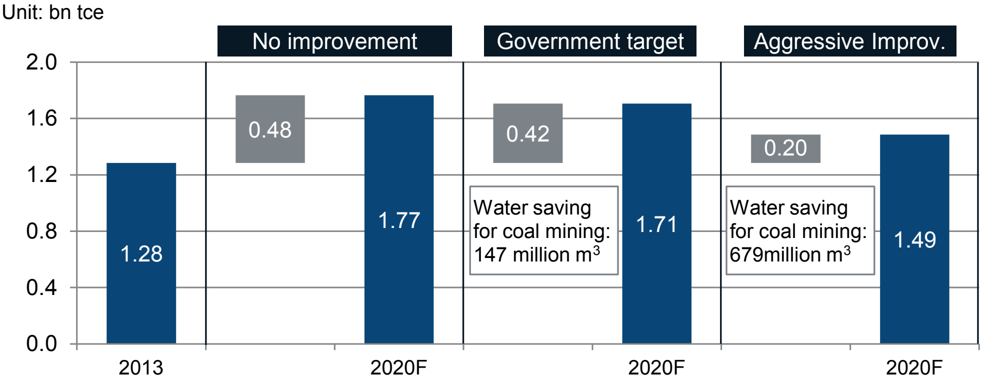
- **No improvement –** we assume that the average coal consumption per kWh in 2020 remains the same as that in 2013, thus the coal consumption for power generation will reach 1.77 billion tce, representing an additional 480 million tce from 2013;

- **Government target –** we assume that the target set by the government plan will be achieved by 2020 (i.e. 310gce/kWh), the coal consumption for power generation will then be 1.71 billion tce in 2020, representing an additional 420 million tce from 2013; and

- **Aggressive improvement –** we assume the most advanced coal-fired power generation technology available, which has been used in the Shanghai Waigaoqiao Power Plant with efficiency at 270gce/kWh, to be used in all the coal-fired power generation fleet in 2020. Although this is very unlikely, it gives us an idea of the maximum water savings from improving power generation efficiency.

2013-2020F Impact of Coal Power Plant Efficiency Improvement

Unit: bn tce



Source: China Water Risk estimates based on Pan et al. 2012, CEC, CNIS

... and water savings as well: NEA plan to upgrade the coal fleet could save up to 85 million tonnes of coal and 147million m^3 of water

As seen from the above charts of these three scenarios, we can clearly see that the NEA's action plan could bring a reduction of coal consumption by 61 million tce (i.e. 85.4 million tonnes of coal) for 2020. Considering a value of 1.73m^3/tonne for coal extraction and processing (see chapter on "Coal & Coal- fired Power" for more details), this represents water savings in coal mining of 147 million m^3. In the most aggressive scenario, the water savings could even reach 679 million m^3.

MANAGING ENERGY IMBALANCE REQUIRES INVESTMENT

Grid and electricity dispatch improvements would reduce losses

Alongside efficiency gains in the power generation sector as discussed above, substantial potential also lies in the grid and electricity dispatch improvements to reduce unnecessary loss. As highlighted by Mr. Nur Bekri, head of the NEA during the National People's Congress meetings in early March 2015, China is also facing internal imbalances in energy supply and demand.

For some energy types with seasonal variability such as hydropower, excess electricity production during resource-rich months (e.g. wet season for hydropower) could lead to wastage of power (see chapter on "Hydropower"). For instance, in 2014, hydropower plants in Sichuan and Yunnan "wasted" potential electricity generation of 10TWh and 20TWh[44], respectively.

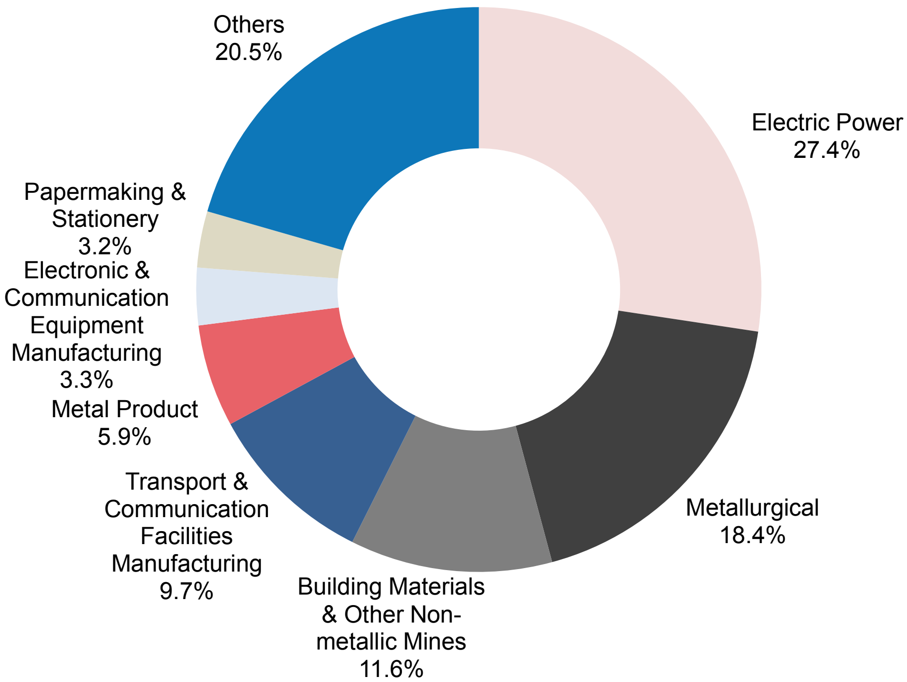
By improving grid linkage and short-term scheduling ability, we could reduce such "wastage" of power. Improvements in the grid will also help renewables such as wind and solar to expand and increase the share of renewables in China's energy mix (see chapter on "Other Renewables").

CUTTING ENERGY DEMAND IN INDUSTRIES CAN BRING ADDITIONAL SIGNIFICANT SAVINGS

Power Sector, Metallurgical and Building Materials are the biggest electricity consumers

As discussed in Chapter 2: "China's Water Energy Nexus" industry is the biggest user of electricity power. Based on the latest available sector-specific information, in 2012, industrial sectors consumed 3.62TWh of electricity. The Top 5 biggest industrial users of electricity are Electric Power (27%), Metallurgical (18%), Building Materials & Other Non-Metallic Mines (12%), Transportation & Communication Facilities (10%) and Metal Product (6%) (See chart below).

2012 Electricity Consumption By Sector



Source: China Water Risk, NBSC

Amongst industrial sectors, the Electric Power sector is the largest user of both coal and electricity. Although electric power sector is to supply electricity to all the other industrial sectors, its production and supply of electric power, heat and gas also require electric power. This will not only include electricity consumption in the power plants, but also consumption in transformer stations, grids and pipelines networks. In addition, other sectors, such as metallurgical and building materials manufacture, also use significant amounts of coal and electricity.

Chinese industry is doubly exposed to water scarcity through its heavy use of power

Indeed, Chinese industry faces a double whammy of water risks: directly exposed to the nation's water scarcity and indirectly due to its heavy power reliance.

THE DOUBLE EXPOSURE OF CHINA'S INDUSTRIAL BACKBONE

"In 2009, industry used almost a quarter of the nation's water and also consumed 84% of all power. We think direct exposure to water scarcity, coupled with indirect exposure (97% of electricity generation is water-reliant) poses risks for the industrial sector – a double exposure."

"HSBC No water, no power– Is there enough water to fuel China's power expansion?" September 2012

Energy conservation can save up to 805TWh or 1 billion m³ of water

Energy efficiency is the most effective strategy when considering carbon and water

According to a recent WRI study[45], *"energy efficiency by end-users is by far the most effective strategy in terms of its net positive impact on both greenhouse gas emissions and water consumption."*

Since 2011, every new large industrial project needs to submit an energy-efficiency assessment. The construction of the facility can be initiated only after the assessment has been reviewed and approved either by the local Development and Reform Commissions (DRCs) or by the NDRC.

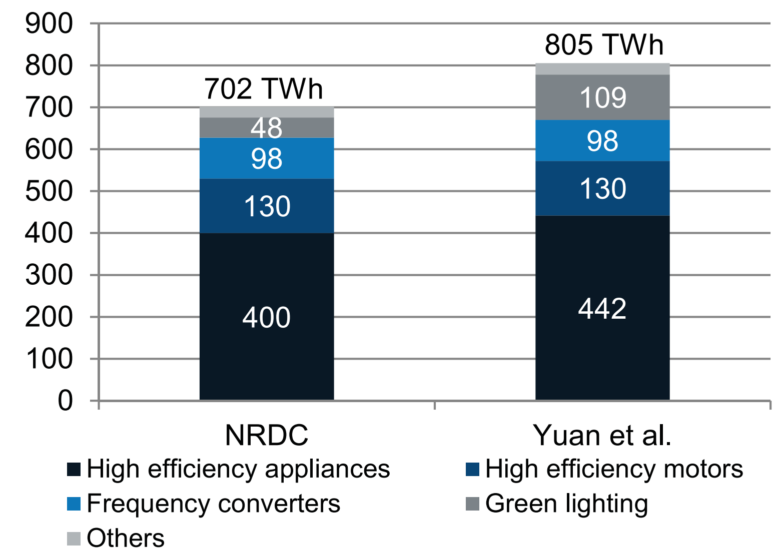
In addition, NDRC updates a list of recommended energy conservation technologies every year. The latest one released on 31 December 2014, lists 218 recommended technologies covering 13 sectors including coal, power and textiles[46]. The list details the applicable conditions, current implementation status, investment, energy saving potentials and CO_2 emissions reduction potential. It also comes with technical guides for each technology. Successful case studies are also included in these guides. Many of these technologies have investment payback periods ranging from a few months to less than 5 years.

Potential electricity savings could reach 805TWh by 2020...

We have set out below two recent studies to provide an idea of energy savings potential by 2020 (also see below chart).

- In a report from the China Coal Cap Project on the "Power Sector Coal Consumption Cap Plan and Policy"[47], supported by NRDC and other over 20 government think tanks, research institutions and industry associations, China's energy saving potential in electricity consumption and power sector is estimated to be 702TWh by 2020. The associated savings mainly come from efficient electrical appliances, efficient machinery, frequency converters and efficient lighting. It is also estimated to almost double to reach 1,394TWh by 2030; and
- Research from Yuan et al. (2014) estimated the potential energy savings to be higher at 805TWh by 2020.

2020F Potential Electricity Saving
Unit: TWh



Source: NRDC 2015, Yuan et al. 2014

...representing a potential water saving of 1 billion m³

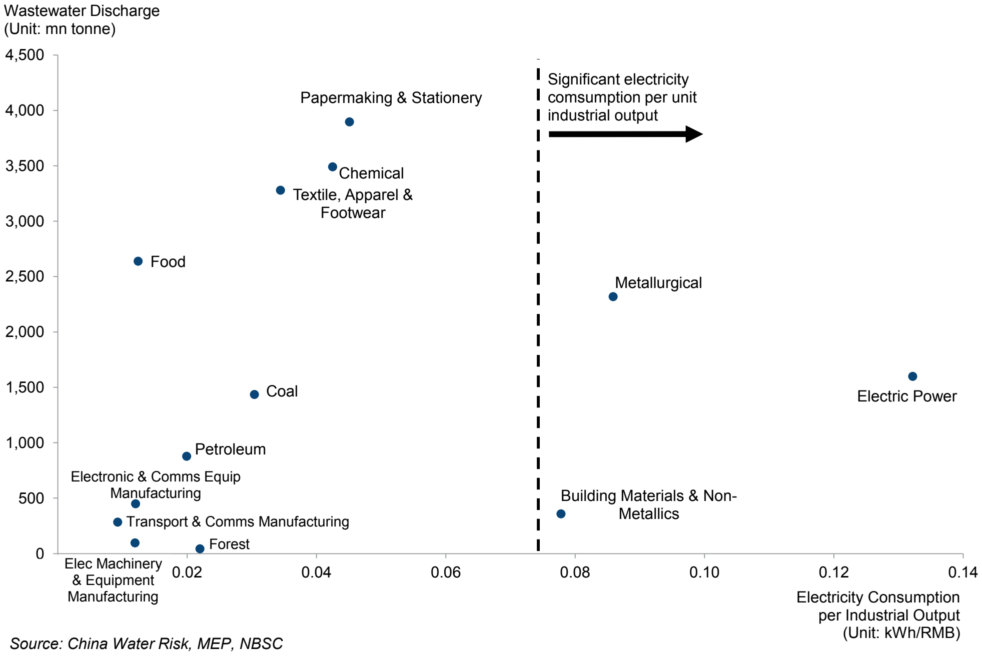
Assuming all this electricity saved was generated by coal-fired power plants, this would represent an annual water saving ranging from 0.95 billion m^3 to 1.09 billion m^3. To calculate this, we assume an average water consumption of 1.35m^3/MWh (see chapter on "Coal & Coal-fired Power" for more details). Note here that this water saving value only concerns power generation and does not include the associated water savings in coal mining.

Energy saving potentials in industries lie in cement and steel

Given the war on pollution, the government will look to curb energy demand in power intensive and polluting sectors

Given the war on pollution and increased scrutiny on industrial wastewater by the government, we analysed industrial wastewater discharge and electricity consumption per unit of industrial output for each industrial sector in 2012 (the latest publically available information). The results are shown in the scatter chart below:

2012 Electricity Consumption vs Wastewater Discharge By Industrial Sector



Source: China Water Risk, MEP, NBSC

Cement and steel sectors should be targeted first as they are both energy intensive and discharge substantial amounts of wastewater

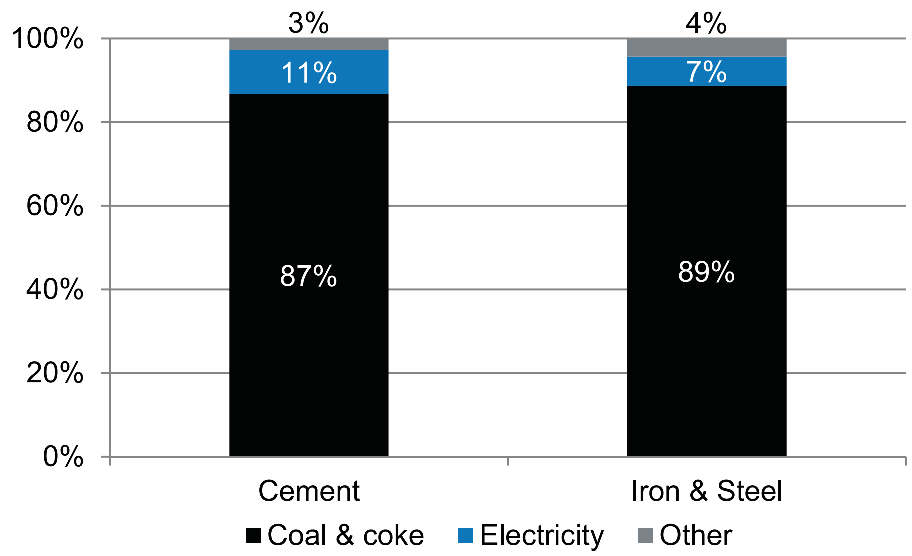
It is clear from the chart above that some industries require a significant amount of power and also discharge a considerable amount of wastewater (right of the dotted line) - Metallurgical, Building Materials & Other Non-Metallic Mines and Electric Power sectors. Clearly, industrial energy savings, especially in metallurgical and building materials sectors, will be key in cutting energy demand. Within these two sectors, steel and cement are two major energy-intensive industries. Therefore, in the below discussion we focus on these two sectors.

Massive saving potential of coal and coke from cement and steel industries

Coking coal is a raw material input for cement and steel...

20.4% of coal in conversion is used for coking. If China is to meet its cap of 4.2 billion tonnes of coal in 2020, it will have no choice but to cut coal consumption in other sectors than power generation. Cement as well as Iron & Steel industries are major energy consumers in Chinese industry, and coal and coke represent a lion's share of their energy uses (see chart below). Given the scale of their production, these sectors are also very large electricity consumers.

Final Energy Share in Cement and Iron & Steel Industry (%)



Source: Ke J. et al. (2012), Lin B., & Wang,X. (2014)

... energy efficiency gains mean water savings as well, but more advanced processes might need more electricity

As discussed earlier, much effort has already been made to improve the energy efficiency of these sectors. The energy efficiency gains in terms of coal could be translated into water savings, since less coal would be extracted, processed and consumed to produce same amount of products. However, word of caution, more advanced production processes might actually require more electricity. Take the steel sector for instance, even though the total energy consumption to produce a tonne of steel is decreasing, the actual amount of electricity required can keep increasing as some modern processes are more power intensive.

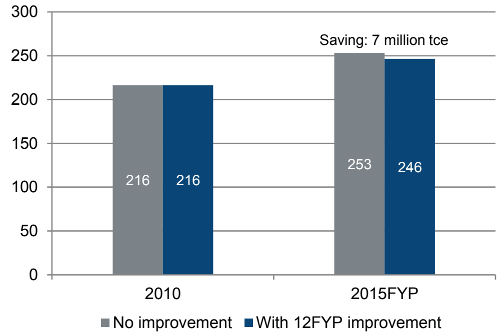
But 12FYP planned energy savings: only 26 million tce or 126 million m^3 of water in cement & steel

12FYP set energy intensity targets for important products

The 12FYP contains specific objectives in terms of energy intensity for main energy intensive products. Between 2010 and 2015, the energy consumption per tonne of cement is expected to decrease from 0.115tce to 0.112tce; for steel, the ambition is to reduce it from 0.605tce to 0.580tce per tonne produced. Moreover, the 12FYP also forecasted cement and crude steel outputs to reach 2.2 billion tonnes and 0.75 billion tonnes respectively in 2015. Meanwhile, by 2015, the production of both cement and steel is expected to increase to 2.20 billion tonnes and 0.75 billion[48] tonnes, respectively, according to the 12FYP. Below we estimated the coal savings from efficiency improvement in production (see below chart).

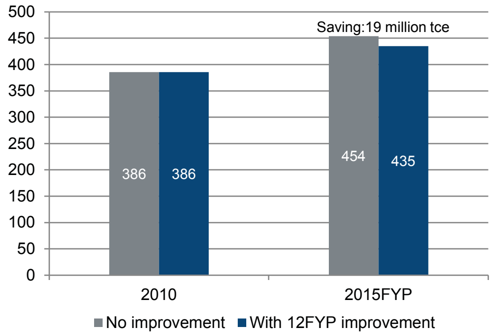
- **No improvement** - we assume the efficiencies in 2015 remain at the current level; and
- **With 12FYP improvement** – we assume the target set by the government to be achieved by 2015.

12FYP Planned Efficiency Gains in Cement Industry
Unit: million tce



Source: China Water Risk estimates based on 12FYP

12FYP Planned Efficiency Gains in Steel Industry
Unit: million tce



Source: China Water Risk estimates based on12FYP
Note: values concern crude steel only

Expected gains remain limited as targets are not aggressive enough

As seen from the above chart, we could see potential energy savings of around 7 million tce in cement production and 19 million tce in steel due to energy efficiency improvement in the production processes. Despite the huge scale of production, the absolute energy savings from energy efficiency improvements seem limited.

These energy efficiency gains could in turn lead to water savings. For reduced coal extraction and coking, we estimate that efficiency improvement would help reducing water use by around 104 million m^3 annually compared to a BAU scenario. For power generation, in case all the electricity was generated in coal-fired power plants, the associated reduction of water consumption would be 22 million m^3. One should note that these estimations are based on the assumption that the final energy share of these products remains constant.

Although energy efficiency is improving, production is still going up

Total output grows faster than efficiency gains, therefore electricity is still on the rise

Many of these efficiency gains have been achieved through a “build large and efficient, shut small and inefficient” policy. In the 12FYP, China defined targets of outdated and excessive capacities to be shut down in 21 industrial sectors. Among others, these entail: 370 million tonnes of cement, 48 million tonnes of steel, 48 million tonnes of iron, and 42 million tonnes of coke between 2010 and 2015. Every year, MIIT has been issuing annual target and work plan of cutting down backward and excess production capacity in the 21 industries targeted in the 12FYP. The list breaks the capacity cut target down to the level of specific production line/equipment and specifies related industry, province and company. After the first three years of the 12FYP, China had already exceeded its initial ambitions for coke, cement, iron, and was very close to achieve it for steel. However, the total output of these industrial products grew faster than the efficiency gains, so that the absolute amount of energy consumed kept increasing.

Energy efficiency per tonne of products improved but total energy consumption keeps increasing: further strategies are required...

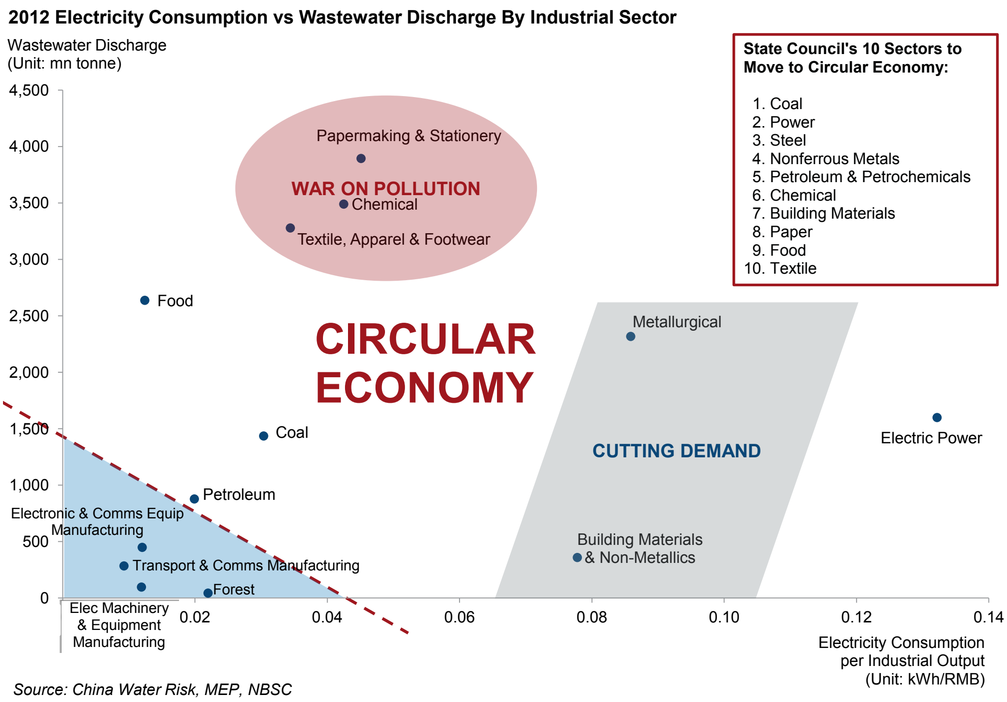
According to the latest official statistics released in February 2015, the energy consumption per RMB10,000 GDP in 2014 went down by 4.8% from the 2013 level. Energy consumption efficiency in industries also has been improving: the comprehensive energy consumption per tonne of crude copper, steel and cement in 2014 decreased by 3.76%, 1.65% and 1.12% from the 2013 level respectively. However, energy demand is still showing an upward trend. In 2014, the total energy consumption still went up by 2.2% and electricity consumption increased by 3.8%.

So as to reduce pressure on its limited resources, China has initiated strategies to further upgrade its industry, as described in the next section.

CIRCULAR ECONOMY IS THE ULTIMATE GOAL

... circular economy means less water, less energy, less resource waste and more recycling

To balance the economy & the environment to ensure long term prosperity, Beijing has no choice but to herd China's key sectors towards a circular economy. A circular economy means less water, less energy, less resource waste and more recycling - all crucial for China if it is to ensure economic growth with its limited resources. In February 2013, the State Council issued 'Circular Economy Development Strategies and Action Plan', which sets out details plans for developing circular economies across ten industries and China's industrial parks.



Source: China Water Risk, MEP, NBSC

China has no choice but to go circular

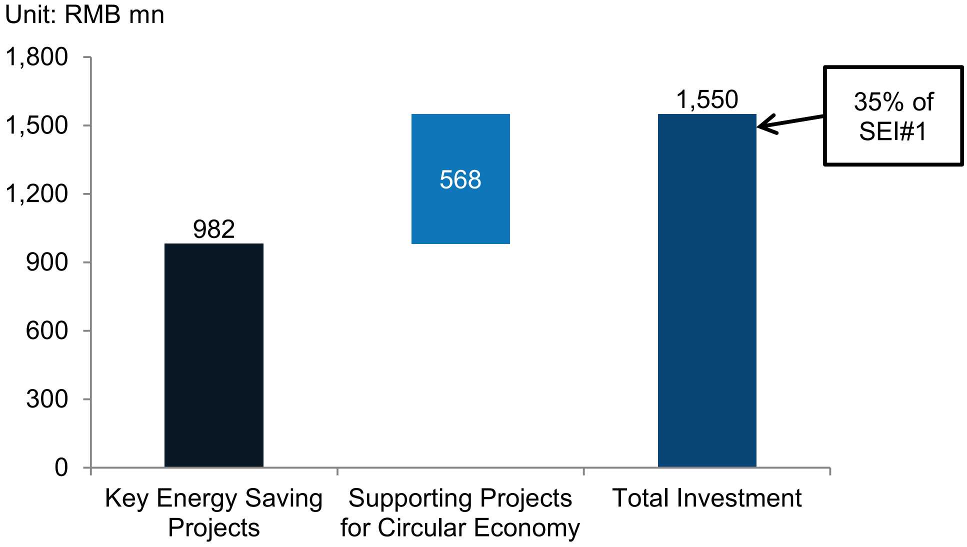
As shown in the above chart, the industries which are relatively more water-polluting and electricity hungry are exactly those that the Chinese government is targeting to move to a circular economy. In China, circular economy is not a "nice-to-do" as part of a water corporate stewardship strategy, it is a "must-do" to protect the environment and save energy.

RMB1.55 TRILLION TO FACILITATE THE TRANSITION TO GO CIRCULAR

RMB982 billion for key energy saving projects and RMB568 billion for the circular economy

In the State Council's 12FYP of Energy Saving, total investment for key energy saving projects is expected to be RMB982 billion, plus RMB568 billion for supporting projects in related industries for circular economy. Both combined is nearly 35% of the expected market size of SEI#1 (see chart below).

12FYP Investment on Energy Saving Projects



Source: China Water Risk, State Council

These efforts will eventually change China's industrial mix away from water and energy intensive industries

These efforts, together with the development of seven SEIs, will eventually change China's industrial mix towards high-end manufacturing away from low-tech more water and energy intensive industries. This will also materially change the total energy demand.

KEY DIRECTIONS OF CIRCULAR ECONOMY FOR COAL, POWER AND STEEL SECTORS

State Council issued circular economy roadmaps for ten industries including coal, power and steel

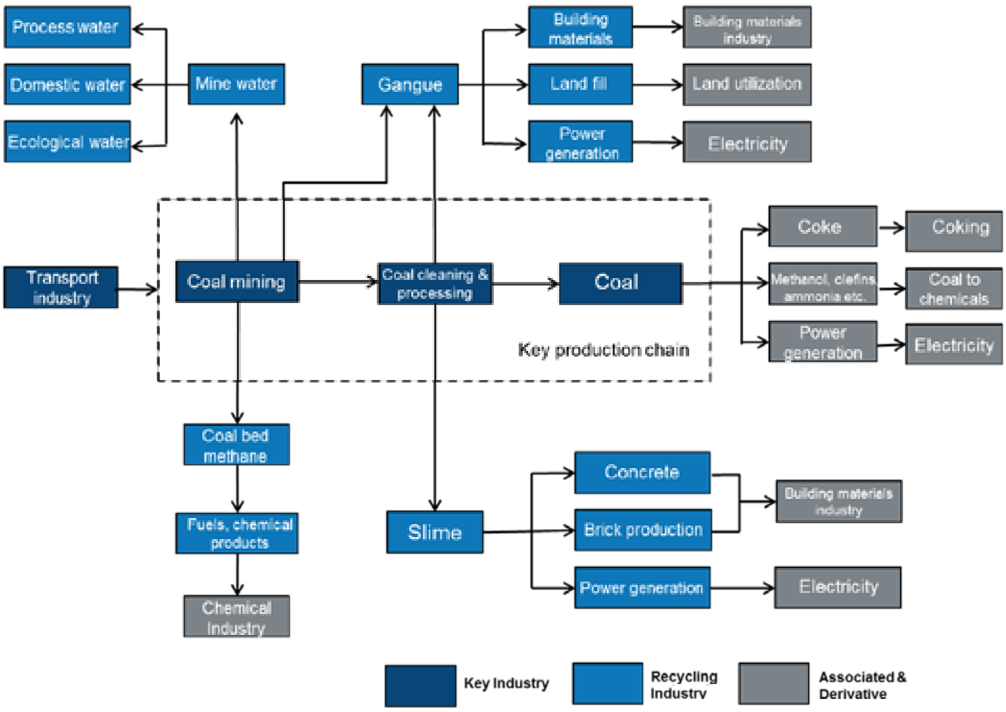
The State Council's circular economy guidelines have shown clear roadmap for each of the ten industries. Below we use the circular economy plans for the coal, power and steel sectors to demonstrate the key directions of the government policy.

Coal sector to be cleaner and more efficient in power and water

Plan promotes reduction and reuse of waste from coal mining

The plan promotes waste reduction and utilization of waste from coal mining in other sectors such as building, power generation, chemicals (see below chart).

COAL INDUSTRY
STATE COUNCIL'S CIRCULAR ECONOMY DEVELOPMENT STRATEGIES & ACTION PLAN



Source: State Council's 'Circular Economy Development Strategies and Action Plan' 2013

It also sets the following targets by 2015:

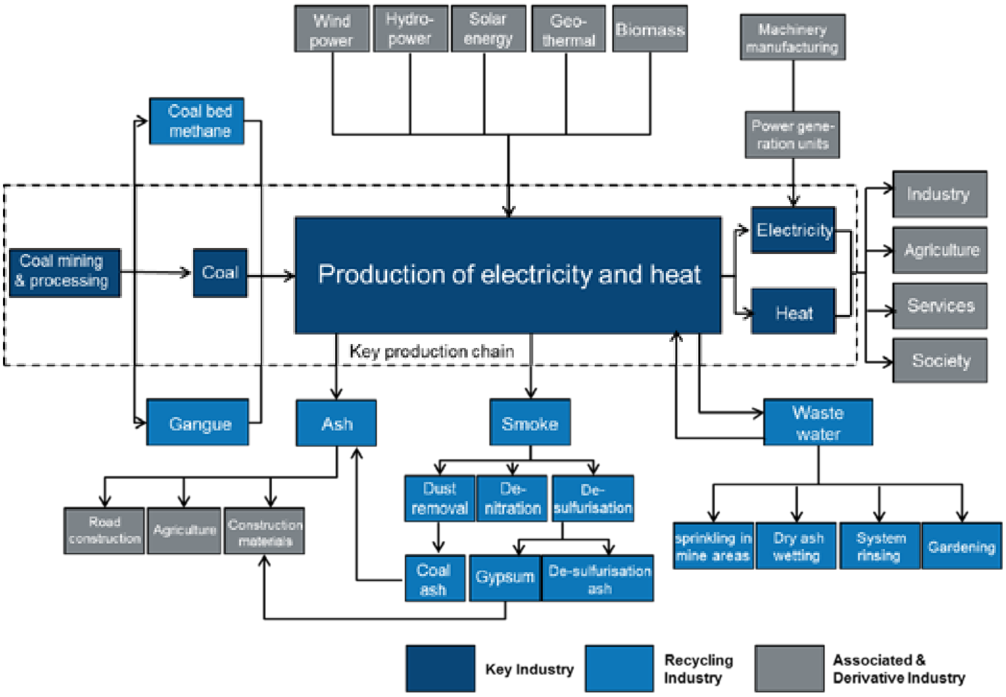
- Mine water utlization rate to reach 75%;
- Raw coal wash rate to reach 60% and installed power generation capacity from coal with lower heat value to reach 76GW, which is almost 8% of coal-fired power installed capacity by 2015;
- Coal bed methane utilization rate to reach 60% and installed power generation capacity from coal bed methane to be 2.85GW; and
- Mine area land recovery rate to reach 60%.

Power sector to produce cleaner energy

The power sector is required to improve efficiency, shutdown backward capacity, upgrade grid and recycle waste

The plan promotes power generation efficiency improvement, cutting down backward generation units, grid upgrading and waste recycling in other sectors such as building (see below chart).

POWER INDUSTRY
STATE COUNCIL'S CIRCULAR ECONOMY DEVELOPMENT STRATEGIES & ACTION PLAN



Source: State Council's 'Circular Economy Development Strategies and Action Plan' 2013

Key points to note are:

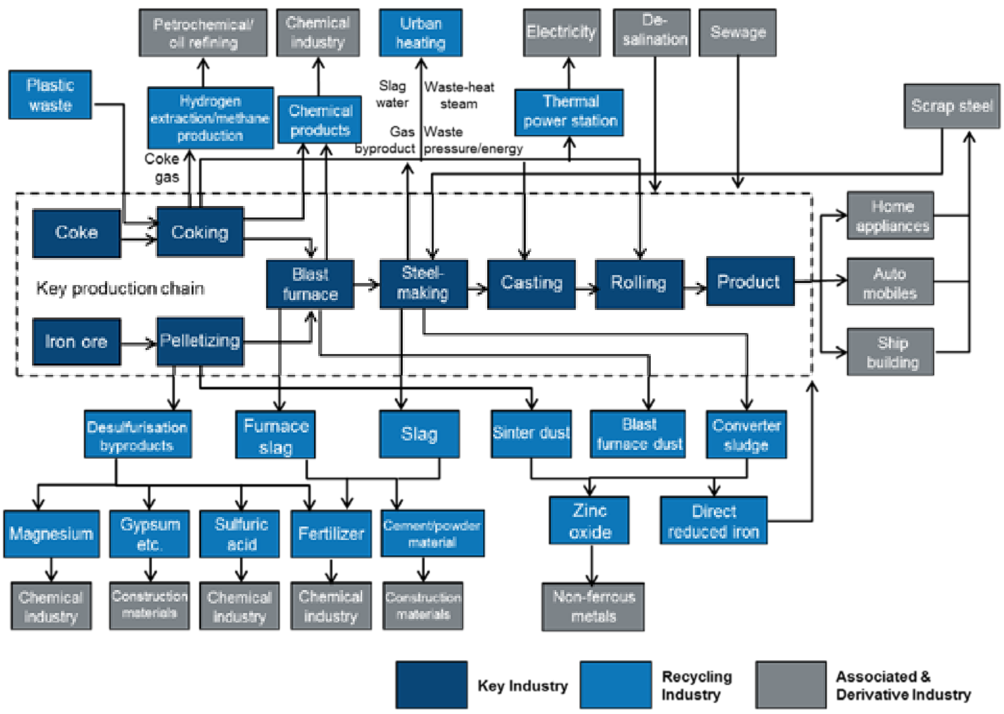
- Renewables such as wind power, hydropower, solar energy, geothermal and biomass are all important parts of the power sectors to provide clean energy;
- For coal-fried power generation, being the vanguard, the key tasks are to promote cleaner and more efficient utlization of coal, to reduce water consumption and to recycle waste and wastewater; and
- Target to reduce the average coal consumption in thermal power generation to 325gce/kWh by 2015. We are glad to see that the average coal consumption per kWh power generation has already dropped to 319 gce/kWh in 2014.

Steel sector: all about energy savings and resource recycling

Targets on coal, freshwater consumption and scrap recycling

The plan promotes comprehensive utilization of iron ores, cutting down of backward capacity and recycling of waste & heat in both production and other sectors such as building and chemicals (see below chart).

STEEL INDUSTRY
STATE COUNCIL'S CIRCULAR ECONOMY DEVELOPMENT STRATEGIES & ACTION PLAN



Source: State Council's 'Circular Economy Development Strategies and Action Plan' 2013

The plan set the following targets:

- To reduce the average coal consumption per tonne of steel to 580kgce;
- To reduce freshwater consumption per tonne of steel to 4m^3 by 2015; and
- To recycle 130 million tonnes of scrap steel annually by 2015.

ENERGY SAVINGS – UPHILL BATTLE TO GO CIRCULAR

Substantial gains have been achieved but energy consumption of industry is still growing

As shown in this section, there are mixed results from government efforts in promoting energy savings. China has achieved substantial gains in terms of industrial energy efficiency in the last decade, particularly during the 12FYP. However, as the total industry production is still growing and outpacing the efficiency gains. Energy consumption of industry is still increasing in absolute terms.

With many of the coal bases and energy bases sitting in water scarce regions as well as competing for water with major agriculture production regions, the management of energy, water and food is key. Moreover, public concern over air pollution and water pollution is on the rise, leaving the government with no choice but to cut energy demand. Thus, China needs to save energy in order to keep within the cap on total coal consumption and keep greenhouse gas emissions down.

This can be achieved through various measures such as improving power generation efficiency, cutting industrial energy demand and reducing electricity losses in the grid during transmission.

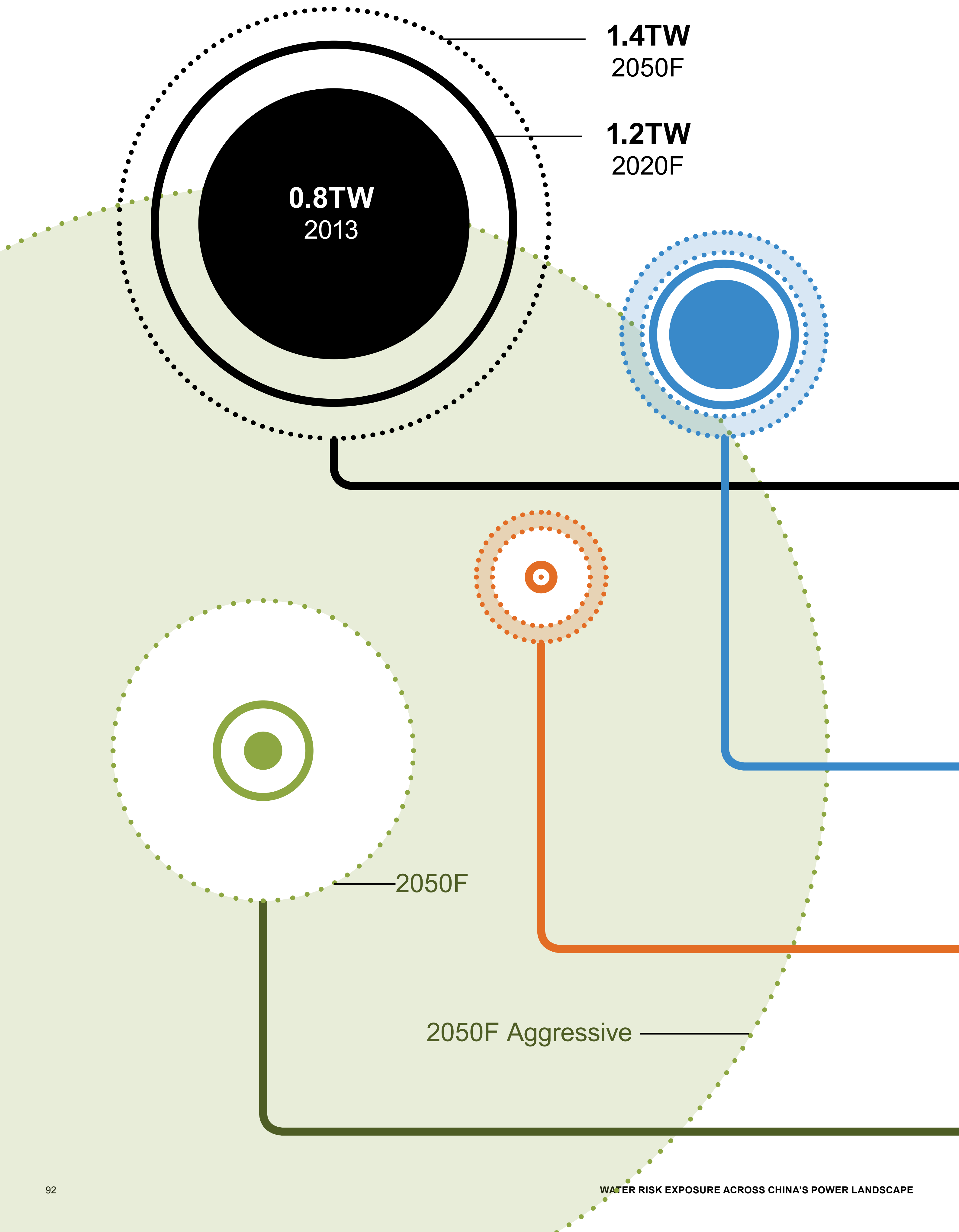
Saving energy is an uphill battle and a mammoth task

It will be an uphill battle and a mammoth task. It does not only require different government bodies but also all industrial sectors to work together to move towards a circular economy. While managing water risks in energy production and industry, we must also keep in mind climate risk as well as geopolitical risk which might arise due to the tapping of transboundary rivers.

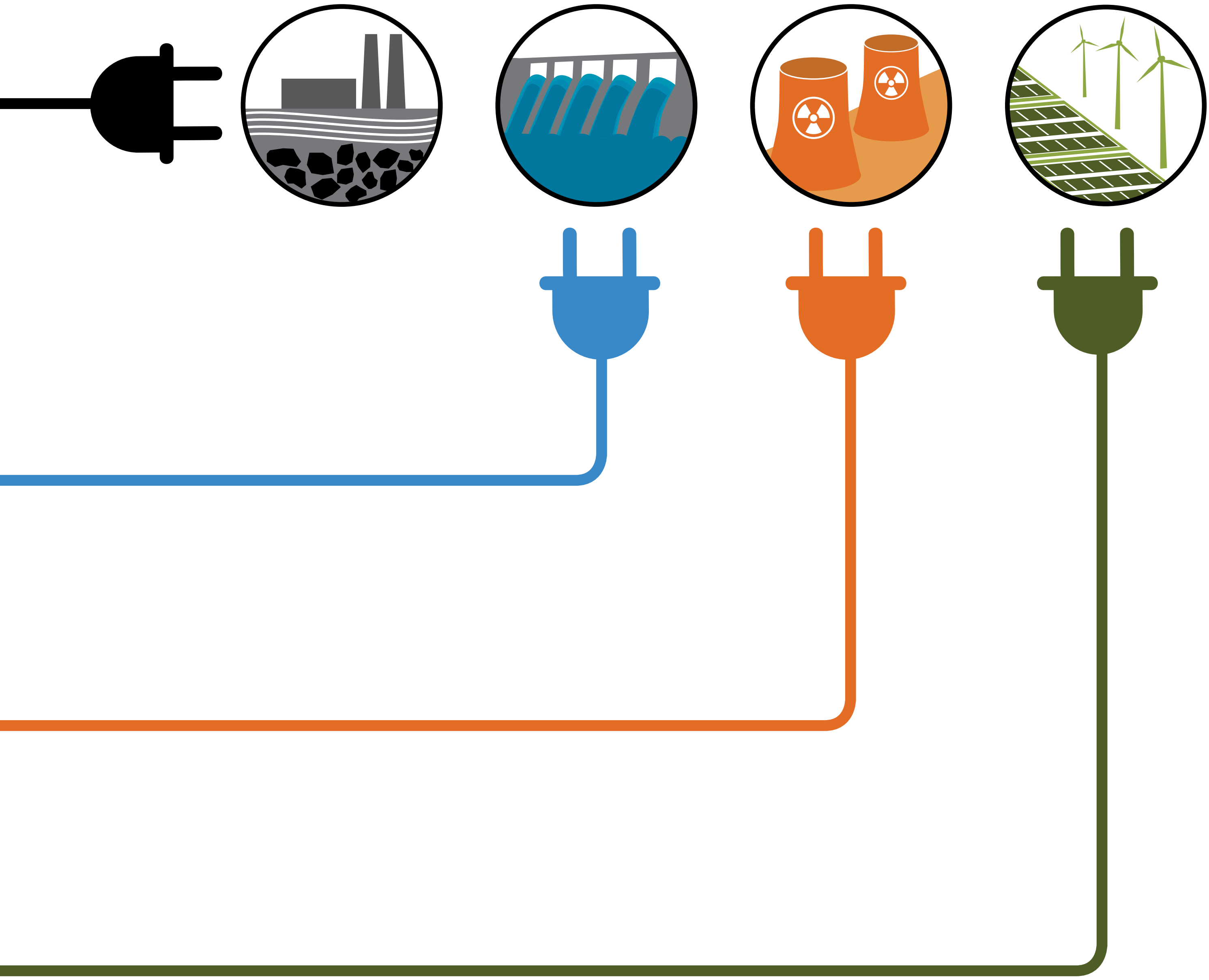
Slowdown of GDP growth could help China move to a circular and more sustainable economy

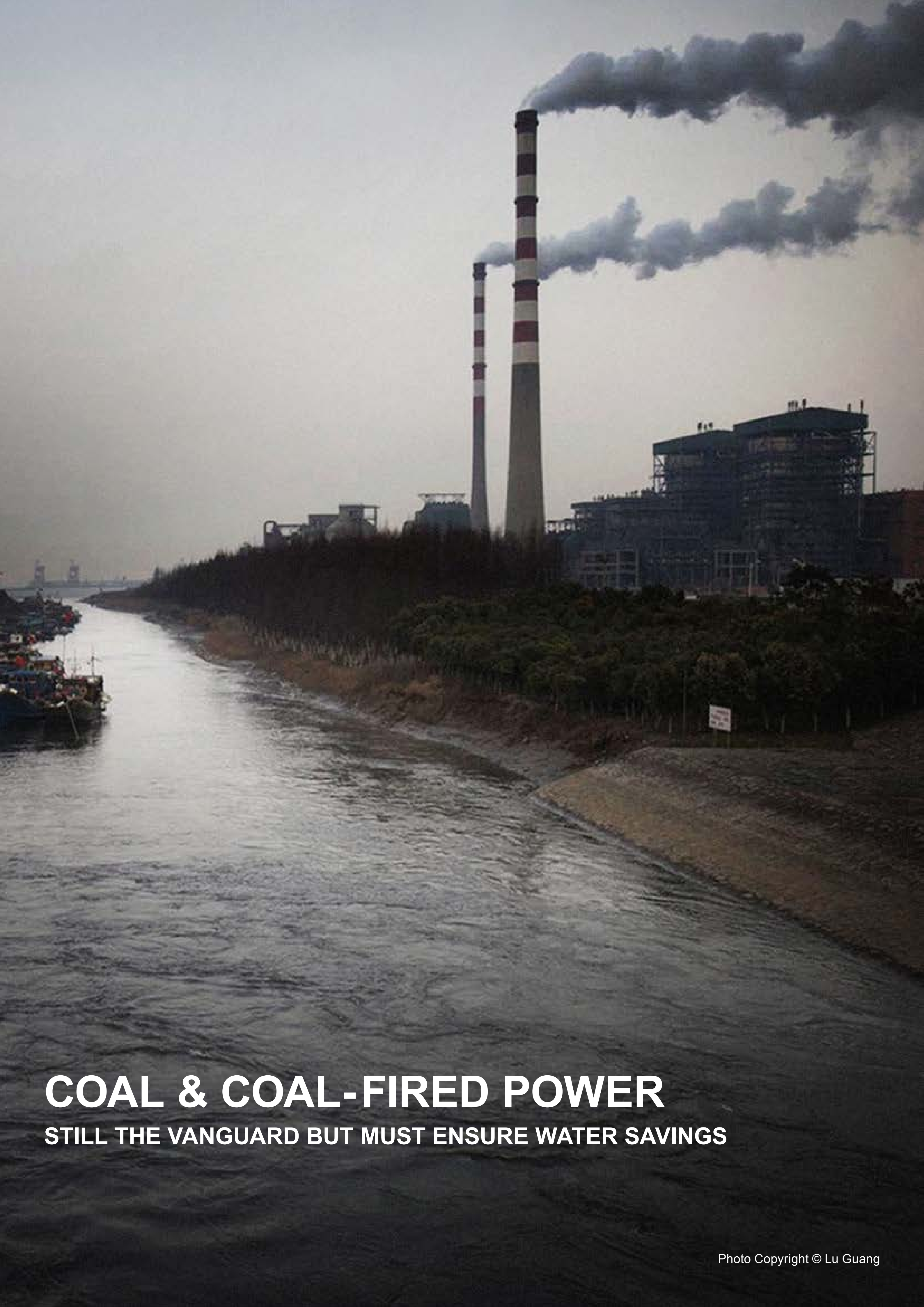
More broadly, China is undergoing a transition period of economic development. The slowdown of GDP growth could help reduce energy demand. Yet, for China to further curb its energy consumption, it has no choice but to optimise its industrial mix and move towards a less energy intensive economy. This will mean further savings in water resources. The slowdown provides the opportunity for China to reset its current model of growth and move to a "circular economy", making sectors cleaner and more resource-efficient.

We expect the government's "battle" in energy conservation to continue in 2015 and into the 13FYP. Although the economy might "suffer" in short-term, such efforts could transform the whole economy; and in the long run move China towards a more sustainable economy.


1.4TW
2050F
1.2TW
2020F
0.8TW
2013
2050F
2050F Aggressive

WATER RISK EXPOSURE ACROSS CHINA'S POWER LANDSCAPE





COAL & COAL-FIRED POWER

STILL THE VANGUARD BUT MUST ENSURE WATER SAVINGS

- Despite concerns over air quality, coal remains the vanguard as China's vast coal reserves provide the nation with energy security. China is the No.1 producer with over half of global coal output in 2013. Coal production fell in 2014 to 3.87 million tonnes and coal consumption, which had been rising, also dipped to 3.51 billion tonnes, due to weak industrial demand and aggressive energy savings strategies.

- The temporary fall in coal consumption and output gives the illusion of peak coal whereas in reality, State Council's 2020 coal consumption target announced in November 2014 of 4.2 billion tonnes allows for +690 million tonnes in coal consumption. This is more than the entire 2013 coal production of India, the 3rd largest coal producer in the world at 605 million tonnes.

- Nevertheless, despite of the increase in coal in absolute terms, coal share of total installed capacity at 66% in 2012 is expected to fall to 58% by 2020 and 42% by 2050, in line with President Xi's promise. Coal's share in China's primary energy consumption will also fall accordingly from 66% in 2014 to 62% by 2020. Analysis of various projections of coal consumption indicates that a business-as-usual approach cannot continue if China is to stay within the 4.2 billion coal cap by 2020.

- The latest statistics show that three-quarters of China's coal is used in conversion, whereas a quarter is consumed directly by industry and household users. Power generation is the largest user of coal accounting for over half of China's coal consumption or 67% of coal in conversion; followed by coking (20%), heating (7%) and coal-to-chemicals (5%).

- State Council has indicated that coal used in power generation is set to rise to 60% by 2020 due to expansion of China's coal-fired fleet. This is forecasted to be 1.2TW by 2020; greater than the US's installed power generation capacity today. With material expansion in coal-fired installed capacity in water scarce regions and a high reliance of China's top GRP earning provinces on thermal power, increasing efficiency and controlling water use in coal-fired power generation are crucial.

- In a bid to better control coal mining and processing as well as coal-fired power generation, China is consolidating coal production into 14 large coal bases and expanding the nine large coal-fired energy bases to 16. Nine of the coal bases and thirteen of the coal-fired energy bases lie in water challenged provinces. Upon consolidation, China will manage water resources in large coal bases with the MWR's Water-for-Coal Plan. In short, regional water availability will dictate future coal base development.

- This is because limited water threatens energy security: 84% of ensured coal reserves sit in water challenged regions. China has been shifting coal output away from water scarce regions but this only depletes coal reserves in water rich regions leaving a larger share of coal reserves in water scarce regions. Analysis of water exposure in Coal Base Provinces also shows that they not only use more water than the national average, but that they are highly reliant on groundwater.

- The Water-for-Coal Plan also tries to control groundwater use and water efficiencies in power generation by prohibiting the use of groundwater with the exception of mine drainage and recommending dry cooling in water scarce regions. Our analysis show that opting for dry cooling for new coal-fired power plants in water scarce regions could save up to 2.5 billion m^3 of water but at a cost of +42 million tonnes of CO_2.

- Technology choices matter, wet cooling (closed loop, once-through) and dry cooling have different implications for water and carbon trade-offs. Even within coal-fired power, there are tough choices to be made in the water-energy-climate nexus. Despite the fact that there are mixed views over the amount of water used to mine and process coal, what is clear is that controlling water use in coal-fired power generation holds the largest potential in water savings along the entire coal chain.

COAL & COAL-FIRED POWER
STILL THE VANGUARD BUT MUST ENSURE WATER SAVINGS

DESPITE CONCERNS OVER AIR QUALITY, COAL REMAINS THE VANGUARD

Public concerns over air pollution, resources scarcity and climate change are rising

Concerns over air pollution, resources scarcity and climate change have been growing in the last few years. A recent documentary on smog called "Under the Dome" by Chai Jing, a famous Chinese journalist, received over 100 million views within 36 hours after its debut online[49]. The documentary inspired millions of people across the country to pay more attention to air pollution as well as other environmental issues such as water pollution and soil pollution. Launched right before the third session of the National People's Congress during 5-15 March 2015, Beijing certainly felt the serious concern of the public. Premier Li Keqiang, in his working report this year, called pollution the "*blight on people's quality of life and a trouble that weighs on their hearts*"[50].

Coal is under strong scrutiny with many caps and targets issued in recent years

With worsening air quality, coal has been under strong scrutiny and accordingly, many caps, targets and political commitments have been issued in recent years. Just last year, the 'Air Pollution and Prevention Control Action Plan' was implemented and the State Council moved to shut 2,000 small coal mines as well as cut coal production in several provinces such as Beijing, Tianjin, Guangdong and Zhejiang amongst others to zero. By November 2014, China's State Council issued the 'Energy Development Strategy Action Plan' (2014-2020) to reduce coal's share in the primary energy consumption mix from 66% in 2014 to 62% by 2020. Finally, there was also the landmark China-US Climate Change agreement in November 2014.

To achieve this, China has placed 2020 caps on (1) total primary energy consumption at 4.8 billion tonnes of standard coal equivalent (tce); and (2) total coal consumption at 4.2 billion tonnes. This has led many to believe that China will reach peak coal by 2020. Although this may be the case, this should not be mistaken for carbon emissions peak or that China's coal-fired power fleet will stop growing post 2020. Indeed, many experts have said it is not realistic to cut off coal consumption in China (see box below).

CONVERSATIONS ON COAL: CHINA NOT READY TO CUT COAL CHINA WATER RISK INTERVIEW WITH PROFESSOR XIE KECHANG

CWR: Many countries are facing pressures to reduce emissions. China has set an ambitious reduction target a few years ago and has been trying to make great strides towards it. Some Chinese organizations are now calling for "coal reduction" and "moving away from coal". But it seems you have different opinion?

XIE KECHANG: I think it's still too early for China to cut off coal. It will only send a wrong message to decision- makers. At the moment it is not realistic for China. The reason that meteorologists are calling for "moving away from coal" is that coal is the main contributor of greenhouse gas. I agree. But we will still use lots of coal in the near future and so we need to find ways to reduce the CO_2 emission from coal.

China's energy mix is dominated by fossil fuels, which accounts for 90% of primary energy consumption; of the fossil fuel consumption, coal represents a 76% in 2013. If we want China to move away from coal, then what will China replace coal with? The current share of renewables in the energy mix is only 10% (hydropower 7% & other renewables 3%); what other energy sources can supply the 90%?

This is why President Xi has mentioned many times that coal is and will remain China's primary energy source; therefore he expects us to more focus on its better utilization.

Source: The above is an excerpt from a China Water Risk interview with Professor Xie Kechang, Vice President of the Chinese Academy of Engineering, April 2015

Coal is exposed to water risks but experts have mixed views over the magnitude of risk

Whilst there is much focus on air quality and carbon emissions due to the China-US Climate Change agreement, there is much work to be done on the water front. As discussed in the previous Chapter 4: "Ensuring Food & Energy Security", many of China's large coal bases and energy bases are located along the Yellow River basin, in some of China's major farming provinces. With limited water resources in these regions, innovative water trading pilots have come out in the region to transfer agriculture water savings to energy bases. The competition for water resources between agriculture and energy production is evident and many including ourselves have questioned whether there is sufficient water to ensure energy security. There are however, various mixed views as to exactly how much water is being used and therefore magnitude of the water risk exposure.

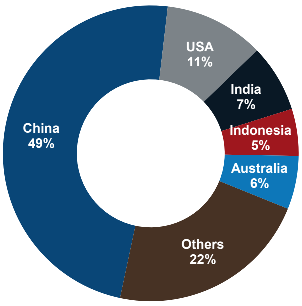
In this section we will discuss the future of China's coal, whether it is peaking, the expansion of coal-fired installed capacity and its water risks. We will look at the 'Water for Coal Plan' vis-à-vis the projected coal output and coal-fired power generation and try to "guesstimate" the water required and potential savings through several water saving scenarios along the coal chain as recommended by the 'Water-for-Coal Plan'.

China's vast coal reserves is one of the main reasons why coal remains the vanguard

CHINA'S COAL RESERVES PROVIDE ENERGY SECURITY & CHINA DOMINATES IN GLOBAL COAL

To be energy secure means not having to rely on another country for fuel. China's vast coal reserves ensure this and is one of the main reasons why coal remains the vanguard.

2013 Global Coal Production = 8,185 mt

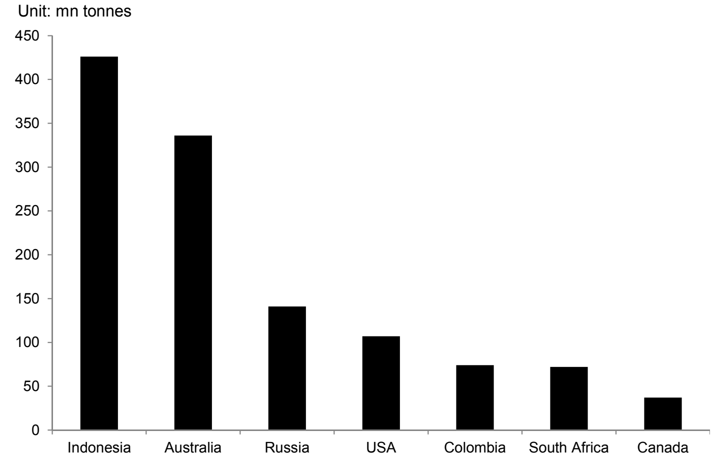


Source: China Water Risk, BP & NBSC

China is the world's No.1 coal producer, consumer and importer. In 2013, global coal production was at 8.2 billion tonnes. China is clearly in the lead producing 3.97 billion tonnes or a share of 49% of global production; it is materially ahead of US which has an 11% share at 893 million tonnes (see chart on the left).

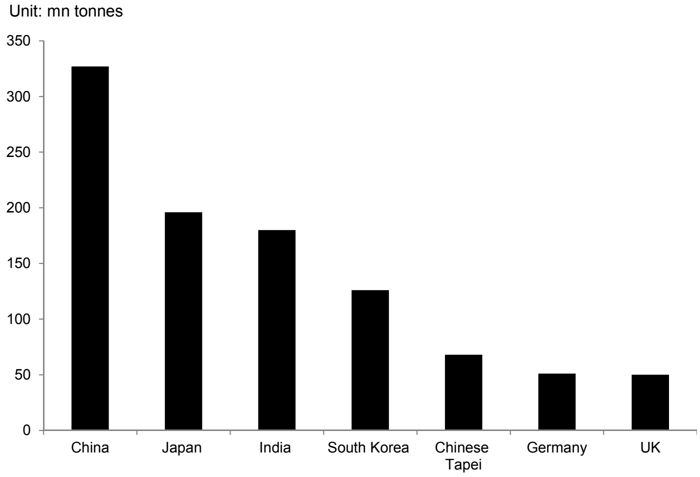
However, China only consumed 3.6 billion tonnes of coal in 2013. At the same time, it also imported 327 million tonnes of coal and exported 7.5 million tonnes, implying a stockpile of nearly 680 million tonnes. As shown in the charts below, China is the #1 importer of coal whilst Indonesia is the main exporter.

2013 Global Top Coal Exporters



Source: China Water Risk, World Coal Association

2013 Global Top Coal Importers



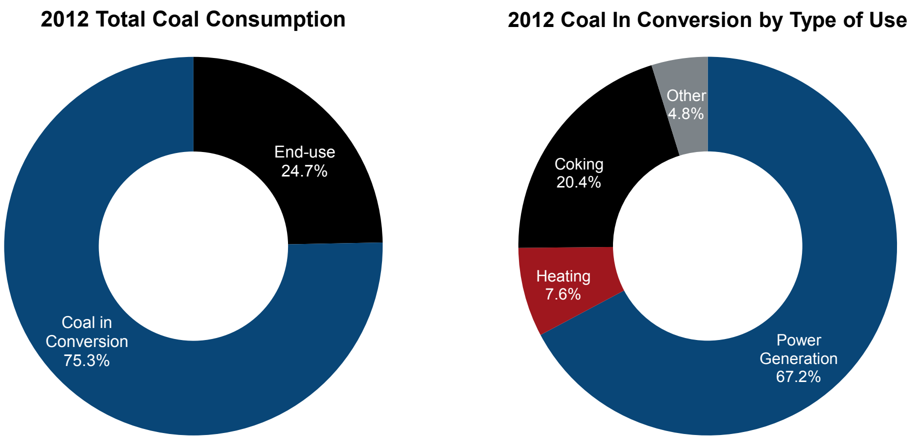
Source: China Water Risk, World Coal Association

POWER GENERATION ACCOUNTS FOR OVER HALF OF CHINA'S COAL CONSUMPTION

75% of coal is used in conversion

The latest available data for coal use in China is 2012. For that year, 75.3% of total coal is used in conversion, and 24.7% of total coal is consumed directly by industry and household users. Of the coal in conversion, 67.2% is used in power generation, 7.6% in heating, 20.4% in coking and other intermediate users such as coal-to-chemicals account for 4.8% (see charts below).

Power generation is the larger user followed by coking and heating...



Source: China Water Risk, NBSC

However, if we look at the whole coal consumption pie, even after taking other end-users in to account, power generation still accounts for 50.7% of total coal consumption. Power generation is expected to continue to drive coal consumption. According to the State Council's 'Energy Development Strategic Action Plan', this percentage is expected to rise to 60% by 2020 (more on this later in this chapter).

It is important to note here that whilst there is significant scrutiny placed on the coal-to-chemicals industry and their water use, in reality although water intensive, coal-to-gas only accounts for 0.2% of coal consumed in conversion and coal-to-liquids an even smaller portion at 0.1%. Curbing coal-to-chemicals expansion will ease water use in coal bases but coal mining and preparation as well as coal-fire power hold the largest potential in water savings.

...therefore saving water and cutting coal are all about reducing coal-fired power generation & coking coal demand

Power generation clearly drives coal consumption and as shown in Chapter 2: "China's Water Energy Nexus", it is clearly the largest industrial user of water. Therefore saving water and cutting coal are all about reducing coal-fired power generation followed by reducing coking coal which inputs into other industries such as cement and steel. As discussed in previous Chapter 5: "Battle to Conserve Energy", aside from cutting coal-fired power demand, controlling the output of the cement and steel sectors could also have a material impact on China's coal consumption. Moreover, there are double gains as cement and steel are also large users of power. For more details see optimizing industry mix in Chapter 5: "Battle to Conserve Energy".

TEMPORARY FALL IN OUTPUT & CONSUMPTION GIVES ILLUSION OF PEAK COAL

The fall in coal production in 2014 resulted from excessive production in 2013, consolidation of coal mines, energy savings and increasing coal imports & stockpiling

Numbers released in late February 2015 show that both coal output and coal consumption have fallen in 2014, reinforcing media speculation that coal consumption and production has peaked. Coal output fell 2.5% from 3.97 billion tonnes in 2013 to 3.87 billion tonnes in 2014, whilst coal consumption fell 2.9% from 3.61 billion tonnes in 2013 to 3.51 billion tonnes in 2014. Before we celebrate 'peak coal' it should be noted that the fall in coal production is expected as coal output in 2013 exceeded the 12FYP target of 3.9 billion tonnes. Aside from meeting the 12FYP target, coal output also fell for the following reasons:

- Consolidation of coal mines: the government has been ordering the shutdown of small & "backward" coal mines which are usually inefficient and polluting. On 12 May 2014, 12 central government bodies including the MEP, NDRC, MLR, MoF and NEA jointly issued a Circular on 'Stepping Up Efforts to Shut Down Small Backward Coal Mines', aiming to close down 2,000 small & "backward" coal mines across the country by the end of 2015;

- Efficiency gains in power generation: coal demand is primary driven by power generation. As the efficiency in power generation improves, the relevant coal demand also slows down accordingly;

- Cutting demand from coal-reliant industries such as cement and steel by shutting down excess production capacity; and

- Increasing coal imports & stockpiling: China has become a net coal importer since 2009, as China recovers from the financial crisis in 2008. With cheap coal prices, we may see China continue to stockpile to ensure buffer to insulate against the impact of droughts and floods as described in the previous chapter. Efficiency gains and cuts in excess capacity in coal and coal related industries are discussed in Chapter 5: "Battle to Conserve Energy".

Coal consumption might fall further due to weak industrial demand & aggressive energy savings...

Some of the above also explain the fall in coal consumption. The slowdown in the economy has also affected industry which accounts for 85% of electricity consumption (see Chapter 2: "China's Water Energy Nexus"). As industry cuts back on electricity consumption, some provinces might be faced with excess capacity. Managing these imbalances so that they are "not wasted" is important optimising energy efficiency is covered in Chapter 5: "Battle to Conserve Energy".

...but primary energy consumption will still grow

Due to a combination of weak industrial demand and aggressive energy savings we expect coal consumption to stay flat or fall further in 2015. However, although the economy is not expected to return to double digit growth, it's perhaps still too early to say coal has "peaked". State Council in November 2014, announced a coal consumption cap at 4.2 billion tonnes by 2020 and recent rhetoric during the 12th National People's Congress also indicate that primary energy consumption is still growing, albeit at a slower rate.

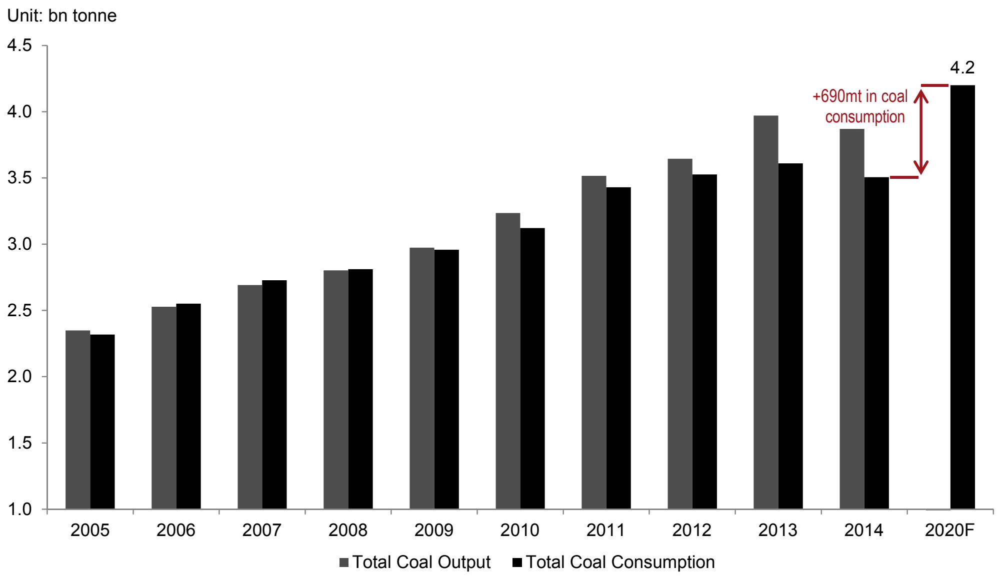
2020 COAL CAP ALLOWS FOR +690 MILLION TONNES IN COAL CONSUMPTION

State Council's coal consumption cap at 4.2 billion tonnes allows for +690 million tonnes from 2014 to 2020

Going forward, State Council has capped coal consumption at 4.2 billion tonnes in 2020. Coal consumption in 2014 is 3.51 billion tonnes. The coal cap at 4.2 billion tonnes means there could be an absolute increase in consumption of around 690 million tonnes by 2020. This is more than the entire coal production of India of 605 million tonnes in 2013, the 3rd largest coal producer in the world.

Coal consumption although currently falling, is likely to continue to rise to 4.2 billion tonnes by 2020. Assuming that all of this 4.2 billion tonnes of coal is produced domestically, coal output could increase by around 330 million tonnes between 2014-2020. This is sizeable – it is equivalent to over a third of US coal production in 2013 of 893 million tonnes.

2005-2020F China's Total Coal Output vs Total Coal Consumption



Source: China Water Risk, NEA, NBSC

DESPITE COAL INCREASE, COAL SHARE FALLS IN LINE WITH XI'S PROMISE

PRESIDENT XI'S DECLARATION

"...the Presidents of the United States and China announced their respective post-2020 actions on climate change, recognizing that these actions are part of the longer range effort to transition to low-carbon economies, mindful of the global temperature goal of 2°C....China intends to achieve the peaking of CO_2 emissions around 2030 and to make best efforts to peak early and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030."

China-US Joint Announcement on Climate Change, Beijing, 12 November 2014

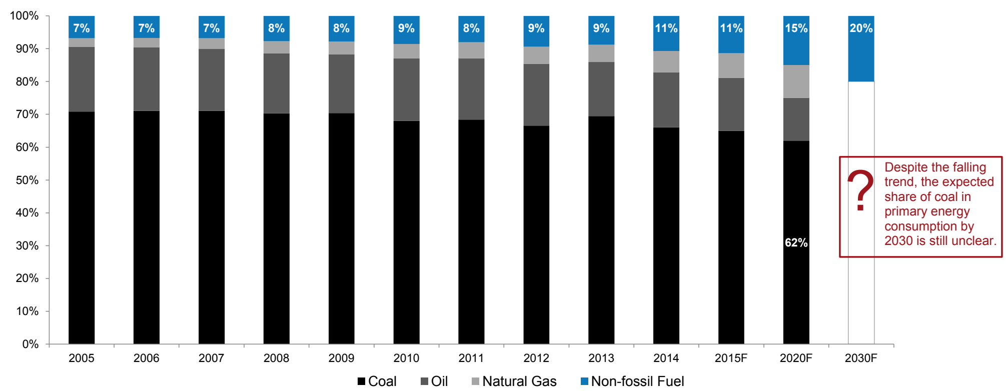
Coal share of total installed capacity is 66% in 2012. This is expected to fall to 58% by 2020, primarily due to aggressive nuclear add and further to 43% by 2050 with the significant additional capacity in wind and solar. This is in line with the fall of coal's share in primary energy consumption as promised by President Xi.

Coal's share in China's primary energy consumption has fallen since 2005...

As per the China-US Climate Change agreement, fossil fuels' share in China's primary energy consumption should further decrease and reach 80% by 2030. As seen from the chart below, coal share of China's primary energy mix has shown an overall falling trend since 2005. The fall has accelerated in recent years and going forward, the share of coal in primary energy will continue to shrink. In 2014, coal share of primary energy consumption in China stood at 66% and is planned to further decrease to 62% by 2020.

...but its share in energy mix was still 66% in 2014, which is expected to fall to 62% by 2020

2005-2030F China's Primary Energy Consumption Mix (%)

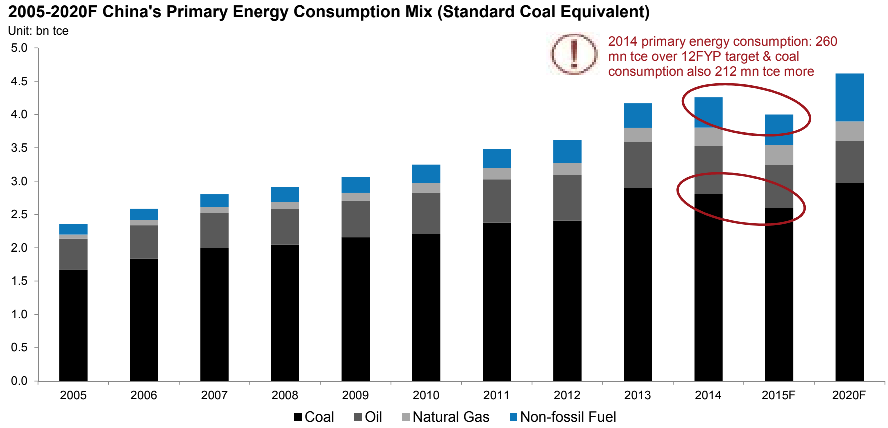


Source: China Water Risk, NBSC, State Council

It is important to note at this point however that despite the acceleration in the change in mix, coal consumption in absolute terms is still rising as shown in the chart below:

Despite a fall in share, coal consumption is still rising in absolute terms

2005-2020F China's Primary Energy Consumption Mix (Standard Coal Equivalent)



Source: China Water Risk, NBSC, State Council

Key takeaways:

- Official statistics show that primary energy consumption reached 4.26 billion tce in 2014, increasing by 2.2% from 2013. This is 260 million tce more than the 12FYP target of 2.6 billion tce. According to the NEA, primary energy growth will grow 3.4% annually to 2020; thereafter it will slow down to about 2.3% between 2020 and 2030.[51] The important word to note here is "growth"; primary energy consumption is still rising albeit at a lower rate;

- It is also worth noting that despite the drop in coal consumption in 2014 by 2.9% from the 2013 level, the coal consumption in 2014 is 212 million tce more than the 12FYP. The drop in coal consumption has been partly offset by an increase of 26 million tce of oil and 59 million tce of natural gas in 2014; and

- Given the large increase of 486 million tce in coal consumption from 2012 to 2013, it makes sense that the government is now making extra efforts to cut coal in order to meet the 2015 target.

As can be seen, coal consumption can still rise in absolute terms but a high add of renewable energy: hydropower, solar & wind will help lower China's carbon reliance and meet President Xi's carbon promise, which although difficult maybe possible.

CAN CHINA DO BETTER THAN THE COAL CONSUMPTION CAP AT 4.2 BILLION TONNES BY 2020?

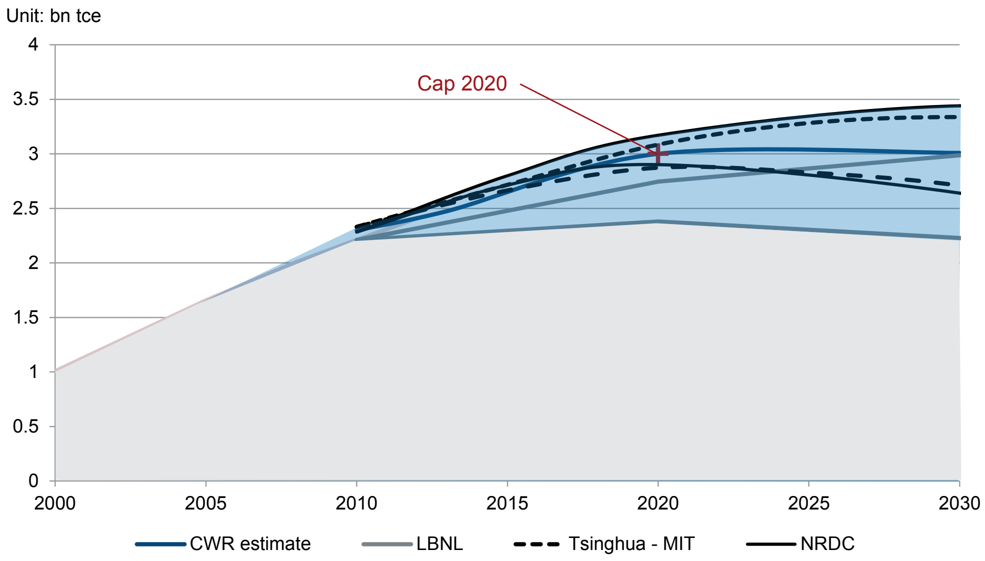
Numerous institutions are forecasting China's future coal consumption...

The future of Chinese coal consumption has drawn much attention from numerous institutions, either as part of global outlooks or Chinese specific. The latter include studies from Lawrence Berkeley National Laboratory (LBNL) (2013), Tsinghua-MIT (2014) and the NRDC (2014). All these studies created two scenarios (a base case and an aggressive case) with different levels of political commitments to curb coal consumption. These studies were conducted before the official announcement of the coal capping to 4.2 billion tonnes of coal consumption in 2020.

...the coal cap is achievable but will require additional non-BAU efforts

Interestingly, as shown in the chart below, we observe that this value lies in between the baseline and the most aggressive policies of the two most recent studies (Tsinghua-MIT & NRDC). In other words, according to these outlooks, although this coal cap is achievable, it will require additional efforts compared to a BAU approach. In this report, our CWR Base Case Scenario used in estimating future water use in mining assumes an intermediate scenario abiding with the 2020 coal consumption cap.

2000-2030F Various Projections of Coal Consumption Scenarios



Source: LBNL 2013, Tsinghua-MIT 2014, NRDC 2014

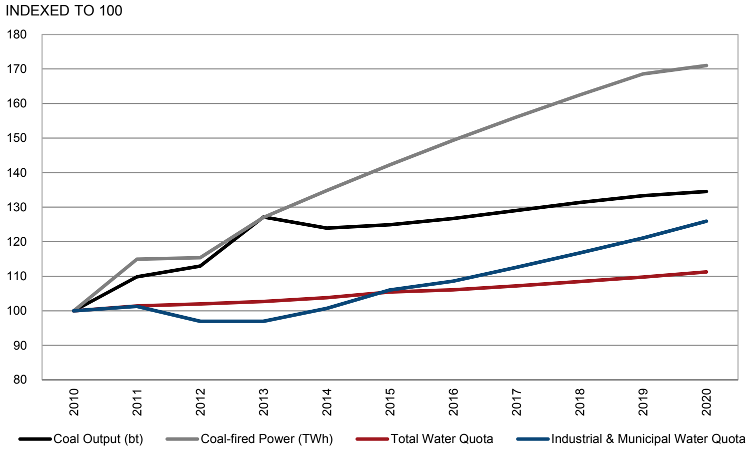
It is clear that a BAU approach cannot continue if China is to stay within the coal cap.

POWER GENERATION SHARE OF COAL TO RISE TO 60% = EXPANSION IN CHINA'S COAL-FIRED FLEET

Coal-fired installed capacity to be 1.2TW by 2020. This is greater than the installed capacity of the US

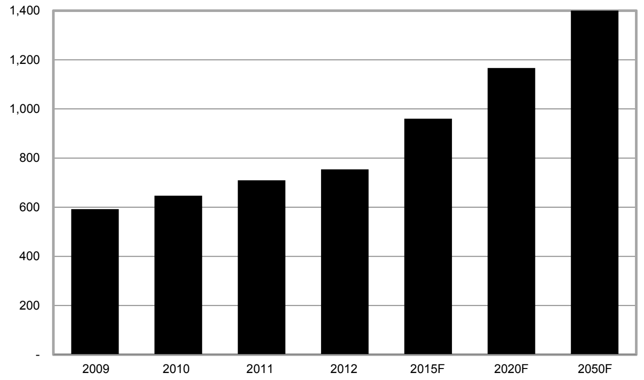
Currently, power generation accounts for around half of China total coal consumption but State Council has indicated that coal used in power generation is to rise to 60% in 2020. This is therefore a "double" increase in coal for power generation implying faster growth in China's coal-fired fleet relative to total coal consumption as seen from the chart below left. That said, there is currently no indication of coal-fired installed capacity under this plan. However, previous plans project installed capacity to be close to 1.2TW by 2020 and 1.4TW by 2050 compared to 754GW in 2013. At 1.2TW, China's coal fleet would be greater than the entire power generation installed capacity of the US today. The chart below right shows existing plans for growth in installed capacity in coal-fired power plants:

Coal Output & Coal-fired Power Growing Faster than the National Water Quota



Source: China Water Risk Estimates based on CEC, State Council

China Coal-Fired Installed Capacity Expansion 2009-2050F (GW)



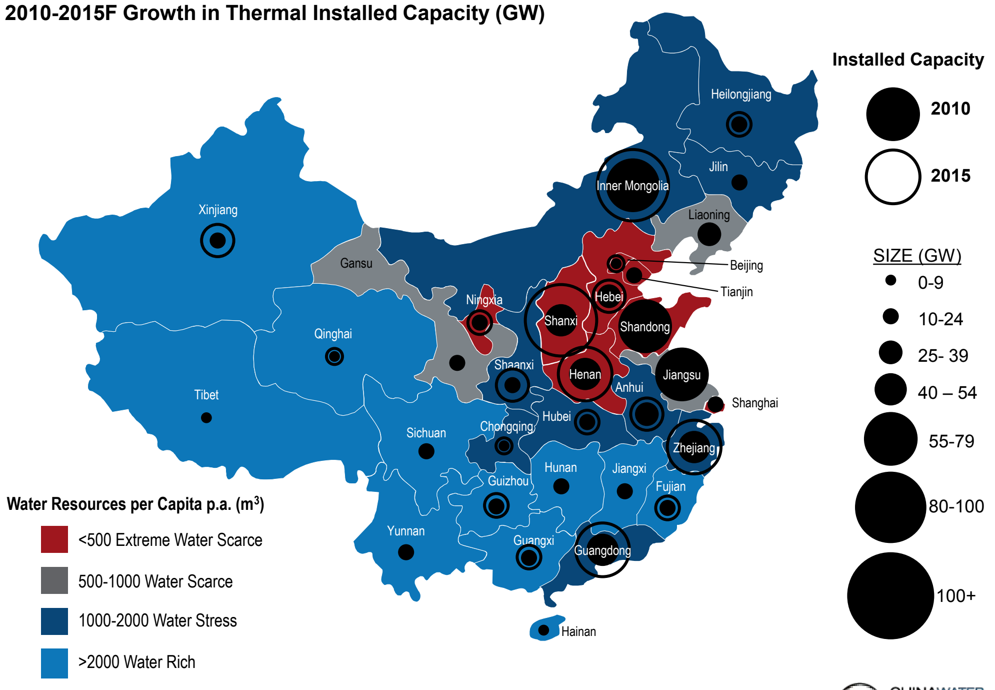
Source: China Water Risk estimates, CEC, NEA estimates, US EIA

2010-2015F NON-NUCLEAR THERMAL INSTALLED CAPACITY EXPANSION IN WATER SCARCE REGIONS

China's coal-fired power represented 92% of non-nuclear thermal installed capacity in 2012

Since power generation is expected to experience the fastest growth in the near term and uses considerably more water than coal mining, we analysed power build-out by province, mapped against available water resources in the map below. At a glance, it can be seen that significant non-nuclear thermal installed capacity expansion between 2010-2015 fall in regions that are water scarce, in particular Shanxi, Henan and Hebei. In 2012, coal-fired power generation installed capacity represented almost all (92%) of non-nuclear thermal installed capacity. It follows therefore that coal-fired power is vulnerable to water risks in particular in Coal Base Provinces.

2010-2015F Growth in Thermal Installed Capacity (GW)



Source: China Water Risk (based on China Statitical Year Book and Provincial 12FYPs)
Note: water resources are historical average values by provinces 2003-2013. Dry 11 denoted by red and grey shaded provinces

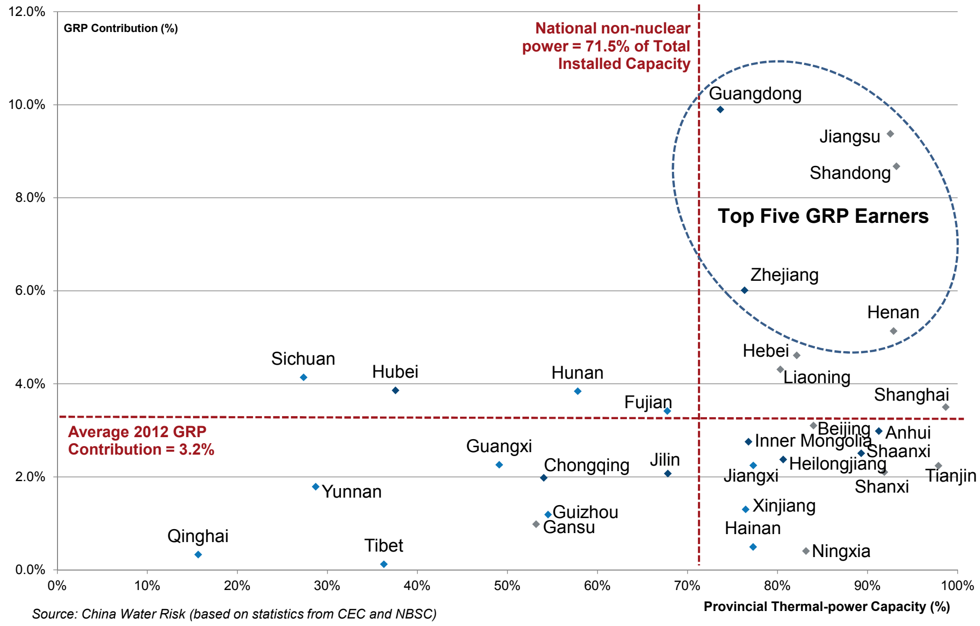
GDP AT RISK: CHINA'S TOP GDP EARNERS ARE HIGHLY RELIANT ON COAL-FIRED POWER

Top 5 GRP provinces are highly reliant on thermal power but three of them are water scarce

Since 85% of electricity is consumed by industry, it follows that large power using provinces are also those that drive China's economy. In order to gain insight into the magnitude of economic exposure to coal-fired power, we analysed non-nuclear thermal capacity against Gross Regional Product (GRP) for each province. From the scatter chart on the next page it is clear that China's Top 5 GRP earners are vulnerable to water risks:

- Top 5 GRP provinces' thermal power reliance range from 73.6% (Guangdong) to 93.2% (Shandong), higher than the national average of 71.5%;
- Three out of the Top 5, namely Jiangsu, Shandong and Henan, are water scarce but yet highly reliant on thermal power (all around 93%); and
- Together the Top 5 contribute 39% to China's national GDP.

Provincial Thermal-power capacity vs GRP contribution (2012)



Source: China Water Risk (based on statistics from CEC and NBSC)

CWR BASE CASE SCENARIO ESTIMATES POWER GENERATION TO BE 5,500TWH BY 2020

Given existing targets, we estimate coal-fired power generation at 5,500TWh in 2020

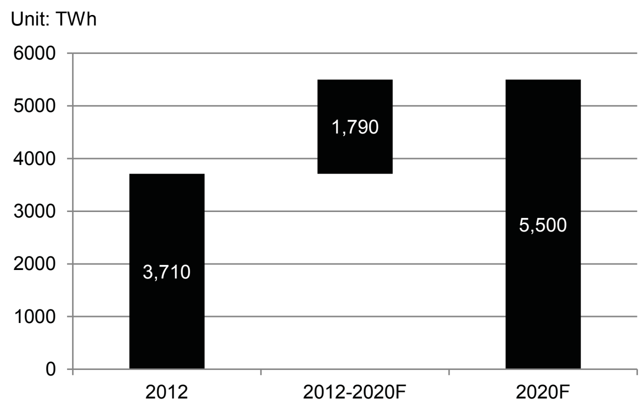
While there is no direct official target in terms of power generation from coal-fired power plants in 2020, we combined existing targets to produce a CWR Base Case Scenario. We estimate a total coal power generation of 5,500 TWh in 2020 after taking into account:

- The coal cap target in 2020 of 4.2 billion tonnes;
- The requirement that 60% of coal is used for power generation; and
- The improvement in the coal-fired power fleet as set by the NEA.

Our estimates are on the high side to establish baseline for water demand

5,500TWh by 2020 is in line with the CEC projections, whilst other institutions such as the NRDC, IEA and US EIA anticipate a lower value range from 4,500TWh to 5,400 TWh, depending on the aggressivenes of coal curbing policies. Although our estimates may be on the high side, we have used this as our base case so that we can obtain a baseline for water use and water consumption in power generation.

2012-2020F CWR Base Case Coal-fired Power Generation



Source: CWR estimates based on State Council and NEA

China is increasing the efficiency of its coal-fired fleet by shutting down inefficient units and building efficient ones

Although it is not clear if the installed capacity will expand in line with previous plans to 1.4TW, China is still increasing the efficiency of the fleet by shutting down outdated and inefficient coal power plants as discussed in the previous Chapter 5: “Battle to Conserve Energy”. Currently, the best technology is now in Shanghai Waigaoqiao Power Plant, which only uses 270g of standard coal equivalent to generate 1kWh; while, the national average is about 319 in 2014. Increasing efficiency can obviously help reduce coal consumption by electricity. China is also undergoing a significant exercise in energy savings – more details in Chapter 5: “Battle to Conserve Energy”.

Significant GDP exposure means no choice but to save energy, adapt its power mix, and ensure sufficient water for coal

With significant GDP exposure, China has to not only adopt energy savings strategies but also change the power mix by building out nuclear, hydropower, wind and solar as discussed in Chapter 3: “Balancing Power Mix for Water & Climate”. In the meantime, ensuring sufficient water for coal is key. Whether or not there is enough water for coal in China’s coal bases is a hot topic and numbers over water use in mining and power generation can vary widely. However, before we examine these, we first took a closer look at the locations of China’s coal reserves and coal bases as well as energy bases and their exposure to water issues.

CONSOLIDATE COAL BASES AND EXPAND COAL-FIRED ENERGY BASES

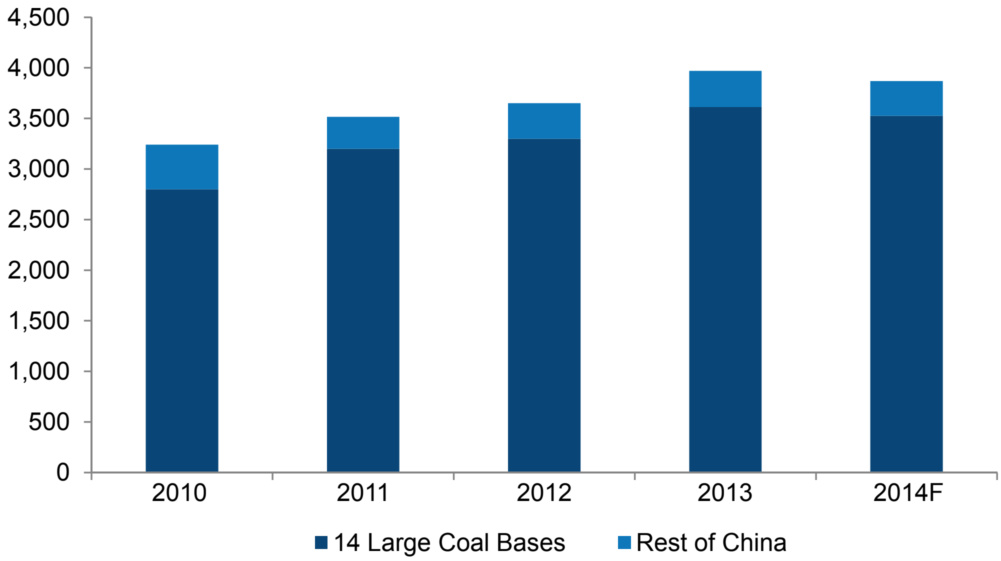
2020 target = 95% coal output in 14 large coal bases

Consolidation of coal production into 14 large coal bases to provide 95% of national coal output by 2020

China’s coal is primarily supplied by 14 large coal bases. China is trying to concentrate its national coal production in these bases. From the chart below, it is clear that in 2010, these 14 coal bases produced 87% of China’s total coal output but by 2013, accounted for 91% of the nation’s total coal output or 3.6 billion tonnes. We estimate that in 2014, although coal output from these bases fell to 3.5 billion tonnes, it still accounted for 91% of China’s coal output. By 2020, the government would like these 14 coal bases to provide 95% of the nation’s coal output.

2010-2014F Coal Production: 14 Large Coal Bases

Unit: bn tonnes



Source: China Water Risk estimates, NEA, NBSC

9 Coal Base Provinces are water challenged and 3 are running a water deficit

The 14 large coal bases are spread over 12 provinces and autonomous regions of Xinjiang, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Shandong, Hebei, Henan, Gansu, Anhui, Yunnan and Guizhou, as shown in the table below:

China's 14 Large coal Bases

No.	Coal Bases	Provinces	No.	Coal Bases	Provinces
1	Shendong	Inner Mongolia, Shaanxi	8	Henan	Henan
2	Mengdong	Inner Mongolia	9	Yungui	Yunnan, Guizhou
3	Jinbei	Shaanxi	10	Ningdong	Ningxia
4	Jinzhong	Shaanxi	11	Jinzhong	Hebei
5	Jindong	Shaanxi	12	Luxi	Shandong
6	Shanbei	Shaanxi	13	Lianghuai	Anhui
7	Huanglong	Shaanxi, Gansu	14	Xinjiang	Xinjiang

Source: NEA

Large coal-fired energy bases to expand from 9 to 16

With anticipated rise in electricity needs, the government intends to expand large coal-fired energy bases from 9 to 16

In addition to the previously mentioned 14 coal bases, the government also plans to develop large coal-fired energy bases. Currently there are nine such bases spread over six provinces of Inner Mongolia, Shanxi, Shaanxi, Ningxia, Xinjiang, and Anhui (see table below).

9 Existing Large Coal-Fired Energy Bases			12FYP Planned 16 Large Coal-Fired Bases		
No.	Coal Bases	Provinces	No.	Coal Bases	Provinces
1	Ordos	Inner Mongolia	1	Ordos	Inner Mongolia
2	Xilingol League	Inner Mongolia	2	Xilingol League	Inner Mongolia
3	Jinbei	Shanxi	3	Shanxi (Jinbei, Jinzhong & Jindongnan)	Shanxi
4	Jinzhong	Shanxi	4	Shaanbei	Shaanxi
5	Jindong	Shanxi	5	Ningdong	Ningxia
6	Shaanbei	Shaanxi	6	Hami	Xinjiang
7	Ningdong	Ningxia	7	Huaidong	Anhui
8	Hami	Xinjiang	8	Binchang	Shaanxi
9	Huaidong	Anhui	9	Zhungeer	Inner Mongolia
			10	Hulunbuir	Inner Mongolia
			11	Huolin River	Inner Mongolia
			12	Baoqing	Heilongjiang
			13	Ili	Xinjiang
			14	Huainan	Anhui
			15	Longdong	Gansu
			16	Guizhou	Guizhou

Source: State Council, NEA

Note that 13 out of the 16 energy bases are located in water challenged regions.

13 of the 16 energy bases are in water challenged regions

Generally, the coal-fired energy bases are located next to the coal bases for economies of scale and transportation. All the current nine large coal-fired energy bases are located in six provinces where large coal bases exist. With the anticipated rise in electricity needs, the government intends to expand these energy bases to form 16 large coal-fired energy bases by the end of 12FYP. The expanded large coal-fired energy bases will now be spread over nine provinces of which eight are Coal Base Provinces with the exception of Heilongjiang. Coal Base Provinces without large coal-fired energy bases are Hebei, Henan, Shandong and Yunnnan.

5 REASONS TO WORRY ABOUT COAL BASES & WATER AVAILABILITY

China will do whatever it takes to guarantee water for coal

As discussed in previous Chapter 4: "Ensuring Food & Energy Security", China will do whatever it takes to guarantee water for coal. Whilst there are many different estimates of water used in coal bases, officials, researchers and NGOs acknowledge that coal is exposed to water risks. Here are 5 reasons why.

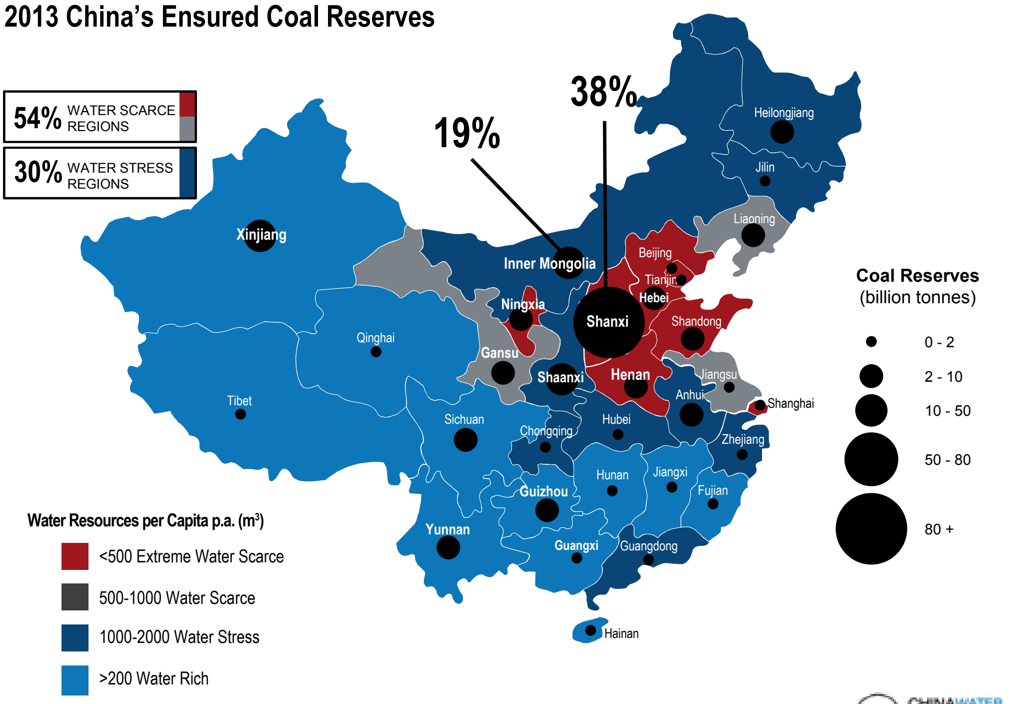
> *"Water availability could be a serious threat for coal and coal-related industries bringing into question the viability of coal as the cornerstone of China's energy policy."*
>
> *CLSA U® 'Water for coal - Thirsty miners will share the pain'*

1. Lots of coal but 84% of reserves sit in water challenged regions

China holds 22% of global coal reserves but 84% of its coal reserves lie in water challenged regions

China has the largest reserves of coal globally. In 2013, China's ensured coal reserves was 236 billion tonnes, which is around 22% of global coal reserves. Unfortunately, 54% of the ensured coal reserves are located in water scarce regions (Dry 11) with a further 30% in water stressed regions (At Risk 9). This means 84% of the coal reserves lie in water challenged regions.

2013 China's Ensured Coal Reserves



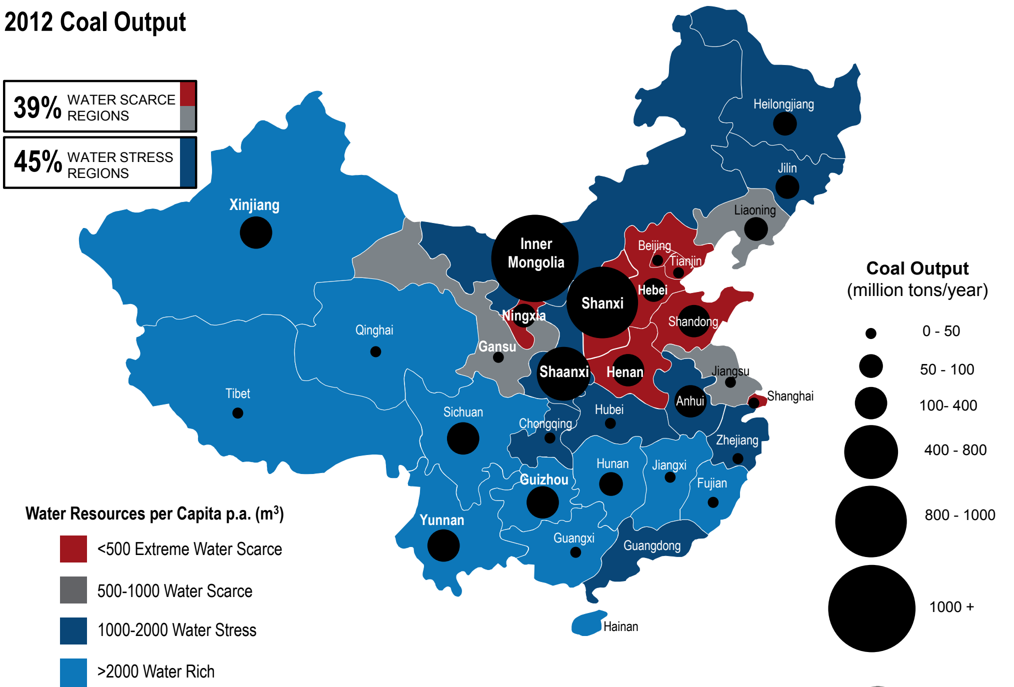
Source: China Water Risk (based on China Statistical Year Book)
Note: water resources are historical average values by provinces 2003-2013. Dry 11 denoted by red and grey shaded provinces

2. 84% of China's coal output is also from water challenged regions

Given the water concerns, coal production in water challenged regions is expected to fall from 84% to 78% by 2015

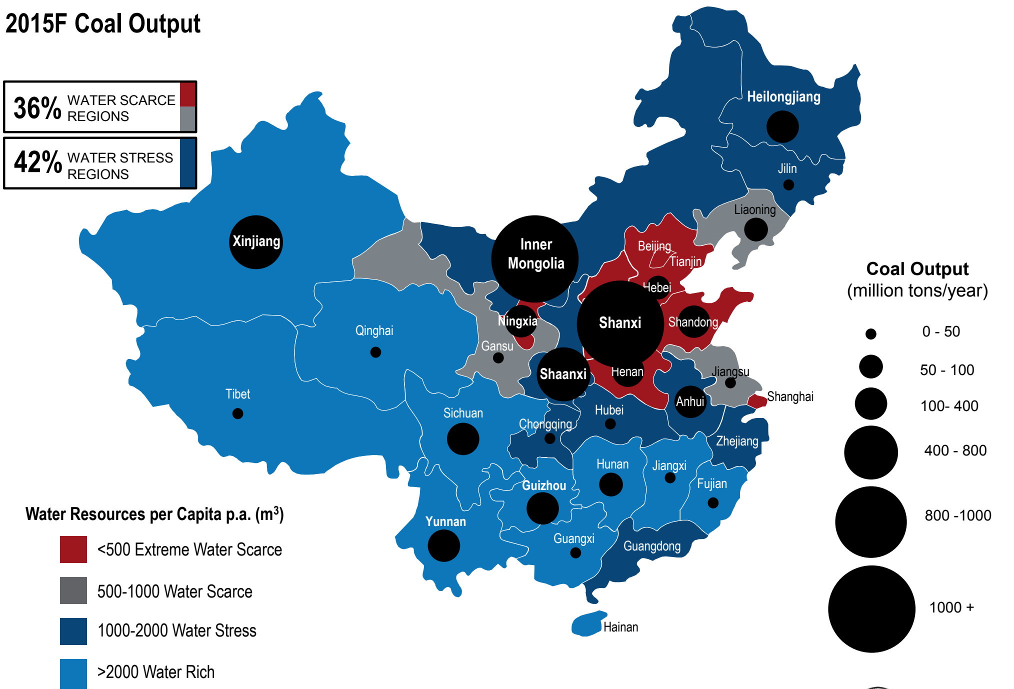
As discussed previously, China's total coal output is expected to continue to grow. In 2012, China's total coal output was 3.65 billion tonnes. Of this, 39% was extracted from water scarce regions and 45% from water stressed regions. Again, this means 84% of the coal reserves are produced in water challenged regions whilst only 16% of coal output is extracted from water rich regions. However, by 2015 this is expected to fall to 78% as shown in the maps below.

2012 Coal Output



Source: China Water Risk (based on China National Coal Association, China National Knowledge Infrastructure (various universities & government departments)
Note: water resources are historical average values by provinces 2003-2013. Dry 11 denoted by red and grey shaded provinces

2015F Coal Output



Source: China Water Risk (based on Provincial FYP and Government Releases Source)
Note: water resources are historical average values by provinces 2003-2013. Dry 11 denoted by red and grey shaded provinces

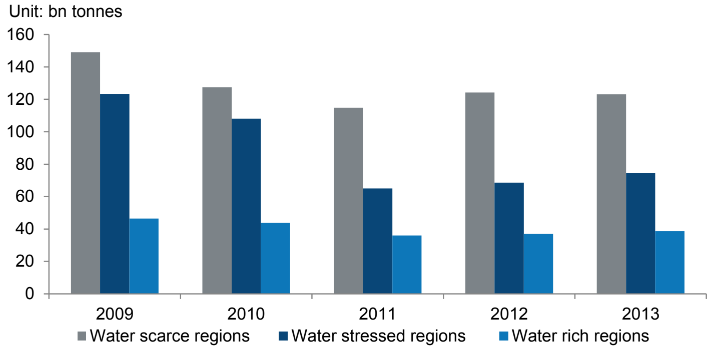
3. 12FYP shifts coal output to regions with more water means coal reserves are increasingly exposed to water scarce regions

With increased coal output comes falling reserves. Ensured coal reserves have fallen from 319 billion tonnes in 2009 to 236 billion tonnes in 2013. However, reserves are declining at different rates across regions depending on coal output.

Coal output is greater in water stressed regions than in water scarce regions

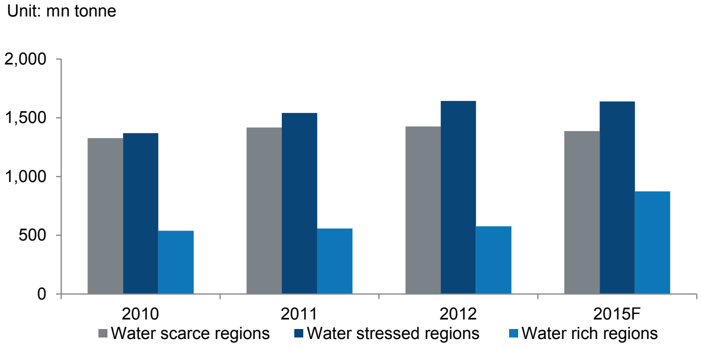
At a glance from the maps above, it is easy to see that coal output in water stressed regions is greater than the output from water scarce regions. Indeed, coal output from water stressed regions has been rising in the past with a corresponding drop in ensured coal reserves from the same regions; coal output from water scarce regions have remained relatively flat. These trends are clearly shown in the charts below:

2009-2013 China Total Ensured Coal Reserves



Source: China Water Risk, NBSC

2010-2015F China Total Coal Output



Source: China Water Risk, NEA, China National Coal Assocaition , NDRC China National Knowledge Infrastructure, Provincial FYPs & other government sources

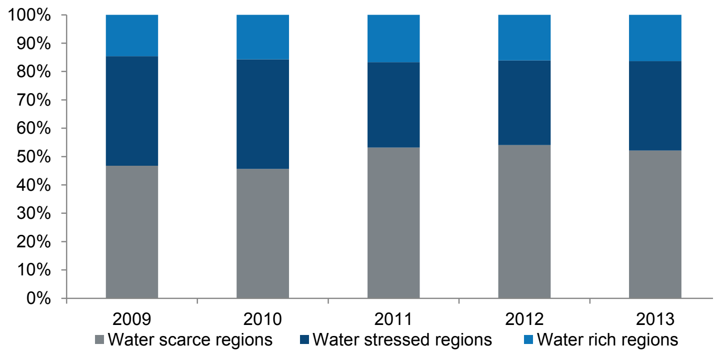
Government is keen to expand coal output to regions with more water, and Xinjiang will host 90% of this expansion...

It is also clear from the graphs above that during the 12FYP the government is keen to expand coal output to regions with more water. Of the 335 million tonnes planned increase in coal output from 2010- 2015 from water rich regions, over 90% is from Xinjiang. This makes sense as Xinjiang it is not only water rich but is the region with the third largest ensured coal reserves behind Shanxi and Inner Mongolia. Xinjiang was the 8th largest producer of coal in 2012.

...but this means that a large share of reserves now lie in water scarce regions

Whilst shifting output to water rich regions may bring respite from water risk exposure, it is difficult to scale-down coal production in the major coal producing provinces as it is not possible to 'shift' coal reserves. Currently, the Top 4 coal producing provinces are Inner Mongolia, Shanxi, Shaanxi and Henan, which together account for a lion's share of China's total coal output at 72% in 2012 (see below for more details on these key coal provinces). Finally, concentrating coal output in regions with more water has meant that a larger share of China's coal reserves now lie in water stressed regions (see chart below).

2009-2013 China Total Ensured Coal Reserves



Source: China Water Risk, NBSC

Ensured coal reserves in water scarce regions have increased from 47% in 2009 to 52% in 2013. China has little choice but to improve on water use in coal production and generating more power with less coal (see Chapter 5: "Battle to Conserve Energy"). Exposure to water risks is more evident at a provincial level.

4. Four drivers of coal: Inner Mongolia, Shanxi, Shaanxi & Henan = 72% of China's coal output by 2015

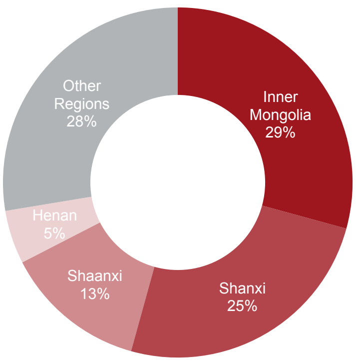
Together, Shanxi and Inner Mongolia account for 57.8% of China's coal reserves...

At the provincial level, Shanxi has the biggest share of coal reserves at 38.4% in 2013, followed by Inner Mongolia with 19.4%. Together, these two provinces account for 57.8% of China's total ensured coal reserves.

...yet, Shanxi has less renewable water resources per capita than Oman

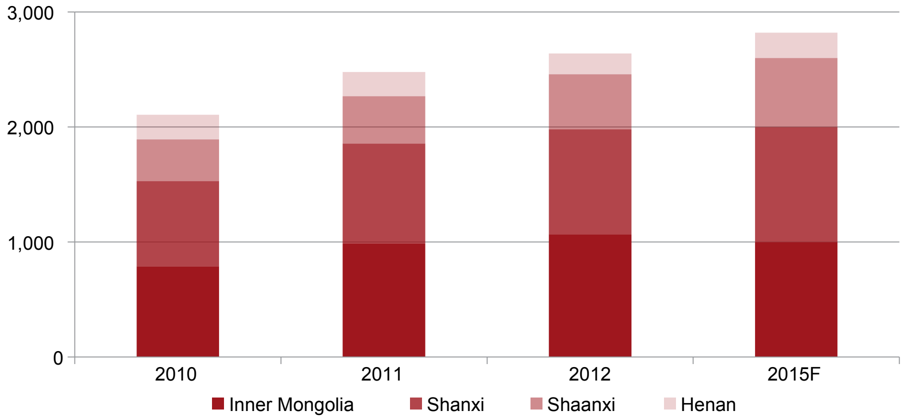
Shanxi and Inner Mongolia are also the largest producers accounting for almost 2 billion tonnes or 54% of China's total coal output in 2012 (see pie chart below left). Yet, Shanxi has less renewable water resources per capita than countries in the Middle East such as Oman. Given this, it is not hard to see why water security is more important than energy security. By 2015, the government plans to discontinue coal mining in Beijing, Tianjin, Shanghai, Guangdong and Zhejiang. This puts mounting pressure on coal production from the Top 4 mining provinces.

2012 China Coal Production = 3645mt



Source: China Water Risk, China National Coal Association

2010-2015F China's Top 4 Coal Producers (mt)



Source: China Water Risk, NEA, China National Coal Association , NDRC China National Knowledge Infrastructure, Provincial FYPs & other government sources

Top 4 coal producing provinces could account for 72% of China's total coal output in 2015, up from 66% in 2010

As illustrated in the chart above right, coal output by China's Top 4 coal producers is projected to increase further. If coal output expansion goes according to plan, they will account for 72% of China's total coal output by 2015, an increase from 66% in 2010. Shaanxi will see the largest increase in coal output increase by 172.5 million tonnes between 2012 and 2015, increasing their share of China's total coal output to 15% by 2015. On the other hand, Inner Mongolia will see its coal output fall by 61.9 million tonnes in the same period. That said, Inner Mongolia will still produce more than a quarter (26%) of China's coal in 2015.

5. Heavy water use & reliance on groundwater by Top 4 coal producers

Top 4 coal producing provinces both rely and apply heavy pressure on groundwater resources

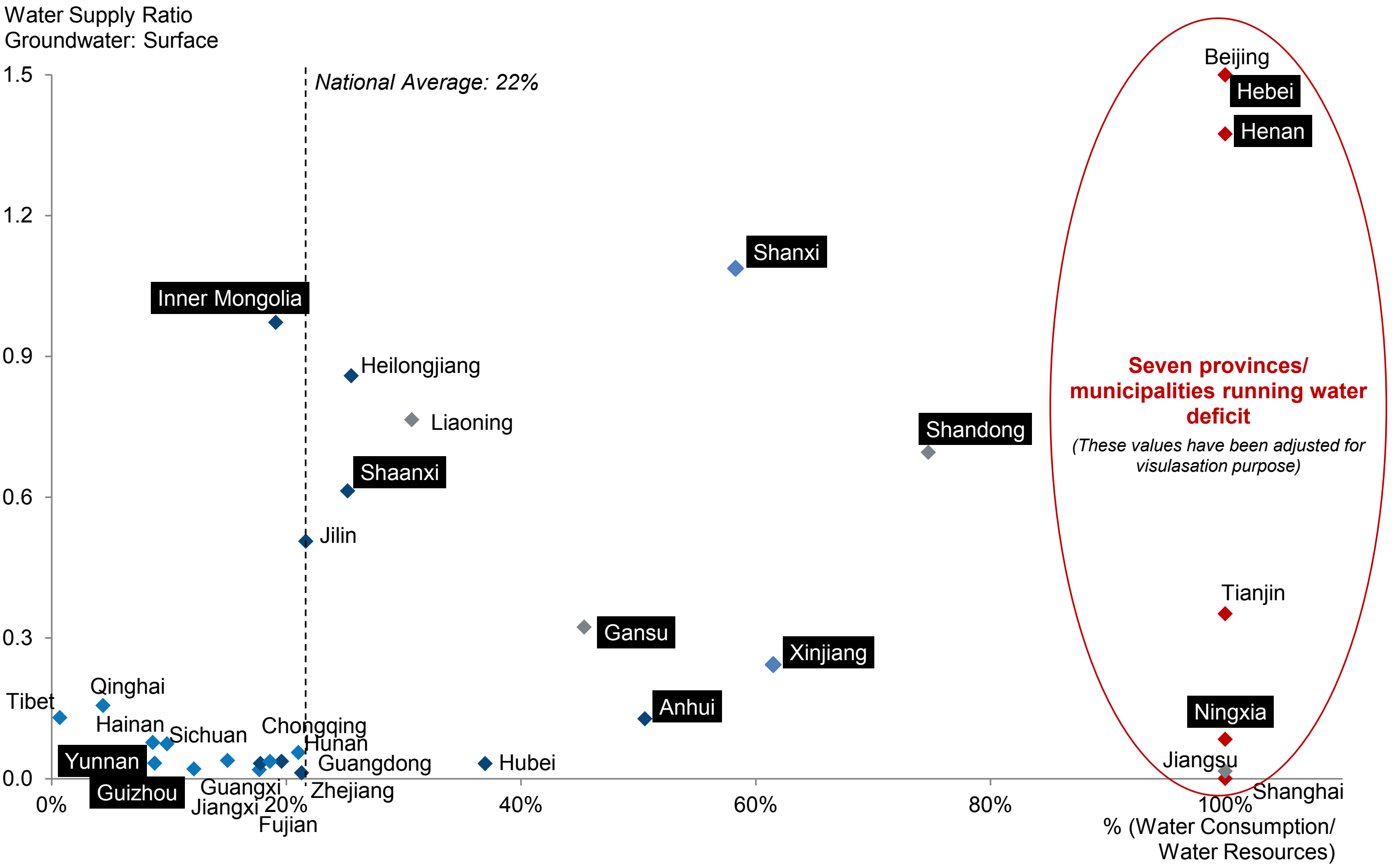
As mentioned in Chapter 1: "China's Changing Waterscape", the North is reliant on groundwater. As such, there are clear pressures on water resources in the Top 4 coal producing provinces:

- Reliant on groundwater with 38-58% of water supplied by groundwater (national average = 18% in 2013); and
- Already use more than 35% of total water resources per annum (national average = 22% in 2013).

Only Yunan and Guizhou are not highly reliant on groundwater use

Therefore, it is important not to just look at water consumption but also at their impact on the groundwater. We plot the 31 provinces/municipalities by the water supply ratio of groundwater:surface water and the percentage of water consumption divided by water resources (see chart below). The 12 Coal Base Provinces are labeled in black.

Coal Base Provinces Use More Water & Highly Reliant on Groundwater (2013)



Source: China Water Risk, NSBC

As of 2013, seven regions are running water deficit, among which three are Coal Base Provinces: Hebei, Henan and Ningxia

As of 2013, there are seven regions running water deficit, meaning water consumed is greater than available water resources. For the purpose of visualization, their values have been adjusted in order to fit all the provinces in a comparable scale. Of these 7 water deficit provinces, 3 are amongst the Coal Base Provinces, Hebei, Henan and Ningxia.

Of the Coal Base Provinces with a water deficit:

Henan and Hubei are also China's Top 4 farmers

- Hebei and Henan are not only running water deficit but also highly reliant on groundwater. For Henan, 42% of its water supply comes from surface water and the other 58% comes from groundwater; the percentage of water consumption/water resources is 113%. Both Hebei and Henan are also amongst China's top farming provinces and coal will compete with agriculture for water; and

- In Ningxia and Henan, water transfer from agricultural water savings from irrigation to coal base projects are in practice and are provinces selected to pilot water use permit trading – more on this the previous Chapter 4: "Ensuring Food & Energy Security".

Six out of the 16 Most Polluting Industries are related to coal and will be also targeted in the war on pollution

Therefore, it is important not to just look at consumption of water but also at the source of water supply. Groundwater in the North is not only over-extracted but already severely polluted. Coal and coal-related industries such as thermal power, mining, steel, cement and chemical have all been singled out by the MEP to be amongst the 16 Most Polluting Industries. Since six out of sixteen are related to coal, it is not difficult to see why a war on pollution means a coal clean-up on both water and air quality fronts. Moreover, pollution is costly: a recent MEP study revealed the external environmental cost of coal in 2010 to be RMB555.54 billion. This is 2.3x of the total amount spent on environmental protection expense or a quarter of coal industrial output value in 2010.[52]

WATER EXPOSURE RECOGNIZED IN THE WATER-FOR-COAL PLAN

China's coal and energy bases have seen significantly increasing exposure to water risk over the past decade

The 5 reasons set out above clearly show why the government is worried. Many of the large coal and energy bases are exposed to water risks. Coal extraction and production, as well as coal-fired power generation are water intensive. China's coal and energy bases have seen significantly increasing exposure to water risk over the past decade. The majority of these bases now operate in areas where baseline water stress according to the World Resources Institute is classified as 'medium' to 'extremely high' risk.

Overlap with major farming provinces raise food security concerns; competition for water will intensity

Moreover, they also overlap with major farming provinces triggering food security concerns. In the longer run, with rising demand for both food and power, competition for water will intensify. Water resources for coal production and coal-fired power production will likely have to be managed in tandem with water for agriculture in order to ensure water for the North China Plain (the agricultural heartland) as well as its coal & energy bases. In this regard, the envisaged "Mountaintop to Ocean Reform" of merging the MOA, MLR, MWR and MEP would help facilitate the holistic management and protection of water, farmlands and coal bases. However, since this is still far away, central government has in the meantime adopted a two-pronged strategy to secure water, energy and food security:

Government has a two-pronged strategy:
(1) Consolidate and centralize, and
(2) Efficiently manage water resources

1. Consolidate and/or shut down small coal mines and centralize coal production in 14 large coal bases. This is to be repeated with large coal-fired energy bases which will expand from 9 to 16 bases, which will mainly lie in Coal Base Provinces with the exception of Helongjiang; and

2. Manage water resources in the large coal bases with the Water-for-Coal Plan. With 95% of coal production by 2020, China cannot afford for these large coal bases not to have enough water. The MWR's Water-for-Coal Plan, as mentioned earlier, states that regional water availability in China will dictate plans for future coal development but also covers the following:

   - Water use & allocation to be "taken seriously"
     - Provincial quotas apply
     - Restrictions on transfer of water use rights by coal base
     - Coal & coal-fired plants must coordinate water use
     - Water use in coal bases shall follow Grade I standard of 'Cleaner Production Standard-Coal Mining & Processing Industry (HJ446-2008)' (see more details in later in this chapter);
     - Air cooling preferred to bring down water consumption in power generation large coal bases to 0.36m^3/ MWh

   - Restrictions on type of water used
     - Groundwater: prohibited with the exception of mine drainage
     - Surface water: stricter use

   - New projects must take into account water
     - MWR & NEA approval for new mine projects on top of EIA approval - feasibility reports must be submitted
     - New coal-fired plants must have a "first save water then use water" mentality through implementation of water efficiency measures

   - Water efficiencies measures to be implemented
     - Coal mine water utilisation rate of 75% by 2015
     - Water reuse & water efficient tech encouraged for coal-fired plants in water scarce regions
     - Coal-fired boilers to be updated, outdated equipment to be updated

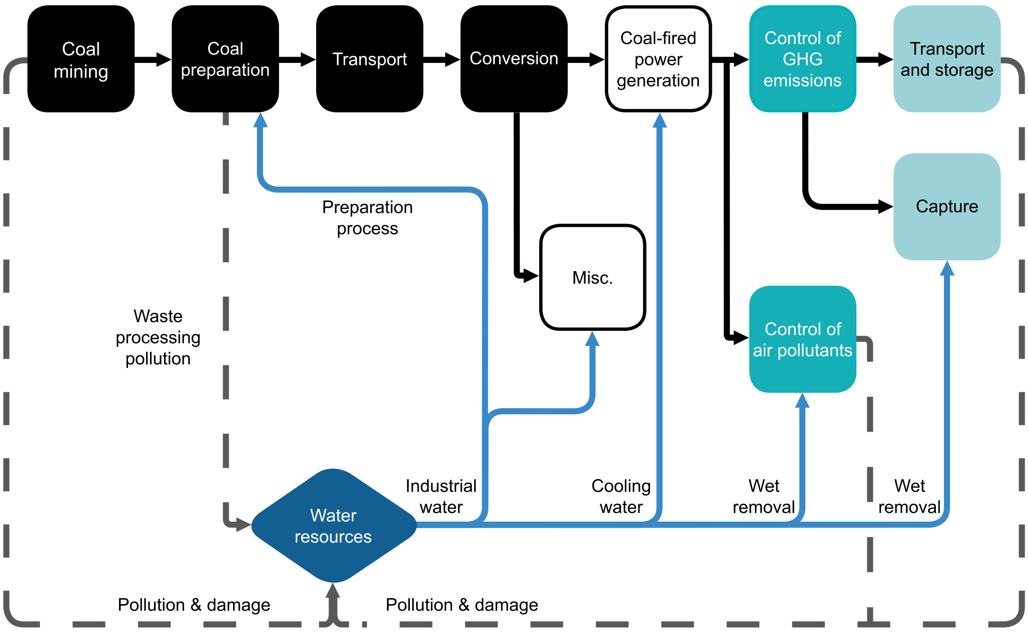
   - Pollution Control
     - Coal & thermal power amongst 16 most polluting industries
     - Water pollution control through treatment of wastewater & mine drainage
     - Coal resource taxes / financing restraints on polluters

WATER IN THE COAL CHAIN

Water is used in almost every step of the coal supply chain

Water is used in almost every step of coal production – extraction, preparation/washing, processing/conversion, transport, storage and disposal of pollutants, emissions and waste. In every step, water is withdrawn from the surface or from the ground, or recycled from the other stages and reuse as shown in the diagram below:

Interaction of a Coal Supply Chain and Water Resources



Source: Pan et al. / Energy Policy 48 (2012) 93 - 102

COAL MINING WATER TERMINOLOGY

There is room for much confusion when it comes to water requirements and discharge for coal extraction and processing. Before proceeding, it is important to distinguish between different water related notions in these processes:

- In coal mining and processing, water is used for different purposes such as equipment cooling, washing and concentration processes. Since a large portion of this water is recycled and used again, the actual water used in these processes is significantly higher than the amount of water withdrawn. However, since we are focusing on the impact on surrounding water resources, we will keep referring to **water withdrawal** when employing the term **water use**, which is consistent with our previously adopted terminology.
- **Water discharge** refers to the water discharged during the mining process, as well as the non-recycled fraction of the coal processing water. In the case of coal mining, much wastewater is also coming from the mine drainage.
- Coal mining is also causing severe **water impacts**. Groundwater contamination for instance happens when groundwater flows into the mine (see box below). The important water drainage of the pit for safety reasons also raises important issues, such as groundwater level declining, surface subsidence, soil salination and land desertification. (L. Pan et al. 2012)

WATER IMPACT OF COAL MINING

In Shanxi province, 1.07m^3 of groundwater reserves are destroyed to mine one tonne of coal according to Wang (2010). Given coal production of 913 million tonnes in 2012, an estimated 977 million m^3 of groundwater reserves are destroyed per annum. This represents 11% of total renewable groundwater resources of Shanxi province for that year. The CAS and Greenpeace report *Thirsty Coal* report estimates this figure to be even higher, at 2.54m^3 of groundwater destroyed per tonne of coal.

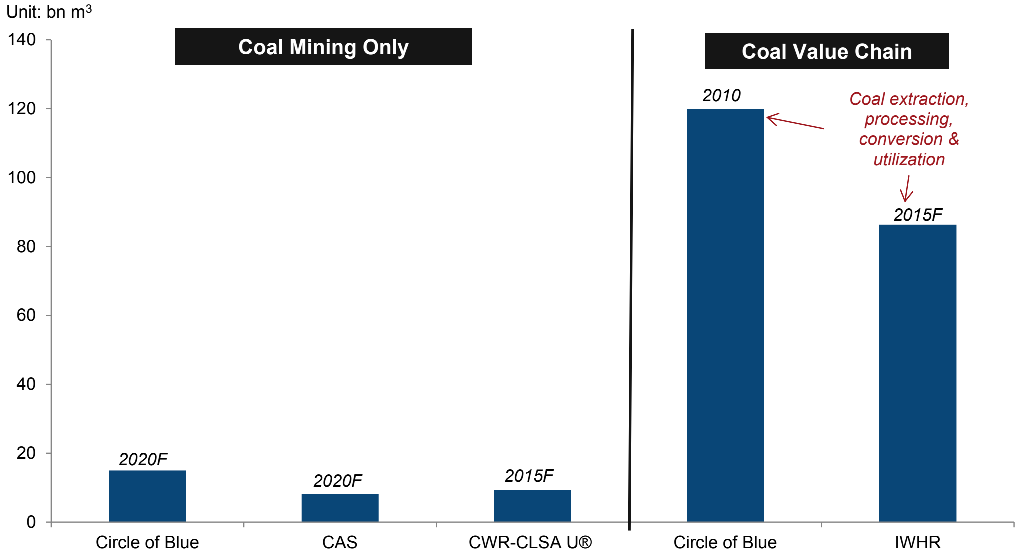
MIXED VIEWS ON IF THERE IS ENOUGH WATER FOR COAL

Concerns have been rightly raised on the impact of coal mining on water resources from NGOs, think-tanks and academic research institutions. Is there enough water for coal? The projections of water for coal vary considerably.

Different sources give wide ranging estimations of water use in coal mining and along the coal chain

We estimated water use in mining in 2015 for CLSA U®'s "Water for Coal - Thirsty miners will share the pain" (2012). Other organisations also estimated water use in coal mining in 2015 or 2020 as well as water use in the whole coal value chain, such as Circle of Blue & Wilson Center's "Choke Point: China" (2011), Greenpeace's "Thirsty Coal Report" (2012), Chinese Academy of Engineering (CAE)'s "Coal and Water Resources" (2014) and China Institute for Water Resources and Hydropower Research (IWHR)'s 'The Strictest Water Resources Red Lines Ask for Coal Production and Use Control' (2014). We have set out the various estimates in the chart below:

Annual Water Use Along the Coal Value Chain By 2015/2020
Estimation From Various Studies



Source: China Water Risk-CLSA U® "Water for Coal: Thirsty miners will feel the pain", Circle of Blue & Wilson Center "Choke Point: China", Chinese Academy of Science and IWHR "The Strictest Water Resources Red Lines Ask for Coal Production and Use Control"

Points to note from the above chart are:

- **Circle of Blue:** said water withdrawals in coal mining is expected to be 15 billion m³ per year by 2020; separately it also estimated water needed in coal mining, processing & consumption (including all the coal-related industries such as steel & cement) to be 120 billion m³ per year;

- **Chinese Academy of Science (CAS):** both Greenpeace and Chinese Academy of Engineering used the study from the CAS as the data source. Based on the CAS study annual water use of large coal bases are estimated to be 6.65 billion m³ by 2015 and 8.15 billion m³ by 2020;

- **CWR-CLSA U®:** estimated water use in coal mining to be 9.4 billion m³ by 2015. This scenario does not include coal washing nor did it take into account technological improvements so that the maximum exposure to water risk can be ascertained;

- **IWHR:** the report is part of the China Coal Cap Project supported by Natural Resource Defense Council (NRDC) and World Wildlife Fund for Nature (WWF). The report analyzed four different water withdrawal scenarios: a baseline reference scenario, a baseline coal cap scenario, a water conservation reference scenario, and a water conservation coal cap scenario. Under the baseline reference scenario, the water withdrawal for the entire coal sector (including extraction, washing and sorting, and conversion and utilization) is estimated to be 86.33 billion m^3 by 2015 and 96.53 billion m^3 by 2020.

Water withdrawal in the entire coal chain is significantly higher than water use in mining only

The key takeaway from the above is that water withdrawal in the entire coal chain is significantly higher than water use in mining. This includes water use in coal extraction, washing and sorting, to power generation, coking and coal-to-chemicals amongst others. The difference is primarily due to water withdrawals by power generation. It should be noted here that if we looked at water consumption by power generation instead, the amount of water "consumed" by power generation is considerably lower. The Greenpeace Thirsty Coal Report report estimated water use in coal mining and coal to chemicals as well as water consumption in power generation to be 9.975 billion m^3 by 2015.

MUDDY WATERS IN WATER FOR COAL: WIDE RANGE IN RESEARCH BENCHMARKS & NATIONAL TARGETS

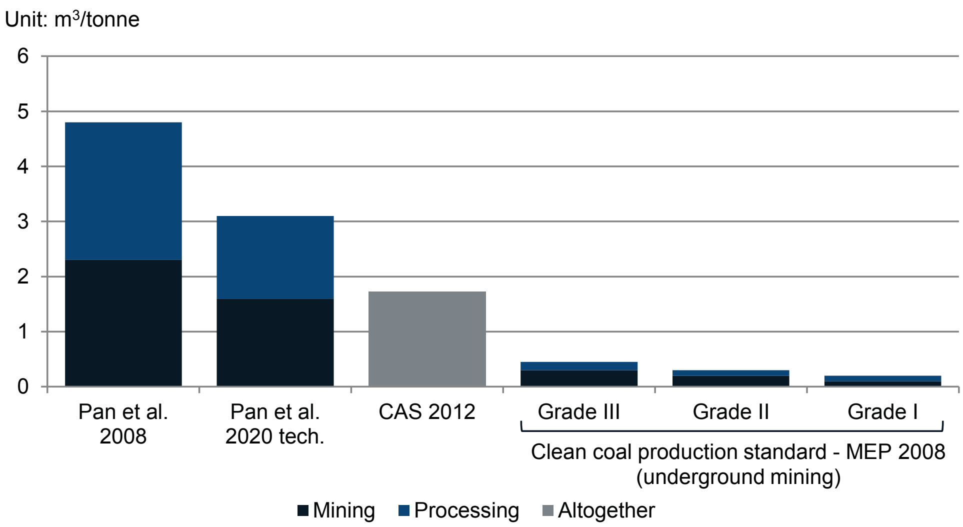
The wide range of estimates differ significantly from the MEP Clean Coal Production Standard

As can be seen, there is a wide range of estimates in total water use in mining. This is largely due to the wide range of benchmarks which unfortunately differ significantly from the standard issued by the MEP. In 2008, the MEP issued a 'Cleaner Production Standard-Coal Mining & Processing Industry' (HJ446-2008) (Clean Coal Production Standard). The standard gives three grades of water use quota in both underground and open mining:

- Grade I: international advanced level
- Grade II: domestic advanced level
- Grade III: domestic base level

Research benchmarks and Grades I – III of the 'Clean Coal Production Standard' for underground mining (since 95% of China's coal is mined underground) are set out in the chart below:

Various Benchmarks of Water and Coal Mining



Source: Pan et al. 2012, CAS, MEP

Range varies from 0.2m³ to 4.8m³ per tonne of coal mined and washed

Pan et al. (2012)[53] estimated the average water use for the coal mining and preparation to be 2.3m³/tonne and 2.5m³/tonne respectively but forecasted this to fall to 1.6m³/tonne to 1.5m³/tonne respectively in 2020. This is significantly different from the 'Clean Coal Production Standard' which set the water quota for coal mining and processing for Grade I at 0.1m³/tonne and 0.1 m³/tonne; Grade II at 0.2 m³/tonne and 0.1 m³/tonne; and Grade III at 0.3 m³/tonne and 0.15 m³/tonne respectively.

Given water risk, more transparency and disclosure are needed in large coal bases

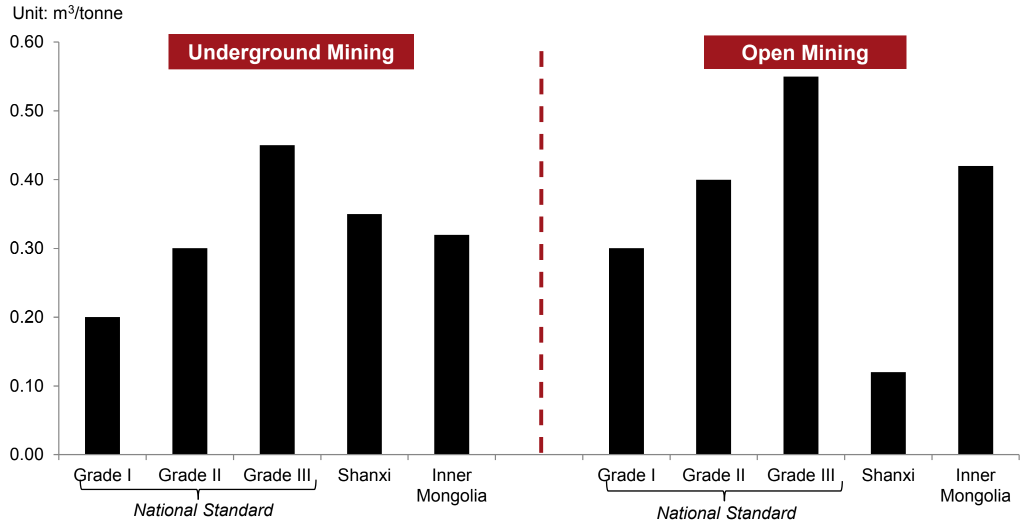
The CAS study relied on statistics from the China National Administration of Coal Geology, and gave an average water requirement for coal extraction and processing of the 14 large coal power bases in 2010 of 1.73m³/tonne. However, no split was given for mining and processing nor was the wash rate disclosed. This is therefore technically not comparable to either Pan et al. or the national quotas but we have included it for reference. In short, the range of values is very wide and much uncertainty surrounds the actual water use in coal bases. Due to the lack of disclosure, reasons for such discrepancy remain unclear. Given large coal base's exposure to water risk, we believe it is time for increased transparency and further research.

VARYING NATIONAL & PROVINCIAL WATER TARGETS IN COAL MINING ADDS TO CONFUSION

Provinces also issued their own water use quotas for coal mining and processing

Along with the national target, several provinces have also issued water used quotas for coal mining and processing. Since Inner Mongolia and Shanxi represent 54% of total coal output in 2012, we choose these two provinces to compare with the national standard (see chart below).

National vs Local Standard on Water Use in Coal Mining
HJ446-2008 vs Shanxi & Inner Mongolia Water Use Quota Standards



Source: China Water Risk, Cleaner Production Standard-Coal Mining & Processing Industry (HJ446-2008), Shanxi Water Use Quota Standard (2008) & Inner Mongolia Water Use Quota Standard (2009)

It is clear from the above chart that:

- The water withdrawal quota for underground mining is stricter than that of open mining. This is because more than 95% of coal in mined underground in China. To achieve this, the government is promoting mining water reuse - mine water utilization to reach 75% by 2015;
- The Grade III level in the national standard for both underground and open mining is less stringent than the local standard of Shanxi and Inner Mongolia; and

MWR wants water use in large coal bases to meet the Grade I benchmark

- As mentioned previously, the MWR's Water-for-Coal Plan promotes best practice and wants to improve water use in large coal bases towards Grade I for both underground and open mining.

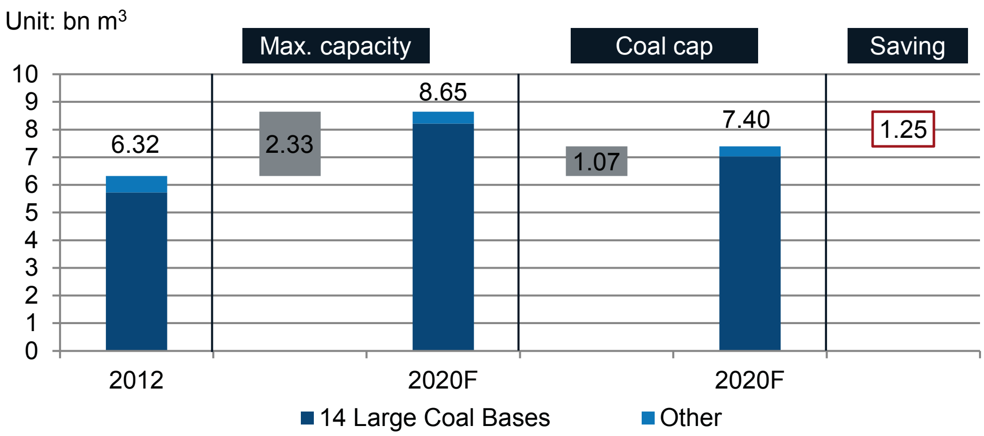
CWR WATER SAVING SCENARIOS IN COAL MINING & PROCESSING

To estimate the water savings scenarios in coal mining and processing, we have used benchmarks from the CAS study, since they provide both maximum capacity and water requirements for each large coal base separately until 2020. In the chart below, we have set out two scenarios:

1. Coal Output at Maximum Capacity - Given the official target to concentrate 95% of the national production in these bases, we estimate the maximum output capacity nationally to be 4.91 billion tonnes in 2020; and

2. Coal Output at Coal Consumption Cap – In this scenario, we assume that China is producing 4.2 billion tonnes, which corresponds to the coal consumption cap in 2020.

2012-2020F Water for Coal Mining - Maximum Output Vs Coal Cap



Source: China Water Risk estimates based on CAS and State Council

In 2012, the 14 large coal bases used 6.32 billion m^3. If operated at full capacity, they would use 8.65 bn m^3 in 2020...

In 2012, the 14 large coal bases produced 3.3 billion tonnes of coal while the total national figure was 3.5 billion tonnes. Based on 1.73m^3/tonne of coal mined and processed, this would require 6.32 billion m^3. Assuming that China fully exploits its coal output to maximum capacity in 2020 it would require 8.65 billion m^3, representing an additional 2.33 billion m^3 from 2012.

...but the coal cap at 4.2 bn tonnes in 2020 would limit the water use to 7.4 bn m^3

However, coal output at the coal consumption cap is lower at 4.2 billion tonnes in 2020, and assuming that China was to fully produce this amount, the water required would be 7.4 billion m^3. Not extracting the difference of 710 million tonnes therefore results in "water savings" of 1.25 billion m^3.

It should be noted at this point that water use and capacity evolution vary significantly among the large coal power bases. For example, while Xinjiang production capacity is expected to increase tenfold between 2010 and 2020, the coal base capacity in central Hebei is expected to fall. Same disparities across coal bases exist in terms of water use, ranging from 0.4m^3/tonne to almost 6m^3/tonne of coal extracted and processed.

WATER SAVING SCENARIOS IN CLOSED LOOP AND DRY COOLING POWER GENERATION

Compared to mining, the water withdrawn for power generation is mostly used for cooling and returned to the environment almost unaffected, except for its temperature...

Before we start, it should be noted that we are using water consumption rather than water withdrawal to assess the water savings potential associated with different technologies in power generation. Compared to mining, the water withdrawn for power generation is mostly used for cooling and, except for its temperature, its quality is almost unaffected. Given the large amounts of water required, most power plants rely on surface water. Part of the water withdrawn is consumed, mostly through evaporation, while the remaining part is sent back to the same water source. This amount of water returning to the source is not 'lost' for the environment and for the other users downstream (except for the additional evaporation due to the increased temperature). We are therefore using water consumption to estimate water savings in power generation.

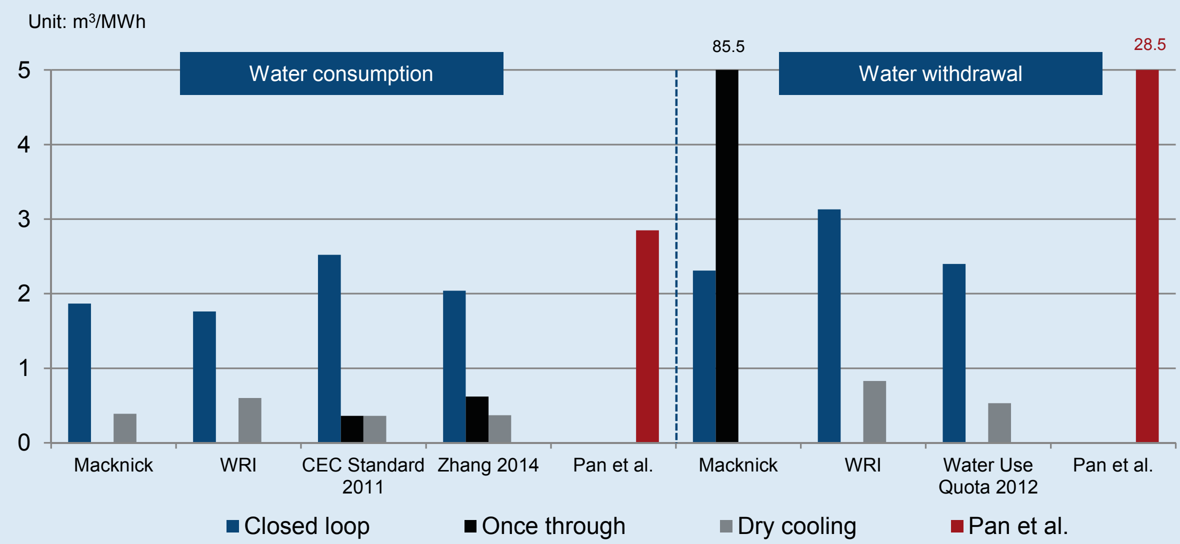
...the focus is thus on reducing water consumption

Whereas in the previous Chapter 4: "Ensuring Food & Energy Security", we have used water withdrawal to assess the risk exposure of coal and coal-related industries to water – in short, if the required amount of water withdrawal for power generation cannot be accessed, you cannot generate power. Once access is secured, it comes down to the choice of technology which consumes the least amount of water. The choice of coal power plant technology is usually considered in terms of thermal efficiency and therefore of coal consumption. Yet, technology choice also has much influence on water consumption, particularly the choice between closed loop, once-through and dry cooling (see box below).

COOLING TECHNOLOGY MATTERS

The levels of water withdrawal and consumption for cooling power plants are highly dependant on the type of technology used. Nowadays, three main types coexist: closed loop, once-through and dry cooling. Within **closed loop system**, after being withdrawn, water is circulated in a loop to cool down the power plant and part of it is evaporated in the cooling tower to evacuate the heat. In the **once-through system**, there is no evaporation step and therefore less water is consumed. However, in order to evacuate the same amount of heat, considerably higher amount of water should be withdrawn from the water source. This makes them unsuitable for water scarce areas. Both closed loop and once-through systems belong to the general category of **wet cooling**. A third option now prioritised for water scarce regions is the **air cooling** (also called **dry cooling**), in which air-cooled condensers are used to evacuate the heat. Hybrid technologies, combining both wet and dry elements, are also being developed. Different estimations for these different technologies are shown below.

Water Consumption and Withdrawal for Different Cooling Technologies

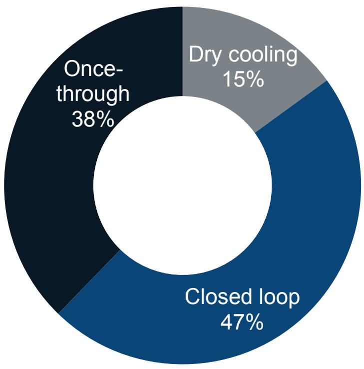


Note: values for 600MW Supercritical plants are used when available. Generic values are considered otherwise
Source: Macknick et al. 2011, WRI, CEC, Zhang 2014, Pan et al. 2012

China's coal-fired power fleet is estimated to consume around 1.35 m³/MWh

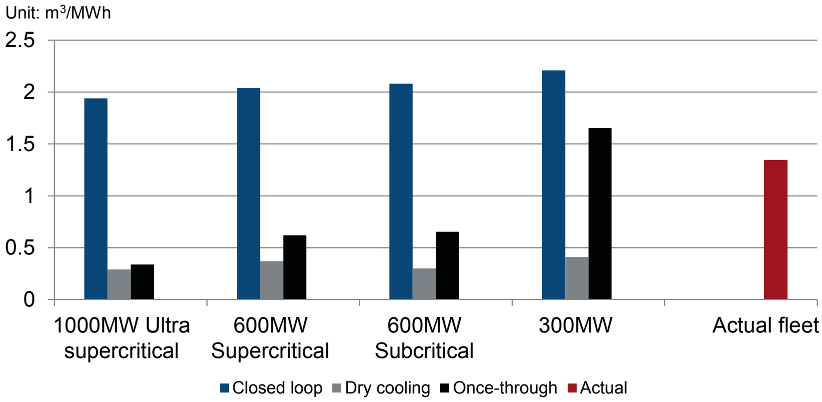
To estimate the amount of water consumed in power generation, we need to first estimate the respective proportions of the different cooling technologies in the current Chinese fleet. Since there is no information on the technology current mix, we use CEC benchmarks to estimate this split to be once-through at 38%, closed loop at 47%, and dry cooling at 15% (see chart below left). Zhang et al. (2014) estimated the respective water consumption levels of different technologies in China. Using our previous estimation of the actual mix of cooling technologies, we can approximate the average water consumption in China coal-fired power fleet to be around 1.35m³/MWh (see chart below right).

2012 Cooling Technology in Chinese Coal Fleet (TWh)



Source: CWR estimates based on CEC

Water Consumption of Different Technologies in China



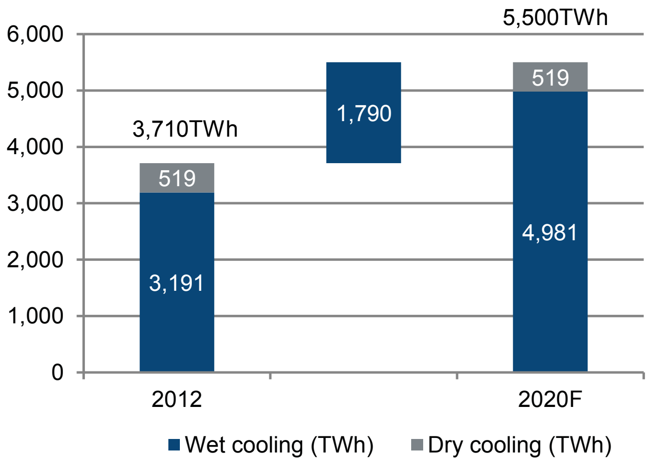
Source: CWR estimates in China based on Zhang et al. 2014 and CEC

Choice of cooling technology will have dramatic impact on Chinese water consumption in 2020

In our CWR Base Case Scenario for coal-fired power generation discussed earlier, China will generate an additional 1,790TWh from coal in 2020, reaching 5,500TWh. The choice of technologies to generate this additional electricity will have dramatic impact on Chinese water consumption in 2020. To illustrate this, we devise two scenarios from 2012 to 2020 in which different cooling technologies are adopted.

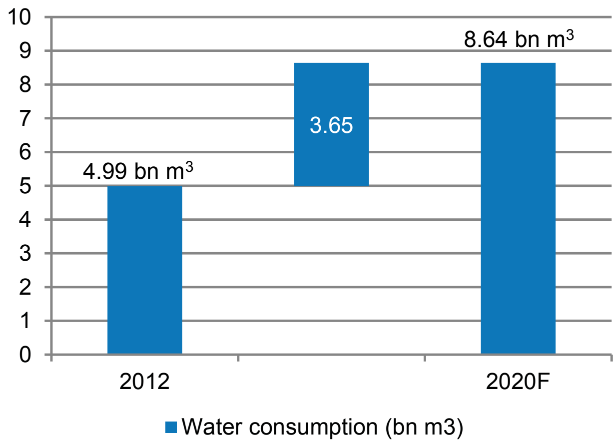
- All Closed Loop Scenario – Assuming that all the additional 1,790TWh will be generated by power plants equipped with closed loop cooling, the annual water consumption from coal power generation will reach 8.64 billion m³ a year. This is an additional 3.65 billion m³ compared to 2012.

2020F All Closed Loop Scenario (TWh)



Source: CWR estimates based on CEC and Zhang et al. 2014

2020F All Closed Loop Scenario (bn m³)

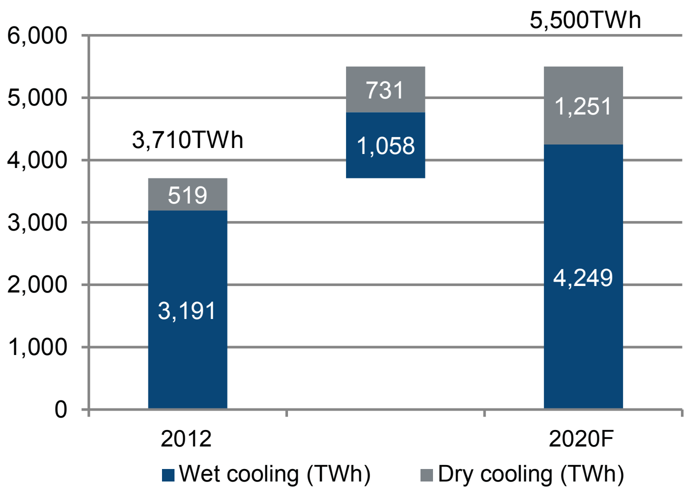


Source: CWR estimates based on CEC and Zhang et al. 2014

Dry 11 - Dry Cooling Scenario only consumes +2.43bn m³ more by 2020

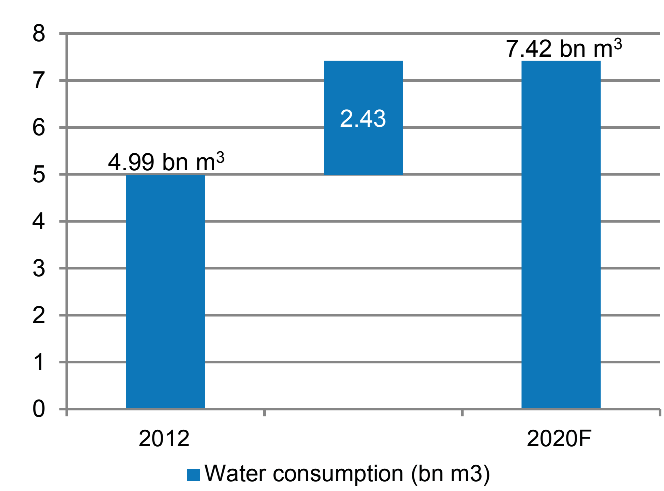
- Dry 11- Dry Cooling Scenario - In this scenario, we consider that all additional coal power plant in Dry 11 regions will opt for dry cooling. This in line with the Water-for-Coal Plan stating that only dry cooling units should now be installed in water scarce regions. Assuming that the coal power generated in the Dry 11 provinces will remain the same as in 2012 (i.e. 41%), we estimate that within the additional 1,790TWh to be generated in 2020, 731TWh will be using dry cooling technologies. The total water consumption for coal power generation in 2020 will then be 7.42 billion m³, which represents an increase of 2.43 billion m³ since 2012.

2020F Dry 11 - Dry Cooling Scenario (TWh)



Source: CWR estimates based on CEC and Zhang et al. 2014

2020F Dry 11 - Dry Cooling Scenario (bn m³)



Source: CWR estimates based on CEC and Zhang et al. 2014

Dry cooling in water scarce regions can save 1.22bn m³ per year...

Accordingly, we estimate the resulting water savings from adopting dry cooling in water scarce regions to be 1.22 billion m³ per year.

Beware! Dry cooling comes at a cost: -1.2 billion m³ of water but +41.7 million tonnes of CO_2.

... but it comes at a cost of increased carbon emissions

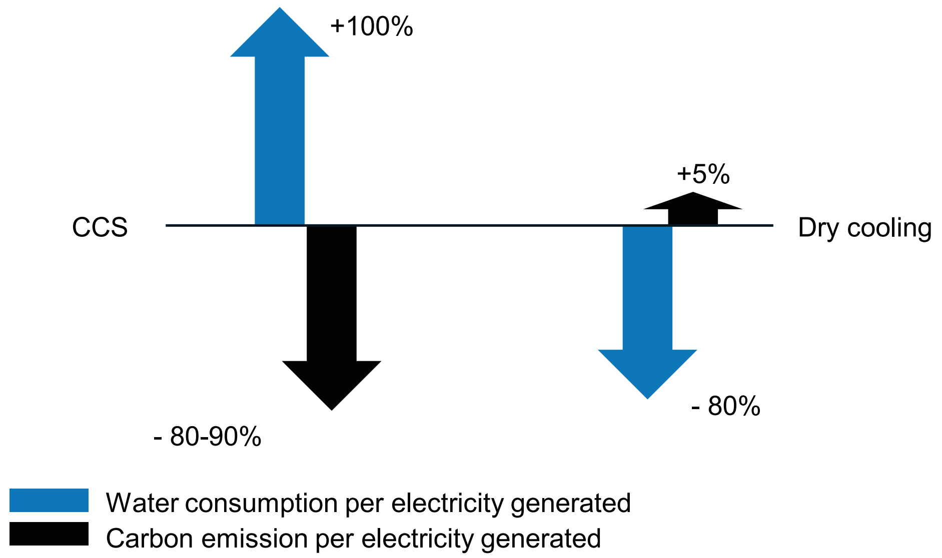
With water consumption savings and significantly greater water withdrawal savings, it appears that dry cooling in water scarce regions could be a solution. However, be warned that the reduction of water consumption associated with dry cooling comes at a cost: the reduction of thermal efficiency, which increases coal consumption to generate the same amount of electricity. Based on Zhang et al. 2014, we estimate that the carbon cost for saving the aforementioned 1.22 billion m³ saved is 41.7 million tonne of CO_2.

CCS could cut GHG emissions by 80% but would simultaneously double the water consumption

This water carbon trade-off is even more prominent in the potential adoption of Carbon Capture and Storage. As highlighted by the recent WRI report, CCS could cut greenhouse gas emission of coal-fired power plants by 80% to 90%, but would simultaneously double the water consumption. As shown below, both dry cooling and Carbon Capture and Storage incur a water carbon trade-off, albeit in an opposite direction.

Dry cooling and CCS are two main examples of carbon vs water trade-off

Carbon vs Water Trade-off for Dry Cooling and CCS



Source: CWR estimates based on CEC, Zhang et al. 2014, WRI

COAL CAP AND DRY COOLING COULD SAVE UP TO 2.5 BILLION M³ OF WATER

As described in this chapter, China faces significant challenges, with coal reserves mostly located in water challenged areas. The recent decision to cap coal consumption at 4.2 billion tonnes in 2020 could help reduce pressure on already scarce water resources in large coal bases. We estimated that by 2020, it could save up to 1.25 billion m^3 of water in coal extraction and processing compared to a situation where China was to fully exploit its coal production capacity at 4.9 billion tonnes in 2020.

The choice of cooling technologies for coal-fired power plants will prove crucial for water scarce regions

However in the medium term, coal output and consumption will keep increasing, driven by the growth of thirsty coal-fired power generation. As can be seen in our scenario analysis, the choice of cooling technologies for coal-fired power plants will prove crucial.

By opting for dry cooling instead of closed-loop cooling for new plants in water scarce areas, as required in the Water-for-Coal plan, China could reduce its water consumption for coal-fired power generation by 1.2 billion m^3 in 2020. This water saving is critical for these water scarce regions. Yet, this would cause additional carbon emissions, illustrating again the water-energy-climate trade-offs when balancing power mix.

HYDROPOWER

REMAINS A STAPLE DESPITE MULTIPLE RISKS DUE TO ITS MANY USES

Photo Copyright © Debra Tan

- China is the No.1 builder of dams globally. The nation's own hydropower installed capacity has more than doubled from 2005 to 280GW in 2013, comprising 258GW of conventional hydropower and 22GW of pump storage capacity. With around 45,800 small dams, small-scale hydropower has dominated hydropower growth over the last decade but large-scale dam building has stepped up.

- Further expansion is expected as this relatively cheap carbon-friendly fuel source helps China meet its 2030 emissions commitments. However, seasonal variability impacts river flow resulting in fluctuations in hydroelectricity generation that require smoothing. Analysis shows that due to coal-fired power's dominant role in smoothing, China's hydroelectricity production demonstrates a strong correlation with non-nuclear thermal power generation. Achieving efficient coal-fired power is therefore key.

- With extreme weather brought on by climate change, reliance on fluctuating river flows means the viability of hydropower comes into question. Expected increasing frequency of droughts & floods in the future might diminish its power generation ability as water is held back in reservoirs to provide drought or flood relief. In such cases, more coal will be required to balance hydropower's diminished capacity.

- Regardless, China will plough ahead with hydropower dam building as these serve multiple functions beyond power generation such as water flow management, rural electrification and provision of water for irrigation. These functions will become increasingly important to mitigate climate risk causing concerns for China's neighbours due to its plans to tap transboundary rivers.

- China is clearly on track to meet its 2015 target of 260GW conventional hydropower installed capacity. Hydropower expansion during the 12FYP has been mainly in water rich provinces, with 80% of expansion in Yunnan and Sichuan. However, these provinces are exposed to seismic risk, which raises concerns regarding further expansion. Moreover, although there are no concrete links between dam building and earthquakes, concerns exist.

- Aside from environmental and social risks, there are also geopolitical concerns as more than 20 riparian countries share China's international freshwaters. China has identified ten large rivers for hydropower expansion; three of the ten are transboundary raising geopolitical risks. Although China's 2015 transboundary hydropower capacity is only 6.5% of the nation's conventional hydropower installed capacity, this could grow to 28% by 2050.

- With +124GW on the Lancang (upper Mekong), Nu (upper Salween) and Yarlung Zangbu (upper Brahmaputra) rivers, China's neighbours are worried. China did not ratify the UN Water Convention (UNWC) but then neither did the US nor Canada. However, experts say that China has been unfairly criticised for intensifying drought conditions downstream on the Mekong and that China's transboundary water strategy does include many of the elements of the UNWC.

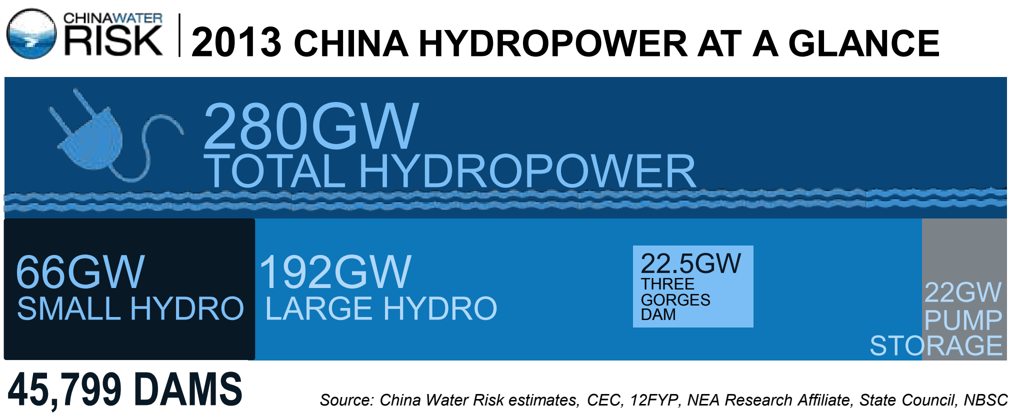
- State Council has a 2020 target for total hydropower at 420GW and the NEA a hydropower cap at 500GW. However, it is not clear whether this is a total or conventional hydropower cap. There are mixed views on how much hydropower China should add. Chinese government affiliated research bodies forecast China's 2050 hydro capacity to be 500-630GW; some NGOs are forecasting 510GW but others believe this is too high.

- To reach 500GW of conventional power, China will have to tap the three transboundary rivers. Given the seismic risk exposure in the Qinghai-Tibetan Plateau, we are of the view that the 500GW cap should be a total hydropower cap. This can be achieved with +60GW of small-scale hydropower, +100GW of pump storage and +50GW large-scale dams. Given that +116GW can be tapped on non-transboundary rivers, the Nu and Yarlung Zangbu rivers can both be free of large-scale hydropower dams.

- With glaciers in the Qinghai-Tibetan Plateau shrinking 15% over the last three decades, the stakes are high. The future of China's hydropower doesn't just impact China; it has regional watershed implications and global climate ramifications. It is time to start productive conversations to find solutions for Asia's water-energy-climate nexus. As the upstream riparian, China will no doubt play central role in regional water security.

HYDROPOWER

REMAINS A STAPLE DESPITE MULTIPLE RISKS DUE TO ITS MANY USES



Source: China Water Risk estimates, CEC, 12FYP, NEA Research Affiliate, State Council, NBSC

CHINA, ALREADY OVER 45,800 DAMS AND COUNTING

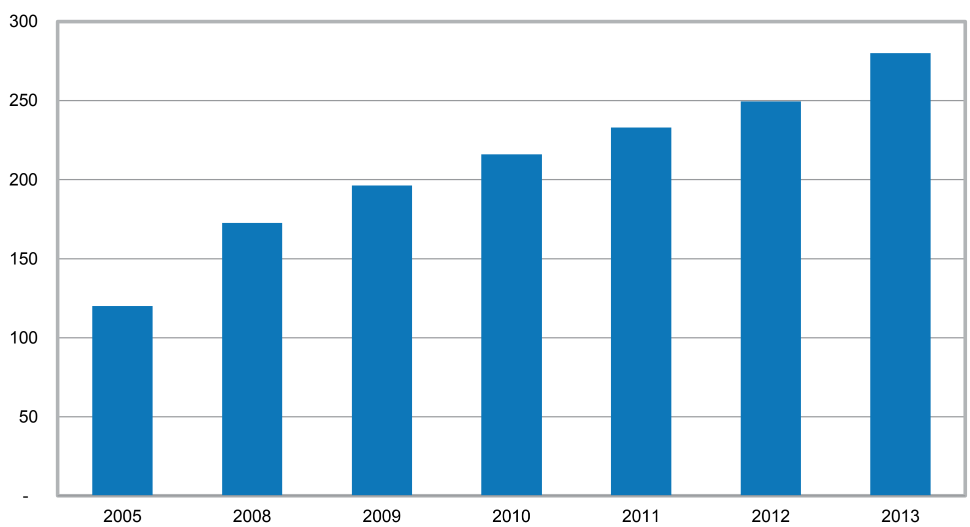
China is the No.1 global builder of dams

China has a long history in harnessing rivers either for irrigation or power by builiding dams. The earliest endeavour of harnessing rivers for irrigation dates back to 256BC when the state of Qin built the Dujiangyan irrigation system, but it was not until 1910 when China built it's first dam for hydropower, the Shilongba Hydropower Plan in Yunnan. Both these hydraulic projects are still used today.

Today, the nation is the No.1 builder of dams globally. Hydropower's total installed capacity stands at 280GW in 2013. As can be seen from the chart below, China has more than doubled total hydroelectric installed capacity since 2005.

China's total hydroelectric installed capacity has more than doubled between 2005 and 2013 to reach 280GW

2005-2013 China's Actual Total Hydroelectric Installed Capacity (GW)



Source: China Water Risk estimates, CEC, 12FYP, State Council, NEA Research Affliate

HYDROPOWER IS NOT ONLY USED FOR POWER GENERATION

The different types of dams serve multiple purposes from water flow management to agricultural irrigation and flood control

China has been adding a mix of small-scale hydropower (<50MW) and medium-scale hydropower (5-100MW) and large-scale hydropower (>100MW). The different types of dams serve multi-purposes; in general:

- Small-sized hydro in rural areas have been a relatively low cost solution for rural electrification phasing out wood & biomass burning by China's rural residents that are not connected to the grid.[54] They have also been used for agricultural irrigation. The last official count of rural hydropower stations was 45,799 dams with a generating capacity of 66GW in 2012; and

- Mediuim-large sized hydropower dams have not only been constructed for hydropower generation but also for water flow management and flood control. The Three Gorges Dam on the Yangtze River is a prime example of this. Although it is China's largest and most controversial hydropower project to date, its maximum generating capacity of 22.5GW is only a mere 8% of China's total hydpower installed capacity today.

Hydropower role in water flow management will become increasingly important in the future due to climate change

Hydropower dams' role in water flow management will become incresasingly important given the rising frequency of floods and droughts in the future due to climate change. Going forward, we may see dimished power generation capacity in hydropower as water is held back in reservoirs to hold back floods or provide drought relief instead of for power generation.

SHIFTS IN HYDROPOWER DEVELOPMENT OVER THE LAST DECADE

From small-scale hydropower (a cornerstone of rural electricfication) to large-scale hydro

Small-scale hydropower has resulted in more than 300mn people having access to electricity

The government has been implementing of a series of policies to promote small hydropower in rural areas since the early 1950s and small-scale hydropower is distributed in more than 1,700 counties in over 30 provinces, regions and municipalities in China. Because of small hydropower more than 300 million people have access to electric power.[55]

Whilst small-scale hydropower has been the cornerstone of China's hydropower generation in the past, the 11FYP and the 12FYP have seen a shift towards medium-to-large scale hydropower. Back in 2005, small- scale hydropower accounted for 35% of China's hydropower capacity in 2005 but by 2010, small-scale hydropower represented just under 30%.

Drive to increase pump storage capacity

China is also pushing to grow pump storage hydropower

Separately, there has also been a push to supplement conventional hydropower with pump storage capacity. In 2013, pump storage capacity (see box) was 22GW, almost the size of the Three Gorges Dam, but still only represents 8% of total hydropower capacity.

PUMP STORAGE HYDROPOWER

"Pumped storage projects move water between two reservoirs located at different elevations (i.e., an upper and lower reservoir) to store energy and generate electricity. Generally, when electricity demand is low (e.g., at night), excess electric generation capacity is used to pump water from the lower reservoir to the upper reservoir. When electricity demand is high, the stored water is released from the upper reservoir to the lower reservoir through a turbine to generate electricity. Pumped storage projects are also capable of providing a range of ancillary services to support the integration of renewable resources and the reliable and efficient functioning of the electric grid."

Source: US Federal Energy Regulatory Commission

Hydropower offers China a relatively cheap and carbon-friendly fuel source, helping it meet its 2030 emissions commitment

Looking forward, as dams serve multi-purposes and are a relatively cheap carbon-friendly fuel source, China looks set to tap its rivers by adding more hydropower capacity. A low-carbon energy source is crucial if China is to meet the climate agreement it made with the US to increase its non-fossil fuel energy contribution to 20% by 2030. In the race to mitigate climate risk, China indeed has ambitious hydropower expansion plans.

However, its reliance on fluctuating river flows means the viability of hydropower also comes into question as increasing droughts and floods in the future might diminish hydropower capacity.

HYDROPOWER DEPENDS ON RIVER FLOWS & THE WEATHER

Hydropower capacity factor is low – coal is used to smooth seasonal variability

Seasonal variability impacts river flows resulting in fluctuations in hydroelectricity generation ...

Hydropower and to a lesser extent pump storage hydropower is dependent on the climate. Seasonal variability, variations in water availability through rain/floods/droughts, means that hydroelectricity cannot be generated year round. In general, hydropower production is high in the wet season and low in the dry season.

Due to this seasonal variability and river flows, hydropower's capacity factor between 2005 and 2013 ranged from 35%-43% (see chart below right). The 2014 capacity factor was 41.7%. This range of year-on-year capacity factors is low compared to 'clean' nuclear at 86% but higher than those of wind & solar at 21.8% and 15.6% respectively (See Chapter 3: "Balancing Power Mix for Water & Climate" for more on capacity factors). Hydropower's low capacity factor can be further affected by smoothing of fluctuations in energy, the size of the hydropower dam and storage of energy in times of excess capacity via pump storage. Finally, poor life-cycle management also adds to inefficiencies. About half of the existing dams are poorly constructed or insufficiently maintained. Currently, dam developers shoulder limited liability in maintenance, and are rarely held accountable should disaster occur.[56]

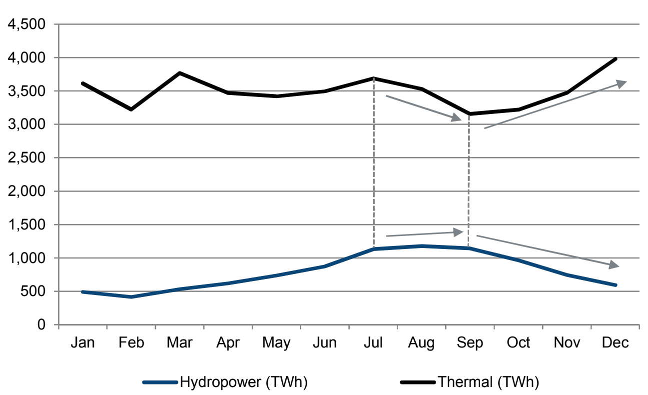
... which means it needs to be balanced with another energy type, which is usually coal...

Hydropower's fluctuations in electricity generation mean that it needs to be 'balanced out'/ smoothed with electricity from another power type. This is usually coal. There is anecdotal evidence that for every large hydropower station constructed in southwest China, so too is a coal fired power station to 'balance out' this variability.[57] The chart below left shows this correlation or 'balancing out', between hydropower and non- nuclear thermal power for 2014. In the summer from July to September, when hydropower is increasing, non-thermal electricity

...therefore achieving efficient coal-fired power is key

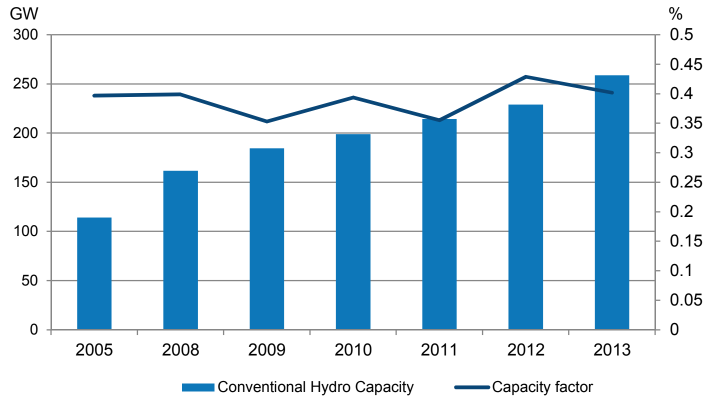
production falls and post September through the end of 2014, the fall in hydropower is offset by the rise in non-thermal electricity, currently dominated by coal. A recent study comparing the contribution of hydropower and coal power between 2010 and 2014 also found a very strong correlation between hydropower and coal.[58]

2014 Hydropower & Non-Nuclear Thermal Electricity Production (TWh)



Source: China Water Risk, NEA

2005-2013 China's Conventional Hydropower Installed Capacity (GW) & Capacity Factor (%)



Source: China Water Risk , 12FYP, NBSC, CEC

Extreme weather brought on by climate change questions the validity of hydropower as an energy source...

The already low capacity factor in hydropower can be further diminished by climate events like floods and droughts, which are becoming increasingly common with climate change. In climate events, even more non-thermal power will be used to balance the grid, thereby increasing reliance on coal. This obviously contradicts the original rational for developing 'greener' hydropower. International Rivers says seasonal variability in hydropower is higher than 30% and is only going to increase with climate change. As coal is the fuel primarily used to smooth hydropower, is it worth continuing with the development of large-scale hydropower?

Extreme weather ahead increases likelihood of power disruptions for businesses

There is rising exposure to climate risk. There is tough weather ahead for hydropower as shifting weather patterns may exacerbate already sub-optimal power generation (see box below).

SWITCH PACIFIC DECADAL OSCILLATION = DRIER TIMES AHEAD?

Apparently it will be wetter in the North, thanks to a switch in the Pacific Decadal Oscillation (PDO) from a warm to a cool phase. The bad news is that this switch will make it drier in the South. The switch between phases happened in 2006 and since 2009, we saw droughts in water-rich Southern provinces like Yunnan, Guizhou and Sichuan. In 2013, it had spread to Hubei and Hunan, where a major drought which has left 384,000 people short of drinking water.

So to dam or not to dam? In light of drier times ahead in the South, surely it is prudent to delay hydro expansion plans. At first glance, there appears to be little upside with sub-optimal hydropower generation and significant downside with a rise in geopolitical tensions with neighbouring countries. But then again, damming may not generate power but could provide relief in times of drought and ensure the safety of staples such as rice (75% of China's rice production lies in the South). Either way, it's not good to be downstream of China. Not only does China control the headwaters of the transboundary rivers with no comprehensive water sharing treaties, but those countries also lie in South Asia and are in for drier weather.

Source: Excerpt from a China Water Risk article titled "China Hydro: Tough Weather Ahead" by Debra Tan, April 2013

... many hydropower stations are operating below capacity due to droughts

Many hydropower stations in China continue to operate below capacity due to ongoing droughts in Southern China. As reported by China Energy News[59], a manager at the Yunnan Power Dispatching & Control Center, laments that run-of-the-river hydropower plants take up a bigger share of reservoir capacity, which in turn lowers its regulating capability. Since the droughts in

Yunnan last longer, the overall regulating capability of reservoirs becomes very limited. Thus, it is urgent to build multi-year regulation reservoirs with better regulating capability or long-distance water diversion projects to solve the increasingly longer droughts. Building larger reservoirs to manage drier times only adds to the anxieties of China's downstream neighbours. (Transboundary issues are discussed later in this chapter)

Hydroelectricity is being wasted due to grid inefficiencies

The flipside is true in the case of floods. According to the State Grid Sichuan Power Company, two-thirds of Sichuan's hydropower is run-of-river with low regulating capacity and therefore the average power generation capacity during the wet season is three times that of the dry season. In 2014, Sichuan could have generated an extra 10TWh of hydroelectricity due to this but did not and as such this was "wasted". As for Yunnan, during the wet season, it could have generated an extra 20TWh but again, due to inability of the grid to absorb the short-term surge, this excess electricity was not used.[60] In order to maximize these imbalances brought on by seasonal variations the grid needs to be upgraded – see chapter on "Other Renewables" for more on the grid.

Power shortages not only affect power production but also disrupt businesses. The authorities in some regions of China have occasionally increased retail electricity prices in order to lessen demand on the grid; certain sectors have also had to pay higher prices for power, especially during seasonal demand; or at worst forced suspension of factories.[61]

Despite issues with hydropower China will go ahead with it due to its multiple purposes beyond power generation

As discussed earlier in Chapter 1: "China's Changing Waterscape", climate change will only serve to make water resource stresses more acute and increase the magnitude of floods. Extreme weather events are also becoming more frequent in China. In the long term, China may have face the fact that hydropower may not be reliable source of power. In light of this, should aggressive expansion even be considered? It appears so.

Despite all these issues surrounding the viability of hydropower, China is still ploughing ahead with hydropower dam building. Naturally, there are not only concerns over the amount of GW to be added, but also how and where it will be added:

1. Which rivers will be dammed?
2. Will transboundary rivers be tapped?
3. Does China really need such an aggressive hydropower expansion policy or are there alternatives?

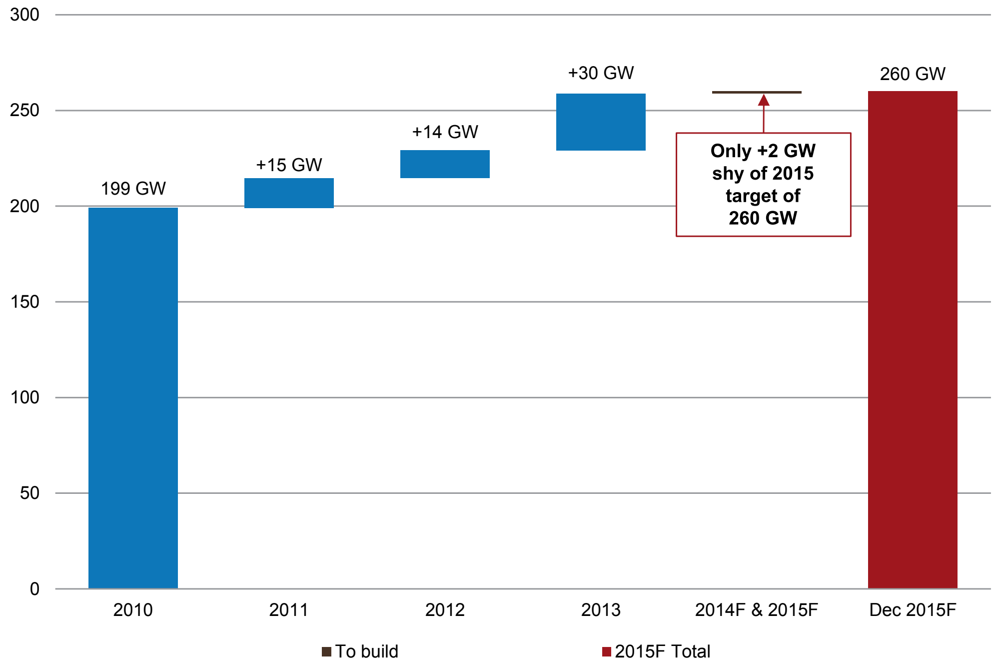
Whether they are small or large dams matter for the environment and whether they are on transboundary rivers may give rise to geopolitical tensions; these risks are explored below.

DAM CONSTRUCTION ON TRACK TO MEET 2015 CONVENTIONAL HYDROPOWER TARGET OF 260GW

The 12FYP target for conventional hydropower installed capacity in 2015 is 260GW. As seen from the chart below, China is on track to meet the 2015 target with hydropower stations in various stages of construction. In addition to the 260GW of conventional power, there is 30GW of pump storage capacity. China looks set to comfortably meet this, bringing total hydropower installed capacity to 290GW by 2015.

China is on track to meet its 2015 conventional hydropower target of 260GW with 258GW in 2013 already

12FYP Expansion in Conventional Hydroelectric Installed Capacity (GW)

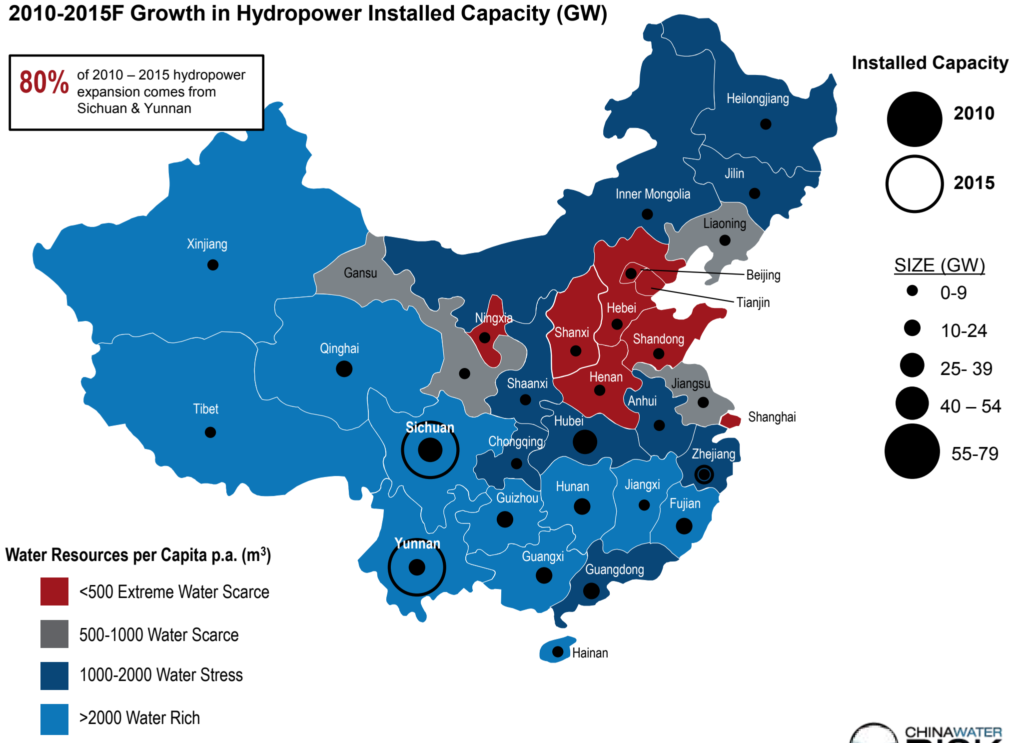


Source: China Water Risk estimates, CEC, 12FYP, State Council

12FYP hydropower expansion has been in water rich provinces with 80% in Yunnan and Sichuan

The above hydropower expansion is planned in relatively water rich provinces in China's South West as shown in the map below. At a glance, it is clear that Sichuan, Yunnan and Hubei are the key provinces for hydropower. Hubei is the home of the Three Gorges Dam. In 2013, these three provinces accounted for 56% of hydroelectricity production but by 2014, this increased to 59% of hydropower generation.

2010-2015F Growth in Hydropower Installed Capacity (GW)



Source: China Water Risk Estimates, NBSC 2011, Provincial 12FYPs

EXPOSURE TO SEISMIC RISK: YUNNAN, SICHUAN & THE QINGHAI-TIBETAN PLATEAU

Though expansion has been in water rich provinces, Yunnan and Sichuan are exposed to seismic risks

What is also clear from the map above is that a large portion of hydropower expansion between 2010 and 2015, 74GW lies in Sichuan and Yunnan – approximately 80%. Both Yunnan and Sichuan are exposed to seismic risks.

Hydropower dams and reservoirs are vulnerable to earthquakes. In 2013, Yunnan experienced three earthquakes each between 5.0 and 5.9 on the Richter scale. Officially, these resulted in 110 casualties, 3 deaths and direct economic loss of RMB2.37 million. Elsewhere, Sichuan experienced two earthquakes – one between 5.0 and 5.9 and the other above 7.0 on the Richter scale. Officially, these resulted in 13,217 casualties, 196 deaths and direct economic loss of RMB67 billion.

There are also concerns of dams triggering earthquakes though there are no proven links

In addition, there have been concerns over dams triggering earthquakes. Although there are no concrete links between dams and earthquakes there are concerns of inter-linkages between the two and the potential impact of China's dam expansion. The most recent was sparked by a Bloomberg article "Are China's Dams Causing Quakes" on 9 October 2014, on the back of a 6.6 magnitude earthquake in Yunnan province on 7 October 2014. Regardless, with increasing seismic activity in the Qinghai Tibetan Plateau, should China persist with the construction of large-scale projects in this region? See box below.

EARTHQUAKES & DAMS

An increase in the number and severity of earthquakes on the Tibetan plateau raises fresh concerns about dam building plans in the region. Dam building in China has seen a huge increase under the 12th Five Year Plan, which pledged that 15% of energy production would come from renewables, primarily from hydropower. The result has been a surge of dam building in China's south-west, with dam cascades to be constructed on the Yangtze, Mekong and Salween rivers on the Tibetan plateau, across parts of Qinghai, Sichuan, Yunnan provinces and Tibet.

An estimated 60 dams will be constructed in the region, with 20 already built and 40 still in the planning stages. However, exploiting the rich hydropower potential of the region comes with high geological risks. A 2012 Probe International report noted that "98.6% of all of these dams, and 99.7% of western China's electricity generating capacity will be located in zones with a moderate to very high level of seismic hazard."

The Tibetan plateau has experienced higher levels of seismic activity. Several unexpectedly severe earthquakes were recorded in August 2013 in southeast Tibet, an area where seismic activity has been historically low. Before last year, only two major earthquakes had been recorded in the area since 1480. The two earthquakes in August, which measured from 4.2-5.7 in magnitude on the Richter scale, caused 87 casualties and damaged 45,000 houses. The scale of the earthquakes is particularly worrying given the proximity to four large hydropower dams planned for construction on the Lancang (Mekong) nearby. The Rumei (or Rongmei in Tibetan) hydropower project, will be one of the highest dams in Tibet once complete and at 315 metres, the second highest in the world.

Source: The above is an excerpt from an article posted on China Water Risk by Yunnan Chen titled, "Dams & Earthquakes", June 2014

GEOPOLITICAL RISKS MAY BE UNAVOIDABLE DUE TO THE TAPPING OF TRANSBOUNDARY RIVERS

China's hydropower is also exposed to geopolitical risks with three of the 10 key large rivers identified for hydropower development being transboundary

In the future, much of China's large-scale hydropower expansion plans lie in Yunnan, Sichuan and the Qinghai Tibetan Plateau on the Jinsha, Lancang, Nu, Dadu, Yalong & Yarlung Zangbu rivers. These rivers are amongst 10 Key Rivers in China that have been identified by the Chinese government as suitable for large-scale hydropower development (see box below). It is clear that there are three transboundary rivers amongst the ten rivers:

1. **The Yarlung Zangbu River (Brahmaputra):** starts in Tibet and flows into India, merges with the Ganges and then into the sea via Bangladesh;

2. **The Nu River (Salween):** starts in Qinghai, flows through Tibet, Yunnan and into Myanmar & Thailand; and

3. **Lancang River (upper Mekong):** starts in Qinghai, flows through Tibet into Yunnan and becomes known as the Mekong flowing through Myanmar, Laos, Thailand, Cambodia and Vietnam.

Should China consider tapping these rivers given significant seismic and geopolitical risks?

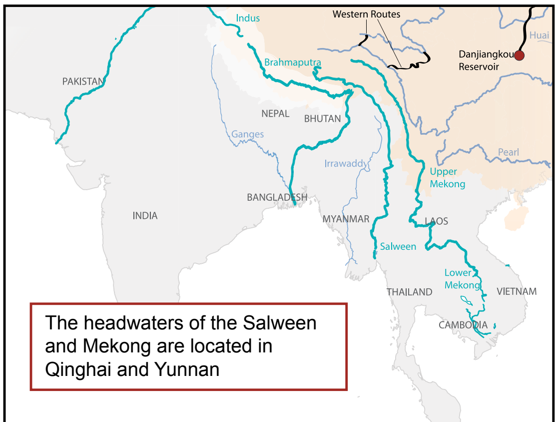
10 KEY RIVERS FOR LARGE-SCALE HYDROPOWER DEVELOPMENT

Ranked from largest to smallest capacity

1. Jinsha River (upper Yangtze)
2. Yarlung Zangbu River (Brahmaputra)*
3. Nu River (Salween)*
4. Yangtze River upper reaches
5. LancangRiver (upper Mekong)*
6. Yalong River
7. Dadu River
8. Yellow River upper reaches
9. Nanpan & Red Rivers
10. Wu River

**Transboundary River*

Source: 12FYP Hydropower Development Plan



Source:www.chinawaterrisk.org

TRANSBOUNDARY HYDROPOWER ONLY 6.5% OF CHINA'S HYDROPOWER CAPACITY IN 2015

By the end of 2015 transboundary hydropower will account for 6.5% of China's total hydropower

Although transboundary projects will represent 6.5% of China's conventional hydropower capacity by the end of 2015, it is still close to 17GW of installed capacity on China's transboundary rivers.

In fact almost all of this, 96% or 16.4GW is on the Lancang; the remaining capacity is a 600MW dam on the Yarlung Zangbu. Currently, the Nu River remains free of large-scale hydropower dams and is often referred to as China's last "wild" river. China's transboundary hydropower expansion is detailed in the box below:

TRANSBOUNDARY HYDRO ONLY 6.5% BY 2015 – BUT 17GW STILL SIZEABLE

The 45,000 strong small hydro dams accounted for almost 30% of China's conventional hydropower in 2010. The rest comes from medium-large scale dams. Not surprisingly, China has a plan as to where these large scale dams (>100MW) are and will be located. China has identified 10 key rivers for large scale hydro development. Three of these 10 are transboundary: Lancang River (Upper Mekong), Nu River (Salween) and the Yarlung Zangbu River (Brahmaputra).

It is clear from the chart on the right that so far:

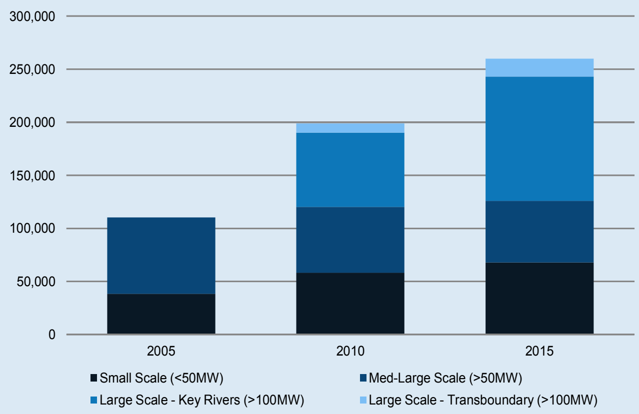
- small hydro has been a key cornerstone of China's hydropower generation;
- most of the development over the last decade has been large scale hydro on China's 10 key rivers; and
- hydropower generation from transboundary rivers only accounted for 4.4% in 2010 and 6.5% in 2015.

So is there much ado about nothing?

Not really. While 6.5% might sound immaterial, it is still close to 17GW of installed capacity and most of this (16.4GW) is on the Lancang.

To put this in perspective, there has been much protest by environmentalists and downstream riparian's Thailand & Laos are bickering over a 1.2GW dam.

Actual and Planned Conventional Hydropower by Size 2005-2015F (MW)



Source: China Water Risk, CEC, 12FYP Hydropower Development

Source: The above is an excerpt from China Water Risk article titled "Avoiding Hydro Wars" by Debra Tan, August 2014

CHINA: UNFAIR BAD PRESS OVER WATER SHARING?

Outside of China there has been significant skepticism over the country's hydropower. China has often recieved bad press on its mega dam projects with the media often claiming that China conducts its hydropower expansion with little or no concern for its downstream neighbours. The two most inflammatory cases are the Mekong and Sino-Indian transboundary waters. Part of this regional skepticism stems from China's voting against the adoption of the United Nations Watercourse Convention (UNWC) that came into force on 17 August 2014. More on keeping the peace on transboundary rivers later in this chapter.

China's water neighbours are worried over China's approach to transboundary water sharing

Given the current set of future expansion plans into 2050 for hydropower, China's neighbours clearly have the right to be worried. Already the construction of dams along the Lancang (upper Mekong) is causing concerns amongst China's downstream neighbours and damming the

Yarlung Zangbu/Brahmaputra is bringing out strong emotions in China's neighbour India. There has been much rhetoric in the Indian media and books have been written over controversial plans to dam the Brahmaputra at its "great U-bend" – some warn that Asia will go to war over water whilst others believe it is much ado about nothing (see box below).

DIVERTING THE BRAHMAPUTRA – MUCH ADO ABOUT NOTHING?

Indian security analyst Brahma Chellaney made some explosive claims in his book "Water Asia's New Battleground" in 2012. China, he argued, Asia's most powerful upper riparian, was in a position to hold its lower riparian states to ransom. China in effect, has control of the tap and could, should it choose to, turn off vital water supplies to India.

Chellaney is a well-known figure in Indian security circles and his views on the China's potential to threaten Indian water supplies are not new. This, however, was a robust and, to many critics, a provocative set of charges. Chellaney's case largely revolves around the highly sensitive issue of the future of the Brahmaputra, which begins its nearly 3,000 kilometre-long journey in the Chemayungdung Glacier in Tibet. It flows generally east at an altitude of more than 5,000 metres, before executing a dramatic 360 degree turn and dropping through its huge, high altitude gorge, whence it emerges into Assam as the Dihang, eventually to combine with the Ganga to enter the vast deltas of the Bay of Bengal. More than 113 million people live in its basin; it drains an area of more than 650,000 square kilometers and its heavy silt load sustains the riches of the delta. Were this titanic river at any point to cease to flow, or to flow elsewhere, it would clearly be a catastrophe. That is the threat conjured by Mr. Chellaney in his book, and widely feared in India as possible.

The choke point this thesis envisages lies within that great bend, where the river drops nearly 3000 meters as it powers through the gorge. Geologically, the gorge is one of the oldest in the relatively youthful Himalaya, older indeed, than the surrounding mountains, which lifted it up in their own moment of creation. For a set of hydro engineers as ambitious as the Chinese, it is a tempting site and the gorge has been extensively surveyed for its potential to relieve China's chronic energy shortages. It is not surprising that China would wish to harvest the energy potential of the Brahmaputra. The questions that this raises, though, are more complex: could this be combined with water diversion, and what would the impacts be downstream?

It would, in fact, be staggeringly expensive and complex to divert the Brahmaputra to the Yellow River, even for a powerful country that has demonstrated its penchant for heroic engineering. The costs in energy and finance of a project that would involve crossing the upper reaches of the Salween, the Mekong and the Yangtze en route are almost incalculable. Even were this project to be pursued — and the Chinese government has repeatedly denied it — it would not turn off the tap: only 14 % of the Brahmaputra's flow is in the river at the point at which it enters the gorge. The other 86% per cent enters the river after it has entered India. Were the Chinese, by some engineering miracle, to divert the entire flow of the river from within their territory, it would still only account for a small percentage of the river's resources.

Harvesting the energy resources is a far more likely proposition: plans exist for a cascade of dams in the bend, which would involve diverting part of the flow into a canal, running it through the dams and allowing it to rejoin the river below them. Although run of river dams of this type can have disruptive effects on a river's flow, Chinese engineers argue that there will be few material impacts in this case. Is this, then, much ado about nothing?

Source: The above is an excerpt from an article on China Water Risk, by chinadiaolgue editor Isabel Hilton titled "Diverting the Brahmaputra: Much Ado About Nothing?" April 2012

Dams in China can be beneficial to downstream countries by helping manage water flows...

Jeremy Bird, the former CEO of the Mekong River Commission and current Director General of the International Water Management Institute said he believed that more dams in China could even out the Mekong's seasonal variations by storing water when it was plentiful and releasing it when scarce.[62] Indeed, the Mekong River Commission Drought Report[63] shows that China is unfairly criticized for intensifying drought conditions downstream.

... though sediment supply, key for preventing floods, is still an issue

The reality is that operation of upstream reservoirs in China results in increased low flows with benefits for downstream hydropower, irrigation and navigation. However, a question mark remains over sediment supply, impact on fisheries, riverbank agriculture – can the flow peaks / troughs be managed differently? Here, Bird believes there is a case for greater regional cooperation in managing variability.

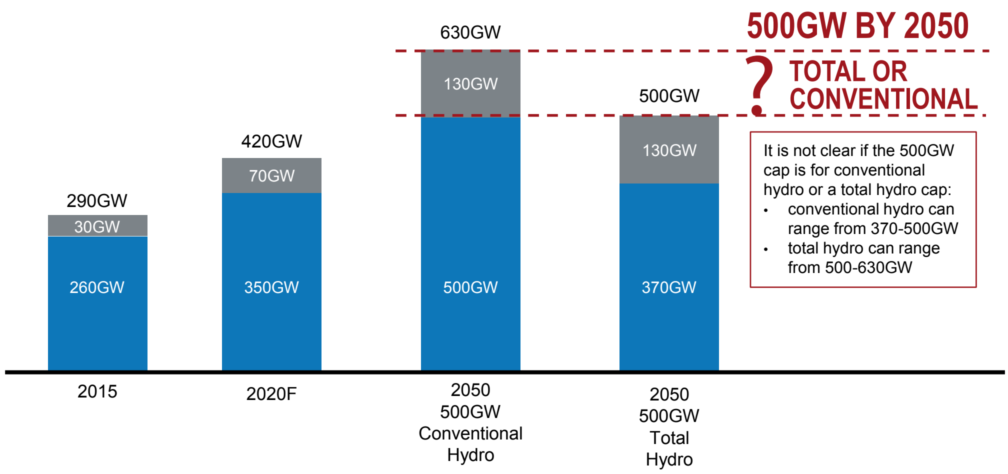
DAMS AND MORE DAMS PLANNED: HYDROPOWER CAPACITY TO ALMOST DOUBLE BY 2050

China's total hydropower installed capacity could almost double by 2050 ranging from 500GW to 630GW

By the end of this year, there will be 260GW of conventional hydropower and 30GW of pump storage capacity. According to the State Council, the target capacity for total hydropower by 2020 will be 420GW and according to the NEA hydropower is capped at 500GW in 2050. Since pump storage capacity is forecasted by the CEC and NEA to be around 60-70GW, conventional hydropower is expected to grow to around 350-360GW by 2020. However, it is not clear whether the 500GW hydropower cap in 2050 is a conventional hydropower cap or a total hydropower cap. As of August 2012, the State Grid expects pump storage to be 120GW-140GW by 2030. Given this, conventional hydropower by 2050 is expected to range from 370GW-500GW so total hydropower capacity by 2050 ranges from 500GW-630GW. These ranges are illustrated in the chart below:

The NEA's 500GW cap by 2050 is unclear: is it total hydropower or just conventional hydropower?

2015-2050F Conventional and Pump Storage Hydropower Installed Capacity Forecasts (GW)



Source: China Water Risk estimates, CEC, 12FYP, NEA Research Affiliate, State Council, NBSC

There are mixed views on the 'right' amount of hydropower China should add

Some say 500GW is too much and others not enough

Assuming a worse-case scenario for China's rivers with a cap at 500GW of conventional power, gives an aggressive add of +240GW in conventional hydropower capacity between 2015 and 2050. This increase of 240GW is almost equivalent to the entire power generation capacity of India at 255GW in 2012 and will require a formidable build out of dams across China's rivers. As the world's largest builder of dams, the question here is not whether China is capable of this expansion but whether it should, given the associated impacts and risks (environmental, social, earthquakes and water wars) as well as hydropower's inter-linkages with coal due to seasonal variability. Indeed, some NGOs are already saying that they are way too many dams, whilst others feel that the NEA cap on hydropower development at 500GW is too low.

Can China continue to drive capacity expansion with large-scale hydropower projects? Related issues and various options discussed below.

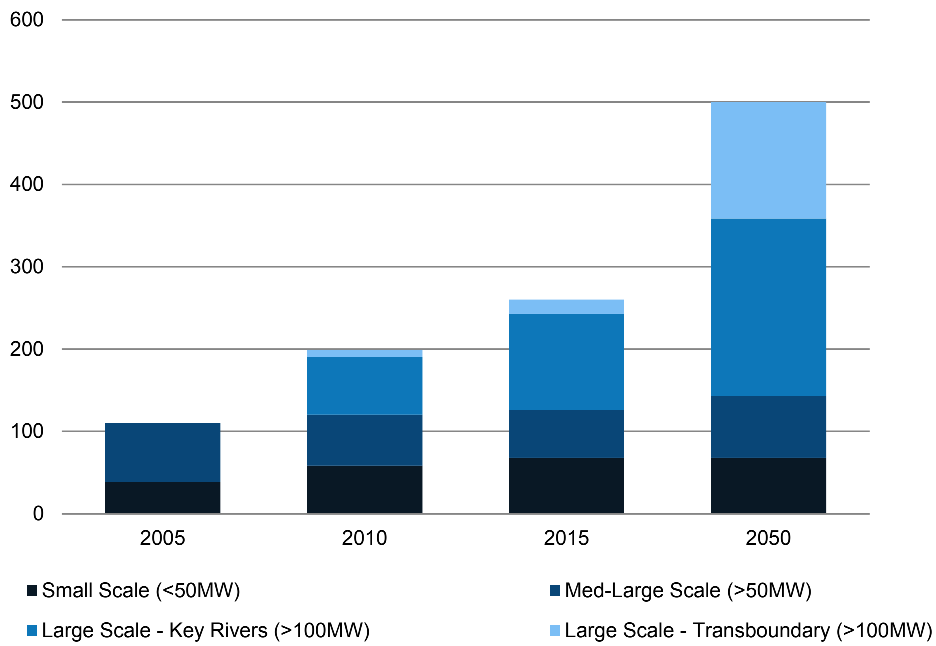
ALL-OUT LARGE-SCALE HYDROPOWER SCENARIO TO REACH 500GW BY 2050 = TAP TRANSBOUNDARY RIVERS

Increasing large-scale hydropower installed capacity means tapping transboundary rivers...

... by 2050 this could account for 28% of China's total hydropower

Firstly, it is important to note here that 500GW is a cap and not a target. Whether it is a 500GW conventional hydropower cap or a 500GW total installed capacity cap is not clear. However for illustration purposes, we are assuming a worse-case scenario for China's rivers with a target of 500GW of conventional power. To reach 500GW, using large-scale hydro only, China will have to tap the 10 key rivers including the three transboundary rivers. This scenario means that large scale transboundary hydropower will rise from 6.5% of total conventional hydropower capacity in 2015 to 28% by 2050. Large-scale hydropower on the other seven rivers will contribute approximately 43% to China's total conventional hydropower capacity.

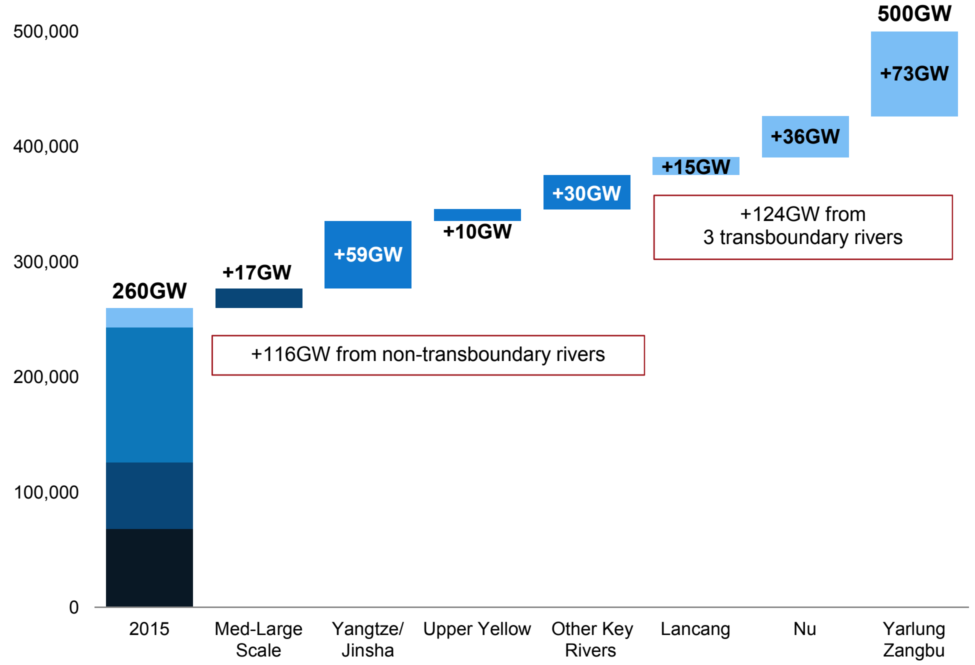
Actual and Planned Hydropower by Size 2005-2050F (GW)



Source: China Water Risk, CEC, 12FYP Hydropower Development

Assuming that (1) the potential target installed capacity identified for each of the 10 key rivers in the 12FYP Hydropower Development Plan is tapped; and (2) that small hydro remains flat at 68GW at 2015. The build out composition of the 240GW is shown in the chart below:

2015F-2050F China Planned Hydropower Expansion (MW)



Source: China Water Risk, CEC, 12FYP Hydropower Development

+124GW transboundary hydropower capacity to be added by 2050

Largest transboundary add to be on Yarlung Zangbu River with +73GW

From the chart above, it is clear that an all-out large-scale hydro scenario will mean:

- The biggest large-scale hydropower add will come from the Yarlung Zangbu River (Brahmaputra). At +73GW, this is the size of at least three Three Gorges Dams;
- The Nu River (Salween) will see around half of that capacity add at +36GW;
- The Lancang River (Upper Mekong) will see an additional +15GW bringing the total amount on the Lancang to 32GW; and

Meanwhile, China is also adding +116GW on non-transboundary rivers

- China is also tapping its 'domestic' rivers especially the Jinsha River (upper Yangtze). There is an additional add of +53GW to the 24GW existing on the Jinsha and a further add of 6GW to the existing 28GW on the upper reaches of the Yangtze River. This means there could be a staggering total of 111GW on the Jinsha/Yangtze by 2050. Whilst this may not increase regional anxieties, there could be significant subsidence and flood risk exposure in China's major cities around the Yangtze River Delta due from decreased silt flow due to damming. Before the Three Gorges Dam, Shanghai would experience an annual flood that brought fertile silt to surrounding agriculture land and also helped maintain water levels.[64] This flood no longer happens due to the dam resulting in decreased water levels. As a result, land is less fertile and salt water is entering Shanghai's drinking water.[65]

China should consider alternatives to transboundary hydropower to avoid going to war over water

Environmental impact issues aside, would China risk rising regional geopolitical tensions with such an aggressive hydropower expansion policy? In light of this, China should seriously reconsider constructing the planned large-scale hydropower projects on transboundary rivers in particular and instead opt for small-scale hydropower. At the same time, China should also consider how to avoid sparking a 'water war' in the event that transboundary rivers are dammed.

MIXED VIEWS ON HOW MUCH HYDROPOWER CHINA SHOULD ADD

There are mixed views on how much hydropower China should develop given environmental impacts, rural population relocation for large dams and exposure to seismic risk as well as hydropower's reliance on coal-fired power for smoothing due to seasonal variability.

Many NGOs see hydropower as a way to tackle climate change due its low carbon emissions...

Many Chinese and international civil society organizations like World Wide Fund for Nature China and NRDC support hydropower expansion plans as a way to tackle climate change and reduce carbon emissions. WWF China's report last year, "China's Future Generation Accessing the Maximum Potential for Renewable Power Sources in China to 2050" details a 'High Renewables Scenario'. This scenario assumes an aggressive build out of hydropower to 510GW by 2050 in order to cut carbon emissions. Although the report does not mention whether this is total or conventional hydropower, this forecast appears to be 10GW greater than China's planned cap of 500GW by 2050.

... but some NGOs worry over the negative environment and social impacts from hydropower

On the flipside is International Rivers, which worries that in the wake of the climate agreement with the US, China will rush to add more dams with support from international NGOs before considering other options. In their latest report, "The True Cost of Hydro" published in November 2014, they propose a 'River Conservation Scenario', which caps hydropower installed capacity at 270GW by 2020 through to 2035. Their scenario further assumes post-2035, dams will be retired in accordance with their 50 year life span and thus hydropower installed capacity will fall in the foreseeable future. International Rivers say their scenario reduces negative impacts on the environment but still allows for China to meets its carbon reduction targets (see box below).

NO NEED TO SACRIFICE RIVERS FOR POWER

Celebrating China's commitments to phase out coal without asking how it will meet its targets is a dangerous game. Because while most might assume that China will replace its demand for coal with abundant and affordable renewable energy like solar and wind, the truth is that there's a type of renewable energy – hydropower – that brings severe risks of its own. Right now, Chinese dam builders and energy planners are getting ready to ramp up construction of new hydropower dams on China's rivers at unprecedented levels. The Government's new carbon targets provide the perfect excuse. And despite the well-proven dangers of this approach, many Chinese and international civil society organizations like WWF China and NRDC are supporting this approach in the name of tackling climate change.

In this context, it's never been more important to have a conversation about the real cost of building large dams on China's few remaining "wild" rivers. International Rivers' new report, the "True Cost of Hydropower", explores the implications of hydropower's significant seasonal variability and shows alternative pathways for China's energy transition pathways that don't irreversibly damage China's valuable southwest rivers whilst meeting China's carbon reduction targets.

The river conservation scenario allows for limited increase in hydropower generation, ambitious investments in renewable energy sources such as wind and solar and no nuclear capacity. This preserves the remaining Southwest Rivers such as the Nu (Upper Salween), and the headwaters of the Jinsha (Upper Yangtze), and Lancang (Upper Mekong), with no substantial increase in carbon emissions per year or a substantial increase in investment levels to implement. Under the scenario, solar and wind constitute 33% and 30% of electricity generation sources by 2050 and gas-fired power is at 31% (at a 60% capacity factor which we found was more economically and financially viable). The river conservation scenario is competitive even when examined against 100% renewable scenario prepared by WWF China, which proposes to increase hydropower capacity beyond government targets to 510GW. Such scenarios would certainly fundamentally change and irreversibly damage China's fresh water ecosystems.

Source: The above is an excerpt from an article posted on China Water Risk by Grace Mang, China Programme Manager at International Rivers titled, "No Need to Sacrifice Rivers for Power", February 2015

It is not just International Rivers that is worried. Concerns over the dam building rush led a group of 19 Chinese environmental NGOs and organisations to author The "Last Report on China's Rivers", a comprehensive assessment of the nation's hydropower development and the state of its rivers drawing on ten years of research from mainly civil society groups working in the basins. Of the coalition of 19 NGOs and organisations, seven of these initiated the report: Friends of

Nature, Institute of Public & Environmental Affairs, Green Watershed, Shan Shui, Chengdu Urban Rivers Association, Green Earth Volunteers and Hengduan Mountain Research Association.

Concerns over ecological disruption from hydropower have increased in recent years

The report recognizes broader ecological and economic values of Chinese rivers beyond power generation and advocates an urgent need for effective ecological "red lines" in new conservation legislation. The authors also encourage a rethinking of clean energy development in favor of truly renewable sources—wind and solar—with a smaller ecological footprint. Many Chinese and international NGOs have been reporting on the impacts and risks from China's hydropower, but concerns have understandably increased following China's continued expansion plans. See box below.

With nature reserves and eco-systems at stake, is adding significant hydropower the best carbon-friendly way forward to power and develop China's economy? Especially when future power generations may require more non-nuclear thermal power to smooth due to increased seasonal variability to droughts and floods? In the face of rising geopolitical tensions and seismic exposure, other alternatives should be explored.

Glaciers and the climate are at risk; need to balance environment and social risks by lowering carbon emissions

On the other hand the additional hydropower capacity will complement the even more aggressive non-hydro renewables add of 808GW between 2013 and 2050. Moreover, hydropower has a higher capacity factor in generating electricity than wind or solar in China and therefore requires less coal-fired power to smooth. Finally, with glaciers at stake, surely every bit of aggressive climate-friendly power-add counts?

For capacity factor comparisons across power types – please see Chapter 3: "Balancing Power Mix for Water & Climate".

NATURE RESERVES REDEFINED FOR HYDROPOWER

Meandering along the upper reaches of the grand Yangtze River in China is an 82-million-acre national nature reserve designed to protect the 189 fish species in this biodiverse area. The boundaries of this reserve were considered "red lines" for environmental conservation. But in 2009, in order to make way for a proposed hydropower station, the Chongqing municipal government persuaded the Ministry of Environmental Protection to redraw these lines.

Constructing a dam on the verge of previously protected areas will not only disrupt the breeding waters of vulnerable fish species, but perhaps more importantly also exemplify the already significant power of dam developers to ignore the ecological and social bottom lines.

ECOSYSTEM IMPACT

It's clear from "The Last Report on China's Rivers" (2013), that hydropower development has been put ahead of environmental protection. According to the report in 2009 the Chongqing municipal government persuaded the MEP to redraw the boundaries of a national nature reserve in the upper reaches of the Yangtze so to construct a hydropower station. This is not an isolated case. Consequences of putting hydropower ahead of the environment have led to:

- Altered freshwater systems;
- Blockage of nutrient flows;
- Decreased fish stocks & breeding
- On the Yangtze River, dams contributed to a 97% decrease of carp population in the river; and
- Decreased silting – silt flowing through the rivers is often blocked, changing flow dynamics downstream that can result in increased flood risk.

RESETTLEMENT

To date the 23 million people who were relocated for dam construction have been poorly compensated and local governments have often ignored their social and economic needs. Consequently, 8 million of the previously resettled are still living below the national poverty line—making up one-third of China's total poverty population. Resettlement disproportionately affects the livelihood and culture of ethnic minority groups in southwest China.

Source: The above are excerpts from an article posted on China Water Risk by Turner & Dong, Wilson Center titled, "Rethinking China's Dam Rush", February 2015

CLIMATE, GEOPOLITICS & WATER SHARING CONUNDRUM

Glaciers in the Qinghai-Tibetan plateau have already shrunk 15% over the last three decades; their meltwaters feed Asia

Ecosystem risks and climate risks need to be weighed by policy makers when deciding how much hydropower to add. Policies decided today have long term implications not just for China, but for the planet. According to the Chinese Academy of Sciences, glaciers in the Qinghai-Tibetan plateau have already shrunk 15% over the past three decades. Whilst China may "own" these glaciers, their meltwaters feeds South Asia and South East Asia. Given this, surely the conversation would be more productive if it was to move away from whether China should or should not dam to how to best protect Asia's watersheds whilst avoiding a 'hydro war'.

There has been a lot of negative chatter around China voting against the UNWC, which first serves as a conflict prevention tool, and second, as a dispute resolution and procedure mechanism. Three countries, China, Turkey and Burundi voted against it but India, a vocal protestor of China's damming of the Brahmaputra abstained from voting. In order for the UNWC to come into force, it required ratification from 35 countries. One would have thought this was easy given 103 countries voted in favour of the convention. However, it has taken them 17 years to gather the 35 ratifications. Whilst, Laos, Thailand, Cambodia and Vietnam all voted in favour of the UNWC, only Vietnam ratified the convention.[66]

There are negative perceptions of China for not ratifying the UNWC but neither has the US nor Canada

The reality is that some UNWC issues that worry China also worry other countries. But instead of voting against it, they either abstained, or voted yes but then not ratified the convention and are therefore not bound by it. Even the US and Canada did not ratify the UNWC. Is it then unfair to penalize China for being frank about its position? But what is China's position on water sharing?

CHINA TO PLAY A CENTRAL ROLE IN TRANSBOUNDARY WATER & THE WATER-ENERGY-CLIMATE NEXUS

China's international freshwaters are shared with 20 riparian countries...

China's international freshwaters are shared with more than 20 riparian countries (North Korea, Russia, Mongolia, Kazakhstan, Kyrgyzstan, Tajikistan, Bhutan, Myanmar, Laos, Nepal, Pakistan (Kashmir), Afghanistan, India and Vietnam to name a few).[67] This puts it in a unique position to play a central role regionally as the upper riparian in keeping the peace and protecting the "Himalayan water towers".[68]

In May 2014, China took a positive step towards this and held its first-ever officially sanctioned International Water Law Symposium, hosted by Xiamen University. Also, in June 2014, China and India signed a new MOU to detail the sharing of hydrological data on the Brahmaputra River. In 2015, we expect to see China continue to play a key role with more focus on the water-energy-climate nexus.[69] In fact China already has more than 50 water-related bilateral treaties and various multilateral environmental agreements that affect its international freshwater regimes.

... is showing positive steps in water sharing

These are positive steps by China but it is not just China but India that also needs to add significant power with limited water resources. Asia's choices to generate power to meet rapid development with the cheaper fuel options of coal and hydro matter. China's actions in this global nexus could lead Asia towards water & energy security whilst keeping climate change in check and side-stepping transboundary conflict. In addition, China's pilot solutions for sharing of water between provinces along the Yellow and Yangtze Rivers discussed in Chapter 4: "Ensuring Food & Energy Security", if successful, could be applied regionally.

According to water law experts China's transboundary strategy does have elements of the two UN water conventions ...

Experts in international water law say that China has soft-soft approach to transboundary water resource management favouring settlement of disputes through peaceful negotiations. According to Dr Wouters, founding director of the UNESCO Centre for Water Law, Policy and Science, a study examining China's transboundary water treaty practice[70], China's actions generally respect the approach of the UNWC. Dr. Wouters is also of the view that despite not having ratified the two UN conventions China's transboundary strategy does include many of the elements from them and that China's recent actions over water allocation with Kazakhstan demonstrate the nation's future approach to transboundary issues.[71] More on this in the box below.

... China will play a bigger role in regional water security

As the upstream riparian, China will no doubt play a bigger role in regional water security. It is time we accepted this. Incorporating some of the provisions and processes in the UNWC framework could be a way forward. It is time to start productive conversations to find solutions for Asia's water-energy-climate nexus; to work with China and not against.

KEEPING THE PEACE: CHINA'S UPSTREAM DILEMMA

While China voted against the adoption of the UNWC, is not a party to the United Nations Economic Commission for Europe Transboundary Waters Convention (UNECE TWC), and, is unlikely to ratify either of these conventions in the near future, an examination of treaty practice and policy statements reveals that China nonetheless embraces the fundamental principles at the core of these global water framework instruments:

- the duty to cooperate;
- the principles of equitable and reasonable use;
- the duty to protect the ecosystem of the watercourse; and
- the peaceful settlement of disputes.

China's transboundary water cooperation is linked directly with its approach to international law. In observations on China's foreign policy, (now) International Court Judge Hanqin Xue has written,

"China pursues an independent foreign policy of peace and promotes equal and mutually beneficial cooperation for common development. In the past two decades, China has improved its relations with the major powers, and further strengthened its ties with the developing countries, particularly its neighbouring countries. ... China is now fully engaged in international affairs. Either for security issues or for development matters, it attaches importance to the role of international institutions and the rule of law in international affairs.... It endorses [the] new security concept and remains committed to common development."

Under President Xi Jinping and Premier Li Keqiang, China, especially over the past year, has actively engaged with regional nations and organisations and concluded many bilateral agreements around the world. This provides the context for understanding China's emerging incremental hydro-diplomacy (i.e. recent agreements on data- sharing with India and the deeper engagement with Kazakhstan).

Source: The above is an excerpt from an article on China Water Risk's website by Dr. Patricia Wouters titled, "Keeping Peace: China's Upstream Dilemma", November 2014

OPTIONS TO REPLACE +124GW OF LARGE-SCALE HYDROPOWER ON TRANSBOUNDARY RIVERS

China's energy choices impact water availability in Asia

China's energy choices not only impact global climate change but affect water availability for Asia. Adding hydropower capacity appears inevitable. So what is the right amount of hydropower? Are NGOs too conservative or too aggressive with their hydropower growth scenarios?

We are of the view that 500GW in 2050 will be a total hydropower cap

We are of the view that 500GW will probably be the capped total hydropower rather than conventional capacity .As such, we have set out the above expansion to illustrate the magnitude of geopolitical risks if the maximum capacity of the seven key rivers and three transboundary rivers are tapped.

There are ways for China to increase hydropower without tapping transboundary rivers

Whilst transboundary risks can be somewhat side-stepped by international water laws and practices as discussed above, there are other ways to get to 500GW without having to tap +124GW of large-scale hydropower on transboundary rivers nor +59GW on the Jinsha River:

1. Maximise small-scale hydro potential = +60GW between 2015 & 2050

Despite the large number of small dams, small-scale hydropower is expected to increase from 66GW in 2013 to 68GW by the end of 2015. However, according to the "World Small Hydropower Development Report 2013", China's small-scale hydropower potential is 128GW. If this is so, then China could add a maximum of 60GW of small-scale hydropowerv between 2015 and 2050. This is almost half of the +124GW on the three transboundary rivers. It should be noted that this is more aggressive than WWF's High Renewables Scenario which forecasts 100GW of small-scale and 410GW of large-scale hydropower by 2050.

China could get 60GW by maximizing small-scale hydropower

Small-scale hydropower will always have a role in China's development because of providing rural electrification and facilitating irrigation. However, the efficiency of small hydropower could be improved. Between 2013 and 2015, the central government will invest around RMB8 billion and local governments and private investment will invest RMB14 billion to upgrade >4,000 rural hydropower plants built before 1995.

This would increase their collective installed capacity from 6.8GW to 8.1GW.[72] With over 45,000 dams, there is clearly a long way to go but it is the right direction.

In March 2014, the MWR began pilots in various counties across China to develop small hydropower to generate electricity to replace the burning of biomass. The main reasons for this are: (1) to reduce greenhouse gas emissions; and (2) to improve the electricity generation efficiency of biomass through the collection of unburned biomass and centralized processing, rather than individual household biomass burning.

But small-scale hydropower development will face financing and low tariff barriers

There will be typical barriers to small hydropower development such as financing and low tariffs. Based on the yardstick of RMB7,000/kW[73] of installed hydropower capacity, +60GW will require RMB420 billion to build. In light of its potential to replace transboundary capacity or the capacity add on the Jinsha River, surely small hydropower is worth investing in, not just for the Chinese government but anyone with significant investments in the Yangtze River Delta or South and South East Asia.

CAUTION: SMALL HYDROPOWER STILL HAS ENVIRONMENTAL IMPACTS

Environmental impacts from small hydropower are along the same themes as large hydropower. These include: land use, altered water flows, altered ecosystems (temperature & chemistry changes) and increased or decreased level of nutrients & silt.

Source: International Union for Conservation of Nature, "Small scale hydro power: Impacts on nature and people" (May 2012)

2. Mid-range pump storage add of +100GW between 2015 and 2050

China could also gain 100GW through increasing pump storage hydropower

By the end of 2015, pump storage capacity in China is on track to be at 30GW. The National Development and Reform Commission (NDRC) in November 2014 released the 'Opinion on Promoting Development of Pump-Storage Power Station', which states plans for pump storage of 100GW by 2025. Geological requirements of pump storage (area for the storage pool) will dictate the location for development but the government has not yet released any locational information. This expansionary directive appears to be in line with earlier announcements by the State Grid in 2012 stating that pump storage capacity is set to increase to 120GW-140GW by 2030.

Pump storage hydropower can help with fluctuating hydroelectricity generation but China will still need other energy sources for smoothing

Part of this expansion is to alleviate energy shortages not just from fluctuations of hydropower but also other renewable power due to seasonal changes. However, pump storage alone is not enough to mitigate fluctuations and so China must still use other energy sources for smoothing (see below).

CAUTION: PUMP STORAGE & THE ENVIRONMENT

Environmental impacts from pump storage hydropower are largely the same as conventional hydropower: land use, altered water flows, altered freshwater systems (temperature & chemistry changes), decreased fish stocks and blockage of nutrients & silt. However, pump storage has two reservoirs so the impacts can be doubled. An approach to minimise these impacts is to build the storage reservoir separated from the river system there by not impacting it. This is known as "closed loop" pump storage.

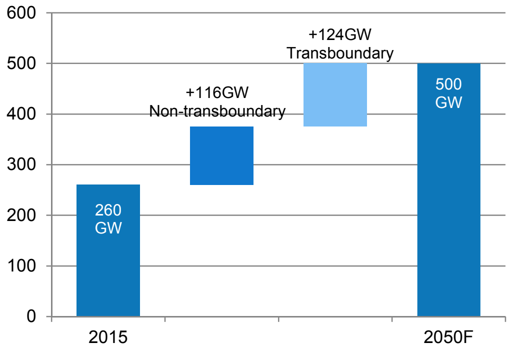
Sources: International Union for Conservation of Nature, "Small scale hydro power: Impacts on nature and people" (May 2012), Last Report" on China's Rivers (2013), National Hydropower Association – Pumped Storage Development Council White Paper "Challenges and Opportunities For New Pumped Storage Development" (2012)

Only +50GW needs to come from large dams for China to meet 500GW in 2050...

...the Nu River can remain wild

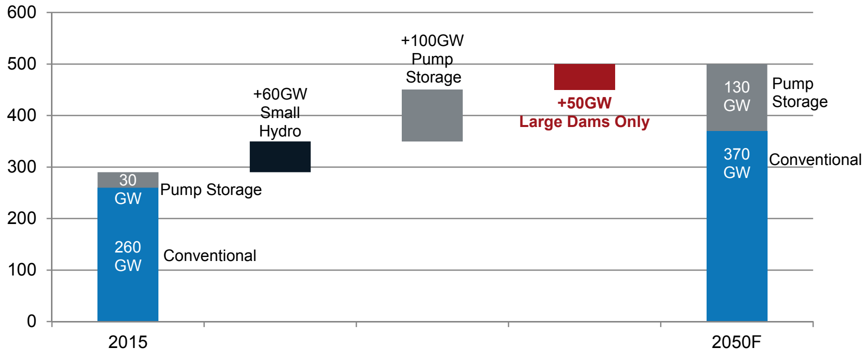
Assuming a mid-range pump storage capacity at 130GW by 2050, it is clear from the chart below that capacity increase in both pump storage and small hydropower amounts to +160GW. Already this will mean that the +73GW on the Yarlung Zangbu River (Brahmaputra) and the +36GW on The Nu River (Salween) are not necessary. China and India can avoid head-butting over regional waters and The Nu River can remain "wild". Not building these dams will have obvious environmental upsides – see CWR 2050 Base Hydropower Scenario in the chart below:

All Out Large-scale Hydropower Scenario (GW)
Conventional Hydropower = 500GW



Source: China Water Risk estimates, CEC, NEA Research Affiliate, 12FYP Hydropower Development

China Water Risk Base Hydropower Scenario (GW)
Total Hydropower = 500GW



Source: China Water Risk estimates, CEC, NEA Research Affiliate, 12FYP Hydropower Development

THE FUTURE OF CHINA'S HYDROPOWER

Despite geopolitical, environmental and social risks, hydropower expansion will continue...

Whilst transboundary risks and geopolitics may be side-stepped with international water law, seismic exposure and other environmental concerns still exist. Watershed and ecosystems are at risk and coastal cities by major river deltas remain exposed to increased subsidence risks due to the reduction in silt flow by damming. Moreover, there is still a question of more extreme weather ahead diminishing operational capacity and increasing reliance on coal-fired power to smooth this seasonal variability.

... it is imperative for China to ease regional anxieties...

Despite all this, hydropower development will continue for the dual purpose of electricity generation and water flow management. China will continue to dam rivers as reservoirs have various purposes like flood control, providing irrigation water and safety nets in times of droughts. Given the possibility of drier weather ahead for Southern China, it is imperative for China to play a more central role in transboundary issues and international water law as this will ease regional anxieties on existing dams.

... although the Yarlung Zanbgu and Nu Rivers are very unlikely to be developed

However, perhaps it is time to slow down China's large-scale hydropower expansion as per CWR's 2050 Base Case Scenario. Li Junfeng, the Director General of the National Center of Climate Change Strategy Research at the National Development and Reform Commission, believes that *"the past decade was the golden age for hydropower in China, but the next decade will see an end to this boom"*. In our interview with him, he said that he expects China's massive hydropower projects to be been completed. Mr Li is also of the view that the large projects on the Yarlung Zangbu and the Nu Rivers *"are very unlikely to be developed"* as *"extreme complex geological conditions & seismic risks are concerns"*. Please refer to the box below for excerpts from our interview.

China could 'swap-out' of hydropower into other power types ...

... +240GW can be replaced by around 100 nuclear reactors

If hydropower expansion was purely viewed from a power generation perspective, all alternative fuels to hydropower should be explored and considered holistically. If China wanted to 'swap out' of hydropower into other power types it needs to consider the different capacity factors, water requirements and environmental, economic and social impacts. For example, to reach 500GW of conventional hydropower, China will need to add 240GW and assuming a capacity factor of 41.7%, +240GW will provide around 877TWh of power. This can instead be generated by 111GW of nuclear installed capacity. Nuclear power will be the most efficient choice as wind and solar will have similar balancing issues as hydropower. In short, +240GW of hydropower dams can be replaced by around 100 nuclear reactors which is at best 25 nuclear power plants. That said, hydropower dams are used to also manage water flows and are therefore here to stay.

TOP VIEWS ON THE FUTURE OF CHINA'S HYDROPOWER CHINA WATER RISK INTERVIEW WITH LI JUNFENG

CWR: On hydropower, the 12FYP approved quite a few large-scale hydropower projects in the Southwest. Where do you see hydropower heading?

LJF: The past decade was the golden age for hydropower in China, but the next decade will see an end to this boom. In essence, China's hydropower development is "a spent arrow". Hydropower is no longer rapidly growing; 80% of China's available hydropower resources have already been developed. China's hydropower capacity has reached 250GW and is expected to increase to 350 GW in the future. Hydropower development should likely reach its final stage by 2025 and by 2030 China's massive hydropower construction should be finished.

CWR: What about the planned large-scale hydropower expansion on transboundary rivers such as the Yarlong, Nu & Lancang Rivers. Without comprehensive water sharing agreements in place, such projects may give rise to geopolitical tensions in the region. What are your views?

LJF: They are very unlikely to be developed. Many of these projects are proposed to be built in areas with extremely complex geological conditions, some even in extremely unstable zones with high risk of earthquake. To build hydropower in those areas it requires great care. As I said, the "golden age" for hydropower has passed. From a political perspective, the high-level decision-makers are also more and more aware of the importance of environmental protection. Former Premier Wen Jiabao approved much fewer hydropower plants during his second term than his first term. Change is slow, but it is happening.

Source: The above is an excerpt from a China Water Risk interview with Li Junfeng, the Director General of the National Center of Climate Change Strategy Research at the National Development and Reform Commission. The interview is titled "Water Over Energy Security", October 2014

China must tackle coal-fired power efficiency to make hydropower as 'green' as possible

As discussed previously in Chapter 3: "Balancing Power Mix for Water & Climate", coal remains the vanguard and will most likely be used to smooth hydropower's seasonal variability. Therefore for "cleaner" and better hydropower, China has no choice but to tackle coal in increasing coal-fired power generation efficiencies, the type of coal burned as well as water savings from extraction to washing and electricity generation. This is covered in more detail in the Chapter 5: "Battle to Conserve Energy" as well as the chapter on "Coal & Coal-fired Power".

Hydropower is a staple in China's energy mix and is here to stay

Hydropower is a staple in China's energy mix and is here to stay. As for how much more hydropower China should add, there is no 'right answer'. Also, the right solution for now may not be the solution for the future. For now, we hope the golden era of hydropower has passed and expect China to adopt the following multiple strategies:

- Improve existing small hydropower efficiencies and life-cycle management as well as develop small hydropower potential to continue rural electrification and provide agricultural irrigation water;

- Develop large hydropower to generate energy and as part of water flow management regarding flood risk whilst keeping the Nu and the Yarlung Zangbu rivers free of mega-dams and the Lancang River free of new-build large scale dams as well as avoiding seismic areas;

- Develop cleaner coal for smoothing hydropower as well as other renewables including switching from coal to gas-fired power for grid-balancing;

- Implement grid improvements for intermittent power feed in – this is discussed in more detail in chapter on "Other Renewables"; and

- Incentivize significant power savings; the only trifecta win for climate, water and power – more on this in Chapter 5: "Battle to Conserve Energy".

Must pay close attention, the stakes are high for Asia with melting glaciers

With glaciers melting, the stakes are much higher than transboundary water disputes. Hydropower expansion needs to be explored weighing all the above in mind. The future of China's hydropower doesn't just impact China; it has regional watershed implications and global climate ramifications. We should be paying closer attention.

NUCLEAR POWER

ALTHOUGH SIZEABLE IS AT A CROSSROAD DUE TO WATER CONCERNS

- China's nuclear power installed capacity reached 20GW in 2014. Although this represents a mere 1.5% of total installed capacity, it generated 2.4% of the total electricity produced that year. That said, nuclear power is growing faster in China than anywhere else in the world. By 2020, China's nuclear power capacity will almost triple to an operational capacity of 58GW with a further 30GW under construction.

- Beyond 2020, the longer term future of nuclear is unclear as no official target has been set. Nuclear installed capacity is forecast to be 200GW by 2030 but forecasts for 2050 range from 340GW to 500GW. At 500GW, nuclear power can generate up to 28% of total power generation in 2050. However, there is much debate as to whether China should follow the path of such aggressive nuclear expansion.

- While carbon-friendly nuclear power can reduce China's reliance on coal and help China peak its carbon emissions around 2030, water concerns pervade. Moreover, while rich in coal reserves, China has limited uranium reserves and must rely on imports. Given the paramount importance of energy security to China, nuclear will likely supplement rather than replace coal as the vanguard.

- Nuclear power plants (NPPs) need a constant flow of water for cooling, even after the power plant has been shut down. Moreover, for the same amount of electricity generated, NPPs withdraw and consume significantly more water than coal or gas power plants. The Fukushima incident reiterated the need for continuous water for cooling and the risk of meltdown when the flow was disrupted by the tsunami.

- Currently, all NPPs are located along the coast as they can use seawater for cooling. However, there are plans for +28GW of inland NPPs with a further +40GW of inland NPPs proposed. This +68GW means 60 nuclear reactors. After the Fukushima incident, China placed a moratorium on NPP construction. This has since been lifted, but only for coastal expansion: +27GW of coastal plants are under construction in 2014.

- Inland nuclear expansion is at a crossroad. Over 70% of the +28GW of inland NPPs are in the Yangtze River basin, raising water contamination fears given China's historically lax pollution enforcement. This watershed is home to 400 million people and produces over 70% of China's rice, 50% of its grain and 70% of its freshwater fish. Wider fluctuations in seasonal variability due to climate change and seismic risk calls for extreme caution in proceeding with inland nuclear expansion; alternatives should be explored.

- The current planned and proposed expansion brings nuclear capacity close to the 2030 forecast of 200GW. Assuming no inland nuclear expansion, coastal nuclear capacity will only reach 124GW, resulting in a gap of +216GW to CWR Base Case of 340GW by 2050. Cutting energy demand is an option but +216GW of nuclear capacity can generate as much as 1,700TWh; Japan only generated 1,088TWh in 2013.

- Aggressive wind and solar expansion is another option: the +216GW of nuclear capacity can be replaced by +822GW of wind capacity or +1.2TW of solar PV capacity. This may not be too far-fetched: indeed NDRC-ERI's recent scenario analysis show that its aggressive projections are +1TW more aggressive than its base case for each of wind and solar.

- Construction of the +28GW of inland NPPs is expected begin in the 13FYP but we believe that serious consideration should be given to replacing this with +60GW of hydropower, +106GW of wind or +161GW of solar. With river basins at risk, inland nuclear expansion should be de-prioritised until China's enforcement of pollution violations has significantly improved. If pursued, special attention should be paid as these inland NPPs will be among the world's first operational units of the new Westinghouse AP1000 model.

- Water risks could dampen China's nuclear ambitions. No official targets beyond 2020 signals an unclear future for thirsty nuclear. Ultimately, at 340GW by 2050, nuclear will represent around 10% of total installed capacity and generate up to 19% of China's electricity. Given the magnitude of the downside risk over safety and watershed contamination concerns, some China experts have commented that nuclear power, albeit sizeable is *"optional rather than essential"*.

NUCLEAR POWER
ALTHOUGH SIZEABLE IS AT A CROSSROAD DUE TO WATER CONCERNS

CHINA NUCLEAR AMBITIONS DAMPENED BY WATER CONCERNS

In 2014, nuclear capacity reached 20GW representing 2.4% of the electricity generated

In 2014, China's nuclear power generation capacity reached 20GW and generated 133TWh. This constitutes a mere 2.4% of the total electricity generated in that year. However, this is set to increase significantly by almost twenty fold in the next few decades. The most aggressive forecasts have nuclear installed capacity at 500GW by 2050, providing up to 28% of electricity consumed by then.

Domestically, several factors drive China's decision to opt for this type of power generation. With its high capacity factor, nuclear can replace coal as a base load power generator. Reducing reliance on coal and the associated smog is probably the most attractive feature of nuclear power in China's "War on Pollution" (see Chapter 1 "China's Changing Waterscape"). The low carbon footprint of nuclear power is also a convincing argument and will help China peak its carbon emissions around 2030, as per the China-US Climate Agreement in November 2014.

Paused after Fukushima, China's nuclear expansion plan is being restarted...

However, the Fukushima nuclear accident in Japan in March 2011 reiterated nuclear power's reliance on water and the need for continuous water for cooling which was disrupted by the tsunami. Following the incident, China announced a moratorium on nuclear power development (coastal and inland) and ordered extensive safety checks of existing nuclear facilities. In October 2012, after more than a year, China lifted the moratorium to continue its nuclear energy expansion cautiously. Today, nuclear power generation capacity is growing faster in China than anywhere else in the world. Indeed, China has ambitions to become a world leader in nuclear technology and is aiming to develop, build and export its own third-generation nuclear power plants (NPPs).

... but safety concerns and public opposition pervade

That said, nuclear power is not without significant risks and limitations; the foremost being safety. Post Fukushima, concerns over safety and water availability have been revived. Public and academia opposition over the construction of inland NPPs is growing. In July 2013, protests in Jiangmen, Guangdong forced local authorities to renounce plans to build a uranium-processing plant.[74] Growing public participation in environmental debate and general distrust in government's ability to enforce pollution and safety standards might prove an important obstacle in China's planned nuclear expansion. Of primary concern is the safe operation of the power plant itself, water contamination and the proper and safe disposal of fuel waste of which some components will remain radioactive for hundreds of thousands of years. These issues are especially pertinent as a material portion of China's thirsty nuclear power expansion will shift inland from the coast into the densely populated Yangtze River basin.

Therefore whilst nuclear could lead China to better air and lower carbon emissions, China's nuclear ambitions to replace coal-fired power may be limited. This chapter explores China's planned coastal and inland expansion of NPPs as well as water concerns including its reliance on water, related water risk exposure and water contamination fears. Other alternatives to allay inland nuclear expansion fears are also considered in this chapter.

THE FUTURE OF NUCLEAR IS UNCLEAR: 2020 TARGET OF 58GW BUT 2050 FORECAST RANGE FROM 340GW TO 500GW

There are plans to reach 58GW of installed capacity by 2020 with a further 30GW under construction

Official targets for nuclear installed capacity have fluctuated historically. Since the lifting of the moratorium on nuclear power development in November 2014, the State Council reiterated its ambition to reach 58GW of operational nuclear installed capacity by 2020 with 30GW under construction at that time[75]. This 2020 operational target of 58GW is higher than the 40GW previously announced in 2007 but lower than the 70GW recommended in 2010 by the NDRC.

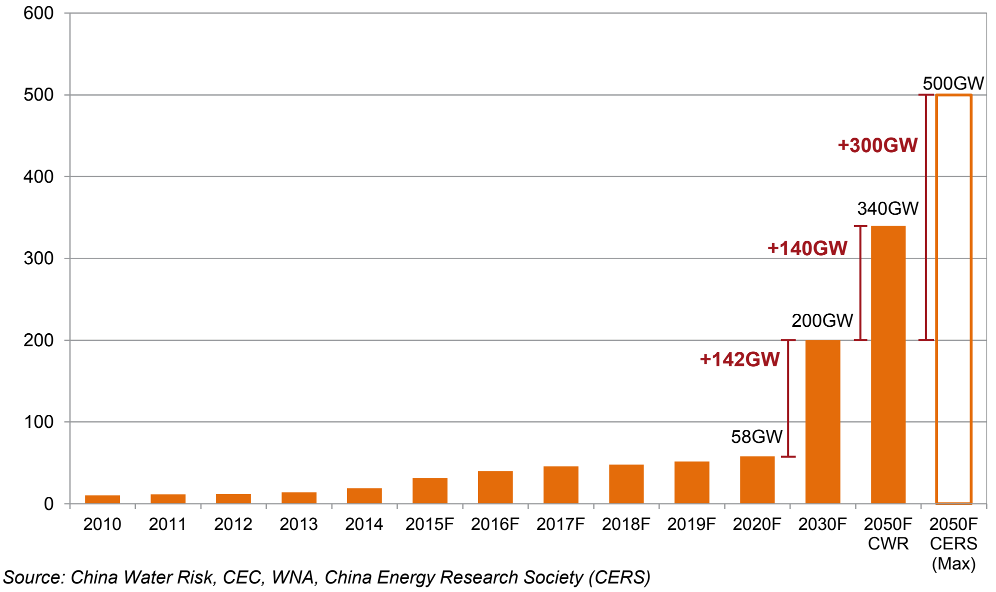
2050F forecasts range from 340GW to 500GW...

In Chapter 3 "Balancing Power Mix for Water & Climate", we considered nuclear power capacity would reach 200GW by 2030 and 340GW by 2050. While there are construction plans for close to 200GW of nuclear power, it remains to be seen if China will up its nuclear capacity to 340GW due to concerns over water and safety issues discussed later in this chapter. Nevertheless, 340GW by 2050 falls within the NEA forecast range of 300GW to 400GW. Incidentally, the Chinese Development Bank also indicated 340GW. That said, the China Energy Research Society (CERS) in October 2014, indicated a more aggressive forecast range of 400GW to 500GW by 2050.

...but no official targets beyond 2020

Uncertainty remains beyond 2020 as there are no official targets. For now, nuclear installed capacity forecasts for 2050 range from 340GW to 500GW. China's nuclear installed capacity expansion between 2010-2050F is set out in the chart below:

2010-2050F China's Nuclear Power Installed Capacity (GW)



Source: China Water Risk, CEC, WNA, China Energy Research Society (CERS)

Marked increase between 2020 and 2030 of +142GW

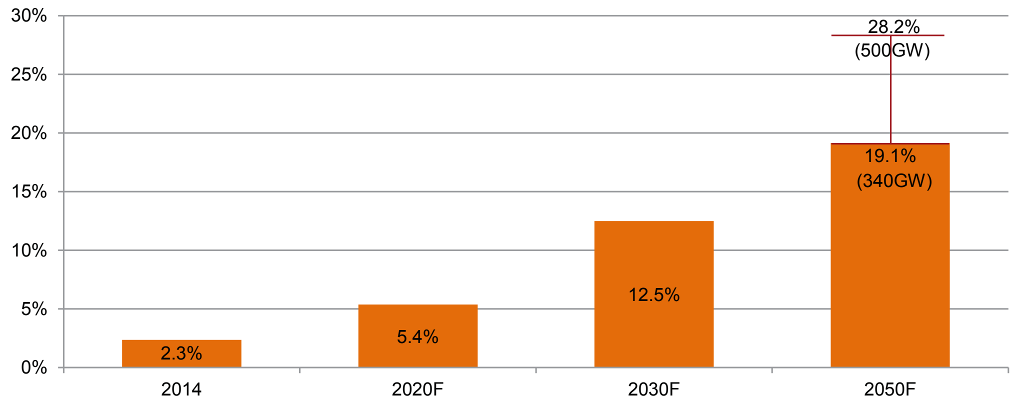
It is clear from the chart above, that China has taken a cautious approach towards nuclear expansion prior 2020. That said, it should be noted that 58GW is close to the entire nuclear power installed capacity of France at 63GW in 2014. However, forecasts show a marked increase of 142GW between 2020 and 2030 followed by a slowdown in the pace of expansion between 2030 and 2050. That said, the forecasted absolute increase in installed capacity between 2020 and 2050 of +282GW to +442GW is staggering. To provide perspective, global nuclear installed capacity ex-China stands at 357GW in 2014 according to the World Nuclear Association (WNA).

AT 500GW, NUCLEAR MAY GENERATE UP TO 28% OF TOTAL POWER GENERATION BY 2050

19-28% of electricity can be generated by nuclear power by 2050

The chart below shows nuclear power's share in China's electricity generation. In 2014, 20GW of nuclear power generated a mere 2.4% of China's total electricity generation. Assuming China will more than double this to achieve its 58GW target in 2020, nuclear would represent 2.9% of total installed capacity but due to its high capacity factor represent up to 5.4% of electricity generated by then. By 2030, if 200GW of nuclear power was developed, it could account for around 12.5% of total electricity generation. This should go some way towards President Xi's promise to increase China's share of non-fossil fuels in primary energy consumption to around 20% by 2030.

2014-2050F Share of Nuclear Power in China's Electricity Mix (TWh)



Source: CWR estimates based on NBSC, State Council, CEC and CERS

By 2050, we project total power generation to be 14,000TWh. Hence depending on whether nuclear installed capacity will reach 340GW to 500GW by 2050, nuclear will account for 19.1% to 28.2% of total electricity generated respectively.

Aggressive nuclear power expansion can clearly reduce China's reliance on coal in power generation and lower carbon emissions. In theory, China could well achieve 28% of electricity generated by nuclear power, but in practice this may be difficult. It is important to note at this juncture, two key points:

1. Nuclear will supplement but not replace coal as China's vanguard fuel; and
2. NPPs reliance on water, water contamination fears and safety concerns may limit their expansion.

Both these issues are discussed in more detail below.

NUCLEAR WILL SUPPLEMENT BUT NOT REPLACE COAL AS THE VANGUARD

Nuclear power can alleviate pressure on Northern coal power bases and their water risk exposure

As indicated above, nuclear power is a way to reduce both the reliance on coal and the associated air pollution. It is also a means for China to alleviate the pressure on coal power bases and their water risk exposure in the North. This not only provides a cushion in energy security but also helps achieve food security given the geographical overlap of coal bases and agricultural heartlands in the North. Given the inevitable rise in competition for water resources between coal bases and agriculture (discussed in detail in Chapter 4: "Ensuring Food & Energy Security"), nuclear will play an increasingly important role in China's power generation.

Limited uranium reserves will prevent nuclear from being the vanguard

Nevertheless, while richly endowed with coal reserves, China has limited uranium reserves (see box below). Therefore, whilst nuclear can provide a cushion in energy security by supplementing coal as the vanguard, it will not be able to replace coal given that energy security is of paramount importance to China. This will (among other reasons discussed later) prevent nuclear from being the vanguard.

LIMITED URANIUM RESERVES LIKELY TO AFFECT ENERGY SECURITY

Domestic uranium currently supplies less than a quarter of China's nuclear fuel needs. Proven Chinese reserves of uranium are small and of relatively low quality. Accordingly, China will heavily depend on uranium imports, thereby affecting its energy security.

Facing these constraints, China adopted a "three-thirds" uranium procurement policy: one third of uranium would be produced domestically, one third secured through acquisition or participation in mines overseas and one third purchased on the international market. However, according to some scholars, the exact balance among these three channels might not be as equal: domestic production could represent a much lower share than expected while reliance on market purchases could be significantly higher. Some experts even anticipate a degree of external dependence as high as 90%.

Tapping into unconventional sources of uranium (although more expensive and still at the experimental stage) is also being considered by central authorities. Such unconventional sources include phosphate rocks, black shale and coal ash, all of which are plentiful in China.

Source: World Nuclear Association, Yan et al. 2011, Zhou 2010, Schell 2014

WATER CONCERNS IN NUCLEAR POWER GENERATION

Water related concerns may dampen China's nuclear plans...

Concerns over water availability and water contamination may dampen China's ambitious nuclear expansion plans. There is currently growing opposition over inland NPPs built along China's waterways. The following water concerns will need to be addressed before the all-out expansion inland:

Nuclear needs a constant flow of water

...NPPs require a constant supply of cooling water for its safe operation

In order to operate properly and safely, NPPs require a constant supply of cooling water. When the flow is too low or the water too warm, the power plant is required to either reduce its power generation or even temporarily stop operating. Another safety concern is that NPPs require a minimal flow of water to cool down the reactor, even after the power plant has been shut down. The absence of such cooling capacity could cause a so-called "loss-of-coolant accident" which might result in reactor damage and the leakage of radioactive material. Therefore, water shortage could be a major threat in terms of nuclear safety.

Ambitious expansion plans will make inland NPPs inevitable, raising water concerns

For these reasons, at the time of writing, only coastal NPPs have been constructed as they can use seawater for cooling. However, if China was to aggressively pursue ambitious nuclear power expansion, inland nuclear power expansion will be inevitable bringing with it concerns over the availability of freshwater for cooling. These concerns over the build-out of inland NPPs are valid especially since river water flow, which is required for cooling and therefore safety purposes, might not be permanently available.

Risks of power disruptions?

Power disruptions because of these sorts of events have already been seen in the U.S. and Europe. For example, because of the extreme heat wave in France in 2003, 17 nuclear reactors were either turned off or operated at a reduced capacity. The potential impacts of climate change (more frequent and extreme weather events and an increased temperature in many areas) will likely exacerbate the risk of nuclear power disruption[76]. Water availability in the Yangtze River basin where the lion's share of inland nuclear expansion is planned is discussed later in this chapter.

Passive cooling systems can ensure safety

In order to reduce such risks with inland NPPs, China has favoured the Westinghouse AP1000 model for inland nuclear expansion which is equipped with passive cooling systems. In this configuration, a large amount of water is stored in a tank above the reactor and can be used to keep the reactor cool if required. This however does not address water contamination fears and concerns remain over the radioactive contamination of the main drinking water sources of highly populated areas (see box below).

INLAND PROVINCES: NUCLEAR AT A CROSSROAD

Nuclear power requires large volumes of water for cooling. Adequate water supply is the key factor for identifying potential plant sites. Pengze was chosen due to its adjacency to the Taipo Lake and the Yangtze River. However, unlike inland nuclear project areas in the United States which often have few people downstream, China is relatively densely populated. China's vast river network and dense population distribution mean inland nuclear power stations have many inherent risks.

If radioactive liquid materials are not safely disposed of, large amounts of water used for cooling could be polluted, and the element boron from the pressurized reactor will be released into the environment along with wastewater. The polluted rivers provide drinking water and irrigation sources for many people living downstream.

Although the Pengze project in Jiangxi was opposed by Anhui province, Anhui itself has also started developing its own nuclear power projects. Wuhu Project is the first of them. It is being developed by China General Nuclear Power Group, who owns several nuclear projects (*see table below*), and is located in Fanchang County along the Yangtze River, upstream of Wuhu City. You can imagine the worry of the people in Wuhu with regards to the nuclear power safety and risk of radiation poisoning.

Nuclear power operators rely on a sufficient water supply. However, in China, water resources are managed by the water conservancy and hydropower authorities, who hold a negative view towards nuclear power.

The battle between hydropower and nuclear power is fierce, and the competition exists in many areas outside of water including lobbying for preferential policies and central investment funds, and securing bank and capital financing.

The politics also differ. The Ministry of Water Resources is trying to choke nuclear growth to protect China's limited water resources while the nuclear power developers are requesting more water allocation for the sake of public safety. In the end, all problems, be they investment losses or threats to the environment, will be ultimately borne by the state and the people.

Source: The above is an excerpt from an opinion posted on China Water Risk by Wen Bo, Policy & Media Advisor for National Geographic Society, "Inland Provinces: Nuclear at Crossroads", August 2014

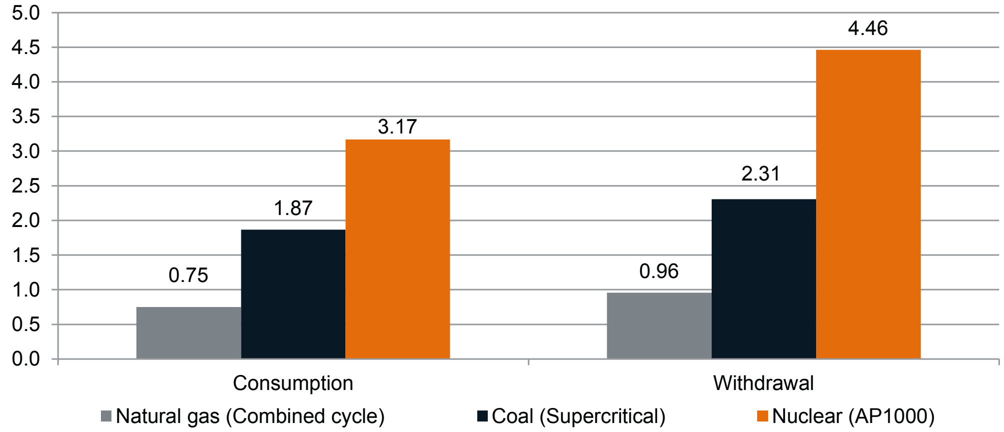
Nuclear power is thirstier than coal and gas

For 1MWh, NPPs consume and withdraw more water than coal and gas power plants

For the same amount of electricity generated, NPPs usually require more water for cooling purposes than coal or natural gas plants. This is true for both water consumption and water withdrawal, regardless of the cooling technology. To compare typical levels of water consumption and withdrawal for these three fuels, we have selected the most commonly adopted technologies for new power plants: natural gas combined cycle, supercritical coal-fired power plants and the Westinghouse AP-1000 (the model most favoured by China for inland NPP expansion). We have also used closed loop cooling across these fuels as all the inland additional NPPs will most likely adopt closed loop cooling option due to water constraints. The chart below illustrates water consumption and withdrawal for these three fuels:

Cooling Water for Different Power Plants (Closed loop)

Unit: m^3/MWh



Source: Macknick et al. 2011, Ding et al. 2014

According to the design documents, the water withdrawal of the Westinghouse AP1000 in China will be around 4.5 m^3 per MWh and the associated water consumption will nearly reach 3.2 m^3 per MWh.[77] These values are respectively 93% and 70% higher than in supercritical coal power plants. It is therefore essential to locate these plants in water rich regions and prevent the construction of NPPs in water scarce regions. Furthermore, given the high amounts of water consumption, inland NPPs could further exacerbate water scarcity.

PLANNED & PROPOSED: +73GW COASTAL AND +68GW INLAND NUCLEAR EXPANSION MAPPED OUT

Already 20GW operating and 27GW under construction along China's coast

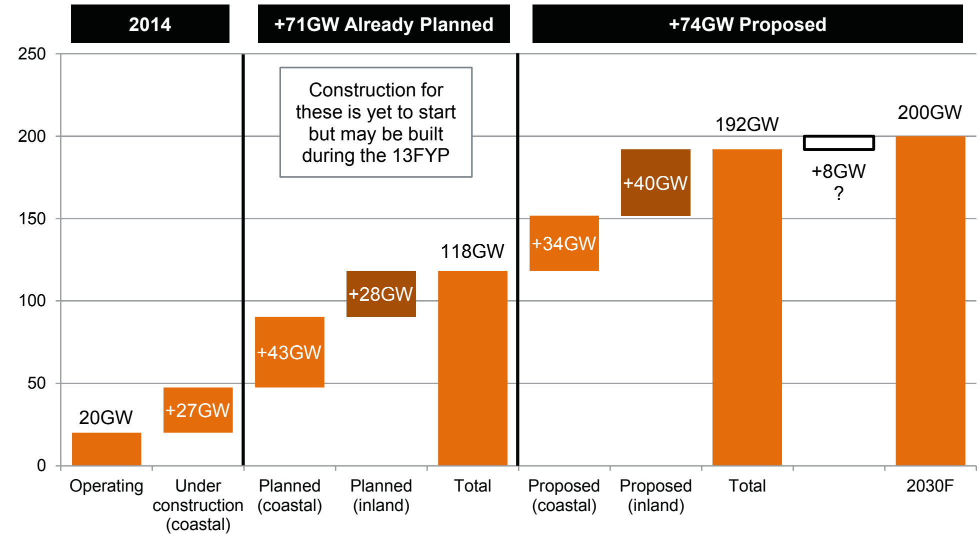
As at the time of writing 20GW of nuclear power is in operation and a further +27GW is under construction along China's coast. Upon completion, this will more than double China's nuclear capacity to 47GW, 11GW shy of the 2020 target of 58GW.

Currently there is an additional +71GW of nuclear installed capacity planned, bringing total nuclear installed capacity to 118GW; of this +43GW is along the coast whereas +28GW is inland as shown in the chart below. Meanwhile, a further +74GW has been proposed by provinces but not yet approved by central authorities; of this, +34GW is along the coast whilst 40GW is located in inland provinces. This brings the current planned and proposed nuclear expansion to 192GW, just 8GW shy of the 2030 forecast of 200GW:

There are plans for +28GW in inland provinces with a further +40GW of inland NPPs proposed but not yet approved

2030F Nuclear Power Generation Capacity Expansion Plans

Unit: GW



Source: China Water Risk estimates based on NBSC and World Nuclear Association

Key points to note here are:

Coastal and inland projects might be resumed and included in the 13FYP

- Construction of the +71GW of planned nuclear plants is yet to start. Comments by the NEA suggest that coast and inland projects will be resumed and included in the 13FYP (2016-2020). However, given that the 2020 target is 58GW and +71GW will bring total nuclear installed capacity to 118GW, it is not clear if all the +71GW will be constructed. Given water availability and freshwater contamination fears, it may not be necessary to construct the inland nuclear plants;

Inland nuclear expansion may be inevitable if China was to pursue 200GW by 2030...

- Nevertheless, given the space constraints in coastal areas and the growing demand of power from inland provinces, inland nuclear expansion may be inevitable if China was to pursue 200GW by 2030. It is important to note here that the +28GW of planned inland expansion is already greater than the current coast plants operating let alone the further +40GW proposed;

...but Beijing is adopting a cautious approach to inland nuclear expansion

- With State Council setting a more conservative target of 58GW by 2020 compared to the recommended 70GW by the NDRC, we believe that Beijing is adopting a cautious approach to inland nuclear expansion. As a consequence of the Fukushima accident, State Council banned the approval and construction of the 28GW of planned inland NPPs during the 12FYP; and

Without inland expansion, China's nuclear installed capacity could reach 124GW

- The future of nuclear remains unclear with only official targets up to 2020 with operational and nuclear plants under construction of 88GW. Without inland expansion, the current planned and proposed coastal expansion will bring China's nuclear installed capacity to 124GW. While below the 200GW target, is still sizeable at 1.25x the nuclear installed capacity of the US at 99GW in 2014.

First coastal, then only consider inland NPPs

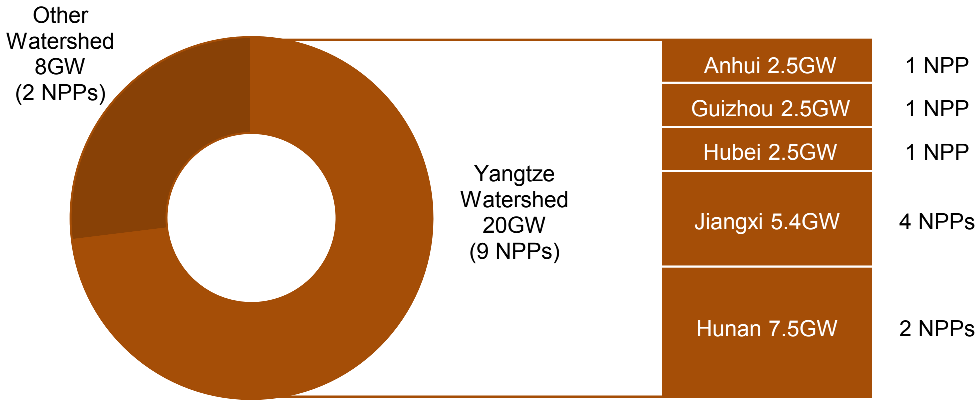
Given the water related risks, we are of the view that coastal nuclear potential should be first exploited before considering inland nuclear power expansion. These risks are discussed below.

OVER 70% OF PLANNED INLAND NUCLEAR EXPANSION IN THE YANGTZE RIVER BASIN

Five provinces in the Yangtze watershed to host 70% of the 28GW of inland NPPs

The +28GW planned inland nuclear expansion comprise 11 NPPs; of these, nine are located in the Yangtze River watershed, either on the Yangtze River itself or along its tributaries. These nine planned NPPs represent +20GW or 71% of the +28GW of planned inland NPPs and are spread over five provinces: Anhui, Guizhou, Hubei, Hunan and Jiangxi. As can be seen from the chart below, Hunan and Jiangxi have a higher share with +7.5GW and +5.4GW respectively:

Location of 28GW Planned Inland Nuclear Power Plants



Source: China Water Risk estimates based on World Nuclear Asssoctiation

For inland provinces, NPPs could reduce both air pollution and reliance on imported coal

For these five provinces, developing NPPs is not only a mean to reduce air pollution; it is also a way to reduce the quantity of coal they import either from other provinces or from abroad; they are poorly endowed with coal reserves (only 7% of coal reserves) and nuclear power is a way to reduce their reliance on coal. Simultaneously, opting for nuclear power will help these provinces avoid transportation bottlenecks presently faced by coal. Indeed, for power generation, 185 tonnes of uranium could replace approximately 3 million tonnes of coal.[78]

Yangtze River could provide enough water but other concerns remain...

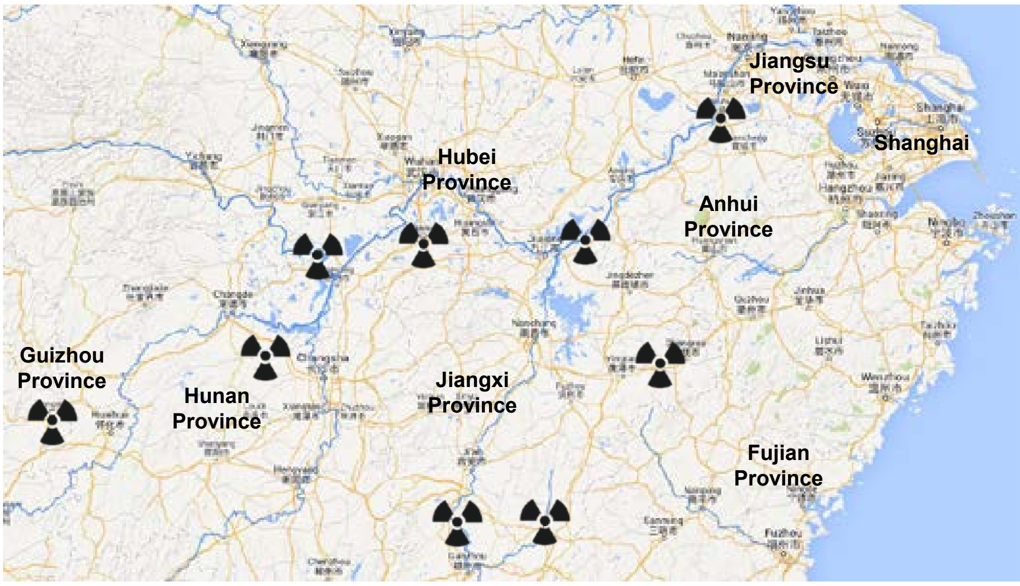
As discussed earlier, NPPs require substantial amount of water for cooling purposes. Assuming a capacity factor of 90%, we estimate that the NPPs planned in the Yangtze River watershed could represent an annual water consumption of 510 million m^3 and withdrawal of 718 million m^3. While substantial, these values are less than a thousandth of the annual Yangtze River runoff of 986 billion m^3. Moreover, the average runoff even slightly increased during the last decades[79]. The amount of water use by these inland NPPs isn't even significant compared to the central and eastern lines of the South-to-North Water Transfer project, which altogether are diverting 27.8 billion m^3 per year from the Yangtze River and its tributaries[80]. Therefore, the water availability for cooling nuclear power plants does not appear to be problematic. However, other considerations should require attention.

YANGTZE RIVER NUCLEAR POWER EXPANSION & WATER RISKS: SAFETY MUST BE A PRIORITY

The map below shows the location of the planned inland nuclear plants along the densely populated Yangtze River Basin:

Even low-level radioactive contamination of rivers will have significant consequences

Planned Inland Nuclear Plants Along the Yangtze River Basin
+20GW (nine plants)



Source: China Water Risk, World Nuclear Association

Despite being water rich, it is not difficult to see why concerns still remain over nuclear expansion along the Yangtze River and its tributaries:

Yangtze River's seasonal variability brings fluctuations in water availability

Water flow of Yangtze River affected by seasonal variability and climate change

The water flow of Yangtze River varies considerably within a year. In winter, the flow can be as low as 2,000m^3 per second (compared to the 40,000m^3 per second in summer). This high variability prevents for instance the adoption of once-through cooling systems because of the high water withdrawal associated with this technology.

Climate change could impact water flows and temperature and with a 60 years lifespan, NPPs are exposed to these changes. The future of the Qinghai plateau, the main source of the Yangtze River, will be particularly important in this regard. According to the Chinese Academy of Sciences, the Qinghai plateau glaciers have shrunk by 15% over the past three decades.

Water contamination could affect water sources of up to 400 million people, farmland, fish and industry

NPPs cooling water is also used as the main irrigation and drinking water source

Inland NPPs raise significant safety concerns. Indeed, surface water used to cool the NPPs is also used as the main irrigation and drinking water source of highly populated areas. The Yangtze River watershed, which hosts most of the already planned inland NPPs, is home to around 400 million people.

400 mn people and over 70% of its rice production are exposed

Furthermore, according to WWF[81], more than 70% of China's rice, 50% of its grain and more than 70% of freshwater fishery are farmed in this basin. Therefore, even low-level radioactive contamination of rivers (for instance caused by leakage of radioactive material) will have significant consequences. This will also impact industrial processes which also draw water from the basin. Indeed contamination by upstream plants will affect provinces downstream, which collectively generate a third of China's GDP.

Public opposition might prove an important obstacle

Since the Fukushima disaster happened in March 2011, public opposition to nuclear expansion has been growing. In July 2013, protests in Jiangmen, a southern city, forced local authorities to renounce plans to build a uranium-processing plant.[82] Growing public participation in environmental debate and general distrust in government's ability to enforce pollution and safety standards might prove an important obstacle in China's planned nuclear expansion.

Seismic risk could bring about technical nuclear incidents

Location of inland NPPs should be chosen with extreme caution...

The frequency of earthquakes and the numerous dams located on the Yangtze River exacerbate the risk of technical incidents. Seismic tremors and their potential impact on dams are indeed major threats and call for extreme caution when designing and choosing the location of inland NPPs.

... alternatives must be seriously considered

Given that construction of these NPPs in the Yangtze River Basin is yet to start, we urge extreme caution in the proceeding with such plans given the magnitude of the potential social and economic downside risk caused by the above. Potential electricity generated from inland nuclear expansion should be seriously weighed against other alternatives.

+28GW OF INLAND NPPS: REPLACED BY +60GW OF HYDRO, +106GW OF WIND OR +161GW OF SOLAR ?

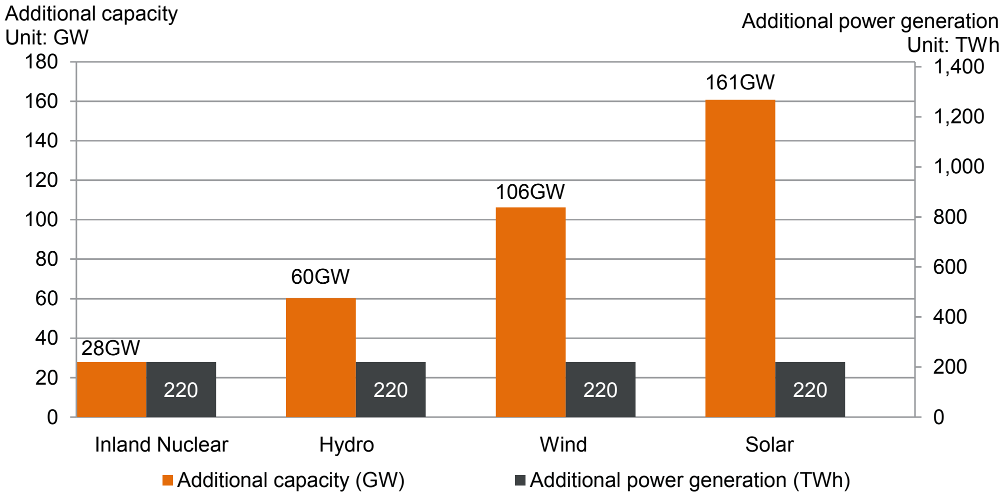
Replacing nuclear with coal or gas is not an option

Nuclear power is a base load power generator and can only be efficiently replaced by coal or gas-fired power. As discussed in Chapter 3: "Balancing Power Mix for Water & Climate", given the difficulties to source natural gas in sufficient quantity, China's natural gas power generation capacity will likely be constrained. Replacing nuclear with coal-fired power defeats the purposes (cleaner air & lower carbon emissions) of its adoption in the first place.

Albeit challenging, an aggressive add of renewables could be an alternative

An aggressive add of renewables could be the answer. Like nuclear power, renewable energies such as hydropower, wind and solar offer a carbon-friendly source of electricity and China has been investing a lot to develop and promote them (see the chapters on "Hydropower" and "Other Renewables"). However, replacing inland nuclear with renewable energies may prove challenging in terms of scale. 28GW of NPP will generate around 220TWh whereas renewables, due to their lower capacity factor, will require construction of significantly higher installed capacity to generate the equivalent power. In the chart below, we estimate the required capacity for different renewable energies to produce as much energy as the 28GW of planned inland power plants.

Renewable Energy Options to Replace 28GW of Planned Inland NPPs



Source: China Water Risk estimates based on NEA and WNA

+28GW of inland NPPs could be replaced by +60GW of hydro or +106GW of wind or +161GW of solar PV

In terms of scale: using the maximum capacity factors described in Chapter 3: "Balancing Power Mix for Water & Climate", replacing the entire +28GW of planned inland NPPs with renewable energy would require an additional:

- +60GW of installed hydropower capacity (2014 = 280GW; CWR 2050F = 500GW); or
- +106GW of installed wind turbine capacity (2014 = 96GW; CWR 2050F=700GW); or
- +161GW of installed solar PV capacity (2014 = 28GW; CWR 2050F=200GW).

Caution: fossil fuels might be required to smooth the intermittence of renewables

It is clear that replacing +28GW nuclear installed capacity would require sizeable additional add to what is already forecasted. A word of caution: given their inherently intermittent nature, the above renewables will require additional thermal power for smoothing. Unfortunately, this is currently either coal or natural gas-fired, making these renewables less carbon-friendly. Finally, each type of renewable has multiple associated water risks (see chapters on "Hydropower" and "Other Renewables") which should also be considered and weighed vis-à-vis those associated with nuclear power expansion.

NO INLAND NPP SCENARIO BY 2050 = +822GW OF WIND OR +1.2TW OF SOLAR

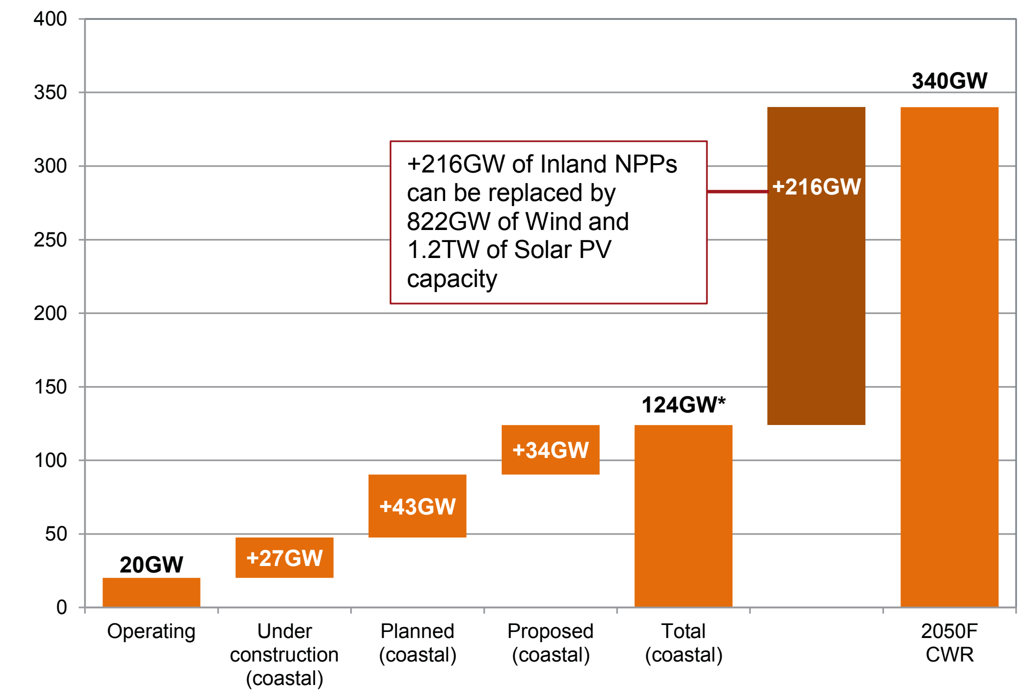
Mix signals: cautious approach to inland nuclear but ambitious nuclear expansion

As discussed above, given the current distrust and past record of the government's ability to enforce pollution in China's waterways, the risks are sizeable and potentially catastrophic with the planned +28GW of inland NPPs let alone the proposed +40GW. That said, current planned and proposed nuclear expansion (coastal & inland) will only bring total capacity very close to the 2030 forecast of 200GW. Given the cautious approach to inland nuclear expansion, it is not clear if this can be achieved let alone the 340GW-500GW by 2050.

Staggering +822GW of wind capacity or +1.2TW of solar PV to avoid inland NPPs by 2050...

Assuming zero build-out of planned or proposed inland NPPs, China's plan and proposed nuclear expansion will only be at 124GW. To reach the lower forecast of 340GW (our base case) by 2050, China will need to add a further +216GW. Assuming that all coastal nuclear potential has been tapped at 124GW, we estimate that this would require close to a staggering additional +822GW of wind capacity or +1.2TW of solar PV capacity as shown in the chart below. To provide perspective, the global wind capacity is only 318GW in 2013 while global solar capacity stood at 139GW.

2050F Coastal Nuclear Power Installed Capacity Expansion (GW)



Source: China Water Risk estimates based on NBSC and World Nuclear Association
**Assumes 124GW is the maximum coastal nuclear potential*

...yet aggressive projections for wind and solar of 4TW by 2050 could make this possible

Perhaps replacing +216GW of nuclear with wind and solar power may not be too far-fetched. As set out in the chapter on "Other Renewables", we have a conservative 2050F forecast in wind and solar of 700GW and 200GW respectively. However, recent NDRC base case has these targets at 1TW for each allowing an "extra" capacity of +300GW of wind and +800GW of solar. NDRC's aggressive scenario forecasts are even higher at 2TW each.

But because of resources location, distributed solar might be a better alternative

However, it is important to note here that whilst theoretically possible, the location of resources may pose a challenge. Wind resources mostly lie in the North and Western regions of China whilst the NPPs they are to replace are located in the South. Distributed solar is therefore probably the better alternative but pursuing more aggressive energy savings will once again bring about the best result for both climate and water.

ENERGY SAVINGS: A WAY FORWARD TO MITIGATE INLAND NPP WATER RISK

Energy savings can also reduce the need for inland NPPs...

The closest thing to a silver bullet to avoid the development of inland NPPs would be the reduction of electricity demand. As detailed in the Chapter 5: "Battle to Conserve Energy", this could be achieved both through energy efficiency programmes and industrial mix restructuring. With a slower growth of electricity demand, it would be easier for renewable energies to play a major role and reduce the need for nuclear power.

...but the scale of savings needed exceeds Japan's total electricity generation

The additional nuclear power capacity of +216GW could generate as much as 1,700TWh in 2050. To give a sense of perspective:

- The electricity consumed by the Top 5 largest consumers of electricity in China: Metallurgical, Chemical, Building Materials, Textile and Papermaking is 2,095TWh; while
- The total electricity generated by Japan of 1,088TWh in 2013.

THE FUTURE OF NUCLEAR STANDS AT A CROSSROAD

Unless the 13FYP reshuffles plans, it is likely that China will reach around 200GW in 2030 but 2050 remains unclear

It is clear that nuclear power will form a part of China's electricity mix to supplement and reduce reliance on coal. Unless the 13FYP reshuffles expansion plans, it is likely that China will reach around 200GW of installed nuclear capacity in 2030. However, this is still far from the 340GW we estimated in 2050 let alone from the 500GW mentioned as an upper limit by the CERS. To reach these installed capacity values, China would have no choice but to install many inland NPPs as space in running short in coastal areas.

With no official target beyond 2020, nuclear stands at a crossroad

There is currently much opposition to inland nuclear expansion. No official targets beyond 58GW in 2020 clearly signals that the future of nuclear stands at a crossroad. On one hand, the government (primarily MWR) is trying to protect water sources by discouraging the shift inland; on the other, pro-nuclear advocates are pushing large-scale expansion of up to 68GW inland or 60 nuclear reactors. Meanwhile, State Council has so far adopted a cautious stance on such expansion and the planned 28GW is yet to be constructed although approved.

Regardless, safety should remain the top priority

If inland expansion was to proceed, particular attention should be paid to the first inland NPPs, for two main reasons: (1) the additional concerns raised with inland NPPs compared to their coastal counterparts; and (2) these will be among the world's first units of the newly designed Westinghouse AP1000 model. In this context, it is crucial that China keeps improving its nuclear safety standards, regulations and practices. Cooperation with international instances such as the International Atomic Energy Association (IAEA) and the World Association of Nuclear Operators (WANO) should be further enhanced.

At 340GW in 2050, nuclear would represent 19% of China's electricity...

Given safety and water concerns as well as the magnitude of the downside risk of inland nuclear expansion, surely other alternatives such as renewables should be seriously considered before making this move. Coastal nuclear potential should be first exploited before considering inland expansion. Ultimately, at 340GW by 2050, nuclear power will represent around 10% of installed capacity and generate up to 19% of China's electricity. Some experts have commented that this makes nuclear power "*optional rather than essential*" (see box below).

...leading some experts to say that nuclear is optional than essential

It is clear that nuclear will not replace coal as China's vanguard. China nuclear stands at a crossroad; ambitious expansion to 340GW or even 500GW by 2050 could well be dampened by water concerns. In the face of more frequent extreme weather events, nuclear plants built today may be subject to operational disruptions due to fluctuations in water availability. Given this and contamination fears, thirsty nuclear's long-term future in China remains unclear.

CONVERSATIONS ON NUCLEAR EXPANSION CHINA WATER RISK INTERVIEW WITH LI JUNFENG

CWR: Should climate patterns shift between the North and the South, does it mean that water-intensive energy projects that are currently located in water stress regions might get more water; while hydropower and nuclear power projects that are mostly in the south might have less water in the future?

LJF: It is possible. Therefore, for provincial decision makers, coal-fired power plant planning needs to consider future water availability. If the water supply will likely decrease, no more plants should be built.

Nuclear is another example. A nuclear power plant has an operational lifespan of around 60 years, long enough for it to be exposed to impacts from climate change. Current nuclear plants in operation are all located in coastal provinces such as Guangdong. Future nuclear power expansion plans to locate some of the new plants to inland provinces like Anhui and Jiangxi, with the hopes of drawing water from the Yangtze River and the Poyang Lake. But is there really enough water in the long term? I doubt that. We have already witnessed flow interruptions in the Yellow River as well as the depletion of the Poyang Lake.

CWR: Speaking of nuclear, some proposed plants have faced resistance from the public. There is also a stronger anti-nuclear voice across the country. How do you see the future of nuclear power development in China?

LJF: Well, in my view, if we are not building more nuclear power plants now, it will be more difficult to build them in the future. The future of nuclear power also depends on the future development of other alternative energies. If wind power and solar energy continue to grow fast, there would be less space for nuclear power. Cost is another factor. More stringent environmental requirements have increased the cost to develop nuclear power, making it less competitive compared to others. For instance, in the US, after the big decline of shale gas extraction cost, no one is willing to invest in new nuclear power plants.

Within China, there are lots of debates going on. Those who support nuclear power claim that China will not be able to achieve energy security without nuclear power development. But is this true? China plans to develop 70GW-300GW of nuclear power by 2020 and 2030, whilst total power installation will reach 1,900GW to 2,000GW by 2020 and 2,700GW to 3,000GW by 2030. So nuclear power will only account for around 10% of the total demand, making it optional rather than essential.

Source: The above is an excerpt from a China Water Risk interview with Li Junfeng, the Director General of the National Center of Climate Change Strategy Research at the National Development and Reform Commission. The interview is titled "Water Over Energy Security", October 2014

OTHER RENEWABLES

BIG WIND & DISTRIBUTED SOLAR BRING HIDDEN WATER RISKS

- China is a global leader in renewable energy. In 2013, it had a 24% share of the global wind capacity and 11% of global solar PV capacity. China is also the No.1 investor in renewables. In 2013, it sunk USD56 billion into renewable energy; this was over a quarter of global investment. During the 12FYP period, China is estimated to have spent RMB1.8 trillion in renewable energy: hydropower has accounted for a material portion but in the future, China has more ambitious plans for wind and solar.

- Wind and solar installed capacity stood at 124GW in 2014. CWR Base Case scenario expects total installed capacity of wind and solar to be at 900GW by 2050 with exponential growth between 2030-2050F, allowing time for grid infrastructure upgrades to better accommodate renewable energy. Other forecasts by government affiliated research bodies are even more bullish with base case forecasts at 2TW and aggressive scenarios at 4TW by 2050.

- Ambitious plans and detailed policies have been set out to consolidate wind power development into large wind energy bases across Coal Base Provinces in the North. This should help alleviate pressure on both China's coal bases and coal-fired bases. Depending on how aggressive wind expansion will be, analysis by province show that wind power can supplement or even replace coal-fired power in seven Coal Base Provinces; six of these provinces are either water-scarce or water-stressed.

- Meanwhile, solar energy bases are to be established in the West and there are plans afoot to shift China's solarscape to a distributed future with distributed solar PV and solar heating in both the North and the South. Biomass, geothermal and ocean energy, although small, are all considered important alternatives to help reduce reliance on coal. At 2TW by 2050, distributed solar can provide relief to hydropower and even substitute China's planned and proposed inland nuclear power expansion.

- It is important to note here that while both wind and solar PV require little water in power generation and are thus classified as "non-water-reliant power" in this report, concentrated solar power (CSP), bioenergy and geothermal require water for cooling. Based on closed loop wet cooling technologies, solid biomass and CSP consume more water than a supercritical coal-fired plant.

- While both wind and solar PV are less thirsty, they come with hidden water risks associated with the manufacture of renewable energy equipment that requires rare earths and steel. Achieving 2TW of wind in the North will increase steel demand by 241 million tonnes or around 30% of total crude steel output in 2014. Moreover, the production of steel is power intensive and coking coal is a key input.

- Of more concern is the inevitable rise in the demand of rare earth elements (REEs) used in the manufacture of wind turbines. The black market and bad practices in rare earth ore (REO) mining and REE production have raised serious concerns over soil and water contamination from untreated and illegally discharged toxic wastewater and radioactive waste. Large mines containing Light REE lie in the North next to the Yellow River while Heavy REEs are mined by smaller mines in Jiangxi near the Dongjiang River, an important watershed for Guangdong and Hong Kong.

- Although State Council is moving to try rein in the rare earths black market, it remains to be seen whether China can effectively enforce the new Environmental Protection Law in force since 1 January 2015 can clamp down on the illegal trade. China needs urgently to address mining practices in the industry before embarking on aggressive renewable expansion. At 2TW of wind by 2050, the increase in accumulative wastewater generated by the increased demand in rare earths could be 20x.

- This is not just China's problem as "made in China" supplies the global movement for a renewable future. In 2012, China accounted for 90% of global rare earths production; reliance on China is unavoidable – Japan and the US are China's largest REE trading partners. The global rare earths and renewable industries need to reinvent themselves. China's REE trading partners should bear some responsibility and work with China to find ways to minimise potentially disastrous impacts on China's key watersheds.

OTHER RENEWABLES
BIG WIND & DISTRIBUTED SOLAR BRING HIDDEN WATER RISKS

CHINA'S PUSH FOR RENEWABLES MIGHT BRING HIDDEN WATER RISKS

China is aggressively promoting the development of renewable energies ...

According to the Intergovernmental Panel on Climate Change (IPCC)[83], renewable energy holds a large potential to mitigate climate change; it could also provide a wide range of other benefits such as "*social and economic development, energy access, a secure energy supply, and reducing negative impacts on the environment and health*".

Indeed, concerns over climate change and negative impacts from burning fossil fuels have been driving the development of renewable energy globally. Being the largest greenhouse gas (GHG) emitter, China has also been aggressively promoting the development of renewable energies. As signaled by the recent government announcements including the China-US Climate Change Agreement and Premier Li Keqiang's statement (see box below), China will continue to push the development of renewables, in order to increase the share of non- fossil fuels (including nuclear and renewables) up to 15% of the primary energy consumption by 2020 and peak its GHG emissions by 2030.

> *"Revolution in energy generation and consumption is vital to any country's development and to the well-being of its people. In China, we will put great weight behind the development of wind power, photovoltaic power, and biomass energy, work actively to develop hydropower, stress safety in developing nuclear power, and exploit and utilize shale gas and coal seam gas.*
>
> *Premier Li Keqiang, report on the work of the Government delivered at the 3rd session of the 12th National People's Congress on 5 March 2015*

... it leads globally renewables installed capacity and investment

Already, China is a global leader in renewables in terms of installed capacity, power generation and investment. In 2013, the installed capacity of all renewables including hydropower reached 373GW or nearly 30% of the nation's total installed capacity of 1.3TW. Hydropower has a significant share of this at 75%. Since we have covered this in detail in the previous chapter on "Hydropower", in this chapter, we focus on other renewables: primarily wind and solar and other alternatives such as biomass, geothermal and ocean energy.

Albeit good for climate, renewables may bring about hidden water risks

China's push for these other renewables albeit good for climate may bring about hidden water risks. In this chapter we explore these hidden water risks across the different types of renewables:

- Wind power generation is being consolidated into large bases in the North. The manufacture of wind turbines and other energy efficiency equipment requires the input of rare earth elements (REE). Pollution concerns over mining practices in rare earth ores (REO) and REE production will grow and water sources could be threatened as demand for REE is set to rise;
- Solar energy is also booming. However, water use and consumption vary amongst different types of solar technologies; Concentrated Solar Power (CSP) plants require the most amount of water for cooling. Expansion strategies between centralized or distributed solar matter when it comes to water; and

- Other alternatives such as biomass and geothermal albeit still small, raise water concerns due to their cooling requirements.

Grid infrastructure may also limit renewable expansion

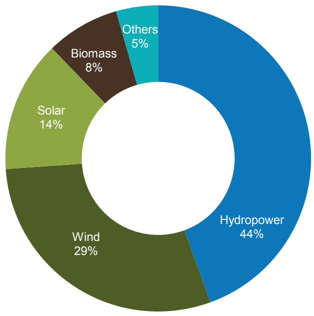
All these "hidden water risks" as well as poor grid infrastructure which limit the scale-up of renewables are discussed in detail vis-à-vis current expansion plans across each type of renewable in this chapter.

CHINA: GLOBAL LEADER IN RENEWABLE ENERGY

China has one-fifth of wind and solar capacity globally

China is the global leader in renewables globally in terms of installed capacity. Based on the latest available global data[84], in 2013, China's installed wind power capacity was about 24% of the global wind power capacity (318GW); meanwhile, China's solar photovoltaic (PV) was about 11.4% of global solar PV installed capacity (139GW). That means as of 2013, China accounted for one-fifth of the world's total installed capacity of wind and solar.

12FYP Investment on Renewables = RMB1,800 bn



Source: China Water Risk, NEA

In addition, China is the No.1 investor in renewables. In 2013 alone, China invested USD56 billion accounting for 26% of global investment on renewable energy, surpassing Europe's investment of USD48 billion. The '12FYP Renewable Energy Development Plan' issued by the NEA estimated total investment in renewables to be RMB1.8 trillion: 44% on hydropower, 29% on wind, 14% on solar and 8% on biomass as shown in the pie chart on the left.

Currently, hydropower is still the cheapest renewable option. Not surprisingly, nearly half of China's investment will go into hydropower development to up the renewable energy portion. However, this might change as the costs for wind and solar have dropped significantly in recent years. Between 2010 and 2014, the weighted average installation cost for onshore wind power has dropped by 4% to 25% whilst solar PV has fallen by 39% to 58%.[85]

Rise in global demand brings added pressure to "made in China" equipment

It is important to note here that the global renewables market is also expanding to address urgent climate concerns. However, with a material portion of the manufacture of these in China, a rise in global demand will bring added pressure to "made in China" wind and solar equipment as well as batteries. A boom in the energy savings globally will also lead to the inevitable rise in demand of some types of REE. Both global and domestic demand for such equipment has negative consequences for China's watersheds.

"MADE IN CHINA" SUPPLIES THE GLOBAL MOVEMENT TOWARDS A RENEWABLE FUTURE

Many of China's installed wind turbines and solar PV panels are manufactured domestically. As is the production of raw material inputs such as coal and steel. Besides supplying its own renewable expansion, China also exports renewable energy equipment. Take solar PV as an example: in 2014, six out of the Top 10 global solar PV producers come from China and total domestic production reached 33GW, of which 68% was exported.

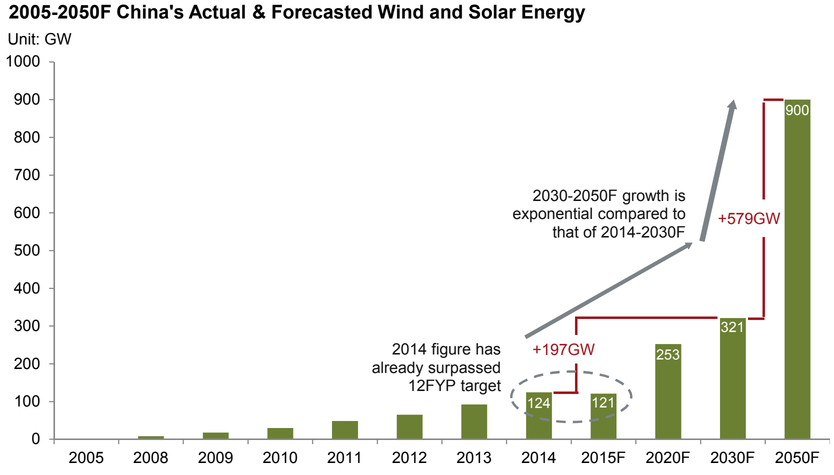
According to Mathews & Tan (2014), the growing scale of Chinese manufacturers and market expansion has been one main reason for the falling cost of wind and solar PV. However, as the world is moving towards a renewable future, there will be even more demand on "Made in China" technologies and products.

Source: China Water Risk, NEA, 2014 Statistics of Solar Energy Development, 15 February 2015, John A. Mathews & Hao Tan. Economics: Manufacture renewables to build energy security, 10 September 2014

WIND AND SOLAR: EXPECTED TO REACH 900GW BY 2050

The installed capacity of wind and solar to be 900GW in 2050

The growth in non-hydro renewables is driven by wind and solar. As we discussed in Chapter 3: "Balancing Power Mix for Water & Climate", CWR Base Case scenario (based on various studies) expects total installed capacity of wind and solar to be at 900GW by 2050. This means an expected add of +776GW for wind and solar installed capacity between 2014 and 2050. Actual and forecasted installed capacity for wind and solar are set out in the chart below:



Source: China Water Risk estimates, CEC, NBSC, 12FYP, State Council, NEA Research Affiliate

Key points to note from the above chart are:

12FYP targets already surpassed in 2014 with 124GW of wind and solar installed capacity

- According to the latest official statistics, the total installed capacity of wind and solar reached 124GW in 2014, surpassing the 12FYP target of 121GW. Given this accelerated development, China has adjusted the original 12FYP target to 135GW for wind and solar; primarily by almost doubling the target for solar power (see the section on solar expansion below for a more detailed explanation). Such aggressive renewable expansion plans are in line with China's plans to reduce the share of water-reliant power as explained in Chapter 2: "China's Water Energy Nexus"; and

Grid needs upgrading to better accommodate renewable power supply

- The 2030-2050F growth in wind and solar is exponential compared to that between 2014 and 2030. This could be due to the current grid infrastructure limitation. Currently, significant wind power generated electricity is 'wasted' every year as it is not absorbed by the grid for various reasons, frustrating wind power developers and investors. Upgrade and reform of the China's grid should alleviate these issues; these are discussed in more detail later in **"Grid Infrastructure & Energy Storage Must Improve to Accommodate Renewable Expansion"**.

Note that in Chapter 3: "Balancing Power Mix for Water & Climate", we only considered wind and solar capacity growth as biomass and geothermal energy contributed a tiny portion of the total non-hydro renewable installed capacity.

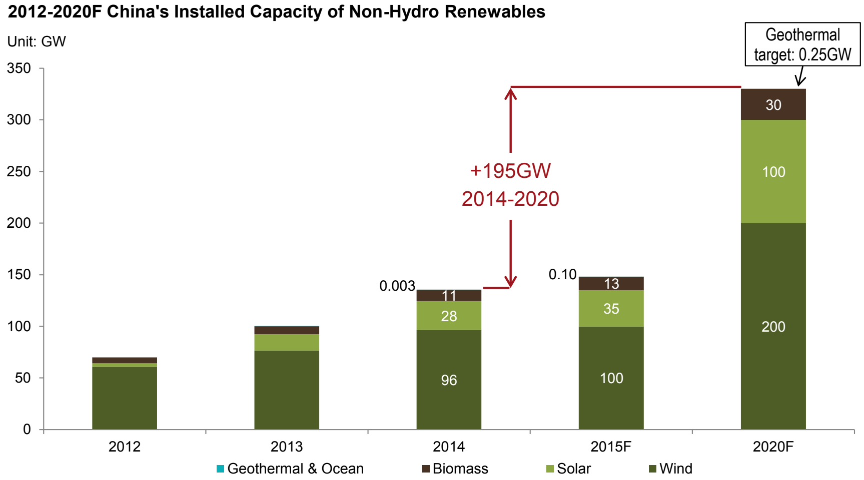
OFFICIAL NEW TARGET: OTHER RENEWABLES PLANNED TO BE 330GW BY 2020

Total non-hydro renewable capacity at 135GW in 2014...

If we take into account all other renewables, including biomass, geothermal and ocean energy, the total non-hydro renewable installed capacity stood at 135GW in 2014. By 2020, this figure is expected to grow to 330GW. This significant planned installed capacity add in other renewables of +195GW between 2014 and 2020 is set out in the chart below:

...and is expected to to be 330GW in 2020

2012-2020F China's Installed Capacity of Non-Hydro Renewables



Source: China Water Risk, State Council, NDRC, NEA, CEC

Wind and solar drive non-hydro renewables growth

It is clear from the above chart that wind and solar are two main primary drivers of other renewables growth:

- Wind power is expected to more than double from 96GW in 2014 to 200GW in 2020;
- Solar is set to experience exponential growth, almost tripling from 28GW in 2014 to 100GW in 2020; and
- Biomass, geothermal and ocean energy, despite official efforts in promoting their development, their installed capacity by 2020 is still limited due to technological limitation and cost factors.

Hidden water risks must be considered before any aggressive expansion

To ensure implementation of the above aggressive renewables expansion, China has set quotas for each province (see box below). In the meantime, different types of renewable energy will face different water challenges. Hidden water risks in their manufacture could also be magnified. These water risks need to be considered before aggressive expansion of the above renewables so that they can be addressed and mitigated during planning and implementation to ensure a secure water future for China.

CHIINA PLANS TO SET PROVINCIAL QUOTAS FOR ELECTRICITY GENERATION FROM RENEWABLES

In August 2014, the 'Draft Measures for the Evaluation of Renewable Energy Electricity Generation Quota' was passed in the internal review of the NDRC and sent on to local governments and grid companies for comments. The draft sets targets of electricity generation from wind, solar and biomass energy for each province by 2015, 2017 and 2020. Some provinces will become net renewable electricity exporters, such as Inner Mongolia, Gansu, Ningxia and Xinjiang; while others will be net importers due to their high electricity demand, such as Jiangsu, Shandong and Guangdong. Although the quotas have yet to be finalized, based on the currently draft, Inner Mongolia, for instance, is expected to generate 10% of its electricity from renewables by 2015, which is expected to increase to 12% by 2017 and 13% by 2020.

Source: China Water Risk, NDRC, NEA

OTHER RENEWABLES' HIDDEN WATER RISKS

Renewables may be good for climate but maybe not for water...

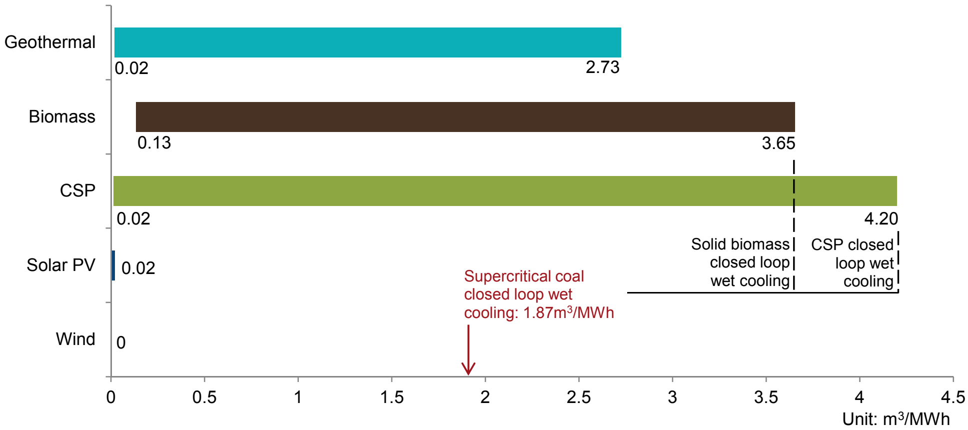
Although there is no doubt that renewables are important to combat climate change, they are not necessarily always good for water. Depending on the type of renewable, there are different concerns from a water perspective ranging from water use and consumption in power generation to toxic pollution from rare earth mining. Therefore while China's aggressive push to lead in renewable energy development is commendable, we should be mindful of these hidden risks brought on by expansion in renewable power and act to mitigate such accordingly. Key risks are set out below:

1. Some types of renewables are thirstier than coal-fired power

... some renewables consume more water than coal-fired power

Water consumption in power generation across different types of renewables based on Macknick et al. (2011)[86] is set out in the chart below:

Water Consumption in Power Generation for Different Renewables



Source: China Water Risk, Macknick et al (2011)

Wind and solar PV require little water but CSP, biomass and geothermal are thirstier ...

It is clear from the above chart that:

- Both wind and solar PV require little water in power generation; while
- CSP, biomass and geothermal consume larger amounts of water depending on the technologies adopted as well as cooling types.

Some energy conversion technologies will require more water than others so technology choices matter. Like thermal power generation, if wet cooling is adopted for CSP, biomass or geothermal, significant amount of water will be consumed compared to dry cooling. Despite switching to dry cooling, the water consumption for CSP, biomass or geothermal is still greater than that for wind and solar PV. For instance, water consumption in biomass power generation ranges from 0.13m^3/MWh for biomass in the form of biogas with dry cooling up to 3.65m^3/MWh for solid biomass with closed loop wet cooling. In comparison, the maximum water consumption for solar PV is only 0.02m^3/MWh and that for wind power is zero. To put things into perspective, comparable water consumption for supercritical coal closed loop wet cooling is 1.87m^3/MWh. CSP closed loop wet cooling can be as much as 4.20m^3/MWh.

... wind power consumes 0.56m³/MWh while biomass up to 24.5m³/MWh

However, it is important to note here that this is water consumption in power generation process only. If we look at water consumption from a life-cycle analysis perspective (as discussed in Chapter 3: "Balancing Power Mix for Water & Climate"), biomass can consumes up to 24.5m³/MWh, compared to 0.56m³/MWh for wind.

Like thermal power generation, cooling technologies matter

There are clear trade-offs which must be considered between climate and water. Significant water savings can be made by switching from wet cooling to dry cooling for CSP, biomass and geothermal. Substituting thermal power generation with wind and solar PV, will also generate water savings from (1) cooling water saved and (2) water used in extraction and processing of fossil fuels, be they gas or coal. For these reasons, wind, solar PV and CSP (with dry cooling), along with hydropower, are amongst the '2nd Choice Group' in terms of water withdrawal per MWh and GHG emissions discussed in "Balancing Water, Climate & Power Generation Capabilities: Technology Choices Matter" in Chapter 3: "Balancing Power Mix for Water & Climate".

2. Big wind has dirty secrets: toxic and radioactive water pollution from rare earth mining will intensify

Making wind turbines and solar panels require rare earths ...

The manufacture of wind turbines and solar panels requires the use of metals such as REE. Aggressive future expansion of wind and solar could push up REE demand which could in turn intensify water pollution from REO mining and REE production. Mining REO as well as the extraction of REE could pollute water and soil and destroy watersheds.

... pollution incidents reported in Guangdong in mines operated by illegal syndicates; the Dongjiang River feeds Guangzhou, Shenzhen & HK

All the processes from REO extraction, REE separation and refining consume significant quantities of water and electricity as well as produce acidic wastewater and radioactive waste. Of serious concern is the fact that many of the REO mines and REE production facilities sit near some important watersheds. In 2009, 80% of China's REE metal production was located in Jiangxi (42%) and Inner Mongolia (38%). China's largest REE mines in the North are near the Yellow River and whilst in the South, Jiangxi's watersheds are the source of the Dongjiang River which feeds millions of people. This includes neighbouring province Guangdong and downstream cities such as Guangzhou, Shenzhen and Hong Kong.

Quota system drove black market in rare earths ...

Currently, many mines are not operating at the level stipulated by industry standards. Moreover, some REO miners and REE producers are illegally discharging their wastewater and radioactive waste. This means that not only is the actual discharged amount likely to be under-reported, toxic and radioactive wastewater is discharged into the environment without proper treatment. Several pollution incidents have been reported. For instance, in Guangdong, rice fields and rivers were polluted by powerful acids and other runoff from open-pit rare earth mines operated by illegal syndicates.[87] Indeed the quota system on the export of REE from China between 1998 and 2014 exacerbated this as the mining of these ores were driven underground creating a significant black market in rare earths.

... improper and illegal discharge of toxic wastewater and radioactive waste has long lasting-impact on key watersheds

If the future wind power growth follows the most aggressive scenario discussed later, the associated wastewater generated by REE production could be twenty times greater than the current wastewater amounts. Note here this does not include the amount of associated radioactive waste let alone the amounts of wastewater and radioactive waste illegally discharged. If China's REO miners and REE producers continue with the current bad practices, the impact on the environment and China's water resources will be disastrous. There will be long-lasting social and economic implications for those who rely on these watersheds. Therefore, in addition to the varying water use requirements across different types of renewables, there are 'hidden' water risks associated to the manufacturing of renewables. Since REEs are also key inputs into the energy savings industry, REO mining practices and REE production processes need to be urgently re-examined as China and the rest of the world are poised for a massive drive in energy savings and renewables expansion.

Rare earth mining concerns are set out in detail in the following pages in "China's Rare Earth Resources & Toxic Impact on Watersheds" whilst analysis on estimated wastewater generated from rare earth mining due to wind power expansion is explored later in this chapter.

Wind & solar: dirty & thirsty partnership with coal & steel

Wind and solar still rely on coal for smoothing but reliance can be mitigated

Wind and solar PV are both intermittent sources of power and thus require smoothing which is currently provided by coal-fired or natural gas-fired power (more in Chapter 3: "Balancing Power Mix for Water & Climate"). The reliance on coal can be mitigated by (1) improving grid infrastructure to better accommodate intermittent power, (2) developing energy storage technologies, (3) optimizing demand-side management, and (4) adopting new nuclear power technologies such as load-following mode for smoothing. In the meantime, the partnership of wind and solar with thermal power (primarily coal-fired) is unavoidable. Thirsty and dirty coal and coal-fired power is covered in detail in the chapter on "Coal & Coal-fired Power".

2TW of wind turbines by 2050 can require as much as 30% of 2014 China's crude steel output

Coal-fired power generation is not only dirty and thirsty; the construction of thermal plants also requires material amounts of steel and cement. Less obvious is renewable energy's use of steel: in particular in the manufacture of wind turbines and construction of solar power plants. Although the amounts used are relatively small, steel demand driven by aggressive wind and solar power expansion should not be ignored. Indeed, as per our analysis set out later in this chapter, additional steel demand driven by aggressive wind expansion to 2TW by 2050 could reach 241 million tonnes or 30% of China's crude steel production in 2014.

Moreover, coking coal is an important raw material input in steel production. In 2012, coking accounted for 20% of coal consumption in conversion, and 84% of the total coal output came from water challenged regions. These less obvious water risks associated with the manufacture of wind turbines and solar plants should be taken into account, providing even more reason to control the steel industry. This is discussed in Chapter 5: "Battle to Conserve Energy" as the steel industry is one of the most power intensive industries and key in China's efforts to control coal consumption and promote energy savings.

Rise in local and global demand for "made in China" renewables will intensify water risks

Although wind and solar power require coal-fired power for smoothing, its expansion can reduce China's overall reliance on coal. However, China is currently the global manufacturer of such equipment and the rise in global demand for "made in China" renewable energy could result in added pressure on water risks in the North, thereby intensifying the competition for water resources against agriculture production (more in Chapter 4: "Ensuring Food & Energy Security").

Grid upgrade and energy storage such as batteries can also be thirsty and dirty

Upgrade of grid and electricity storage also increase demand for materials; the mining of these raise water concerns

As can be seen from the analysis later, China could have even more aggressive wind and solar targets than already discussed in the longer term. As mentioned above, this cannot be optimised without a massive upgrade of China's grid and development of electricity storage technologies. Grid infrastructure upgrade will draw on the steel sector and other materials such as copper and aluminum. China is a major producer across all these metals. Mining practices for these raw materials must be re-examined in order to minimize water use and pollution impact on watersheds.

Bad mining practices in REO, copper, lead and coal must be reined in to safeguard water resources

China has set a path of aggressive renewable expansion. This will bring about unavoidable water risks as discussed above and increases the urgency to address current mining practices. The downside cost (both socially and economically) of a lax regulatory environment in REO mining and REE production is too great. The REE black market must be reined in. Mining practices for REO and REE as well as copper, lead and coal must be tightened to safeguard China's groundwater and surface water resources.

Various water risks are examined in more detail for wind, solar as well as biomass and geothermal in this chapter.

CHINA'S RARE EARTH RESOURCES AND TOXIC IMPACT ON WATERSHEDS

Rare earths & their uses

Rare Earth Elements (REE) are a group of 17 elements including 15 lanthanides, plus two non-lanthanides (scandium and yttrium). REEs are not actually "rare" but are named as such due to the difficulty in finding commercially viable sources. In addition, complexity in the separation process makes their extraction difficult and costly. REEs can be categorized into two groups: Light Rare Earth Elements (LREE) with atomic number ranging from 57 to 63 and Heavy Rare Earth Elements (HREE) with atomic number ranging from 64 to 71. These 17 elements are set out in the table[88] below:

Summary of Rare Earth Elements

Lanthanides				Non-Lanthanides	
Light Rare Earth Elements (LREE)		Heavy Rare Earth Elements (HREE)			
Name	Symbol	Name	Symbol	Name	Symbol
Lanthanum	La	Gadolinium	Gd	Yttrium	Y
Cerium	Ce	Terbium	Tb	Scandium	Sc
Praseodymium	Pr	Dysprosium	Dy		
Neodymium	Nd	Holmium	Ho		
Promethium	Pm	Erbium	Er		
Samarium	Sm	Thulium	Tm		
Europium	Eu	Ytterbium	Yb		
		Lutetium	Lu		

Source: UNCTAD Secretariat from the Great Western Minerals Group LTD, US Geological Survey 2011

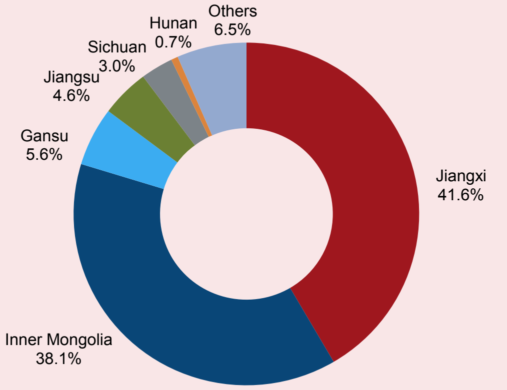
REEs are crucial for many of the processes and products in our daily lives. Generally, LREEs are used more widely but HREEs remain pivotal. According to the United Nations Conference on Trade and Development (UNCTAD) 2014 report, REEs are mainly used in three areas: green energy, lifestyle appliances (such as LCD, smartphones, tablets and X-ray, etc.) and defense system (such as lasers, sonar transducers and aircraft, etc.). For green energy, REEs are important input materials for wind power and rechargeable batteries.

China has 23% of global REO reserves & accounts for 90% of global REE production

According to the State Council's white paper 'Status and Policies of China's Rare Earth Industry'[89], as of 2012, China has around 23% of total global REO reserves. REO containing LREEs are concentrated in the north (mainly Inner Mongolia and Sichuan), while REO with HREEs are mostly in the South (mainly Jiangxi and Fujian).[90]

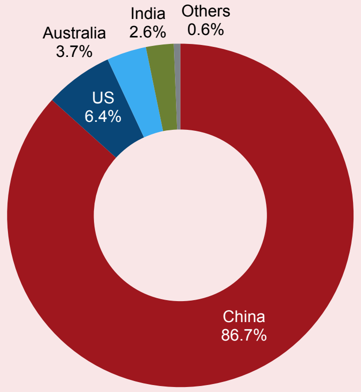
As a result, China's main REE production is located in Inner Mongolia, Sichuan and Jiangxi. In total, these three provinces accounted for more than 93% of extraction quotas between 2007 and 2011. Provincial production data is not easily accessible. Based on data collected by Wübbeke (2013)[91] which uses 2009 data, Jiangxi and Inner Mongolia are by far the two largest producers at 42% and 38% respectively as shown in the chart below left. In recent years, China has become the No.1 producer globally. According to the UNCTAD 2014 report, as of 2012, China accounted for 87% of global production as shown in the chart below right:

2009 China's REE Metal Production By Province = 23,057 tonnes



Source: China Water Risk, Wübbeke (2013)

2012 Global Rare Earth Production = 110,000 tonnes



Source: China Water Risk, UNCTAD, US Geological Survey

The production of permanent magnets in wind turbines requires the use of neodymium, a LREE and dysprosium, a HREE. While LREEs in China mainly come from large-scale mines in Inner Mongolia and due to the natural location and scale of mines are relatively less polluting, HREE is found in the South, mainly in Jiangxi, where mines are often small-scale and more polluting. Managing pollution in HREE production is key, especially when China dominates global HREE production. LREE production is less China-reliant.

Environmental concerns and water risks from rare earth mining

Like many other mining processes, rare earth mining could cause negative impacts on the environment such as hazardous waste, air pollution and water pollution. As reported by L. Hayes-Labruto et al. (2014)[92], one tonne of REE can produce 60,000m^3 of waste gas that contains hydrochloric acid, 200m^3 of acid-containing sewage water, and 1–1.4 tonnes of radioactive waste. The State Council's white paper also mentioned that processing one tonne of rare earths produces 2,000 tonnes of toxic waste. In addition to water pollution, the REE processing processes including ore extraction, separation and refining all consume significant quantities of water, acidic substances and electricity[93].

From the water perspective, the biggest threat is that many of the REE mines and production facilities sit near some important watersheds. For instance, the mines in Baotou, Inner Mongolia are just adjacent to the Yellow River, the primary water source for millions of people downstream. According to the MEP, in the Baotou mine alone, about 50,000 tonnes of radioactive waste is generated every year.

China has recognized the negative environmental impacts from REO mining and REE production. In May 2011, the State Council issued the 'Opinions on Healthy Development of the Rare Earths Industry'[94]. It forbids new construction of rare earth processing projects and limits the expansion of existing projects during 12FYP, with the exception of state-approved merging or optimization of production capacity. Meanwhile, the MEP issued the national 'Emission Standard of Pollutants from Rare Earths Industry' (GB26451-2011)[95], which has been in force since 1 October 2011. In April 2014, the MEP issued the 'Guideline on Available Technologies of Pollution Prevention and Control for Rare Earth Metallurgical Industry'. However, such efforts have been curtailed by the lax enforcement, previous absence of a punitive environmental protection law and lucrative nature of the REO and REE market, triggering a substantial black market in the rare earth trade.

China's fight against a sizeable REE black market

Illegal REO mining and REE production and trading has always been a serious issue in China. Since 1998, a quota system was adopted by the central government to regulate the REE production and export to address environmental concerns arising from illegal REO mining and REE production. According to the State Council's white paper, the volumes of rare earth products imported from China as per statistics collected from foreign customs were 35 %, 59% and 36% higher than the official volumes exported during 2006, 2007 and 2008, respectively. In short, this 2012 white paper acknowledges the existence of the black market.

However, the fight against rare earth smuggling has been tough. In 2011, the imbalance reached as much as 120%. The existence of the sizeable illegal trading in the REE black market also distorted the quota system and has led to an oversupply causing the price of REEs to fall in recent years. Accordingly, cheap REE exports increased whilst export revenues fell. The 2014 statistics from China Customs show that China's total REE exports increased by 27.3% from 2013 to 28,000 tonnes, while total revenues fell by 35.6% to RMB2.3 billion.[96]

The quota system clearly provided more impetus to the development of the black market to the detriment of China's environment and water sources and was hence abolished on 31 December 2014 by the Ministry of Commerce. In its place is a license system for rare earth export[97]. The government hopes this could help rein in the black market. However, should China be solely responsible for the rare earth black market? After all it is driven by demand. In 2014, Japan was the largest recipient of China's REE exports at 43% followed by the US at 32%. REE demand will inevitably rise in the future driven by both domestic and global expansion of wind power and attempts at massive energy savings. However, given the serious water concerns, China's rare earth industry needs to reinvent itself and become a cleaner "catalyst" for not just the nation's but the global green revolution. China's REE trading partners should also bear some responsibility towards ensuring REE purchased are not negatively impacting China's environment.

BIG WIND FROM THE NORTH CAN COMPLEMENT COAL-FIRED POWER

Wind power not only cuts GHG emissions from power generation but also avoids water consumption and withdrawal for cooling in thermal power plants. Given the double benefits for water and climate, China has welcomed expansive growth of wind power with many large-scale wind farms.

Wind power development to consolidate into large bases in Coal Base Provinces

Nine large wind energy bases are being built ...

Similar to coal-fired power, China's wind power development is also moving towards large, concentrated wind energy bases. Such strategy is largely to do with the distribution of wind resources across China. Large wind energy bases are being built in northern China alongside large coal bases and energy bases. According to the '12FYP Renewable Energy Development Plan', China is establishing large wind energy bases in the "Three North" areas (Northeast, Northwest and North China) as well as some coastal areas (onshore) (see table below):

...mainly in the "Three North" areas

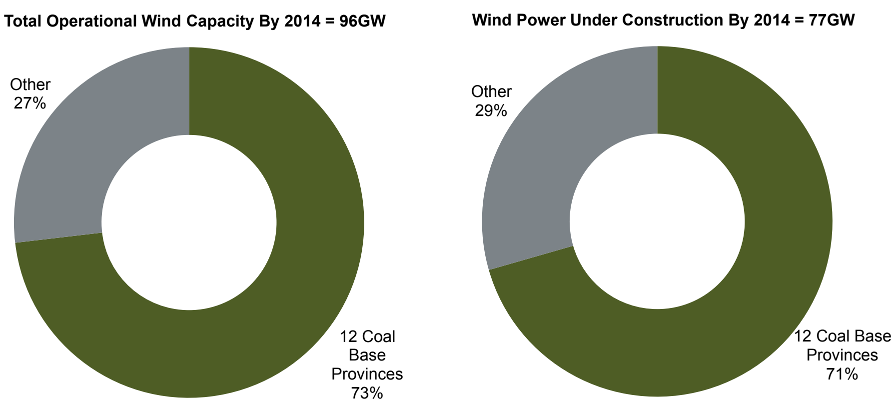
Nine Large Wind Energy Bases (unit: GW)

	Planned Capacity by 2015	Planned Capacity by 2020
Heibei	11	16
Mengdong (eastern Inner Mongolia)	8	20
Mengxi (western Inner Mongolia)	13	38
Jiuquan (Gansu)	11	20
Hami (Xinjiang)	10	20
Jilin	6	15
Coastal areas of Jiangsu	6	10
Coastal areas of Shandong	8	15
Heilongjiang	6	15
TOTAL	**79**	**169**

Source: NDRC

Over 70% of wind power capacity concentrated in Coal Base Provinces

By the end of 2014, the total approved wind power capacity amounted to 173GW, of which 96GW have been installed and connected to the grid whilst 77GW are still under construction. There is considerable overlap with the 12 Coal Base Provinces: 73% of the 96GW of operational wind power capacity (see chart below left) and 71% of wind power capacity under construction (see chart below right):



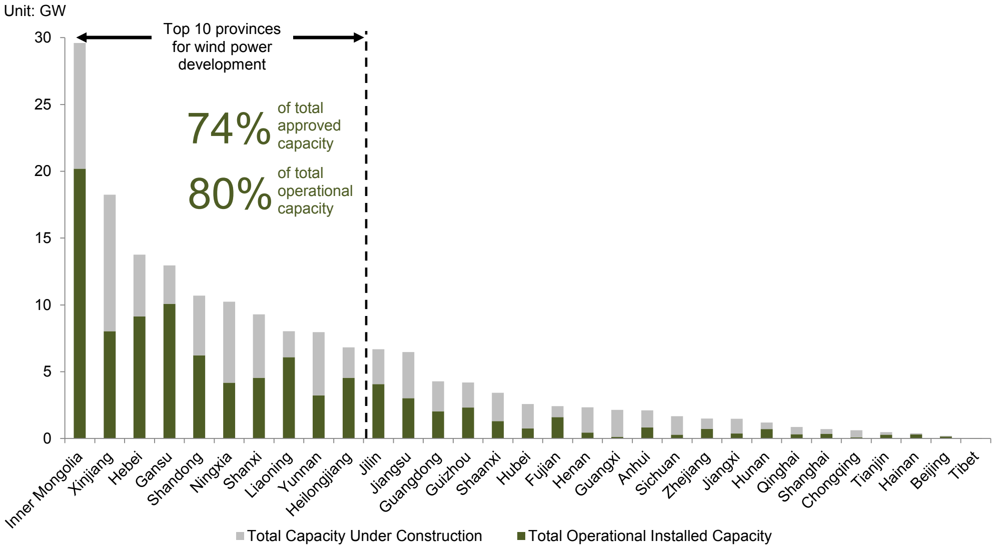
Source: China Water Risk, NEA

Provincial wind development to reduce coal-fired reliance in the North

Plans to have 74% of total approved wind capacity spread over 10 Northern provinces ...

Amongst all the provinces in China, Inner Mongolia is the No.1 in terms of wind power installation, representing 20.9% of total operational installed capacity. The other top wind provinces include Gansu, Hebei, Xinjiang, Shandong, Liaoning, Shanxi, Heilongjiang, Ningxia and Jilin. All these 10 provinces are located in Northern China and account for: 74% of total approved capacity (operational & under construction); and 80% of the national total operational installed capacity:

Provincial Wind Power Development By 2014: Operational vs Under Construction



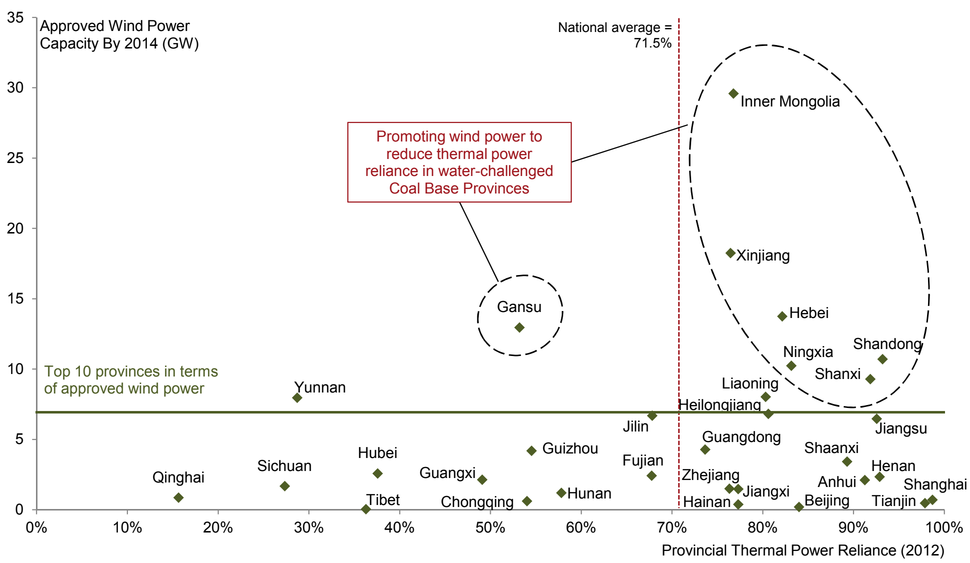
Source: China Water Risk, NEA

... this can help reduce reliance in seven Coal Base Provinces ...

These proposed onshore wind energy bases also overlap with some of the large coal-fired energy bases. As can be seen in the scatter chart below which compares the approved wind power expansion versus the thermal power reliance by each province, development of wind farms in these areas could complement and alleviate the pressure of coal-reliance for: Inner Mongolia, Xinjiang, Hebei, Gansu, Ningxia, Shandong and Shanxi. Except for Inner Mongolia and Xinjiang, the rest of these provinces are water scarce.

...except for Inner Mongolia and Xinjiang, the rest are water scarce

Approved Wind Power Capacity vs Provincial Thermal Power Reliance



Source: China Water Risk (based on statistics from NEA, CEC and NBSC)

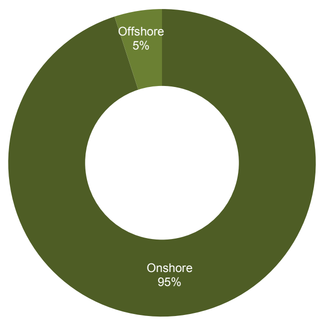
BIG WIND AMBITIONS: 2050F WIND INSTALLED CAPACITY BASE SCENARIOS RANGE FROM 700GW TO 1TW

China on track to meet 12FYP and 2020 targets

12FYP target: 100GW; 95% to be onshore wind farms

The State Council's '12FYP Energy Development Plan' issued in 2012 set the target of wind power installed capacity to reach 100GW by 2015, of which 95% will be onshore wind farms as per the chart below. In addition, although most of wind power installations are onshore, China is promoting offshore wind farms by developing some pilot projects in the coastal areas of Jiangsu, Shandong, Hebei, Shanghai, Guangdong and Zhejiang. Such pilot projects include the 100MW Donghai Bridge Offshore Wind Farm in Shanghai and 150MW Rudong Offshore Wind Farm in Jiangsu.

2015F Total Wind Power Installed Capacity = 100GW



Source: China Water Risk, State Council

On track to meet 2015 and 2020 targets

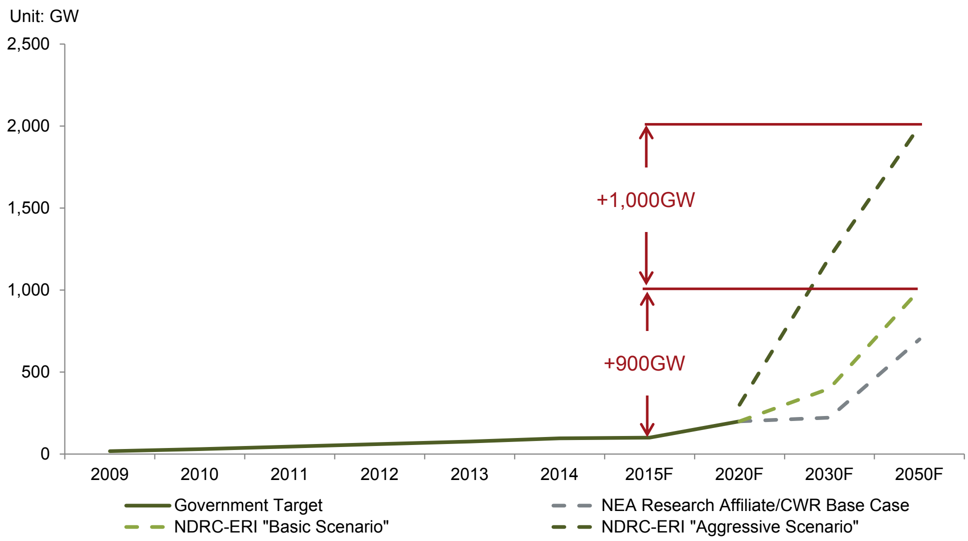
China is currently on track to meet the 12FYP target. In 2014, China's on-grid wind installed capacity reached 96GW and a further 78GW is under construction. This means China will have 174GW of wind capacity, which indicates that it is also well on track to meet its 2020 target of 200GW.

The future of big wind can be as much as 2TW

Scenarios forecast 700GW to 2TW of wind power capacity by 2050

On 19 November 2014, the State Council's 'Energy Development Strategic Action Plan (2014-2020)' set a 2020 target to increase wind power installed capacity to 200GW. Meanwhile, various government affiliated research bodies have forecasted the future development of wind energy from 2020 to 2050. These forecasts are set out in the chart below:

2009-2050F China's Actual & Forecasted Wind Power Installed Capacity



Source: China Water Risk, State Council, NEA Research Affiliate and NDRC-ERI

Key points to note from the chart above on the different projections are:

All wind scenarios are aggressive

- **NEA Research Affiliate/CWR Base Case:** Back in 2012 and 2013, several NEA affiliated research institutes (such as State Electric Energy Research Institute and State Electric Power Planning Design & Research Institute) conducted studies on China's mid-long term electric power generation demand and supply.[98] These studies forecasted the wind turbine installation to reach 200GW, 222GW and 700GW by 2020, 2030 and 2050 respectively; and

- **NDRC-ERI:** In December 2014, NDRC affiliated Energy Research Institute (ERI) published a report "China Wind Energy Development Roadmap 2050" with the IEA.[99] The report provides two scenarios:

  - Basic Scenario - wind power installed capacity to reach 200GW, 400GW and 1,000GW by 2020, 2030 and 2050, respectively; and

  - Aggressive Scenario - wind power installed capacity to reach 300GW, 1,200GW and 2,000GW by 2020, 2030 and 2050, respectively.

If China follows the "Aggressive Scenario", it will add +1.9TW of wind capacity between 2015 and 2050; even with the "Basic Scenario", the 2050 figure is still +900GW more than 2015 target.

Regardless of differences, all forecasts indicate big wind ambitions.

China's maximum wind potential can be more than 2TW given current technology

Wind resources potential can exceed 3TW

According to China National Renewable Energy Centre's study, China has rich wind resources with a potential for more than 3,000GW, mainly in the "Three North" areas (Northeast, Northwest and North China): of which, the onshore wind potential is more than 2,600GW (grade 3 or above at 70 m hub height), and near offshore wind capacity at water depth of less than 50 m (above 100m hub height) could amount to 500 GW with technology currently available.

With the current wind turbine technology, wind power capacity could reach more than 2,000GW.[100] Therefore, the current installed on-grid capacity of wind power is merely 4.8% of the 2,000GW potential, and the approved capacity accounts for only 8.7%.

Caution! A big wind future could pollute watersheds with acidic water & radioactive waste

As discussed earlier in this chapter, the power generation process of wind power basically does not require any water. Thus, it is a top energy choice in terms of withdrawal/consumption and GHG emissions.

Neodynium and dysprosium required for production of permanent magnets in wind turbines

However, if we extend our examination to the production of wind turbines, hidden water risks are revealed. For some types of wind turbines, the production of permanent magnets requires use of rare earth metals (mainly neodymium which is LREE, and dysprosium which is HREE). Moreover, the manufacturing of wind turbines require significant amount of steel and carbon fibres.

Wind dirty secret: Rare earth demand from forecasted wind power expansion and associated wastewater discharge

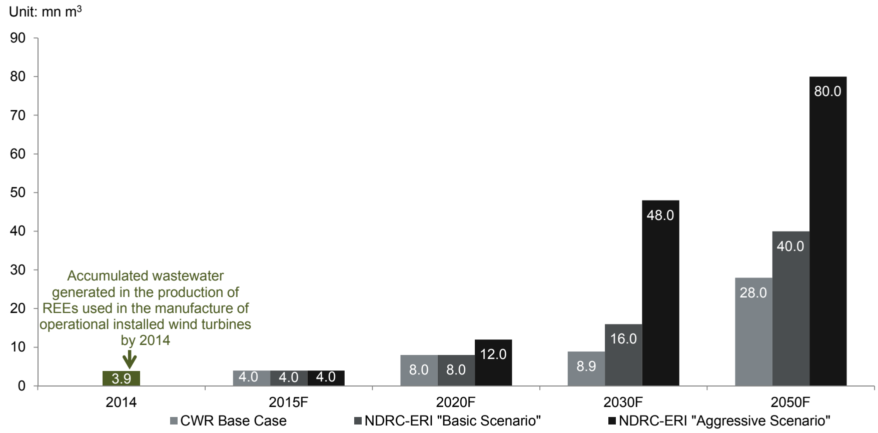
Wind's dirty secret: expansion will bring toxic REO and REE wastewater discharge

Studies have shown that a typical 2MW wind turbine contains about 341-363kg of neodymium and about 59kg of dysprosium.[101] This means to produce 96GW of wind turbines that were installed and put into operation by 2014, China would have consumed about 16,431-17,491 tonnes of neodymium and 2,843 tonnes of dysprosium. To add +100GW wind power from 2015 to 2020, it will require additionally about 17,050-18,150 tonnes of neodymium and 2,950 tonnes of dysprosium. Note that this does not include rare earth demand resulting from the ongoing maintenance of the wind turbines.

One tonne of REE can produce 200m³ of acid-containing wastewater

As discussed in **"China's Rare Earth Resources & Toxic Impact on Watersheds"**, these rare earths are primarily supplied by China. The mining of rare earths has caused negative environmental impacts including water pollution. One tonne of REE can produce 200m^3 of acid-containing wastewater. Therefore, to add +100GW wind power from 2015 to 2020 could lead to approximately 4.0-4.2 million m^3 of acidic wastewater; and depending on the expansion scenario, wastewater discharged could either double or triple by 2020 or increase 7x to 20x by 2050. The below chart illustrates the accumulated amount of wastewater discharge from REE production due to forecasted wind power expansion under three different scenarios: CWR Base Case, NDRC-ERI "Basic Scenario" and NDRC-ERI "Aggressive Scenario":

2014-2050F Accumulative REE Wastewater Generated from Manufacture of Wind Turbines



Source: China Water Risk, State Council, NDRC, NEA Research Affiliate, NDRC-ERI, China National Renewable Energy Centre

Note: the figures represent accumulated wastewater generated from the production of REEs, which are used in the manufacture of wind turbines with the forecasted installed capacity by the indicated year. Only operational capacity are considered.

Wastewater discharged can double or triple by 2020 and increase 7x-20x by 2050

It is clear from the above chart that across the three scenarios, the wastewater discharge will either double or triple between 2014 and 2020. Whereas from 2020 to 2030, wastewater discharge could face a twelve-fold exponential growth if NDRC-ERI's 'Aggressive Scenario' was to be adopted.

Strong regulation of REO and REE prioritised

Clearly, before embarking to tap China's massive wind power potential, toxic and radioactive water risks to China's watersheds need to prioritised. As mentioned before, without strong regulation of the rare earth industry, future increase in REO mining and REE production driven by the wind industry could be disastrous for China watersheds in both the North and the South. Given the current forecasts, there is a ten-year window to achieve this.

Steel demand from forecasted wind power expansion

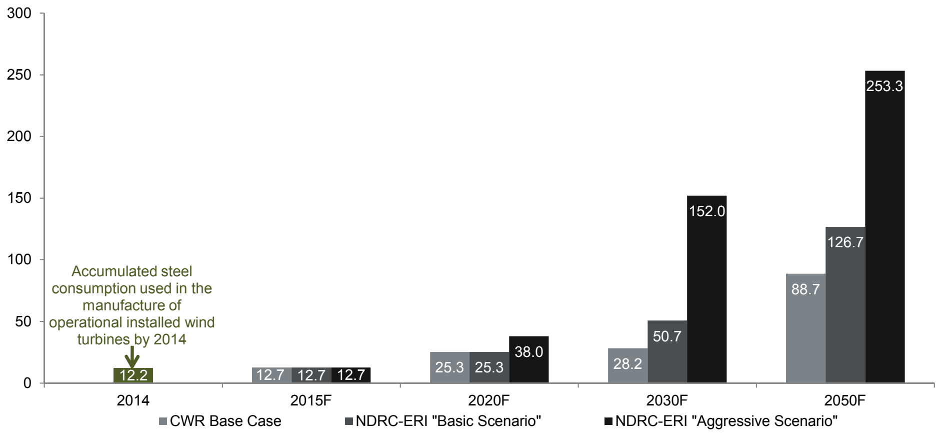
Steel demand will also rise; 2TW of wind by 2050 means additional demand of 241 million tonnes by 2050 ...

Market survey data in 2009[102] showed that per 1MW wind turbine average steel consumption was 126.67 tonnes. This means, to add +100GW wind power from 2015 to 2020, it will require in total 12.67 million tonnes of steel, or 2.53 million tonnes per year. This amount is insignificant compared to annual steel production. However, if China goes for more aggressive wind power development, the increase in steel requirement will be multifold.

As shown in the chart below, under the most aggressive scenario of wind expansion to 2TW by 2050, additional steel demand is estimated at 241 million tonnes. This is 30% of China's crude steel production in 2014. Aggressive wind capacity expansion could thus bring about significant steel demand along with associated coal, power and water requirements in steel production as discussed above.

2014-2050F Accumulative Steel Demand from Manufacture of Wind Turbines

Unit: mn tonne



Source: China Water Risk, State Council, NDRC, NEA Research Affiliate, NDRC-ERI, China National Renewable Energy Centre

Note: the figures represent accumulated steel consumption, which is used in the manufacture of wind turbines with the forecasted installed capacity by the indicated year. Only operational capacity are considered.

... and making steel is power intensive and coking coal is an input

More on energy conservation and government action in the steel sector in Chapter 5: "Battle to Conserve Energy" and for more on water risks exposure in the coal and coal-fired power, see the chapter on "Coal & Coal-fired Power".

CHINA SOLAR: THE FUTURE IS BRIGHT & DISTRIBUTED

Like wind, solar can cut GHG emissions and avoid water use, but only if right tech is used

Solar like wind not only cuts CHG emissions but also can avoid water withdrawals and consumption in generating electricity if the right technology choices are made. There are different ways to convert sunlight into usable energy forms. Currently, solar energy technologies in China are mainly solar photovoltaic (PV), concentrated solar power (CSP) and solar heating. These are defined in the box below.

SOLAR TERMINOLOGY

Solar photovoltaic (PV): directly converts solar energy into electricity using a PV cell made of a semi conductor material.

Concentrated solar power (CSP): concentrates energy from the sun's rays to heat a receiver to high temperatures. This heat is transformed first into mechanical energy (by turbines or other engines) and then into electricity. Currently there are several CSP technologies: parabolic trough, Dish Stirlings, linear Fresnel reflector and solar power tower.

Solar heating: technologies to capture solar radiation and convert it into heat for a wide number of applications such as domestic hot water heating and swimming pool heating.

Source: IEA, US Department of Energy, Macknick et al (2011)

China's solar PV plants dominate the current solarscape

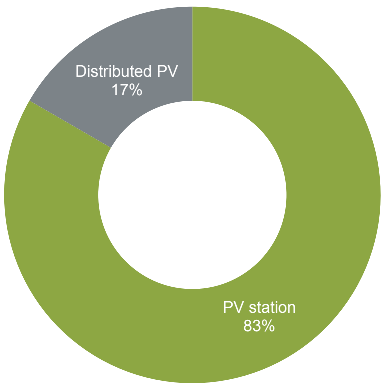
Solar power can be centralized or distributed, on-grid or off-grid

Although China has a few small pilot CSP plants, the majority of solar energy applications are solar PV and solar heating, which can either be centralized (PV station) or distributed. While centralized PV stations are connected to the grid, distributed solar PV can either be on-grid or off-grid. Electricity generated from a distributed PV project is mainly for self-consumption of a single user or a community. In case of excess electricity generated, it could be either stored or sold to the local grid subject to the grid connectivity, capability and regulation.

China's solar power is now mainly centralized solar PV stations

Solar PV is developing faster than planned in China. In 2013, China's on-grid installed solar PV capacity reached 16GW, which is 11% of the global solar of 139GW.[103] By 2014, solar PV capacity almost doubled to 28GW, far exceeding the original 12FYP target of 21GW. The 12FYP target has since been reset by the State Council to 35GW.[104] At 28GW in 2014, China looks comfortably set to reach this new target. Of the total 28GW of on-grid installed solar PV capacity in China, 5GW or 17% is small-scale distributed PV whilst 23GW or 83% is in the form of centralized PV stations as shown in the chart below:

2014 Total Solar Power Installed Capacity = 28GW



Source: China Water Risk, NEA

China's solar power is now mainly centralized solar PV stations

Most of this solar capacity is located in the West. Currently, China's on-grid centralized Solar PV plants are mainly in Qinghai, Gansu and Xinjiang. Indeed, China is establishing solar energy bases in these three provinces as per the '12FYP Renewable Energy Development Plan' due to abundant solar energy resources and the availability of large areas of unused land.

According to the latest "China Wind and Solar Energy Resources Bulletin" published by Wind and Solar Energy Resources Center of China Meteorological Administration in February 2015, the areas with the most abundant solar energy resources lie in Qinghai, Mid-Western Tibet, Western Gansu, Western Inner Mongolia, Eastern Xinjiang and Western Sichuan. With the exception of Western Sichuan, Qinghai and Mid-Western Tibet, the rest are also home to big wind bases.

Distributed solar can power remote areas; in the South it can complement hydro & nuclear

Whilst Solar PV plants in Gansu, Inner Mongolia and Xinjiang can complement the wind and coal-fired power, the upside in solar expansion is from distributed solar which has the advantage of bringing electricity to remote areas at a relatively lower cost in the South. Here it can also complement or even counter hydropower and nuclear expansion, depending on the scale of solar expansion. Currently, based on installed capacity, distributed solar PV is most popular in Jiangsu, Zhejiang, Guangdong, Shandong and Hunan.

On 16 March 2015, the NEA announced to add 18GW on-grid solar PV in 2015 with specific provincial quotas, mainly in the Northwest and Eastern provinces including Xinjiang, Hebei,

Quotas and preferential policies set for on-grid solar

Jiangsu, Zhejiang, Anhui, Qinghai, Ningxia, Guangdong, Inner Mongolia and Shandong.[105] These 10 provinces account for 56% of the total quota. While there were limits set for each of these provinces, there were no limits set for on-grid solar PV installations in Beijing, Tianjin, Shanghai, Chongqing and Tibet. Preferential policy measures for on-grid solar PV were also detailed in this document to ensure full accommodation of electricity generated by solar PV by the grid. Financial assistance in developing these projects as well as monthly monitoring of the installation works were also included in the document.

Plans afoot to shift China's solarscape towards a distributed future

Distributed solar PV is also favoured by the central government...

The message is clear. Central government wants to promote distributed solar PV projects, especially those that could be connected to local grids. This shift is reinforced by various policies issued by State Council and the NEA over the past two years:

- 4 July 2013: State Council set out a series of policies measure to promote "healthy development" of the solar PV industry, especially for distributed solar PV.[106] It aims to establish 100 pilot districts and 1,000 pilot communities (townships/villages) for distributed solar PV, provide financial support as well as improve grid connectivity and electricity tariff system. Following this document, many provincial governments issued local policies on promoting distributed solar PV;

- 22 August 2013: NEA and China Development Bank announced the provision of financing support to distributed solar PV projects including preferential loan schemes and funding platforms;[107]

- 2 September 2014: NEA issued a notice to push further implementation of relevant policies set by State Council and provincial governments for distributed solar PV;[108] and

- 21 November 2014: NEA issued a notice to develop 30 pilot districts for distributed solar PV in Beijing, Tianjin, Heibei, Shanghai, Jiangsu, Zhejiang, Anhui, Henan, Jiangxi, Shandong and Guangdong.[109]

...distributed solar future looks bright

Therefore, although distributed solar PV only accounts for a small portion of the current solar PV installation in 2014, it appears to be set to grow in the future. The government will also continue to push for its growth with innovative pilots (see box below) given the many environmental and social benefits that distributed solar PV could bring to its people and local communities. Solar heating also forms a part of this distributed drive and is discussed below.

INNOVATIVE APPLICATION OF DISTRIBUTED SOLAR PV

According to the NEA, among the basic infrastructure projects using private investment encouraged by the NDRC, there are 30 distributed solar PV pilot projects, with completed capacity of 500MW and 600MW capacity under construction, involving private investment of more than RMB10 billion. Examples include:

- The world's largest PV-hydropower hybrid project, Longyangxia Project in Qinghai: The completed Phase I has installed capacity of 320MW, and Phase II with installed capacity of 530MW is expected to operate in 2015. Such hybrid project solves the low stability issue of solar power generation; and

- Solar PV is installed in greenhouses, fish farms, abandoned mining areas & restored desert areas.

In addition, according to the '12FYP Renewable Energy Development Plan', solar power system could be combined with off-grid tidal power plant to supply electricity to residents on isolated islands.

Source: NEA, NDRC

China's 12FYP target solar heating installations will cover over half of Singapore

Solar energy can also be used for heating...

Solar energy can not only be used for power generation, it can also be used for heating purpose. It is important to note at this point that distributed solar heating is not included in the above Solar PV installed capacity figures nor in the forecasts discussed below. Nevertheless they play an important part in China's energy landscape.

...alleviating bad air and water risks associated with burning coal

China intends to not only supply energy to remote areas that still lack grid connection but also mitigate water risks and air pollution by avoiding the burning of coal for heating. In 2012, the household coal consumption (primary for cooking and heating) was 91.5 million tonnes. Whilst this is only around 10% of end-use coal consumption for 2012, Beijing's coal consumption for the same year was 25 million tonnes. Replacing coal for heating with solar heating will alleviate pressure on coal consumption and help China control coal production in the dry North.

In 2013, China accounted for over 65% of solar hot water heaters

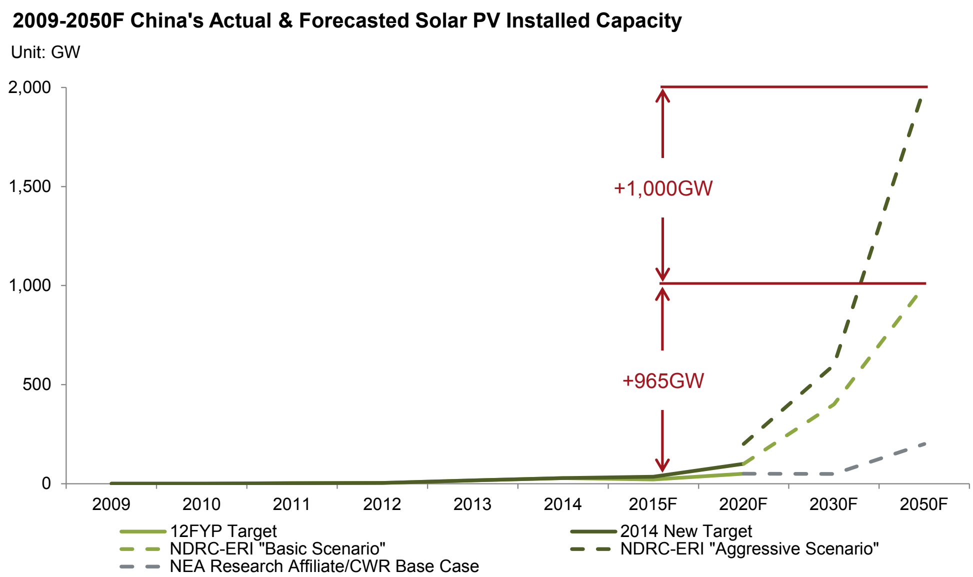
As of 2013, China accounted for over 65% of global installations of solar hot water heaters.[110] According to the '12FYP Renewable Energy Development Plan', China aims to install in total 400 million m^2 of solar heaters by 2015. This is equivalent to over half of Singapore's land area or more than 56,000 football fields. Moreover, China also plans to install 2 million solar cookers in rural areas. Based on the current trend, we expect distributed solar heating to experience a further boom in the future.

Solar is fast-tracked to soar: 2050F solar installed capacity base scenarios range is 200GW–1TW

Solar is growing faster than expected; targets are revised from 50GW to 100GW

Solar has been growing faster than expected. After revising the 12FYP target, the State Council's 'Energy Development Strategic Action Plan 2014-2020' released on 19 November 2014, set a target of total installed capacity of solar PV of 100GW by 2020. This is double the original target of 50GW by 2020 set by the NDRC in the '12FYP Renewable Energy Development Plan' issued in July 2012. Central government is clearly signalling big ambitions to fast-track solar development.

The long-term future of solar energy in China looks bright with wide-ranging 2050F forecasts. We have set out the forecasts by various government affiliated research bodies in the chart below:



Source: China Water Risk, State Council, NEA and NDRC-ERI

Key points to note from the chart above regarding the different projections are:

Solar scenarios are wide-ranging from 200GW to 2TW by 2050

- **NEA Research Affiliate/CWR Base Case:** As mentioned in the discussion of wind power forecast, several NEA affiliated research institutes' studies on China's mid-long term electric power generation demand and supply back in 2012 and 2013 also forecasted the solar PV installation to reach 200GW by 2050; and

- **NDRC-ERI:** In December 2014, NDRC-ERI's report "China Wind, Solar and Bioenergy Roadmap 2050"[111] provided two scenarios:

  - Basic Scenario – solar power installed capacity to reach 100GW, 400GW and 1,000GW by 2020, 2030 and 2050, respectively; and

  - Aggressive Scenario – solar power installed capacity to reach 200GW, 600GW and 2,000GW by 2020, 2030 and 2050, respectively.

If China follows the "Aggressive Scenario" it will add just shy of 2TW of solar PV capacity between 2015 and 2050; even with the "Basic Scenario", the 2050 figure is still +965GW more than 2015 target.

CAUTION! WRONG CHOICE OF SOLAR TECH CAN GUZZLE WATER

Choice of solar technologies matters as some are thirsty

The manufacture of solar PV panels and battery storage infrastructure both require REEs. The negative impacts of REO mining and REE production on watersheds and the environment have been discussed above. However, the choice of solar technologies matters as some of them are thirsty. These are discussed below:

SOLAR PV PANELS: REGULAR CLEANING MAXIMISES ENERGY EFFICIENCY

The power generation efficiency of a solar PV module will be affected by the solar radiation intensity effectively received by the module. Dust, sand, snow, moss and other natural or artificial particles on the surface of the module could obstruct or distract solar radiation from reaching the solar cells.

Studies (Sulaiman et al. 2011; Mejia et al. 2014) have confirmed that the accumulated dust on a surface of solar PV panel could reduce its efficiency, although the exact impacts vary greatly among different test conditions from 16% up to 50%.

Source: Sulaiman et al. 2011. Effects of Dust on the Performance of PV Panels. World Academy of Science, Engineering and Technology, Vol. 5; Meijia et al. 2014. The Effect of Dust on Solar Photovoltaic Systems. Energy Procedia, 49: 2370-2376

Solar PV does not need water to generate power but may need some water for washing

Albeit small amounts, solar PV require water for washing...

As discussed in the beginning of this Chapter, solar PV requires little water in power generation. However to maximize the energy efficiency of solar PV module, regular cleaning of the panels is often suggested to remove dust and other particles on the surface of PV panel (see box below).

...but dry alternatives exist

Water washing is the most common way. However, according to Macknick et al. (2011), the amount of water used for such maintenance is considered minimal. Moreover, many operators do not wash their PV panels in practice. Some operators have also come up with water-free ways to clean the PV panels. For instance, a solar farm located in Israel's Negev desert uses robots for the cleaning. The automated system has soft microfiber elements and an airflow cleaning system. It is powered by solar energy and works during the night to optimise efficiency. These robots are reported to remove up to 99% of the dust on the panels.[112]

CSP plants can guzzle more water than coal-fired plants

Choose wisely, some CSP tech can consume as much as 4.2m³/MWh

Like thermal power generation, most CSP technologies require cooling, with the exception of Dish Stirling. According to Macknick et al. (2011), if wet cooling is adopted, water consumption can be as high as 4.2m^3/MWh. Switching to dry cooling can reduce water consumption to 0.098m^3/MWh but this is still higher than that using Dish Stirling of around 0.019m^3/MWh. It is clear that in developing CSP plants, technology choices impact water. This is particularly pertinent if such plants are located in water scarce or stressed regions. There are also environmental impacts to consider as set out in the box below.

IMPACTS OF LARGE-SCALE CONCENTRATED SOLAR POWER ON LOCAL ENVIRONMENT

Developing CSP can reduce GHG emissions, air pollution and waste by substituting conventional energies such as coal. However, its installation and operation require large areas of land in sunny areas. Fresnel reflectors are made of many thin, flat mirror strips to concentrate sunlight onto tubes through which working fluid is pumped.

Water consumption - CSP plants use water for a number of reasons, such as for steam generation to turn turbines, for cooling and to clean dust off the mirrors in the arid and semi-arid conditions. Water consumption is highly dependent on the specific CSP technology used. For example, a 50MW CSP plant using water cooling would use 1.6 million m^3 of water annually, whereas an equivalent plant using 'dry' cooling technology (such as dry air or water-air hybrid cooling) would only use around 0.4 million m^3 of water.

Soil erosion and soil temperature - During CSP plant construction, damage to vegetation, construction traffic and the digging of foundations would all increase soil erosion in the immediate area. CSP structures lower soil temperatures by between 0.5 to 4 °C in spring and summer and increased temperatures by 0.5 to 4 °C during the winter. This finding could be important where land use is combined with growing crops, as plant growth can be especially sensitive to soil temperature.

Source: Wu, Z., Hou, A., Chang, C., et al. (2014). Environmental impacts of large-scale CSP plants in northwestern China. Environmental Science Processes & Impacts, 16(10), 2432–41

CSP is only 2.4% of global solar capacity; in China CSP expansion must first consider water

CSP plants are currently not widely used globally. In 2013, the global installed capacity of CSP plants was only 3.4GW[113] or around 2.4% of global solar capacity. However, with a higher capacity factor than solar PV, CSP is a more efficient way to mitigate climate risk and may in the longer term become competitive vis-à-vis thermal power generation given the falling technology cost. Therefore, in China where water could be limited in sunny regions, when considering solar expansion, the water use of CSP plants as well as environmental impact should be weighed against those of solar PV.

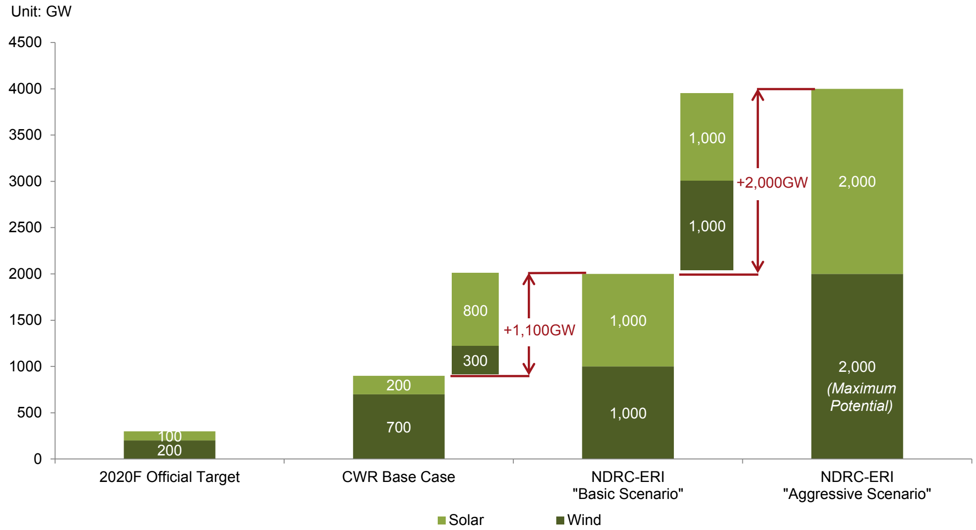
VARIOUS 2050 FORECASTS INDICATE EVEN MORE AGGRESSIVE ADD OF WIND AND SOLAR

As previously discussed, all future scenarios for both wind and solar capacity forecasts in China are aggressive. The following are set out in the chart below:

All future scenarios of wind and solar are aggressive

- CWR Base Case – as discussed in Chapter 3: "Balancing Power Mix for Water & Climate";
- NDRC-ERI "Basic Scenario" and NDRC-ERI "Aggressive Scenario" as discussed earlier in this chapter.

Various Forecasts of China's Installed Capacity of Wind and Solar By 2050F



Source: China Water Risk, State Council, NDRC, NEA Research Affiliate, NDRC-ERI

Key takeaways are:

- Given the current rate of expansion, China is on track to reach the 300GW target by 2020F;

Albeit high, current development signals that 900GW is easily possible

- There are still doubts as to whether China can achieve the CWR Base Case of 900GW by 2050. However, the current accelerated development of wind and solar suggests that it is possible for China to reach this by 2050F;

NDRC-ERI Basic Scenario has 2TW of solar and wind capacity by 2050 ...

- The NDRC-ERI "Basic Scenario" for both wind and solar capacity is +1.1TW more than the CWR Base Case. Reaching 2TW of wind capacity is an additional +300GW of wind and +800GW of solar from the "CWR Base Case" scenario. To gain perspective:
  - The +300GW of wind installation alone (expected to primarily be located in Northern inland regions) could replace approximately 79GW of coal-fired installed capacity (more in the chapter on "Coal & Coal-fired Power"); and

... Aggressive add of wind and solar can provide relief to coal-fired bases ...

  - The +800GW of solar will more likely come from distribute solar PV power generation and solar heating rather than CSP given water concerns explained earlier. This aggressive build out of solar capacity can help alleviate water risks in two ways:
    - Promoting of solar heating, especially in water-challenged regions, could replace some of the coal directly consumed for heating purpose and mitigate the water risk arising from coal mining (more in the chapter on "Coal & Coal-fired Power"); and

...distributed solar can complement hydro and nuclear in the South

- Distributed solar can be used in the South to replace the currently slated inland nuclear power expansion of 28GW. +800GW of solar power could replace approximately 139GW of forecasted inland nuclear installed capacity (more in the chapter on "Nuclear Power"); and

- NDRC-ERI "Aggressive Scenario" is even more aggressive, doubling the figure in the NDRC-ERI "Basic Scenario" to be 4TW for wind and solar combined. This is +3.1TW more than our "CWR Base Case" scenario. It is worth noting here that 2TW of installed wind power capacity means tapping 100% of China's wind power potential given current technology.

But without massive grid upgrade, China will not achieve maximum results

Regardless, no matter how aggressive the forecasts are, power generation efficiency and grid connectivity will limit the scale-up of wind and power. Without a massive upgrade of the grid, China will not be able to achieve maximum results in delivering electricity generated by the planned targets of wind and solar. In this regard, China has been pushing to increase its grid connectivity and also to develop new technologies such as smart grid and electricity storage technologies, all of which are important to accommodate electricity generated from renewable energy. See **"Grid Infrastructure & Energy Storage Must Improve to Accommodate Renewable Expansion"** set out in the following page.

CHINA'S POWER SYSTEM AND ITS REFORM

China started reforming its power sector in 2002 by breaking up the then State Power Corporation into six regional clusters with weak interconnectors (the North, Northeast, Northwest, Central, Eastern and South regions). Each cluster consists of several provinces that act as a balancing area. There are interconnected lines that facilitate trade within the regional clusters.
There are three main grid groups:

- State Grid Corporation of China: manages distribution from subsidiaries in the North, Northeast, East, Central and Northwest;

- China Southern Power Grid Company: manages distribution in China's five southern provinces including Guangdong, Guangxi, Yunnan, Guizhou and Hainan; and

- Local independent grid companies: including Inner Mongolia Power Company, Tibet Power Company, Shanxi International Electric Power Co.,Ltd., Shaanxi Provincial Electric Power Company and local hydropower companies.

At the time of writing this report, the central government is about to issue guidelines on deepening the reform of the power sector. The reform is expected to break the monopoly and attract private investment. Moreover, it will further relax electricity tariff, relax sale and distribution of electricity, and establish an independent trading platform.

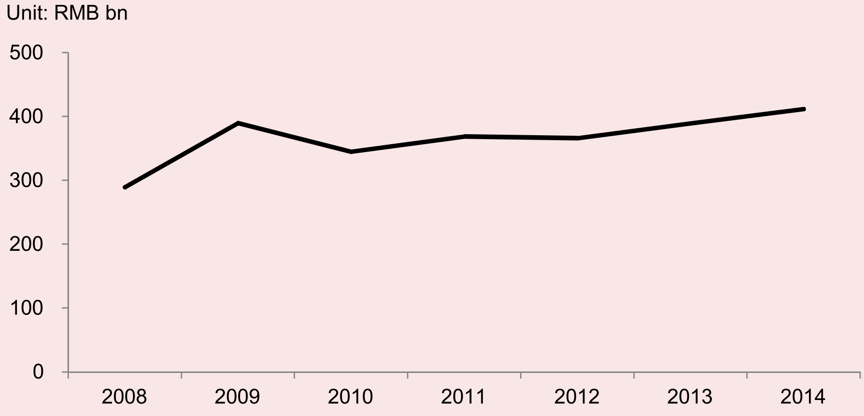
Source: NEA, State Grid Corporation of China and China Southern Power Grid Company. Xinhua News Agency, 12 March 2015. http://news.xinhuanet.com/energy/2015-03/12/c_1114610571.htm

GRID INFRASTRUCTURE & ENERGY STORAGE MUST IMPROVE TO ACCOMMODATE RENEWABLE EXPANSION

China's grid infrastructure is currently a bottleneck for renewable power generation. Without sufficient grid penetration and high-quality grid infrastructure, the electricity generated by on-grid renewable energy cannot be delivered to the end-user. Moreover, because of the intermittent nature of renewables, it brings the challenge of integrating variable renewable electricity generation with the existing power generation mix. Without viable technologies to store generated electricity, we still need fossil fuel-fired power plants both as back-up capacity and for smoothing renewable energy supply (see more in the Chapter 3: "Balancing Power Mix for Water & Climate"). Accordingly, the '12FYP Renewable Energy Development Plan' promotes technologies on smart grid, integration of intermittent renewable energy sources as well as large-scale energy storage development.

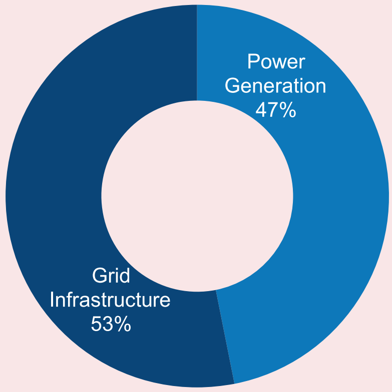
China has been investing a lot in order to upgrade its grid infrastructure. According to the '12FYP Energy Development Plan', the total length of China's transmission lines with voltage above 330kV is expected to reach 200,000km, which is equivalent of circling the earth five times. From the chart below left, we can see an overall increasing trend for investment on grid infrastructure. Since 2013, the total investment on grid infrastructure surpassed the investment on power generation. in 2014, it reached RMB412 billion, accounting for 53% of total investment in power sector (RMB776 billion) as shown in the chart below right:

2008-2014 Total Investment on Grid Infrastructure



Source: China Water Risk, CEC

2014 Investment in Power Sector = RMB776 bn



Source: China Water Risk, NEA

Looking forward, if China wants to expand its renewable energy capacity as planned, even more investment will be needed. In particular, more funds should be provided to develop electricity storage technologies. On 20 March 2015, NDRC and NEA issued the 'Guidance on improving grid operation and regulation to promote the accommodation of renewable energy generation'. This new guidance requests local grid companies:

- To prioritize generation capacity from renewable energy in the annual power generation planning;
- To ensure full acquisition of renewable electricity under the premise of grid security and stability;
- To prioritize renewable electricity generation and electricity import from other regions to meet new energy demand;
- To incentivise the use of coal-fired power generation as peak regulation to ensure maximum power generation from renewable electricity; and
- To upgrade transmission infrastructure and develop smart grid technology in renewables-rich regions.

BIOMASS & GEOTHERMAL COOLING NEEDS MAKE THEM AS THIRSTY AS COAL-FIRED POWER

Other renewable alternatives such as biomass, geothermal and ocean energies will remain limited in China's total energy mix. However, since China is looking to also tap these climate-friendly sources for power, water risks associated with these are set out below.

Biomass energy: recycles waste but is thirsty

Biomass can be very thirsty but potential to generate power and reduce waste is sizeable

There are many ways to utilize biomass. In fact, biomass was probably the earliest energy source that our ancestors used to make fire and cook food. Today there are still people using the traditional way of using wood, charcoal, agricultural residues and animal dung for cooking and heating. Such application is often considered unsustainable and inefficient, and brings negative impacts on the air and human health due to the smog and ash produced. For this report, we only consider modern application of biomass as a type of renewable energy. According to IPCC and IEA's definitions, it can be categorized into two groups:

- **Modern bioenergy** encompasses: (1) electricity generation or combined heat and power (CHP) generation from biomass, municipal solid waste (MSW) and biogas, (2) residential space and hot water in buildings and commercial applications from biomass, MSW and biogas; and (3) liquid transport fuels; and

- **Industrial bioenergy applications** include heating through steam generation and self-generation of electricity and CHP in the pulp and paper industry, forest products, food and related industries.

Main resource: agriculture and forestry biomass, followed by waste incineration and biogas

According to the '12FYP Biomass Energy Development Plan'[114] issued by NEA in July 2012, there are several types of biomass waste that could be used for energy purposes:

- Biomass waste from agriculture and forestry, which would previously have been burned, dumped or used for feedstock. In agriculture, an annual amount of around 0.4 billion tonnes (*0.34 billion tonnes from farming wastes and 0.06 billion tonnes from processing wastes*) can be used for energy;

- Biogas generated from organic waste. 50% of sludge from municipal wastewater treatment can be used for producing biogas. The annual biogas production potential is 30 billion m^3 from organic wastewater in >20 food & beverage related industries, and 40 billion m^3 from livestock waste; and

- Waste incineration, mainly organic wastewater from municipal wastewater treatment plants and landfills.

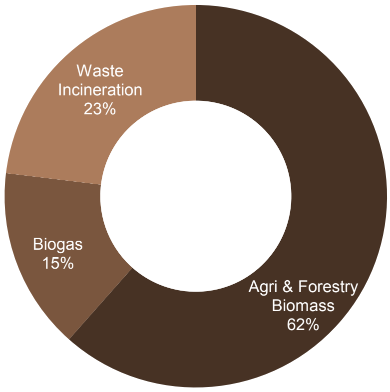
In 2013, biomass capacity reached 8.5GW...

In 2013, the installed power generation capacity from biomass reached 8.5GW, of which 1GW are CHP plants. The electricity generation from biomass energy was about 37TWh, accounting for only 0.7% of the total electricity generation in 2013.[115]

12FYP target = 13GW

The 12FYP expects the total installed power generation capacity from biomass to be 13GW in 2015. As shown in the chart below, 62% will be from agriculture & forestry wastes, 15% from biogas and 23% from waste incineration. However, even if this target is met, it would be merely 0.88% of the total installed capacity of all energy types in 2015 in China. By 2015, China aims to reach an annual utilization amount of 50 million tce for biomass.

2015F Planned Biomass Power Generation = 13GW



Source: China Water Risk, NEA

First generation bioenergy is not a viable option for China as it will compete for food; second generation bioenergy is favoured

Moreover, although biomass energy is generally considered carbon-neutral and hence considered important to combat climate change, it also raises concern over food security as energy crops will compete with food crops for land and water, and water risks in biomass power generation. As we have mentioned in Chapter 2: “China’s Water Energy Nexus”, from the life cycle perspective, biomass consumes much more water compared to other types of energy sources including coal, oil, nuclear, natural gas, solar PV and wind, to generate 1MWh of electricity. Water concerns in biomass power generation are set out in the box below. Second generation bioenergy, using ligno-cellulosic biomass should be favoured as it does not compete with food. Given food and water security concerns, first generation bioenergy is not a viable option for China.

WATER CONCERNS IN BIOMASS POWER GENERATION

Fossil fuels are formed from organic matters underground overall millions of years. The difference between fossil fuel and biomass is the impact on the climate. Burning of fossil fuels will produce carbon emissions along with other pollutants, which has been confirmed to be a major contributor to the current climate change.

Biomass from plants and vegetation, in contrast, are considered low-carbon or carbon-neutral. When the plants grow, they absorb sunlight and carbon dioxide from the atmosphere and convert them into nutrients and energy through photosynthesis. When these plants are burned in a biomass power plant, carbon dioxide is released back into the atmosphere. This repetitive cycle of carbon dioxide is in a much short time frame and considered carbon-neutral on the atmosphere.

However, although bioenergy is good for the climate, it is not necessary good for water. Biomass power plants require water as thermal power plants if wet cooling is adopted. The actual water withdrawals and consumption will depend on the specific cooling technology. Moreover, water is also needed to produce the biomass feedstocks and the actual water use could vary greatly among different types of crops.

Source: J Macknick, R Newmark, G Heath and K C Hallett. 2011. A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies. National Renewable Energy Laboratory (NREL), March 2011

Geothermal: to reach 100 million tce or 2% of primary energy consumption by 2030

The IPCC defines geothermal energy as *"accessible thermal energy stored in the Earth's interior, in both rock and trapped steam or liquid water (hydrothermal resources), which may be used to generate electric energy in a thermal power plant, or to supply heat to any process requiring it"*.[116]

China has one-sixth of global geothermal reserves, and plans to use this to provide hot water to 1.2mn households by 2015

China has one-sixth of the global geothermal reserves.[117] Geothermal is mainly used for heating purpose. According to the '12FYP Renewable Energy Development Plan' issued by the NEA on 6 July 2012, by 2015 geothermal is expected to supply heating for an area of 580 million m^2 and provide hot water to 1.2 million households. The total geothermal utilization will reach 15 million tce by 2015.[118]

Plans to increase this 6.6x by 2030 but it will still be 2% of China's primary energy consumption

According to the 'Energy Development Strategic Action Plan (2014-2020)', this amount will increase to 50 million tce by 2020. As per Li Qi, deputy head of the NEA, it is expected to reach 100 million tce by 2030.[119] That means the share of geothermal in China's primary energy consumption is expected to increase from 1% in 2020 to 2% in 2030. Although it is a very small portion in China's energy pie, it will help China to achieve the target of capping fossil fuels in the primary energy consumption at 80% by 2030.

OCEAN ENERGY: DEVELOPMENT POTENTIAL OF 600GW BUT ONLY 50MW BY 2015

According to IPCC's definition, ocean energy is "energy that is obtained from the ocean via waves, tidal ranges, tidal and ocean currents as well as thermal and saline gradients". According to 12FYP, China's total installed capacity of ocean energy is expected to reach 50MW by 2015 whilst the global installation was 530MW in 2013.

The State Oceanic Administration estimates China's theoretical coastal ocean energy resources to be 1.67TW and development potential to be 600GW, which is equivalent to about 27 Three Gorge Dams. China built its first tidal power plant "Jiangxia Tidal Power Plant" with an installed capacity of 4MW in Zhejiang as early as in 1980. However, despite the large potential and an early start, the overall development has been low due to technology barriers and lack of funding.

Source: NEA, State Oceanic Administration

HIDDEN WATER RISKS MUST BE ADDRESSED AS THE WORLD HEADS INTO A ROSY RENEWABLES FUTURE

The future points to aggressive expansion of wind and solar

For water, the choice of renewable energy and the type of technology adopted in electricity generation matters. Although electricity generation from wind and solar PV does not require much water, CSP, biomass and geothermal all require water for cooling. Since China is trying to reduce the share of water-reliant power in its power generation mix, expansion of renewable energy is dominated by wind and solar. Indeed, all future forecast scenarios point to aggressive installed capacity expansion of wind and solar with biomass, geothermal and ocean energy remaining small. As the world's largest GHG emitter, increasing the share of renewables in its energy mix also helps it keep the promise of capping its GHG emissions by 2030.

Ambitious plans and detailed policies have been set out to consolidate wind power development into large wind energy bases in the Coal Base Provinces in the North. This should help alleviate pressure on both China's coal bases and coal-fired energy bases. Meanwhile, solar energy bases are to be established in the West and there are plans afoot to shift China's solarscape towards a distributed future with distributed solar PV and solar heating projects across the country.

The most aggressive expansion of wind and solar can help substitute coal-fired power in the North, avoid inland nuclear expansion and complement hydropower...

As shown in the analysis above, the most aggressive 2050F scenario of wind and solar expansion to 2TW each could mean that big wind can substitute coal-fired power in the North; and distributed solar PV can complement hydropower and replace inland nuclear expansion. That said, before we embark on this aggressive expansion, hidden water risks should be taken into account. These hidden water risks are associated with the manufacture of renewable energy equipment such as wind turbines and solar PV panels. All of these require raw material inputs such as steel which is power intensive to manufacture. Moreover, coking coal is a key raw material in the manufacture of steel. Achieving 2TW of wind capacity by 2050 whilst positive for coal bases in the North will also increase demand in steel by 241 million tonnes or 30% of total crude steel output in 2014. Reform of the steel sector towards a circular economy is therefore key.

... but serious contamination risks from REO mining and REE production looms over China's key watersheds

Of more concern is the inevitable rise in demand for REE brought on by renewable expansion and China's push to extract maximum energy savings. The black market and bad practices in REO mining and REE processing have raised serious concerns over acidic wastewater and radioactive waste. Large mines containing LREE in the North lie next to the Yellow River while smaller mines containing HREE are located in Jiangxi near the source of the Dongjiang River. China's key watersheds are exposed to serious contamination risk if lax REO mining and REE production practices are not tightened. Already the government is moving to rein in the rare earth black market. China needs to sort out pollution from REO mining and REE production before exponential growth of wind and solar between 2030 and 2050. A white paper from the State Council stated, "*China will never develop the rare earth industry at the expense of its environment*".[120] This was issued in 2012. It remains to be seen whether the newly amended Environmental Protection Law, in force since 2015 can help achieve this. Strong law enforcement, education and more stringent water resources management are musts to protect China's watersheds.

The rare earths black market needs to be reined with tighter enforcement of mining practices across materials

However, this is not just China's problem. China's dominance in REO mining and REE production means that much of this is exported. Japan and the US are China's largest REE trading partners. Also China's key position in the global manufacture of renewables means that "made in China" supplies and will continue to supply the global movement towards a renewable future. China needs to tackle these hidden water risks. The rare earths industry needs to reinvent itself. China's REE trading partners should also bear some responsibility and work with China to find ways to minimize the negative impacts on China's watersheds. There is a window of 10 years to achieve this before the expected exponential growth of China's renewables between 2030 and 2050.

China's REE trading partners should also bear some responsibility...

...powering the world with cheaper clean energy cannot come at the expense of China's environment

In the future, the hidden water risks will come from both domestic and international expansion of renewable energy and energy savings programmes. It will be irresponsible to power the world with cheap "clean" energy at the expense of China's environment. Measures should be taken to discourage actions that might bring negative impacts through sustainable and responsible supply chain management.

As the whole world steps up its renewable and adopts massive energy savings, so will the demand for REO, REE, steel, copper and aluminium rise. Therefore, aside from rare earths, the extraction and production of these important commodities (where China is a key global producer) are all worth a revisit. It is imperative that China, the renewables industry as well as the energy savings industry start focusing on this today. Serious actions need to be taken to address these hidden risks.

ABBREVIATIONS

11FYP	11th Five Year Plan (2005-2010)
12FYP	12th Five Year Plan (2011-2015)
13FYP	13th Five Year Plan (2016-2020)
BAT	Best available technology
BAU	Business-as-Usual
BP	British Petroleum
CAE	Chinese Academy of Engineering
CAS	Chinese Academy of Sciences
CCS	Carbon capture and storage
CEC	China Electricity Council
CERS	China Energy Research Society
CHP	Combined Heat and Power
CNIS	China National Institute of Standardization
CSP	Concentrated solar power
CWR	China Water Risk
DRC	Development and Reform Commission
EIA	Environmental Impact Assessment
ERI	Energy Research Institute
FAO	Food and Agriculture Organisation of the United Nations
GCE	Gramme of standard coal equivalent
GDP	Gross Domestic Product
GHG	Green House Gas
GRP	Gross Regional Product
GW	Gigawatt
GWh	Gigawatt hour
HREE	Heavy Rare Earth Element
IAEA	International Atomic Energy Association
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IWHR	China Institute for Water Resources and Hydropower Research
KW	Kilowatt
KWh	Kilowatt hour
LBNL	Lawrence Berkeley National Laboratory
LREE	Light Rare Earth Element
MEP	Ministry of Environmental Protection
MLR	Ministry of Land & Resources
MIIT	Ministry of Industry and Information Technology
MOA	Ministry of Agriculture
MSW	Municipal Solid Waste
MW	Megawatt
MWh	Megawatt hour
MWR	Ministry of Water Resources
NBSC	National Bureau of Statistics of China
NCP	North China Plain

NDRC	National Development and Reform Commission
NEA	National Energy Administration
NPP	Nuclear power plant
NRDC	Natural Resources Defense Council
REE	Rare Earth Element
REO	Rare Earth Ore
SEI	Strategic Emerging Industry
Solar PV	Solar Photovoltaic
SNWDP	South-to-North Water Diversion Project
TCE	Tonne of standard coal equivalent
TW	Terawatt
TWh	Terawatt hour
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNECE TWC	United Nations Economic Commission of Europe Transboundary Waters Convention
UNWC	United Nations Watercourses Convention
USGS	United States Geological Survey
US EIA	United States Energy Information Administration
WANO	World Association of Nuclear Operators
WNA	World Nuclear Association
WTO	World Trade Organisation
WWF	World Wide Fund For Nature
WRI	World Resources Institute

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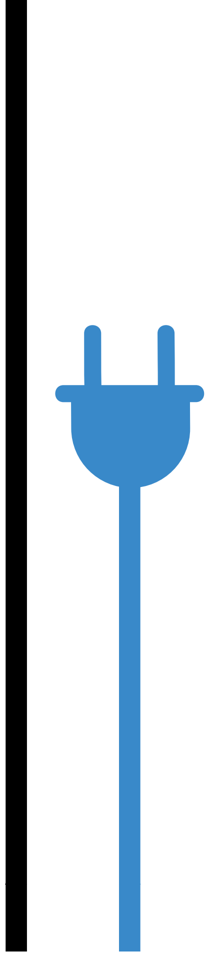

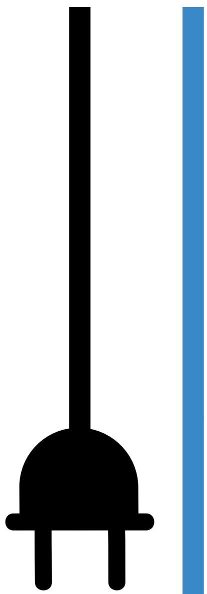

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