IRENA
International Renewable Energy Agency

REmap 2030
A Renewable Energy Roadmap

# RENEWABLE ENERGY PROSPECTS:
# CHINA

November 2014

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The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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## Disclaimer

# Renewable Energy Prospects: China

## *REmap 2030 analysis*

*November 2014*

# FOREWORD

REmap 2030 – the global roadmap prepared by the International Renewable Energy Agency (IRENA) – assesses how countries can work together to double the share of renewable energy in the global energy mix by 2030. It represents an unprecedented international effort that brings together the work of more than 90 national experts in nearly 60 countries, who continue to collaborate through global web discussions, regional meetings and national workshops involving technology experts, industry bodies and policy makers. Following the global REmap report released in January 2014, IRENA is producing a series of country-specific reports built on the same detailed analyses.

As the largest energy consumer in the world, China must play a pivotal role in the global transition to a sustainable energy future in an increasingly 'carbon-constrained' world. The country is already a global leader in renewable energy, with massive potential to harness a diverse range of renewable sources and technologies, both for power generation and for end-use sectors.

Compared to energy systems based on fossil fuel, renewable energy offers broader participation, enhances energy security, creates more jobs and provides an effective route to reducing atmospheric pollution and carbon dioxide ($CO_2$) emissions – a goal that becomes increasingly urgent by the day. Renewable energy technologies now provide the most cost-effective option for delivery of energy services in a growing range of locations and conditions, while innovation and increasing deployment continue to drive costs down even more.

Under current policies and investment patterns, the share of renewables in China's energy mix is projected to only reach 17% by 2030 compared to 13% in 2010. REmap analysis, however, shows that the country could realistically achieve scaling up modern renewables to 26%. The required investment of USD 145 billion could potentially save China more than USD 200 billion, factoring in the benefits of improved health and lower $CO_2$ emissions.

While countries must make energy decisions based on their own circumstances, each decision needs to be based upon the most comprehensive and transparent data available. China has demonstrated that it possesses the technical and human resources, as well as the dynamism, to spearhead a transformation of global energy use. REmap 2030 suggests concrete pathways to be considered to meet this generational challenge: to attain a clean and secure energy system in China and for the world.

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# EXECUTIVE SUMMARY

## HIGHLIGHTS

- China has become a global leader in renewable energy. It has vast resources and great potential for future development. In 2013, China installed more new renewable energy capacity than all of Europe and the rest of the Asia Pacific region.
- The main drivers for this shift are the increasing cost-competitiveness of renewable energy technologies and other benefits such as improved energy security and decreased air pollution.
- The share of renewables in China's energy mix was 13% in 2010, including an estimated 6% traditional use of biomass, and 7% modern renewables. Hydroelectricity (3.4%) and solar thermal (1.5%) accounted for most of China's modern renewable energy use.
- Under current policies and investment patterns, the share of modern renewables in China's energy mix will rise to 16% by 2030. REmap 2030 estimates that it would be both technically and economically feasible to increase the share of modern renewables to 26%.
- Reaching a 26% share for modern renewable energy would require investments of USD 145 billion per year between 2014 and 2030. Accounting for improved health and reduced carbon dioxide ($CO_2$) emissions, renewables would bring savings of between USD 55 and USD 228 billion per year to China's economy.
- Under REmap 2030, the share of renewables in the power sector would increase from 20% to nearly 40% by 2030. This assumes accelerated growth in wind and solar PV, and full deployment of hydroelectricity. To achieve this requires significant growth in grid and transmission capacity, and power market reform.
- Significant potential exists for renewable energy in end-use sectors. Industry can achieve a 10% renewable energy share, compared to almost none at present. The building sector can transform its fuel mix to two-thirds renewables. Solar thermal heat and electrification can help, as can modern biomass for process heating and space/water heating.

## The case for renewable energy in China

China's energy policy matters globally. The country is the world's largest energy user, accounting for one fifth of all global energy consumption. By 2030, China's energy consumption is expected to increase by 60%. China's energy choices will be a major influence on the world's ability to curb climate change.

There are rising concerns over energy security. As of 2014, about 30% of China's natural gas supply is imported, but this could increase substantially. China imports more than half of its crude oil supply, and this will also increase. Shale gas was considered as an alternative, but local exploration proved challenging. Until recently, China has been meeting most of its energy demand with coal. However, growing concerns over the environmental impacts of coal (severe air pollution that caused 1.2 million premature deaths in 2010, high water consumption compounding water scarcity) have prompted a shift in policy.

As a result, China is turning to renewable energy. It already has the world's largest installed capacity of wind and hydroelectric power, as well as the vast majority of solar heating and biogas installations. In 2013 China installed more solar photovoltaic (PV) capacity than the whole of Europe.

This strategy is bringing substantial economic returns. China has become a major exporter of renewable energy technology, accounting for two-thirds of global solar PV module production. Its renewable energy sector employed 2.6 million people in 2013. And it has the financial ability to invest further.

Under a business-as-usual scenario, China could fall far short of its full renewable energy potential. However, given the implementation of the right mix of policies, the country has the resources and the dynamism to lead a transformation of the global energy system.

## REmap 2030: China's renewable potential

REmap 2030 shows how the share of renewable energy in the global energy mix can be doubled by 2030. China's role is crucial for it to succeed.

Using projections from the Chinese Renewable Energy Centre (CNREC), IRENA calculates that the share of modern renewables (which excludes traditional uses of biomass) in China's energy mix will rise from about 7% in 2010 to 16% by 2030 under the business-as-usual scenario (the Reference Case in this study).

Under REmap 2030, however, with the right policies and support, the share of renewables in the energy mix could quadruple to 26% with technologies currently available. That would make China the world's largest user of renewable energy, accounting for about 20% of global use. Hydroelectricity, wind power, solar PV, solar thermal and modern biomass would constitute most of the renewable energy mix of the country.

## A strategy for a diverse mix of renewables in the power sector

China has massive potential to harness renewable energy for power. Currently, 20% of the country's electricity comes from renewables. Under the business-as-usual scenario, this rises to 30% in 2030. With REmap 2030 options, it approaches 40%. Hydroelectricity would be the largest type, as is the case today, but wind and solar PV would see the largest growth and would play an essential role.

**Hydro:** China's hydroelectricity potential by 2030 is 400 gigawatts-electric ($GW_e$). Already envisaged in the business-as-usual scenario, this will require significant cross-boundary coordination, as well as enhanced river and water management. Total pumped hydro capacity, crucial for energy storage, should reach 100 $GW_e$.

**Wind:** Wind became China's second largest source of renewable power in 2013 and has potential to grow further. The best wind resources are found in the northwest and northeast. REmap 2030 envisages a fivefold increase in onshore wind capacity, from 91 $GW_e$ in 2013 to 500 $GW_e$ by 2030 (twice the current installed capacity worldwide) and an additional 60 $GW_e$ capacity in offshore wind. For this to occur, the realisable resource potential by 2030 in northern China would need to be deployed, and the early retirement of some coal capacity would be necessary (mainly in western China). New grid and transmission capacity (including 100 new DC power lines) will be needed to link wind power with demand in southern and eastern China.

**Solar PV:** China installed 13 $GW_e$ of solar PV capacity in 2013, a substantial increase which resulted in a total installed capacity of 20 $GW_e$. 1 $GW_e$ came from distributed projects, such as rooftop solar PV on residential or commercial buildings. China aims to raise the total to 70 $GW_e$ by 2017, with equal contributions from utility-scale and distributed projects. REmap 2030 envisages a total installed capacity of 308 GW by $2030_e$ which is twice the current installed capacity worldwide. Nearly 40% of this would be distributed.

### Challenges and solutions:

- **Costs and externalities:** Wind and solar PV cannot compete with the low cost of coal power generation, based on today's market prices. They do become cost-competitive, however, when accounting for coal's significant externalities, such as air pollution and its impact on human health. China would need a nationwide price of about USD 50 per tonne of carbon dioxide ($CO_2$) to raise the cost of coal power generation sufficiently to make distributed solar PV cost-competitive. Prices closer to USD 25-30 per tonne $CO_2$ would ensure that wind and solar PV could compete with coal at utility scale.
- **Grids and transmission:** Power generation from both utility scale solar PV and wind in China has been curtailed by a lack of sufficient grid infrastructure, and because coal power plants are given priority dispatching. This is improving as preferential policies for renewables are introduced. Grid and transmission capacity issues will gain more importance in the future, as an important share of China's wind and solar PV will need to be built far from population centres. Better regional coordination is needed to create power exchange and new interconnectors between provinces, and power trading with neighbouring countries (*e.g.,* hydroelectricity from Siberia and Southeast Asia, or wind from Mongolia.)

- **Distributed solar PV** offers another solution. For this to be successful, business models need to be developed that result in higher rates of return, uncertainties in ownership should be resolved, and capacity growth needs to be accelerated.
- **Power market design and infrastructure planning:** The current electricity grid is not designed to handle high shares of variable renewable power. In order to accommodate this, accelerated power market reform will be needed, including establishing an electricity retail market segment, which would not only encourage competition on electricity retail prices, but also innovation in creating business models for applications of distributed generation renewable electricity. In parallel, China should expand the study on its future grid, particularly incorporating smart technologies to cope with large-scale variable renewables located in Northern and Western China, far away from the centers of the demand.

## The role of biomass in the renewable energy transition

Under REmap 2030, modern biomass would account for a quarter of all China's renewable energy use, primarily for end-uses such as fuel and heating. Reaching this potential poses significant challenges for data collection, substituting modern for traditional use of biomass, and transport logistics.

### Challenges and solutions:

- **Biomass feedstock:** China has abundant biomass resources, but utilising them sustainably and affordably will require carefully crafted policies. The main forms of biomass are straw (concentrated in the northeast and the lower Yangtze River) and fuel-wood (in the southeast and northeast). There is also potential from forestry residues. Transport of biomass feedstock from areas that are scattered across the country to specific centres of demand is a major challenge.
- **Cooking/heating/power generation:** Nearly all biomass today is used in traditional forms, *i.e.* for cooking. The share of the population that relies on traditional use of biomass is decreasing, and the use of modern cooking stoves is increasing. But the numbers are uncertain, and data collection needs to improve to assess the challenge ahead. Power production from biomass and waste could account for 10% of the total renewable power generation by 2030.
- **Industry**: Biomass in Chinese industry is currently limited to pulp and paper making, and only in small amounts. By 2030, biomass and waste could account for up to one-fifth of the process energy needed to produce clinker, one of the production processes that account for the largest share of energy use in China's manufacturing industry. Biomass could also be used in industrial combined heat and power (CHP) plants and heaters to generate process heat (*e.g.*, steam), but would still meet less than 5% of the industry sector's total fuel demand. To utilize these potentials from limited use today requires significant efforts from the industry sector.
- **Transport:** The government is promoting the production of advanced biofuels from sustainable feedstocks. REmap 2030 envisages production rising from 2.5 billion to 37 billion litres. Already today around 200 million electric two and three-wheelers are on the road in China, by 2030 this could reach 500 million. The magnitude of growth in advanced biofuels production represents a challenge.

**Renewable energy options other than biomass:** Realising the biomass potential in REmap 2030 would require at least two-thirds of China's total biomass supply potential to be utilized. Solar thermal for heating and different forms of electric transport are renewable energy technology options other than biomass. China is a global leader in solar thermal, and could increase its installed capacity six-fold under REmap 2030: 30% in manufacturing, and 70% in residential and commercial buildings. Electric vehicles already carry hundreds of millions of passengers every year, and could meet up to 20% of projected car demand by 2030, and as China's power system becomes more renewable, so will the electricity these technologies consume.

## The cost of REmap 2030

The investment needed to achieve REmap 2030 would average USD 145 billion per year, between now and 2030. This is an increase of USD 54 billion per year in investments in renewable energy technologies over current projections.

REmap quantifies costs from two perspectives: those of businesses, and those of governments.

- From the **business perspective**, which includes end-user tax and subsidies, REmap Options could be deployed at an average incremental cost of USD 20.2

per megawatt-hour (MWh), or USD 5.6 per gigajoule (GJ).

- From the **government perspective**, which excludes energy tax and subsidies, the cost would rise to USD 24.8 per MWh (USD 6.9 per GJ). This translates to a bottom line additional cost of USD 58 billion per year for the entire energy system.
- When externalities are taken into account, such as human health and $CO_2$ emission reductions, REmap 2030 results in net savings of USD 55-228 billion per year.

## Reducing $CO_2$ emissions

China is the world's largest emitter of $CO_2$, driven by its use of coal. Its power and end-use sectors produce around 7 Gt of $CO_2$ per year in 2012, and under business as usual scenario, this will grow by 50% by 2030. REmap 2030 shows that it is possible to limit this growth to 25% by substituting coal, mainly in the power sector.

However, even with the potential of renewables estimated in this study, China's coal use by 2030 will be very similar to its current levels. China will need to continue to deploy renewables beyond 2030, and improve energy efficiency in end-use sectors, in order to transition to a sustainable energy system.

If REmap Options were achieved worldwide, coupled with higher energy efficiency, atmospheric $CO_2$ concentration would stay below 450 parts per million (ppm) of $CO_2$ helping to prevent average global temperatures from rising more than two degrees Celsius above pre-industrial levels.

## Policy needs

REmap 2030 provides several recommendations to accelerate the transition to renewable energy. They include:

### Renewable energy policy:

- Develop a comprehensive national energy plan that accounts for the needed infrastructure for transmission and distribution of electricity, heat and gas
- Introduce taxation, caps, and/or $CO_2$ trading systems to account for the damage of $CO_2$ emission and other air pollution from coal combustion
- Assess the socio-economic, energy security, health, land and water use impact of various technologies
- Set targets for renewables in manufacturing, buildings and transport

### Power supply system and market design:

- Establish the national power market, creating economic incentives for flexible operation, and bringing in new investors
- Develop the grid to better integrate renewable energy, enhance trade and deal with variability

### Technology focused policies:

- Enhance government support for innovation, research and development to reduce renewable energy costs
- Support development of next-generation renewable energy technologies
- Improve knowledge and data collection on biomass and develop a working biomass feedstock market

China's energy use has grown rapidly in recent years, and by 2030 it will increase by another 60%. In a business as usual scenario, the country will not only be the world's largest energy consumer by far, but also emit over twice the quantity of $CO_2$ of the next largest emitter. Without increased deployment of renewable energy, China's energy system will continue to result in high levels of air pollution, negatively affecting health, economic growth and the environment. Without the diversification of its energy system and a transition towards renewable energy, the country will become increasingly reliant on imported fossil fuels, affecting its national energy security and economic growth.

China can choose a different path by accelerating the shift to renewable energy. There are challenges, including enhancing grid and transmission infrastructure, as well as biomass collection and logistics. These challenges can be overcome through effective planning and by creating mechanisms that value the external benefits of renewable energy. If China acts decisively to increase the role of renewables in its energy system, it can significantly reduce the pollution of its environment, enhance its energy security, benefit its economy and play a leading role in mitigating climate change.

# 1 INTRODUCTION

REmap 2030 is the global renewable energy roadmap of the International Renewable Energy Agency (IRENA) that shows how accelerated penetration of renewable energy in individual countries could contribute to doubling the share of renewables in the global energy mix by 2030.

Key factors in achieving a doubling are the use of biomass for heating, power generation and biofuels, as well as wind and solar technologies and greater electrification of the energy sector. Based on the analysis of 26 countries, REmap 2030 suggests that existing and future renewable energy expansion, as currently planned, will result in a 21% share of renewables worldwide in 2030 (IRENA, 2014a). This leaves a 15 percentage-point gap to achieve the doubling – 36% renewable energy share in the global total final energy consumption (The World Bank, 2013).

REmap 2030 is the result of a collaborative process between IRENA, national REmap experts within the individual countries and other stakeholders. The current report focuses on the actual and potential role of renewable energy in China, a major energy producer and consumer, and a major contributor of carbon dioxide ($CO_2$) emissions. In 2010, China was the largest energy consumer in the world with a total final energy consumption (TFEC) of 57 exajoules (EJ) per year (or 1,950 million tonnes of coal equivalent, Mtce)[1], equivalent to 18% of the global TFEC (IEA, 2012a).

China's TFEC is projected to grow by 60% in the period between 2010 and 2030, according to the New Policies Scenario in the International Energy Agency's *World Energy Outlook* (WEO) 2012 (IEA, 2012a)[2]. In the same time period, according to IEA and China National Renewable Energy Centre (CNREC) estimates, China's share of modern renewables in the TFEC will grow from just 7% in 2010 to only 16% in 2030 (excluding traditional uses of biomass[3]).

China has significant potential to go beyond its Reference Case if all the potential renewable energy technologies identified in REmap are deployed in addition to the Reference Case (IRENA, 2014a). The deployment of technologies required to fill this gap are called the REmap Options. Given the size of the country, renewable energy technologies and their related potentials vary by region and include geothermal, wind and various forms of solar and biomass. Annex G provides maps of the distribution of various energy sources and their potential.

This national potential is of global importance. Figure 1 provides a breakdown of total renewable energy use across the 26 countries that have developed REmap Options. Six of these countries account for three-quarters of the total additional renewable energy potential and more than half of the worldwide REmap Options. China has the largest renewable energy potential worldwide, accounting for 20% of the total global potential. The engagement of China is essential if the goal of doubling the share of global renewable energy use is to be achieved.

The objective of this report is to provide detailed background data and the results of the China REmap country analysis, as well as to make suggestions as to how these results could be translated into action.

The report starts with a brief description of the REmap 2030 methodology (Section 2). It continues by explaining the present energy situation and recent trends for renewable energy use (Section 3). Section 4 provides details of the China Reference Case find-

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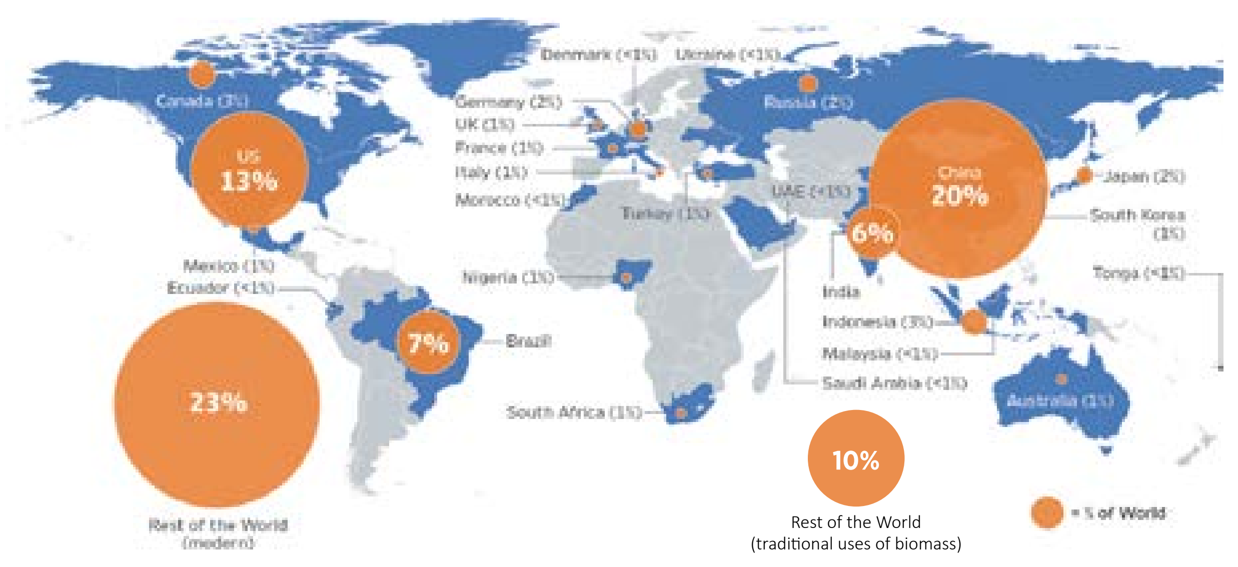
[1] 1 tce is equivalent to 29.3 GJ. 1 EJ is equivalent to $10^9$ GJ or 34.1 Mtce.

[2] The Reference Case of China has been prepared based on the IEA's WEO 2012 which projects 5% lower TFC compared with the IEA's WEO 2013 projection of 103 EJ in 2030 (IEA, 2013a). However, the growth rates for 2010-2030 and 2011-2030 are similar in both projections, estimated at approximately 2.2% per year.

[3] Estimates for traditional uses of biomass vary widely depending on the source. For a detailed breakdown of the information available, see Section 3 and Annex I.

*Figure 1: Contribution of individual countries to total global renewable energy use in REmap 2030*



***Six countries (Brazil, China, India, Indonesia, Russia and the United States) account for half of global potential and 75% of the estimated scale-up through REmap Options in 26 countries***

ings – the business-as-usual. Section 5 discusses the current policy framework. Section 6 discusses the potential of different renewable energy resources in China. Section 7, the heart of the report, quantifies the REmap Options – the potential to go beyond the uptake of renewable energy sources outlined in the Reference Case. This is followed by a discussion of the opportunities and barriers for renewable energy use in China (Section 8).

Section 9 provides policy recommendations for an accelerated renewable energy uptake for China.

# 2 METHODOLOGY AND DATA SOURCES

This section explains the REmap 2030 methodology and provides information about the background data used for the analysis of China. Annexes A-F provide the data and background assumptions in greater detail.

REmap is an analytical approach for assessing the gap between current national renewable energy plans, additional renewable technology options potentially available in 2030 and Sustainable Energy for All's (SE4All) objective of doubling the share of global renewable energy by 2030.

REmap 2030 assesses 26 countries: Australia, Brazil, Canada, **China** (in the present study), Denmark, Ecuador, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Morocco, Nigeria, Russia, Saudi Arabia, South Africa, South Korea, Tonga, Turkey, Ukraine, the United Arab Emirates, the United Kingdom and the United States of America.

The analysis starts with national-level data covering both end-use (buildings, industry and transport) and the power and district heat sectors. Current national plans using 2010 as the base year of this analysis are the starting point[4]. The Reference Case represents policies in place or under consideration, including energy efficiency improvements if they are contained in these projections. The Reference Case includes the TFEC of each end-use sector and the total generation of power and district heat sectors, with a breakdown by energy carrier for the period 2010–2030. The Reference Case for China was based on CNREC estimates and the IEA's *WEO 2012 New Policies Scenario*. Where necessary, 2010 IEA energy balance for China has been updated with information originating from other national sources or own estimates. This was the case in particular for the traditional use of biomass in the residential sector.

Once the Reference Case was prepared, then additional technology options were identified. These are defined as REmap Options. The choice of an options approach instead of a scenarios approach is deliberate: REmap 2030 is an exploratory study, not a target-setting exercise.

The sources of the REmap Options for China originate from a range of research that includes:

- For power sector: CNREC estimates, historical trends, IEA China Wind Energy roadmap (IEA, 2011a) and IRENA renewable energy industry roadmap and its accompanying data were used (IRENA, 2014b)
- For transport sector: IRENA estimates were used
- For industry sector: a recent IRENA renewable energy in industry roadmap (IRENA, 2014b) and its accompanying data was used
- For building sector: an internal analysis of Reference Case developments and REmap Options was used in addition to the draft "Roadmap Research of China Solar Thermal Development" (Ruicheng, Tao and Xuan, 2014)

IRENA developed a REmap tool that allows staff and external experts to input data in an energy balance for 2010, 2020 and 2030, and then assess technology options that could be deployed by 2030 consistent with an accelerated deployment of renewable energy. In addition to what is provided in the Annexes of this report, a detailed list of these technologies and the related background data are provided online. The tool includes the cost (capital, operation and maintenance) and technical performance (reference capacity of installation, capacity factor and conversion efficiency) of renewable and conventional (fossil fuel, nuclear and traditional use of biomass) technologies for each sector analysed: industry, buildings, transport, power and district heat.

Each renewable energy technology is characterized by its costs and the cost of each REmap Option is represented by its substitution cost. Substitution costs are the difference between the annualised cost of the REmap Option and of a conventional technology used to produce the same amount of energy, divided by the total renewable energy use in final energy terms (in 2010 real US Dollar (USD) per gigajoule (GJ) of final re-

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[4] To the extent data availability allows, information for more recent years (*e.g.,* 2012, 2013) is provided where relevant.

newable energy)[5]. This indicator provides a comparable metric for all renewable energy technologies identified in each sector.

Substitution costs are the key indicators for assessing the economic viability of REmap Options. They depend on the type of conventional technology substituted, energy prices and the characteristics of the REmap Option. The cost can be positive (incremental) or negative (savings), as many renewable energy technologies are already or could be cost-effective compared with conventional technologies by 2030 as a result of technological learning and economies of scale.

Based on the substitution cost and the potential of each REmap Option, country cost supply curves were developed from two perspectives for the year 2030: government and business. In the government perspective, costs exclude energy taxes and subsidies, and a standard 10% discount rate was used, which allows comparison across countries. Estimating a government perspective allows for a comparison of the 26 REmap countries with each other and for a country cost-benefit analysis; the government perspective shows the cost of doubling the global renewable energy share as governments would calculate it.

For the business perspective, the process was repeated to include national prices (including, for example, energy taxes, subsidies and a national cost of capital of 8% for China in order to generate a national cost curve. This approach shows the cost of the transition as businesses and investors would calculate it. Assessment of all additional costs related to complementary infrastructure, such as transmission lines, reserve power needs, energy storage or fuel stations, are excluded from this study. However, where relevant we discuss the implications of infrastructure needs on total system costs based on a review of comparable literature.

Throughout this study, renewable energy share is estimated related to TFEC[6]. Based on TFEC, the renewable energy share can be estimated for the total of all end-use sectors of China or for each of its end-use sectors (with and without the contribution of renewable electricity and district heat). The share of renewable power and district heat generation is also calculated. Further details of the REmap 2030 methodology can be found online in IRENA's REmap webpage at: [www.irena.org/remap](www.irena.org/remap).

This report also discusses the finance needs and avoided externalities related to renewable energy. Three financial indicators are developed, namely net incremental system costs, net incremental investment needs and subsidy needs. These indicators are briefly defined as:

1) Net incremental system costs: This is the sum of the differences between the total capital (in USD/year) and operating expenditures (in USD/year) of all energy technologies based on their deployment in REmap 2030 and the Reference Case in the period 2010-2030 for each year.
2) Net incremental investment needs: This is the difference between the annual investment needs of all REmap Options and the investment needs of the substituted conventional technologies which would otherwise be invested in. Investment needs for renewable energy capacity are estimated for each technology by multiplying its total deployment (in gigawatts, GW) to deliver the same energy service as conventional capacity and the investment costs (in USD per kilowatt, kW) for the period 2010-2030. This total is then annualized by dividing the number of years covered in the analysis (*i.e.*, 20 years between 2010 and 2030).
3) Subsidy needs: Total subsidy requirements for renewables are estimated as the difference in the delivered energy service costs for the REmap Option (in USD/GJ final energy) relative to its conventional counterpart multiplied by its deployment in a given year (in petajoules (PJ) per year).

In addition to the investment and subsidy needs, external effects related to greenhouse gas (GHG) emission reductions as well as improvements in outdoor and indoor air pollution from the decreased use of fossil fuels have been estimated. As a first step, GHG emissions from fossil fuel combustion are estimated for each sector and energy carrier. For this purpose, the energy content of each type of fossil fuel was multiplied by its

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[5] 1 Chinese Yuan Renminbi was equivalent to 6.8 US Dollars in 2010.

[6] Renewable energy share is estimated by dividing the total final renewable energy use by the TFEC. Total final renewable energy use includes: (i) total fuel use in end-use sectors to generate heat (process heat, space/water heating, cooking, etc.); (ii) motor fuels in the transport sector; and (iii) total power and district heat consumption generated from renewable sources.

default emission factors (based on lower heating values, LHV) as provided by the Intergovernmental Panel on Climate Change (Eggleston *et al.*, 2006). Emissions were estimated separately for the Reference Case and REmap 2030. The difference between the two estimates yields the total net GHG emission reduction from fossil fuel combustion due to increased renewable energy use. To evaluate the related external costs related to carbon emissions, a carbon price range of USD 20 to 80 per tonne of $CO_2$ is assumed (IPCC, 2007). This range was applied only to $CO_2$ emissions, but not other greenhouse gases. According to the IPCC (2007), the carbon price should reflect the social cost of mitigating one tonne of $CO_2$ equivalent GHG emissions.

The external costs related to human health are estimated in a separate step, which excludes any effect related to GHG emissions. Outdoor air pollution is evaluated from the following sources: 1) outdoor emission of sulphur dioxide ($SO_2$), mono-nitrogen oxides ($NO_x$) and particulate matter of less than 2.5 micrometres ($PM_{2.5}$) from fossil fuel-based power plant operation, and 2) outdoor emissions of $NO_x$, and $PM_{2.5}$ from road vehicles. To evaluate the external costs related to outdoor emission of $SO_2$, $NO_x$ and $PM_{2.5}$ from fossil power plant operation, the following parameters for respective pollutants were used: (a) emission factor (*i.e.*, tonne per kWh for 2010 and 2030 taken from the IIASA GAINS database ECRIPSE scenario (IIASA, 2014)), and (b) unit external costs (*i.e.*, Euro-per-tonne average for the European Union (EU), adapted for China from the EU CAFE project (AEA, 2005)). Values for the potential differences in external effects between the EU and China are accounted for based on the difference in gross domestic product (GDP).

An extended version of the methodology of the REmap analysis can be found online[7].

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[7] www.irena.org/remap

# 3 RECENT TRENDS FOR RENEWABLE ENERGY AND THE PRESENT ENERGY SITUATION

## Key points

- The renewable energy share in China's total final energy consumption stood at 13% in 2010, the base year of REmap 2030 analysis.
- Hydroelectric (hydro) accounted for 85% of total renewable power generation in China in 2013, a share that has fallen as other forms of power generation have been rolled out. Wind power is growing significantly and in 2013 China had 77 gigawatts-electric ($GW_e$) of installed wind capacity. As a result, wind now accounts for nearly a quarter of total renewable power generation in 2013 in China.
- Modern and traditional uses of biomass are estimated to account, together, for more than half of China's total renewable energy use today. However, there are large uncertainties around the actual consumption of traditional forms of biomass. Based on the review of existing literature and bottom-up analysis, this study adopted the mean value of the estimated range of 1 EJ-8 EJ, *i.e.* 4 EJ (136 Mtce).
- China has a long history of developing biogas for households that stretches back to the 1960s, with total investments reaching nearly USD 15 billion between 2003 and 2012. About 50 million households use a total of 16 billion cubic metres of biogas per year today.
- China has the largest solar thermal capacity in the world, accounting for two-thirds of the total global capacity of 270 gigawatts-thermal ($GW_{th}$) in 2012. All of this capacity is located in the building sector.
- There are important regional differences. Wind generation is concentrated in the northwest and northeast. Utility-scale solar photovoltaic (PV) generation is concentrated in the northern and western parts of China. Distributed solar PV is picking up, with a shift that started in 2013 and is expected to continue, mainly in eastern parts of China. Biomass, depending on the type of feedstock, agricultural residues and waste available, is concentrated in central and northern parts of the country and residual forested areas in various parts of China.

This section discusses the current energy situation of China at the level of sector and energy carriers. It also provides a brief overview of the latest renewable energy development and capacity additions.

## 3.1 Status of renewable energy development

### Power sector

By 2013, China exceeded the United States in terms of total electric power generation capacity. In 2013 alone, overall capacity grew by 8% on the previous year, to 1,234 gigawatt-electric ($GW_e$). China's power generation capacity is expected to more than double by 2030 or even before.

Renewable energy projects have taken an increasingly important share of this total. Figure 2 shows the increase in total renewable energy power plant capacities in China between 2005 and 2013. Total installed renewable capacity reached 380 $GW_e$ in 2013[8]. Installed capacity has more than tripled since 2005.

With an installed hydroelectricity generating capacity of 280 $GW_e$[9] at the end of 2013, China remains the world's leading investor in hydro (CNREC, 2014). As a result,

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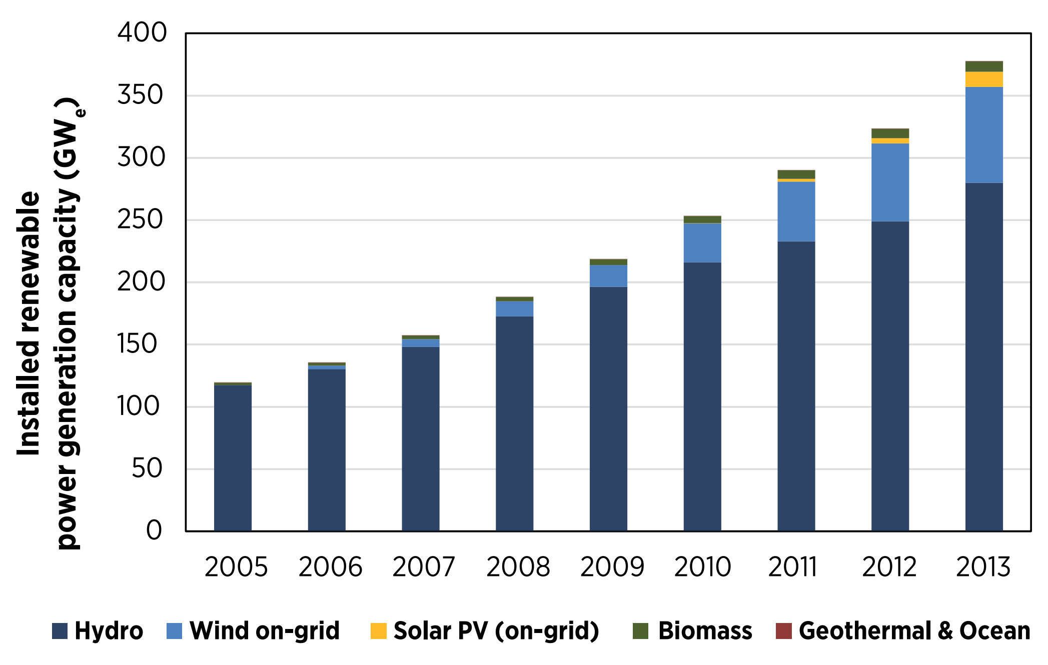
[8] Excluding 20 $GW_e$ pumped hydro.

[9] This includes more than 50,000 small-scale hydroelectricity facilities with a total installed capacity of around 67 gigawatts.

*Figure 2: Cumulative renewable power plant capacity in China*



*Source: IRENA analysis based on CNREC (2013a,b;2014)*

*Note: Excludes distributed solar PV capacity which reached 5 gigawatts in 2013 (CNREC, 2014).*

## *Since 2013, China has the largest total electric power production capacity worldwide which is expected to more than double by 2030*

hydro accounted for nearly three-quarters of the total installed renewable power generation capacity in China.

Ten provinces account for more than 70% of total power production from hydro (CNREC, 2013a). One third of all provinces and a quarter of the population relies on small hydroelectricity for power supply. China's capacity of small-scale hydro is also the world's largest. In 2012, China had 34.3 $GW_e$ of distributed energy capacity, of which small hydro accounted for 26.7 $GW_e$ (not all small hydro is considered distributed energy). Distributed energy is also viewed as a way to improve rural incomes and supply irrigation.

Most major Chinese hydroelectricity developers are state-owned enterprises: Sino Hydro Group has developed 65% of China's hydroelectricity projects. Private companies have thus far had difficulty entering this market. However, Hanergy, a private company focused on hydroelectricity, wind and solar development, is the builder of the Jin'anqiao, Mujing, Huangtian, Wulanghe and Kunlong hydroelectricity plants.

Installed capacity today accounts for only around 40% of its technical potential, well below the average across the developed countries. It was planned for hydro to reach 420 $GW_e$ by 2020, including 70 $GW_e$ of pump storage (WRI, 2014). Realizing this target would require the construction of more than 50 large-scale dams on the Jinsha, Yalong, Dadu, Lancang and Yarlung Tsangpo rivers.

Hydroelectricity is followed by wind. Wind power investments have accelerated in recent years, as shown in Figure 2. As of the end of 2013, total installed capacity had reached 91.4 $GW_e$; making China the world's leading user of wind energy (GWEC, 2014a). The gap between newly installed capacity and new additions to the grid has also narrowed in the past three years, with 77.1 $GW_e$ of the total installed capacity now connected to electricity distribution grids.

After the six-fold growth of total generation capacity between 2008 and 2013, wind power had become the third largest source of Chinese power production after thermal and hydro, albeit accounting for only 2.5% of the total. This suggests there is considerable room for the industry to grow. Between 2010 and 2012, newly added capacity averaged 15 $GW_e$ per year. The size of wind parks is also increasing. In 2012, average unit capacity had reached 1.4 megawatts-electric ($MW_e$), double the figure in 2005 (CNREC, 2013a).

As of 2013, the total number of wind turbine projects in the pipeline were equivalent to 60.2 $GW_e$ of additional capacity. If these can be completed and connected to the grid in the next 2-3 years, it is expected to nearly double China's total installed on-grid wind power generation capacity (CREIA, 2014a).

Private and foreign ownership in the sector remains limited, accounting for 5% and 1% of total wind capacity, respectively. About 80% of the total is state-owned, while 14% is accounted for by Sino-foreign joint ventures (CNREC, 2013a).

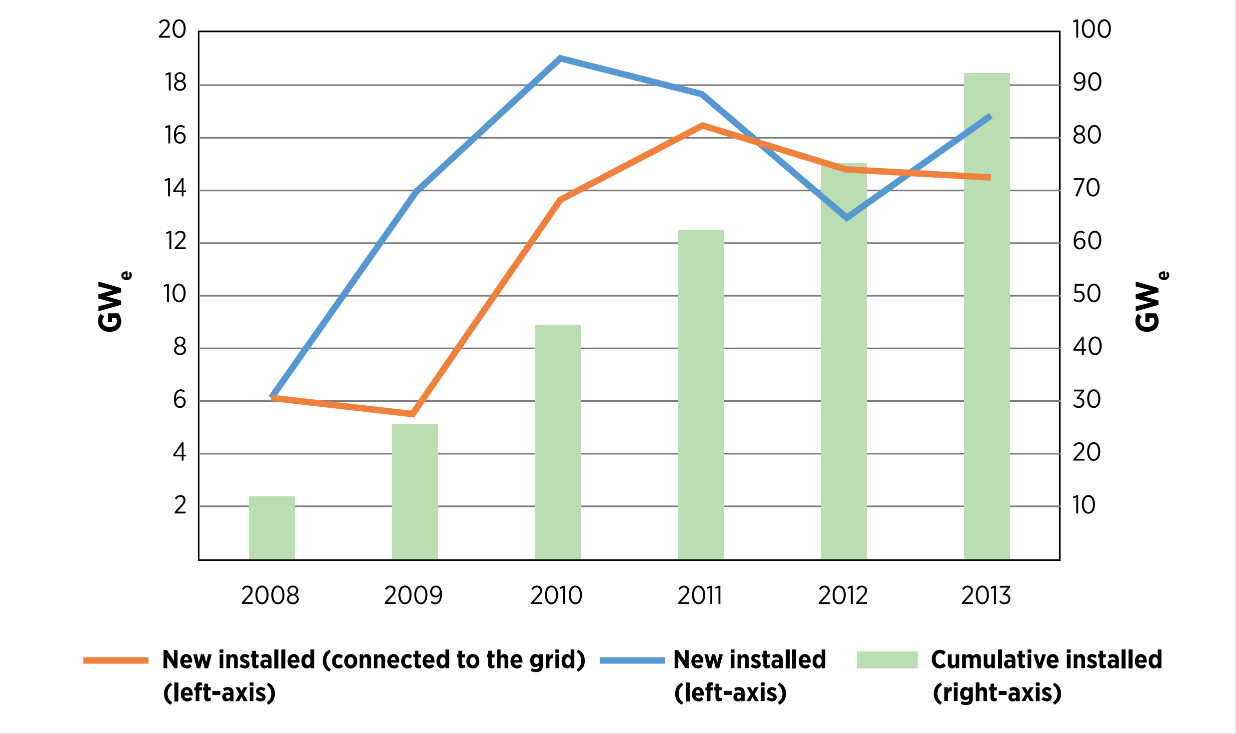
North China accounts for about 70% of the total installed wind capacity. Hebei and Gansu provinces also have high installed capacities: 7.1 $GW_e$ and 6.3 $GW_e$, respectively (CNREC, 2013a; Perera, 2014).

## *Wind power is the third largest source of electricity in China, although it still only accounts for 2.5% of the total*

China had installed 390 $MW_e$ of offshore wind power by the end of 2012, with the majority in Jiangsu Province and Shanghai City, where all facilities have been connected to the grid. Two-thirds of the total capacity was located in intertidal zones where Donghai Bridge (close to Shanghai) is the largest single location with the largest capacity (102 $MW_e$). The remaining projects mostly consist of small prototypes for demonstration and testing purposes (Carbontrust, 2014). The biggest offshore demonstration project in China had a total capacity of 150 $MW_e$ in Jiangsu Rudong. Other installations are the second phase of the 65.6 $MW_e$ Donghai Bridge project, with 8.6 $MW_e$ installed in 2011 (GWEC, 2014b; WP, 2013).

There are also an increasing number of solar PV projects in China. Installed generation capacity based on solar PV has increased considerably in recent years. The period from 2010 to 2012 saw a nearly tenfold increase, from 0.8 $GW_e$ to 7 $GW_e$. In 2012 alone, about 4 $GW_e$ – more than the total installed over the previous five years – was added.

*Figure 3: China wind power capacity growth, 2008-2013*



*Source: CWEA (2014); CHPDI (2014)*

Driven by a new target of 35 $GW_e$ by 2015 – an increase of 40% from its previous target of 21 $GW_e$ – announced at the very beginning of 2013, and partly by the ending of a 16 US cents per kWh feed-in tariff (FiT) for large grid-connected PV projects, the record of the annual new addition of installed capacity was reset at nearly 13 $GW_e$ by 2013. This makes the total installed capacity 19.6 $GW_e$ including 16.3 $GW_e$ of ground-mounted solar PV systems and 3.1 $GW_e$ of distributed solar.

Following the strong momentum seen in 2013, a new target was set in May 2014 of 70 $GW_e$ by 2017 in the context of the Action Plan on Prevention and Control of Air Pollution. This target indicates that the record growth of 13 $GW_e$ a year would have to be sustained for the next four years (SolarServer, 2014). Although the addition of distributed solar PV generation capacity in 2013 was about 800 $MW_e$, the new goal set for 2014 is to install 8 $GW_e$ of distributed solar PV as opposed to 6 $GW_e$ ground-mounted utility-scale solar PV farms (CREIA, 2014b). It highlights the importance of distributed solar PV as well as the development of utility-scale solar PV in western China (Haugwitz, 2014), in the context that distributed solar PV accounts for about 38% of the total installed. However, in the first half of 2014 only 2.3 $GW_e$ of ground-mounted utility scale capacity was installed while about 1 $GW_e$ of distributed generation solar PV was installed, but with another 3 $GW_e$ at least commissioned in the same time period. If the targets set for 2014 are to be achieved, considerable efforts need to be made in the near future.

Qinghai, Xinjiang, Tibet, Inner Mongolia, Sichuan and Gansu Provinces account for the largest share of installed solar PV capacities, given they represent more than two thirds of the national solar energy resource potential (CNREC, 2013a).

Concentrated solar power (CSP) has only recently been introduced in China. In 2011, there were five approved projects under construction. Their total capacity is 342.5 $MW_e$ and all of them use parabolic trough technology. Plants are located across Gansu, Inner Mongolia, Ningxia and Qinghai (Eurobserv'er, 2014; ESTELA, 2012). Expected installed capacity growth to 2018 is 1.4 $GW_e$, mainly driven by the 12th five-year plan (FYP) (2011-2015) (for which the target is 1 $GW_e$), the ample availability of low-cost financing and flexibility from hybridisation with coal or storage (IEA, 2013c). By 2020, China aims to have 3 $GW_e$ of installed CSP capacity.

Two CSP projects, each with a capacity of 50 $MW_e$, received total lending of USD 250 million (RMB 1.7 billion) from the Asia Development Bank. One of them was in Qinghai, which received USD 150 million (estimated to produce 197 GWh annually); the other was in Gansu, which received USD 100 million (parabolic). The loans were made in 2013 and 2014, respectively (Lee, 2014).

In August 2014, NDRC set a tariff of USD 19.2 cents per kWh for the first CSP project, the Delingha installation operated by SUPCON Group, which has a designed capacity of 50 $MW_e$. Phase I, worth 10 $MW_e$, has been in commercial operation since early 2013. The nearly two-year-long operation has provided data for policy makers to set future tariffs. The current tariff is not as high as the CSP industry had expected, suggesting that future FiTs for CSP will be differentiated from those for PV projects. This would be of great significance for the CSP industry as the previous prevailing wisdom was that the same level of tariffs would be applied to both forms of solar power plant. It is estimated that a universal tariff structure for CSP will not likely be issued until a few projects are up and running and generating sufficient amounts of operational data on which to base a judgement.

The relatively low tariffs for the pilot CSP projects might also reflect an attempt to encourage the use of local components. Currently, the two biggest challenges facing the Chinese CSP industry include resource assessment and system optimisation. It has been widely acknowledged that the levelised cost of energy (LCOE) would be decreased dramatically if and when Chinese manufacturing capacities in CSP increase. This might bring the technology back to the table.

***The first CSP pilot project was subject to a comparatively low feed-in tariff, indicating that policy makers are keen to encourage investment in the sector***

Installed biomass power generation capacity increased from 1.4 $GW_e$ in 2006 to 8.5 $GW_e$ in 2013. After hydro it was the second largest form of renewable capacity installed until 2007, before wind caught up. The majority of biomass capacity is in eastern China, with Shandong alone accounting for 14% of the total. Henan, Jiangsu, Heilongjiang and Hubei each have around 500 $MW_e$ capacity installed as well (CNREC, 2013a).

Biomass installed capacity numbers vary by source. Half of the total installed capacity (4.1 $GW_e$) today is accounted for by agriculture and forestry biomass direct combustion power generation plants. At the end of 2012 there were 100 such steam cycle plants in operation, most with a unit capacity of 12 $MW_e$ but some with up to 50 $MW_e$. A quarter (2.3 $GW_e$) of this capacity comes from waste incineration, around 0.3 $GW_e$ is from biogas. 1.2 $GW_e$ from sludge and biomass gasification power generation, and 1.7 $GW_e$ from bagasse power plants[10] (CNREC, 2014). Biomass co-firing is limited. Government has set a target of 30 $GW_e$ for biomass-based power by 2020.

Power generation from modern biomass was about 34 TWh in 2012 (using around 0.5 EJ biomass). Solid biomass use for power generation is projected to increase to 0.7 EJ in 2015, while biogas will grow to 0.5 EJ, solid biomass for heating to 0.18 EJ and biofuels to 0.18 EJ (total 1.6 EJ).

The target for biomass power generation is 13 $GW_e$ by 2015. This includes 8 $GW_e$ agricultural/forestry residues, 3 $GW_e$ municipal solid waste and 2 $GW_e$ biogas. This could double power generation from 2012 levels of 34 TWh/year.

European high-pressure, high-temperature technology has been adapted to the Chinese market. Such boilers can achieve efficiencies of up to 32%. China has mature combustion technologies. There are plants with up to 50 $MW_e$ capacity in operation. Three high temperature and ultra-high pressure circulating fluid bed boilers have been in operation since 2012 (Van Sambeek *et al.*, 2013). Manufacturing in China has reduced engineering, procurement and construction (EPC) costs from USD 2,500 per kW in Europe to USD 1,000 to 1,200 per kW for the same base technology. Special attention is needed for fuel handling and fuel feeding, combustion, boiler and flue gas cleaning (Brendstrup, 2012).

### *Investments in biomass have increased steadily, aided by European technology and reduced engineering, procurement and construction costs*

With extensive but low-temperature geothermal resources (30-90° C in most locations), China has since 1999 been the world's largest user of geothermal energy for non-electric applications such as space heating and recreation. A few locations have the potential for high-temperature geothermal use, notably in southern Tibet, western Yunnan and western Sichuan, located on the Himalayan Geothermal Belt. However, it remains uncertain whether these resources could be exploited in an economically viable and environmentally benign manner. As a result, China's geothermal power generation capacity has hovered around 27 $MW_e$ for many years (CNREC, 2014). The largest project, Yangbajing Geothermal Power Plant, is located in Tibet with a total capacity of 25.2 $MW_e$ and has been in operation since 1977 (built between 1977 and 1991, starting with a 1 $MW_e$ capacity). Many other plants with much smaller capacities existed in Tibet, Guangdon and Hunan but have since ceased operation.

No major developments in the sector have taken place in China since 1992 (Worldview, 2012). However, geothermal potential for power generation is estimated at between 50 $MW_e$ and 90 $MW_e$ in Yangbajain (Bertani, 2010) and China aims to arrive at a total installed capacity of 60 $MW_e$ by 2015 (GEA, 2012).

## Transport sector

In the transport sector, two main technology options are liquid biofuels and electric mobility. Fuel ethanol production in China doubled between 2005 and 2012, reaching a total of 2.5 billion litres (CNREC, 2013a). Biodiesel production in China is rather limited, with about 0.5 million tonnes from a total production capacity of 3 million tonnes in 2009, and production levels remaining stagnant today (Qiu *et al.*, 2012; USDA, 2012; CNREC, 2013a).

Cane, sweet sorghum and cassava can be used for ethanol production. However, the government is concerned about food versus fuel competition. For this reason, ambitious plans for transportation biofuel production based on food crops have been abandoned; instead at-

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[10] Bagasse is a by-product of the sugar cane industry. Sugar cane production of China amounted to about 110 Mt/year in 2010. This yields approximately 36 Mt/year bagasse (with 40-50% moisture content). This is equivalent to 300 PJ per year bagasse generation. This is used for on-site power generation in a total installed capacity of 800-1,700 $MW_e$ today; that is equivalent to about 50-100 PJ/year bagasse demand which means only 15-35% of the actual amount generated was utilised.

tention has focused on advanced biofuels. Of 100 such projects worldwide, 18 of are located in China, which accounts for 40% of the potential capacity (an annual production capacity of 2.5 billion litres per year) (IFPEN, 2013).

The first cassava ethanol plant in the world was built in Guangxi in 2007. The plant has an annual production capacity of 250 million litres per year. Another ethanol plant using sweet sorghum as feedstock was completed in 2012 in Inner Mongolia with a total capacity of 64 million litres per year (USDA, 2013). COFCO/Sinopec with Novozymes as partner is investing in Zhaodong to produce ethanol from agricultural residues with a total capacity of 64 million litres per year. There are also two other projects, one in Shanghai and another in Caofeidian, each with an annual capacity of 0.4 million litres, which aim to produce ethanol from waste carbon monoxide from steel mills. The plant in Shanghai is expected to expand its production to 120 million litres per year (AEC, 2013; E2, 2013). There is a plant in Shengguan based on corn cob residues available onsite (originally a corn to furfural company) with 22 million litres per year capacity. Another plant with 56 million litre capacity in Longlif (originally a conventional biofuel company) also uses corn cobs as feedstock. A smaller plant with 11 million litre-per-year capacity runs in Hennan Shengguan. Finally, another plan in the Anhui province is to invest in a biorefinery for the production of ethanol, bioglycols and power from a mix of wheat straw, corn storver and lignin co-products (Biomass Magazine, 2013).

In addition, a shift in transport modes, such as the use of high-speed trains with renewable power instead of diesel-based trucks or city trams for passenger cars, are other options for the transport sector.

### Other end-use sectors

In buildings and the manufacturing industry, conventional fuels used to generate space and water heating, cooking and process heating can be substituted with a range of technologies. These include solar thermal, geothermal heat, heat pumps and biomass-based heat. All of these technologies are already deployed in China and have significant further potential. The main challenge is the substitution of traditional uses of biomass in China with modern forms of bioenergy and other renewables.

## 3.2 Base year renewable energy situation

### Sector-level breakdown

In 2010, China consumed 100 EJ of total primary energy (3,410 Mtce) (excluding non-energy use of around 5 EJ) (IEA, 2013a)[11, 12]. In final energy terms, China's total energy demand in 2010 was 57 EJ (1,950 Mtce) of which 59% was consumed by industry, 21% by the building sector and 13% by the transport sector (Figure 4). Electricity accounted for 20% of the TFEC of which 75% was consumed in the industrial sector, with the remainder used mainly in buildings. District heat is also important for China. Its production had increased to 3 EJ in 2010. It provides about 4% of the TFEC in each of the industry and building sectors. About 70% of the total district heat demand was consumed in the industrial sector.

The breakdown of TFEC at a sector level has changed in the past three decades (IEA, 2013a). In the 1980s building energy demand accounted for more than half of TFEC and the transport sector had a share of around only 5-6%. The industry sector's share was about 40%. In comparison, today industrial energy use accounts for more than half of China's total energy demand, while the share of the transport sector has tripled to 15% at the expense of the building sector, which now only accounts for 30%.

Modern and traditional forms of renewable energy accounted for 13% of the TFEC in 2010. It is not easy to make a distinction between the amount of biomass used in its traditional and modern forms – depending on the sources used, the traditional use of biomass in China ranges anywhere from 1 EJ to 8 EJ (see Annex I for further details). When this amount is excluded from the mix, modern renewables account for 7% of TFEC (IEA, 2013a)

Renewable energy use is concentrated in the end-use sectors. When excluding electricity and district heat

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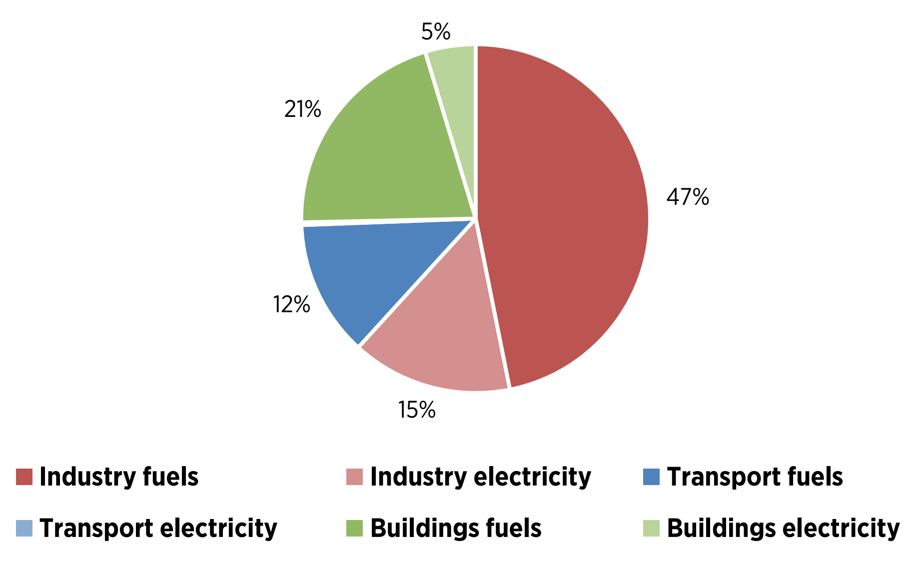
[11] According to CNREC (2013a), the total primary energy consumption of China in 2012 was 3,620 Mtce, which is approximately 106 EJ.

[12] Primary energy consumption refers to the direct use or supply of all energy carriers (*e.g.,* crude oil) without being converted or transformed to another form of energy (*e.g.,* heat). It is therefore higher than TFEC, which only looks at the consumption of energy carriers such as fuels for the transport sector or electricity for appliances (see footnote 1).

*Figure 4: China TFEC breakdown, 2010*



*Source: IRENA estimates based on IEA (2013a)*

consumption, this amounted to 16% in the building sector. By comparison, renewable energy use is negligible in the industry and transport sectors[13]. When it comes to power generation, 19% of electricity sources were renewable, while in the district heat sector the share of renewable energy was only 1% in 2010.

### *Industry accounts for 62% of China's total final energy consumption, the highest share amongst large economies, but industry sector has the least share of renewables in its fuel mix*

The industrial sector is by far the largest energy user in China, accounting for 62% of its TFEC. It is projected that its share will fall slightly below current levels to between 50% and 55% by 2030.

Today, for nearly all bulk materials, such as cement, steel and textile fibres, China accounts for the largest share of production worldwide. The high importance of industry compared with other sectors is a specific feature of the Chinese energy system. The iron and steel sector was the largest industrial energy user, accounting for 40% of China's TFEC. Other large industrial energy uses include non-metallic minerals (18%), chemicals and petrochemicals (12%) and machinery (6%) (IEA, 2013a).

Industry has a high demand for steam for different processes. However, the share of industrial combined heat and power (CHP) is rather low, with much of the process heat production coming from boilers (IEA, 2009).

In China most existing CHP production is based on coal. It is often integrated with municipal or industrial district heating systems or tied to power plants selling steam to nearby industrial sites or district heating loops. With investments in new capacity the overall efficiency of these systems are improving, but there are many industrial systems that are based on old, inefficient coal boilers and heating loops (average district heating boiler efficiency in China is 60 to 65%, while the heat loss from district heating pipelines is estimated to be between 20% and as much as 50%) (IEA, 2009).

Besides their comparative lack of energy efficiency, these older forms of CHP also make the reduction

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[13] Providing the renewable energy share excluding power and district heat demand provides the contribution of renewable technologies in the sector's total fuel use only. This is important to know to exclude the effect of renewable power and district heating which are often outside the boundaries of end-use sectors.

of pollution and GHG emissions a challenge. However, there is an opportunity for major GHG reductions through the use of localised, customer-based CHP at individual industrial facilities and in new commercial and residential developments – utilising more efficient and clean systems based on natural gas and renewable and waste fuels.

## *The application of cleaner forms of CHP at the local level could increase energy efficiency and help reduce air pollution*

More than three quarters of the transport sector's energy use is related to road transport. Domestic navigation accounts for another 8%. Rail transport, pipeline transport and domestic aviation together account for 13% of the transport sector's TFEC (IEA, 2013a). More than half of the traffic is on highways (1,676 billion passenger-kilometres out of the total of 3,098 in 2011). Aviation accounts for about 15% of the total passenger transport. Railways are increasingly gaining importance, with their share of total passenger transport reaching 30% in 2011. Nearly half of total freight movements were via navigation in 2011, with road transport accounting for a third and railways about 20% of the total (LBNL, 2013).

In 2011, the number of vehicles (excluding motorcycles and tractors) on the road has reached 93.6 million, of which 74.8 million are categorised as passenger vehicles. Trucks represented 17.9 million of the total civilian motor vehicle stock (LBNL, 2013). The demand for transportation is growing rapidly. In 2011, 18.5 million vehicles were sold. Further growth is expected but projections are uncertain, amounting to anywhere between 25 million and 75 million cars in the long term (Economist, 2012). By 2030, the vehicle stock will have reached 500-600 million vehicles, according to some estimates (Wang *et al.*, 2013). Ma *et al.* (2012) project that the vehicle population in China will increase to 294 million in 2030, with an average annual growth rate of 11%.

For intercity passenger transportation, the total traffic volume in 2030 will be around 7.6 trillion passenger-km, nearly three times the volume in 2010. The share of aviation in total passenger transportation is expected to double. In 2030, freight traffic volume could double compared to 2010. The share of railways could decrease from 30% to 19% the share of water transport could increase from 23% to 33%, and highways share to 48% (Ma *et al.*, 2012).

After industry and transport, the building sector is the third largest user of energy. Residential energy use accounts for 86% of the total with the remainder accounted for by the commercial sector. Building energy consumption can be distinguished between urban residential, rural residential and the commercial sector.

Based on literature review, space heating accounts for about 30% of the total residential energy demand (including electricity use), with that share rising to at least 50% for commercial buildings. More than half of the total energy demand is for cooking in rural areas (Zhou *et al.*, 2007; PNNL, 2012; Xia, 2013; CPI, 2013). However, the breakdown of the data is largely dependent on how biomass is accounted for.

China has more than 20 billion square metres ($m^2$) of rural residential building area. The urban residential building area is about 15 billion $m^2$, while the total area for commercial buildings is about 8 billion $m^2$ (CPI, 2013). Besides these total figures, attention should also be paid to China's changing demographics and building use. On the one hand, the household size in China is decreasing: in 1980 the average size of a household was five people; in 2004, the figure was fewer than four. On the other hand, the dwelling area is increasing. For example, the period between 1980 and 2004 experienced a more than tripling of the area of the average household, from 35 $m^2$ to 100 $m^2$ (Zhou *et al.*, 2007).

## *More than half of the energy use in buildings in rural areas is for cooking, while nearly half of the total energy use in commercial buildings is for space heating*

China has varying climate zones. The heating period in cold areas such as the northeast and west of the country can last for as long as 200 days. In other areas, it might be as few as 90 days (IEA, 2009). Total energy consumption for heating accounts for nearly a quarter of the total building sector energy demand. The total building heating area in China was about 8.8 billion $m^2$ in 2008. About 38% of this is met by CHP central heating (3.3 billion $m^2$), and another 36% by gas/coal boiler-based central heating (3.2 billion $m^2$). The remaining

26% is provided by distributed systems which also include heat pumps and electric heating (2.3 billion $m^2$) (Xia, 2013).

District heating for hot water is an important technology in China. Half of all major cities in China are connected to district heating systems. According to DEA (n.d.), district heating floor space has reached nearly 4.8 billion $m^2$. This is more than triple the total area in 2001. This increase was a result of national policies and regulations as well as the use of surplus heat from the industrial sector. CHP is gaining a market share in district heat systems and today it accounts for more than half of the total district heating (DEA, n.d.; Euroheat & Power, 2013).

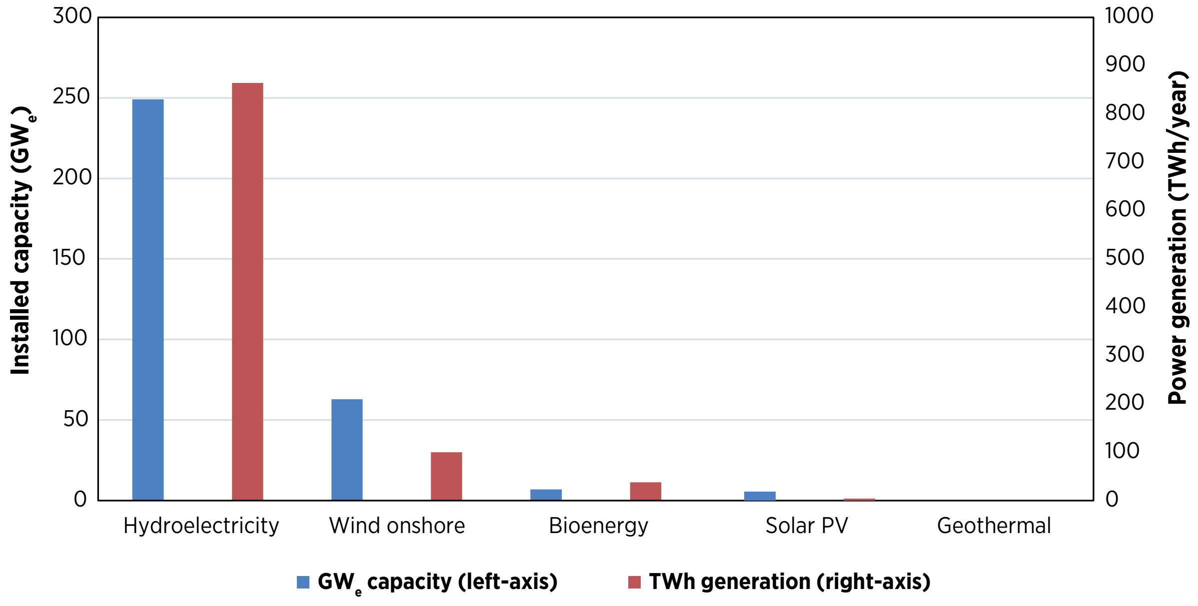
District heating capacity has increased by about a half in recent years, from 224 $GW_{th}$ in 2007 to 339 $GW_{th}$ in 2011. The increase in the length of heating pipelines grew by about the same percentage in the same period, from 102,000 kms to 147,400 kms. The vast majority of all pipelines are used for hot water. The total heat supplied reached about 2.8 EJ in 2011, and can be split into 2.3 EJ hot water and 0.5 EJ steam. Hot water demand is increasing whereas the use of steam is slowly decreasing (Euroheat & Power, 2013).

By the end of 2010, China had some 38.5 million household-scale digesters, and around 27,500 large- and medium-scaled biogas plants for agricultural waste (Chen *et al.*, 2012). Installations continue to grow apace. As of the end of 2012, China had nearly 50 million biogas cooking systems in place in rural areas.

***Half of all major cities in China are connected to district heating systems, many of which are designed to use surplus heat from industry***

Coal still plays a leading role in the energy industry of China. Around half of all coal is used for power generation, accounting for nearly 80% of the total of 4,980 TWh/year generated in 2012. Total generation from natural gas and oil products was less than 2%, while nuclear accounted for 1.2%. Overall, installed fossil fuel and nuclear generation capacities in 2012 were equivalent to 840 $GW_e$, which is 71% of the total generation capacity of 1,144 $GW_e$ (CNREC, 2013a). As discussed earlier, renewable energy sources account for about 20% of power production, with hydro by far the biggest form of renewable, followed by wind and biomass.

*Figure 5: Renewable power capacity and generation, 2012*



*Source: IRENA analysis based on CNREC (2013a)*

### *Hydroelectricity accounts for 85% of the total renewable electricity generation today*

In the residential sector, traditional and modern uses of biomass as a source of heating and cooking made up nearly all renewable energy used in 2010. Next to biomass, total installed solar thermal capacity for heating in the building sector in 2010 was 130 $GW_{th}$ (CNREC, 2013a). Excluding traditional uses of biomass, the modern share of renewables was 16% of the sector's total energy demand. In terms of fossil fuel products, 32% of the sector's total energy demand was provided by similar amounts of coal and oil products. Natural gas accounted for 7% of demand (IEA, 2013b).

Oil products are the main sources of energy in the transport sector, accounting for more than 90% of the total demand, with smaller amounts of natural gas and coal providing the remainder. Around 2 billion litres of biofuels were consumed, which is less than 1% of the sector's total energy demand.

Total biomass use in the industrial sector was limited to black liquor combustion of around 100 PJ per year. This quantity, which was excluded from the IEA energy statistics, is estimated based on total chemical pulp production of around 5 Mt per year. The sector relies heavily on coal to meet demand from energy-intensive industries such as steel and cement production.

## Traditional uses of biomass

The traditional use of biomass in China deserves special attention because of its size as well as the difficulty in establishing reliable data due to the wide range of sources and variety of estimates. Worldwide, the number of people using solid fuels for cooking and heating has increased over the last decade to 3.2 billion, with about 2.4 billion using traditional biomass. Roughly 800 million today use improved cooking stoves, partly due to efforts in the last two decades in China (Pachauri *et al.*, 2012).

Biomass is the main source of energy in most provinces of rural China for space heating, cooking and water heating (An *et al.*, 2014). In comparison, a negligible amount of biomass is used by the urban population in China. According to the IEA (based on World Health Organisation estimates), about 445 million people in China, who represent three-quarters of the total rural population, still rely on traditional uses of biomass (IEA, 2013a). According to other sources (*e.g.*, Zhang, Watanabe and Lin, 2010), the share of the total rural population relying on traditional uses of biomass in 2008-2009 was 50-60%.

In China, between 1983 and 1996, improved cooking stoves were distributed to 177 million households. The energy efficiency of improved fuel wood stoves is between 20% and 30%. Although some studies suggest that these stoves are still mostly in use, it is unclear what their status and acceptability is (Pachauri *et al.*, 2012).

Comparison of the literature shows that there is an important issue regarding the actual value of solid biomass used in China in traditional forms for cooking and heating in households. While there is no lack of information, the data vary widely from about 2 EJ to 8 EJ (see Table 1 and Annex I).

### *While traditional uses of biomass are key in China's energy mix, consistent and reliable data for the sector are still lacking*

In addition to the statistical data, there is also literature which provides estimates for per capita consumption of energy in China. Based on the literature, and the share of the rural population relying on traditional use of biomass, total demand could range from between 0.8 EJ and 4.2 EJ (see Annex I).

Based on the comparison of various sources above, we assume that in the rural residential sector, 1.9 EJ (65 Mtce) of fuel wood and about 2 EJ (68 Mtce) of straw[14] are used for cooking and heating today. Of this total amount of around 4 EJ (135 Mtce), we assumed that about 0.5 EJ (17 Mtce) is modern biomass used in efficient cookstoves[15]. However, this is certainly an area which requires further research and data collection.

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[14] According to Xiajiao (2012), 18% of the 700 Mt of total straw generated is used for energy purposes (1.6 EJ). According to Yishui and Liying (2011), 215 Mt is used for energy generation (2.7 EJ). According to Zhang (2014), 40% of a total of 350 Mt straw available for energy is already used (1.8 EJ).

[15] The status of the 180 million modern cookstoves is unknown. Assuming that about 25-75 million are still in use with an average capacity of 1-3 $kW_{th}$, total demand for modern biomass would be about 500 PJ/year on average in 2010.

*Table 1: Summary of biomass use in China based on different sources*

| | **IEA (2013b)** | **FAOSTAT (2014)[1]** | **LBNL (2013)** | **Xia (2013)** | **CNREC** | **Chen, Yao and Li (2010)** |
|---|---|---|---|---|---|---|
| **Year data refers to** | **2011 (EJ/year)** | **2011 (EJ/year)** | **2007 (EJ/year)** | **2011 (EJ/year)** | **2012 (EJ/year)** | **2008 (EJ/year)** |
| **Solid biomass** | **8.5** | **1.9** | **7.4** | **3.7** | **0.6** | **5.1** |
| *Residential* | 8.0 | | 7,4 | 3.7 | | 5.1 |
| Fuel wood | | | 2.7 | | | |
| Crop stalk | | | 4.7 | | | |
| Briquette | | | | | 0.1 | |
| *Power & DH generation* | 0.5 | | | | 0.5 | |
| **Liquid biofuels** | **0.05** | | | | **0.1** | |
| **Biogas** | **0.3** | | **0.2** | | **0.3** | |
| **Total** | **8.9** | **1.9** | **7.6** | **3.7** | **1.0** | **5.1** |

*[1] Data converted from $m^3$ to EJ assuming a density of 450 kg/$m^3$ for coniferous and 700 kg/$m^3$ for non-coniferous wood, and a LHV of 17.5 GJ/t.*

## Conventional fuel markets

China's economy is growing rapidly; its urbanisation rates have increased substantially in recent years and are expected to increase even further. Fossil fuels, and in particular coal, play an important role in meeting this energy demand.

In 2012, total coal production reached 3.5 billion tonnes (nearly 80 EJ), which was sufficient to meet domestic demand (CNREC, 2013a). China also produces oil and natural gas. In 2010, its crude oil production exceeded 4 million barrels per day (mb/d), which is around 8 EJ. Natural gas production reached 96.8 billion cubic metres in 2010 (4.2 EJ) (see Figure 6).

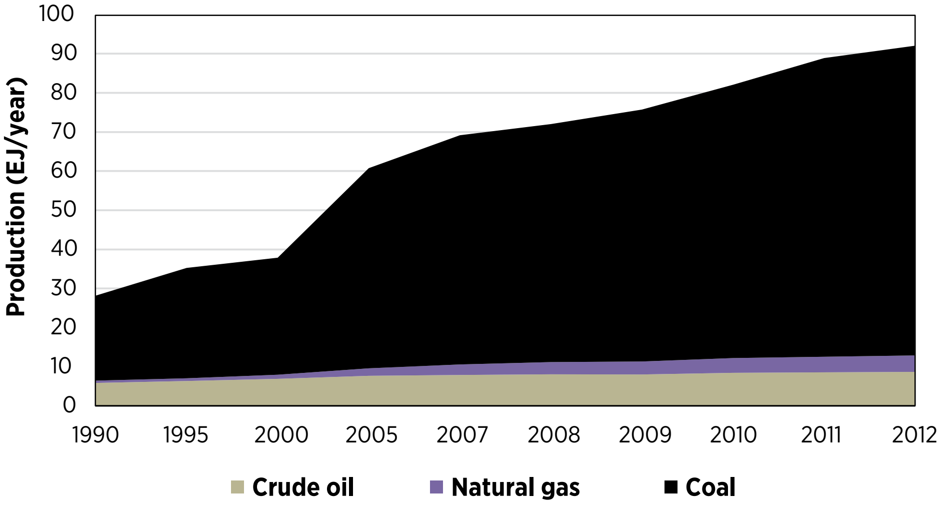
Crude oil production has shown a steady increase between 1990 and 2012, growing at about 1.8% per year. Northern and western parts of China account for the majority of the output. Heilongjiang, Tianji and Shaanxi provinces contribute a half of the country's total production (LBNL, 2012). The oil market is dominated by four national companies, namely China National Petroleum Corporation (CNPC), Sinopec, China National Off shore Oil Corporation (CNOOC) and Sinochem. In an attempt to meet the surging demand for oil products, China has also invested in refining capacity, pipelines and also port infrastructure. Total oil storage capacity reached 103 million barrels (under the first phase of the Strategic Petroleum Reserve, or SPR). As new phases of the SPR are completed by 2020, combined storage capacity will further increase by a factor of 8 (IEA, 2012b).

In the same period, natural gas production has increased by 9.3% per year on average. Compared with two decades ago, when production was mainly used for meeting the demand from industry and the construction sector, today demand from the residential, commercial and transport sectors is also high (IEA, 2012b). China aims to increase its production from conventional and unconventional resources even further to improve gas security. The majority of production originates from western provinces including Xinjiang and Sichuan (LBNL, 2012). The same national companies which control the oil industry also dominate upstream natural gas production in China.

China's coal production increased by an average of about 6% per year between 1990 and 2012. In the period between 2000 and 2006 in particular, production accelerated, reaching 10% per year growth. Inner Mongolia, Shanxi and Shaanxi provinces account for more than half of the total production (LBNL, 2012).

In addition to fossil fuel production trends, the increase in demand for oil products, natural gas and electricity over the past two decades is striking. Coal use has been increasing steadily since the late 1990s, averaging more than 6% annual growth, mainly as a result of the growing demand in the power generation and manufacturing industry sectors. While coal still predominates, oil and gas demand has been growing rapidly. Though much smaller in volume, the growth in oil products of 7-8% a year outpaced coal growth as a result of the grow-

*Figure 6: China coal, crude oil and natural gas production, 1990-2012*



*Source: IRENA analysis based on IEA (2012a;2013a); CNREC (2013a)*

ing demand in the transport sector. Finally, demand for natural gas, particularly over the past decade, has reached more than 20% annual growth. The State Council of China has approved a coal consumption target to keep it below 4 billion tonnes of coal equivalent by 2015.

Growth from China is accounting for an increasing share of the global demand for oil products and will continue to account for an even larger proportion in the short term due to higher car ownership. The IEA projects overall growth of nearly 70% between 2010 and 2030, which is somewhat lower than the current trends but still significant (IEA, 2012a). Demand for coal is expected to increase by 25% in the same period. Natural gas supply in comparison is projected to increase by at least a factor of four, higher than the growth of both oil and coal, though still accounting for a relatively small proportion of the total.

### *Demand for oil products has grown rapidly in the past decade, driven by a marked increase in car ownership*

Demand for natural gas will be met partly by shale gas production, partly by imports by pipeline and in the form of liquefied natural gas (LNG), as well as from domestic sources including tight gas, coal-bed methane and others. China has the largest technically recoverable shale gas resources in the world, amounting to some 25.1 trillion cubic metres (IEA, 2012b). The country has specific shale gas production targets to 2015 of 6.5 billion cubic metres per year with 990 horizontal wells drilled. By 2020, China aims to produce some 80 billion cubic metres annually, however, this target has been recently halved due to technical challenges (Reuters, 2014a). Water scarcity is the main obstacle to meeting these targets. Although the 13.8 million cubic metres a year of water which would be required by the industry in 2014 is less than 1% of total industrial water demand, it may be a challenge to supply this for hydraulic fracturing, or fracking, in some provinces where a substantial share of the water is not recoverable (Forbes, 2013).

Trade is an important component of China's conventional energy market. China is a net importer of crude oil and in 2010 crude oil imports reached more than 10 EJ. 55% of the oil consumed is imported, a share which will continue to rise in the future. Half of this total originated from Saudi Arabia (19%), Angola (17%), Iran (9%) and Oman (7%) (LBNL, 2012).

With increasing demand for natural gas, China also started importing LNG in 2006. By 2010, total imports had reached 9.3 billion cubic metres (equivalent to

355 PJ). Australia (48%) and Indonesia (18%) account for the majority of LNG supply. Pipelines also play an important role for the natural gas trade of China. Turkmenistan is the largest supplier of natural gas, accounting for more than half of total imports. The most recent development is the new agreement China signed with Russia in May 2014, to import natural gas worth USD 400 billion over a period of 30 years (to deliver about 40 billion cubic metres of gas per year from 2018). A memorandum of understanding was signed on 9 November 2014 to develop a second route between Russia and China for natural gas supply (Al-Jazeerah, 2014). China also continues to invest in gas storage facilities, interregional gas pipelines and LNG terminals as part of its strategy to ensure security of gas supply (IEA, 2012b).

Although China is a major producer of coal, it exports negligible amounts. On the other hand, its imports have grown rapidly, reaching 165 Mt in 2010. One third of this total originated from Indonesia and nearly a quarter from Australia (LBNL, 2012). Since 2011, China has been the largest importer of coal worldwide, with Japan being the second. Despite the huge scale of domestic coal production, there could be various reasons for the rapid increase in imports such as transportation bottlenecks, environmental and safety considerations (related to mining), economic factors or depleting coking coal reserves (Tu and Johnson-Reiser, 2012).

## Renewable energy markets in heating and transport applications

Heating/cooling and motor fuels are the two thermal markets where renewables play a role today. A wood pellet market is emerging in China. Production has reached 0.8 Mt per year. There are about 260 manufacturers in China producing straw pellets (Xiajiao, 2012). Some of the largest pellet mills worldwide are located in China with capacities ranging between 100 and 200 kilotonnes (kt) per year (see Table 2). Production is dispersed across the country with plants of small size ranging from 10 to 50 kt/year. Production is projected to grow (Vakkilainen, Kuparinen and Heinimoe, 2013; Goh *et al.*, 2013). The target is to grow pellet manufacturing to 50 Mt per year by 2020.

China is also a large producer of charcoal. It ranks sixth in the world following Brazil, several African countries and India, with a total production of 1.7 Mt/year (Vakkilainen, Kuparinen and Heinimoe, 2013).

*Table 2: Largest pellet mills in China*

| Location | Production capacity (kt/year) |
|---|---|
| Linyi, Shandong | 200 |
| Guangzhou, Guangdong | 150 |
| Yangzhong, Jiangsu | 120 |
| Taicang, Jiangsu | 120 |
| Shenyang, Liaoning | 100 |
| Feicheng, Shandong | 100 |
| Nanyang, Henan | 100 |
| Xuzhou, Jiangsu | 100 |
| Foshan, Guangdong | 100 |

*Source: Vakkilainen, Kuparinen and Heinimoe (2013)*

In 2010, pulp production in China was 20 Mt/year which is equivalent to 10% of total global production (including mechanical pulp making) (FAOSTAT, 2014). Chemical wood pulp production yields an organic residue called black liquor which is combusted in recovery boilers to generate energy. The total production of chemical pulp is about 5 Mt/year. This would yield about 100 PJ of black liquor (based on 22 GJ per tonne of pulp). Some of the largest recovery boilers are located in China; two of which have total production capacity of 7,000 and 5,000 tonnes black liquor dry solids (BLDS) per day, equivalent to 29 PJ and 21 PJ per year, respectively. Another large-scale recovery boiler is under construction in Beihai with a daily capacity of 4,000 tonne BLDS.

China has had an ambitious biogas programme for half a century and accounts for 90% of biogas installations worldwide, with around 35 million units in operation in 2010 and 5 million new units being added every year. Most units are small-scale installations in farms integrated to livestock production. The trend is, however, toward centralised and industrial production as more than half of China's commercial pork originated from industrial scale farms in 2007 (Hallding *et al.*, 2012).

Around 90% of all biogas was produced in small-scale units in 2010. Of the medium and large-scale pig farms, typically only 5% of the potential has been utilised (Hallding *et al.*, 2012). Biogas production stood at 16 billion $m^3$ in 2012, or around 0.25 EJ. The installation of household biogas plants has slowed, and there are about 50 million such installations nationwide.

In keeping with this trend, current policies have begun to focus on large-scale applications. Distributed biogas digesters in rural areas account for more than 85% of biogas production in China. The installations receive investment subsidies in the range of RMB 1300-3500. Also, large-scale projects receive a 25-45% investment subsidy from the national government as well as a 5-25% subsidy from local governments (Van Sambeek *et al.*, 2013). A variety of biogas systems can be discerned that cater to specific needs (IISD, 2014):

- The 'three-combined' model. Traditionally in rural China a domestic biogas digester is integrated with the toilet and livestock pen, allowing animal and human waste to be fed in easily.
- The 'one-plus-three renovation'. This system is also known as a 'rural biogas digester and three renovations', because a rural household renovates the livestock pen, toilet and kitchen when constructing the biogas digester.
- The 'three-in-one' model in southern China. This system prioritises the efficient use of bio-slurry. Originally, the three-in-one name referred to 'pig-biogas-fruit', using pig manure for biogas production and then bio-slurry as fertiliser for orange trees. This system has improved both the quality and quantity of fruit production.
- The 'four-in-one' model in northern China. A biogas digester, a cattle pen and a toilet are all installed inside a greenhouse, which is also used for vegetable or fruit production. In these colder regions, the higher temperature in a greenhouse enhances biogas production, animal growth and vegetable production.
- The 'five-in-one' model in northwest China. Designed for arid areas with water shortages and long, cold winters, this is similar to the 'four-in-one' model, except that the greenhouse is used as a warm enclosure for livestock, and a rainwater collection cellar is included to meet the water needs of the household and to support biogas production

China has some 1,000 gasification installations, mainly downdraft gasifiers that provide villages with gas for cooking (Chen, 2011). Current developments focus on larger installations with 10-15 $MW_e$ capacity, mostly fluidised beds and circulating fluidised bed units.

### *Investment in biogas as a source of energy has other spin-off benefits such as an increase in agricultural production*

Liquid biofuel use is rather small compared with other forms of biomass in China. The target is to produce 5 billion litres of ethanol and 1.2 billion litres of biodiesel a year by 2015.

Ethanol is produced from corn, wheat and non-grain feedstocks. Biodiesel is largely produced from used cooking oil, waste animal fats and wild oilseed plants (Qiu *et al.*, 2012). The emphasis is on the use of lignocellulosic crops to avoid competition with food production. In 2012, there were 159 ethanol plants recorded in China, of which five are licensed to produce fuel ethanol (see Table 3) (Qiu *et al.*, 2012; USDA, 2013). The plant in Guangxi is the first cassava plant worldwide; it was built in 2007 (USDA, 2013). The only government-approved, cellulosic ethanol plant in operation is in Shandong province. The facility has been operating since October 2012 and produces ethanol from corn cobs, with a total production capacity of 50 kt/year. In 2012, a sweet sorghum-based plant was built in Inner Mongolia with a total production capacity of 50 kt/y; this capacity is projected to reach 100 kt/year by 2015 (USDA, 2012;2013).

*Table 3: Five largest ethanol plants in China*

| Location | Production capacity (kt/year) | Production (2008) (kt/year) | Feedstock |
|---|---|---|---|
| Jilin | 500 | 450 | Maize |
| Heilongjiang | 400 | 140 | Maize |
| Henan | 450 | 440 | Wheat/maize |
| Anhui | 320 | 320 | Maize |
| Guangxi | 200 | 150 | Cassava |

*Source: Based on Qiu et al. (2012)*

For biodiesel, the industry is lobbying the government to make the tax exemption on biodiesel (5%) from waste cooking oil permanent (USDA, 2012).

### *Biofuel policies in China targets production from feedstocks that do not compete with crops for human consumption*

Solar thermal and geothermal also play a role in China in meeting heating and cooling demand. 1,000 geothermal projects are planned with a heating/cooling area of 50 million $m^2$ while 100 solar thermal heating projects are planned with an area of 1 million $m^2$.

In 2010, China had an installed solar thermal capacity in operation of 130 $GW_{th}$, which increased to 152 $GW_{th}$ in 2011. By 2012, installed capacity had reached 180 $GW_{th}$. This was equivalent to 67% of the global total. The majority of the installed capacity by 2012 was accounted for by evacuated tube collectors (ETC) (168 $GW_{th}$). The remaining 12 $GW_{th}$ is flat plate collectors (FPC) (CNREC, 2013a; AEE-INTEC, 2014).

According to the "2005 Chinese Geothermal Environment Bulletin" released by the Ministry of Land and Resources of China, the direct utilisation of geothermal energy for non-electric purposes reached 10.5 GWh/year. In 2005, installed geothermal energy capacity reached 10,779 $MW_e$ (Delman and Chen, 2008). The installed capacity of direct use geothermal plants as of end-2011 was 8.9 $GW_{th}$ which generated about 75 PJ of geothermal heat. The use of geothermal heat pumps (GHP) has grown substantially, with installed capacity reaching 5.2 $GW_{th}$ by the end of 2009 (IEA-GIA, 2013). According to IEA energy statistics (IEA, 2013), geothermal heat consumption in 2010 was 150 PJ/year. 80 PJ of this was in the residential sector, 44 PJ in commercial buildings and 6 PJ in industry.

Renewables make up a negligible share of total district heat generation (less than 1%) today. The majority of the demand is met by coal. Given the country's increasing heating demand and technologies available, there is considerable potential for various forms of renewables to play a bigger role.

## Electric vehicles

According to the Ministry of Science and Technology's 12th FYP for electric vehicles and the State Council's Energy-Saving and New Energy Automotive Industry Development Plan (2012-2020) which were released in 2012, by 2015, 500 000 electric and plug-in hybrid vehicles are expected to be on the road. This will be supported with 400 000 charging piles and 2 000 charging or battery-switching stations. The nation aims to have 5 million electric and plug-in hybrid vehicles on the road by 2020, less than 3% of all vehicles. Of global annual sales of between 20 and 30 million, more than 90% were in China. In 2010, the total number of electric two-wheelers reached more than 200 million (IEA-ETSAP, 2013).

In September 2013, the Ministry of Finance, the Ministry of Science & Technology, the Ministry of Industry & Information Technology and the National Development & Reform Commission (NDRC) issued a joint decision approved by the State Council on the extension of subsidies for three years from 2013 to 2015 to promote new energy vehicles.

The new subsidy scheme has three main attributes: 1) it expands the scope of pilot cities to 88 across the country, particularly those cities where fine particle pollution has posed a serious threat to public health; 2) it provides differentiated subsidies for different types of new energy vehicles; 3) degressive rates of 10% and 20% will be applied to all electric vehicles and plug-in hybrid vehicles excepting buses for 2014 and 2015, respectively from the 2013 subsidy level. In addition, the new subsidy policy unifies the subsidies of all regions, changing the previous situation where subsidies varied across the country.

In July 2014, the State Council issued its Guidance on Accelerating the Use of New Energy Vehicles. The document proposes waiving a 10% purchase tax for eligible vehicles including electric vehicles, plug-in vehicles and fuel-cell vehicles from 1 September 2014 to 31 December 2017. It is hoped that the reduced purchase cost will make the new energy vehicles more financially attractive. In particular, emphasis was placed on the need for the rapid development of charging infrastructure and the creation of new business models. The council also requested relevant authorities to present proposals for a fiscal stimulus policy for 2016-2020 by the end of 2014.

The output of the 628 models identified in the directory of recommended energy-saving and new energy vehicles of the Ministry of Industry and Information Technology reached 24 800 in 2012. This increase is equivalent to 94% per year, and in 2012 included 13 300 electric vehicles, 10 400 conventional hybrid vehicles, and more than 1 000 plug-in hybrid vehicles. Efforts need to be accelerated further to meet government targets.

The total annual amount of new energy vehicles deployed in the 25 pilot cities (under the “10 Cities and 1 000 Vehicles” programme) remained at 10 000. This is much lower than the initial goals set by some cities, where the total number of new energy vehicles to be reached was 30 000 within four years. By the end of 2012, more than 27 000 new energy vehicles were on the road in the 25 cities after two years following the implementation of the subsidy policy. Most of these are public vehicles. This is more than half of the goal, and two main factors explain the lacklustre progress:

- First, like elsewhere at present, electric vehicles are relatively expensive in China. Even with subsidies of RMB 120 000 (about USD 17 650) and up to RMB 60 000 RMB (about USD 8 800) from central and local governments (the highest local subsidy exists in Shenzen), the off-the-lot price of a BYD E6 (a popular Chinese-made electric vehicle) is between RMB 170 000 and RMB 180 000 (USD 25 000-26 500). That is twice the price of a conventional internal combustion engine vehicle with similar configuration and performance. As a result, demand is still weak among private consumers.
- Current charging infrastructure does not meet recent trends in demand and more investments are needed if the targets are to be reached. By the end of 2012, the 25 pilot cities had only 8 107 charging piles and 174 charging or battery-switching stations. For example, the number of street charging piles in Shenzen reached 1000 in April 2013. This is much lower compared to the target to surpass 40 000 by 2012. By end of 2012, 60 charging or battery switching stations and 1 080 charging piles were built. Similarly, this is also much lower than the goals of 256 stations and 42 000 piles by 2015. According to the information from the State Grid Corporation of China and China Southern Power Grid, only 4% and 13% of the 2015 targets were achieved by 2011 for charging piles and charging or switching stations, respectively. As a result of the shortage and uneven distribution of charging facilities, varying technology preference and interests between the state grid (favouring battery switching solutions) and most automobile companies (preferring charging solutions), makes it inconvenient to own an electric vehicle.

China’s electric vehicle deployment have benefited from ambitious targets and government support in recent years. However, without further coordination of the market and policy incentives by the government, the industry’s future will remain unclear (WRI, 2013a).

### *Despite attempts to encourage people to buy electric vehicles, their high cost and poor infrastructure have hampered efforts to introduce them*

China is also aiming for 30% of new government vehicles to be powered by alternative forms of energy by 2016. At least 15% of new vehicles introduced in in 2014 in places such as Beijing and the Pearl River Delta will use new energy. The cabinet announced a new exemption law which will apply from 1 September 2014 for battery electric and hybrid vehicles. The law will run until the end of 2017. China will offer subsidies for new-energy vehicles that cost below USD 29 000 and also request local governments to build more facilities (Spiegel, 2014; BNEF, 2014a).

In China, there are also electric vehicle technologies other than cars. K9 is an electric bus manufactured by BYD and it is powered by iron-phosphate battery developed by the manufacturing company. On one single charge, it drives 250 km under urban road conditions. On September 2010, the first BYD electric bus was on the road in Changsha city in Hunan province. By the end of 2012, more than 1 200 electric bus offers were received by the BYD from countries across the world (BYD, 2013). Production costs are expected to drop as the company escalates output.

Anhui Ankai Automobile Co., Ltd. is another company producing buses. 44 hybrid and electric buses were incorporated in the ministry’s directory of recommended new energy and energy-saving vehicles. The company is one of the leading players in the domestic new energy bus sector. By end of 2012, in 27 cities including Beijing, Shanghai, Dalian and Hefei, 1 000 new energy buses were on the road which were manufactured by Ankai (Reports, 2013).

While electric cars have proved hard to introduce, by contrast electric two-wheelers (e-bicycles, e-scooters and e-motorcycles) are rapidly gaining ground. Of global annual sales of two- and three-wheelers between 20 and 30 million, more than 90% were in China. In 2010, the total number of electric two -wheelers reached more than 200 million (IEA-ETSAP, 2013). E-bicycles account for more than three quarters of the market. By 2018, China will have 355 million cumulative sales of such products. This means one vehicle per four persons. To some extent these vehicles substitute cars (GCC, 2012).

The use of urban rail transport is also growing. There were 1,688 kilometres (km) of operating metro railway in 14 cities at the end of 2011. By 2015, there will be 3000 km of metro railway, and by 2020 6200 km are planned. By 2050, mainland cities will have 11700 km of metro railway, accounting for at least half the world's total (SCMP, 2013).

In Beijing around 40% of all passengers use public transportation, compared with 25% in Shanghai and Kunming. This percentage has been rising in Beijing and Kunming (Yang, 2013).

An aspiration is that by 2030, 39% of all city transportation will consist of cars and 29% of buses; others include two-wheelers (15%), subways (4%) and walking (13%) (Yang, 2013). Within the car park the share of internal combustion engine and hybrid cars would decline to 85%, the remainder including around 7% electric vehicles as well as other technologies (Yang, 2013).

## Transmission and distribution grids

China has five state-owned power generation companies: CDC: China Datang Co.; CGC: China Guodian Co.; CHDC: China Huadian Co.; CHNG: China Huaneng Group; and, CPIC: China Power Investment Co.

China also has two state-owned grid companies, State Grid Corporation of China (SGCC) and China Southern Power Grid Corporation (CSG). SGCC accounts for approximately 80% of the total grid. CSG has the remaining 20%. These two companies cover almost all power transmission, distribution, and metering activities in China. SGCC is the largest, covering 26 provinces, whilst CSG covers five provinces in the south.

SGCC is the biggest utility company worldwide. SGCC's core business is to build and operate power grids; the service area covers 26 of 31 provinces and oversees 88% of China's territory. By the end of 2013, the installed capacity of SGCC was more than 900 $GW_e$ (4,448 TWh generation) and the maximum peak load reached 654 $GW_e$. Coal power accounted for 73.6% of installed capacity, hydro 18%, and wind 7% (70.2 $GW_e$).

China's power system consists of six regional clusters with weak interconnectors (The north, northeast, northwest, central, eastern and the south regions). Each cluster consists of several provinces that act as a balancing area. There are interconnection lines that facilitate trade within the regional clusters.

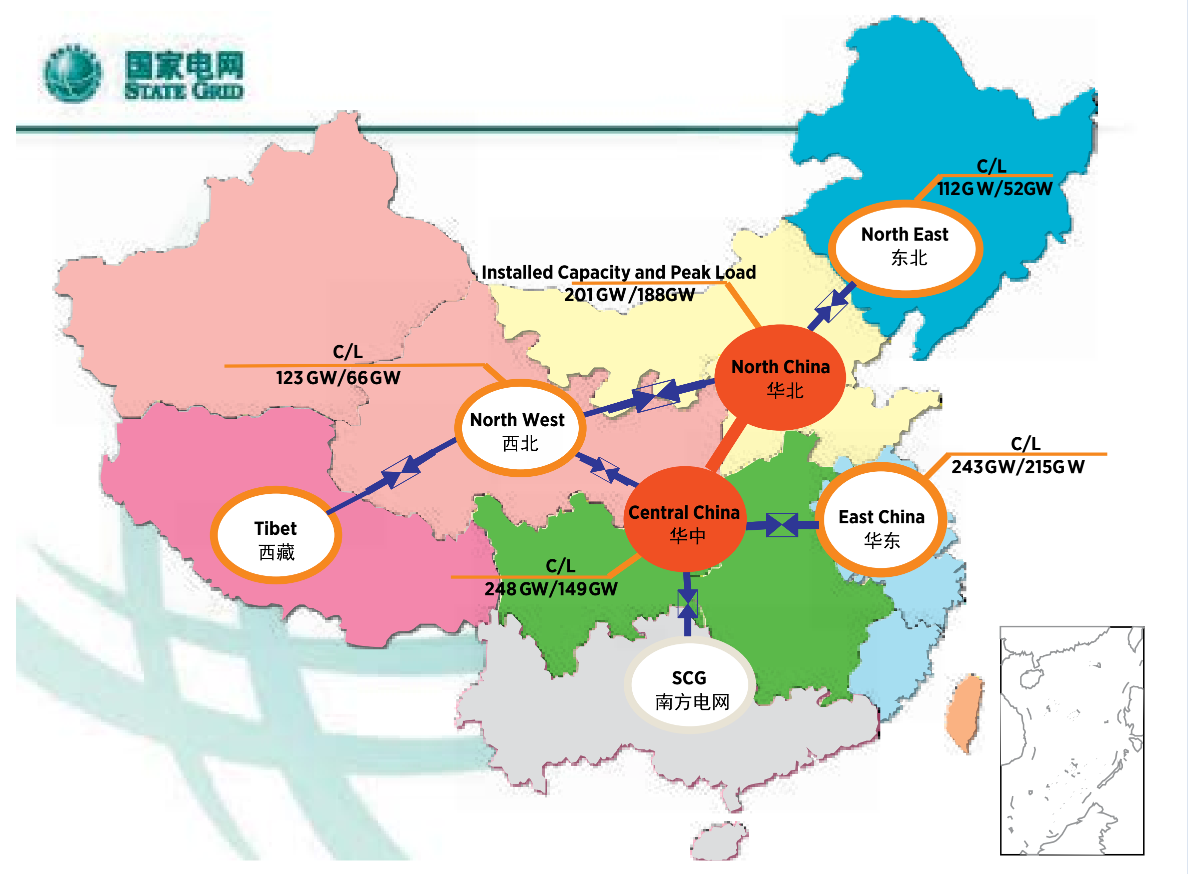
*Table 4: Regional power generation capacities and peak demand of the State Grid Corporation of China*

| | Installed capacity ($GW_e$) | Peak demand ($GW_e$) |
|---|---|---|
| North China | 201 | 188 |
| North East China | 112 | 52 |
| North West China | 123 | 66 |
| Central China | 248 | 149 |
| Eastern China | 243 | 215 |
| Total | 927 | 654 |

*Based on SGCC (2013)*

*Note: data represents the situation end of August 2013*

*Figure 7: Installed capacity and peak load of State Grid Corporation of China*



*Note: data represents the situation end of August 2013*

*Source: SGCC (2013)*

In terms of dispatch and planning, six regional grids and the provinces which belong to them have considerable autonomy. This creates opportunities for local influence on grid operation although, under this system, transmission projects may be underutilised.

Thermal power plants are assigned a fixed number of full load hours every year and the volume of inter-provincial trading is decided a year ahead. Day-ahead dispatching takes these two rules into account. There are fiscal incentives to maximize local production. The variability of wind power, notably, interferes with the allocation of full load hours and trading practices.

Peak loading and transmission constraints make it hard to transport power into high consumption areas. The current transmission system was designed to accommodate a base load and slowly varying output of coal power. Transmission lines in China reach an annual peak loading on average of 50% of capacity. However, this average can be misleading because many lines are at full capacity while others are operating sometimes with nearly no capacity (DB, 2012).

Sustained electricity growth requires both long-distance and higher capacity transmission. This is particularly important for China where resource potential is widely distributed and far from demand centres. As a result of concerns over air pollution, railway congestion, and to be able to meet the increasing growth of electricity demand, north and western parts of China are becoming electricity production centres.

The China Electricity Council, in its 2014 projections and recommendations, focused on the northeast's excess capacity problem, recommending that the central government "strictly control" new coal and wind construction in the region. It projected a smaller (though still substantial) increase in coal-fired capacity nationwide of 30 $\text{GW}_e$. CEC's other projections for new installations

### Box 1: Rural grids and mini-grids

Since the 1950s, China has pursued the development of small hydroelectricity plants, firstly in terms of stand-alone projects and later those connected to the national grid as it expanded. In 2002, there were 42,000 small hydroelectricity plants with a total capacity of 28 $GW_e$ providing distributed energy. Today, China has roughly 60,000 diesel and hydro mini-grid systems, most of which have been connected to the centralized grid. Between 2003 and 2005, China's Township Electrification Programme constructed 721 solar PV and PV/wind hybrid systems (20 $MW_e$) along with 146 small hydro stations (264 $MW_e$) to provide electricity to 1.3 million people (LBNL, 2013). A Village Electrification Programme, implemented between 2005 and 2010, connected another 3.5 million people to renewable sources of energy. By the end of 2015, China aims to address the challenge of providing power to another 2.73 million people without electricity, including 1.54 million by grid extension and 1.19 million by independent solar PV power supply utilisation. By the end of 2008, there were more than 400,000 off-grid solar home systems in China (IRENA, forthcoming).

in 2014: 23 $GW_e$ hydro, 17 $GW_e$ wind, 14 $GW_e$ solar, 6 $GW_e$ nuclear and 5 $GW_e$ gas.

### *Investment in long-distance and higher capacity transmission networks is essential for sustained electricity growth in China*

With the air pollution plan, 12 west-east "air pollution control transmission corridors" are being planned. These will reduce coal-fired electricity generation in eastern parts of China where population is high. In the southern lines, hydro will be primarily connected whereas in the northern lines wind and coal will be bundled as they originate in areas of development of both energy sources.

A synchronised UHV alternating current (UHV-AC) grid could lead to more centralised control of the national power system. In comparison, an asynchronous UHV direct current (UHV-DC) grid would not necessarily disturb the current setup, and it is seen as a hedge against greater monopolisation (Davidson, 2014).

UHV-AC is planned to connect north and central grids (Huainan-Shanghai). UHV-DC is planned to connect the power generation in the west with centres of demand in the east (Hami-Zhengzhou). Total UHV transmission grid capacity is projected to increase to 200 $GW_e$ by 2020 (10-15% of total generation capacity). Meanwhile, a UHV-AC synchronous grid is planned for northern, central and southern areas. The UHV grid lines in China use 900 kV, the highest rating in the world. The grid will give shape to a system of three vertical and three horizontal axes. The vertical, north-south axis will connect the biggest coal and wind production areas of Inner Mongolia, Shanxi and Shaanxi to the north central and eastern parts of the country.

An ultra-high transmission corridor to increase the integration of renewable energy resources is outlined in China's 12th FYP. The 2090-km-long 800 kV UHV-DC Jinping-Sunan transmission line is the second largest in the world, allowing 7.2 $GW_e$ to be transmitted, and is owned by SGCC. The project cost USD 3.5 billion, and transports hydroelectricity from power stations along the Yalong river in Sichuan province to the industrialised coastal area of Jiangsu. This power line was built by ABB together with CEPRI and other Chinese partners. And even higher capacities are being developed. The third largest UHVDC transmission network in the world is also in China, comprising the 1980-km-long line that connects the Xiangjiaba hydroelectricity plant to industrial users around Shanghai with a rated capacity of 6.4 $GW_e$. It was the first such commercial operation in the world, and completed 30 months ahead of schedule. There are also projects to integrate these HVDC lines into a HVAC grid based on technology by CEPRI.

The latest development suggests that SGCC will spend an additional USD 162.8 billion on eight UHV transmission lines to be built before 2021, both for renewables and coal-fired power stations located further away from the big cities. Another estimate states that by 2020, China would be spending about USD 107 billion in UHV transmission lines and related capacity. Investment in end-points of the transmission lines account for around half of the total investments, for both AC and DC, and

*Table 5: Installed and under construction pumped hydroelectricity*

| | Installed ($MW_e$) | Under construction ($MW_e$) |
|---|---|---|
| North China | 4300 | 1200 |
| East China | 5860 | 4360 |
| Central China | 3790 | 1200 |
| Northeast | 1500 | – |
| Northwest | 90 | – |
| South | 4800 | 2480 |
| Total | 20340 | 9240 |

*Source: Based on Perera (2014)*

*Note: data represents the situation end of August 2013*

include transformers, reactive power control devices, circuit breakers, isolation switches, surge arrestors and other related subsystems. The remaining half consists of the cables, insulators and towers (DB, 2012).

### Renewables such as pumped hydro can play a key role in balancing output, although there is no scope for arbitrage unless price flexibility is introduced

In addition to these considerable developments in grid expansion, technologies for accommodating the increasing share of variable renewables will gain further importance. Pumped hydro can play an important role in balancing variable renewables. However, in the current system there is no possibility for arbitrage as electricity prices are set by the state and there is no special price for electricity from pumped hydro.

China has over 20 $GW_e$ of pumped hydro installed and more than 9 $GW_e$ is under construction (see Table 5). Another 120-130 $GW_e$ of pumped hydro projects are in the planning stage; the target for 2030 is more than 100 $GW_e$ (Perera, 2014). Pumped hydro can help to stabilise power generation from variable renewables. Total pumped hydro capacity is more or less equally distributed across China's eastern, southern, northern and central provinces (Perera, 2014).

The development of the smart grid is also very important to achieve the aims of the 12th FYP, which mandates that 15% of the primary energy consumption has to be provided by non-fossil fuels in order to reduce carbon emissions. The supply and demand of power through the national distribution network are managed more effectively with smart grids. For doing so, smart grids introduce high-tech communications to the system. They also accommodate renewable power sources such as solar and wind more efficiently.

For the future, China has developed a smart grid plan which will be gradually deployed in three phases; construction investment entered a large-scale phase in 2012. Since 2009, some 298 demonstration projects have been set up across China (SGCC, 2014). As of 2011, eight substations adapted to smart gird technology had been constructed in regions including Beijing, Shanghai and Chongqin. Also in 2011, the State Grid Company deployed more than 50 million smart meters (ESTELA, 2011).

*Table 6: Operating performance of pumped hydro plants, 2008 and 2012*

| | 2008 | 2012 |
|---|---|---|
| Average capacity factor (hours/year) | 2649 | 1450 |
| Capacity factors (%) | 30.2 | 16.5 |
| Average standby (hours/year) | 5350 | 6266 |
| Planned outage (hours/year) | 689 | 849 |

*Source: Based on Perera (2014)*

*Table 7: China's three stage smart grid plan*

| Stages | Title | Target |
|---|---|---|
| Stage 1 (2009-2012) | Planning and trial phase | Establishing master plan, carry out key technology research and key equipment development, and proceed with demonstration projects |
| Stage 2 (2011-2015) | Full scale construction phase | Formulate standards and requirements for strong and smart grid, to evaluate construction progress based on the needs and technical development of smart grid and construct smart grid in full scale |
| Stage 3 (2016-2020) | Leading and enhancing phase | Evaluate contraction of smart grid in full range |

*Source: Based on ESTELA (2011)*

It is worth noting that China's smart grid development is different from others in the West. In the USA and the EU, for example, the well-established power systems have little or flat future demand for electricity and thereby the focus of smart grid development is on distribution networks. By comparison, in China the focus is on backbone transmission networks due to the continued growth of electricity demand and the mismatch of generators and load centres.

Regarding smart grids for renewables, there are a number of activities that have been promoted. One of the key applications (in terms of investment streams) has been the deployment of smart meters. China has just under 250 million smart meters installed (Worldwatch, 2014). Another area that has been promoted is wind forecasting to support renewable energy grid integration. There are plans to provide wind forecast data with high spatial and time resolutions (9 km grid, every 5 minutes).

***China has more than 250 million smart meters installed, twice as many as the total number of households in the USA***

There are also a large number of demonstration projects on smart grid development for renewable energy integration. For example, the Zhangbei Demonstration Project includes 100 $MW_e$ of wind, 40 $MW_e$ of PV, and 14 $MW_e$ of storage combined with smart substations, intelligent control systems, and forecasting methods.

*Table 8: China's estimated annual $CO_2$ reductions from strong, smart grid*

| Mechanism | 2005 Figure | 2020 Figure | Diference between 2020 and 2005 figures | Avoided $CO_2$ emissions 2020 (Mt $CO_2$) |
|---|---|---|---|---|
| Raising the consumption of "clean energy" | 39 $GW_e$ | 411 $GW_e$ | 320 $GW_e$ | 1,018 |
| Decrease in transmission losses | 6.59% | 5.7% | Save 14.17 million TCE | 39 |
| Increase efficiency of coal burning for generation | 343 grams/kWh | 305 grams/kWh | 38 grams/kWh; save 189 Mtce | 524 |
| Increase in energy efficiency of electricity sector and consumers | 18% of consumer energy consumption is in the form of electricity | 26% of consumer energy consumption will be in the form of electricity | N/A | Not yet calculated |
| Promotion of electric vehicles | | 30 000 000 EVs | 35.5 million tonnes of petrol use will be avoided | 68.7 |
| | | | **Total** | **1,649** |

*Source: Based on Lu (2010)*

# 4 REFERENCE CASE DEVELOPMENTS TO 2030

This section explains the Reference Case renewable energy trends in China between 2010 and 2030.

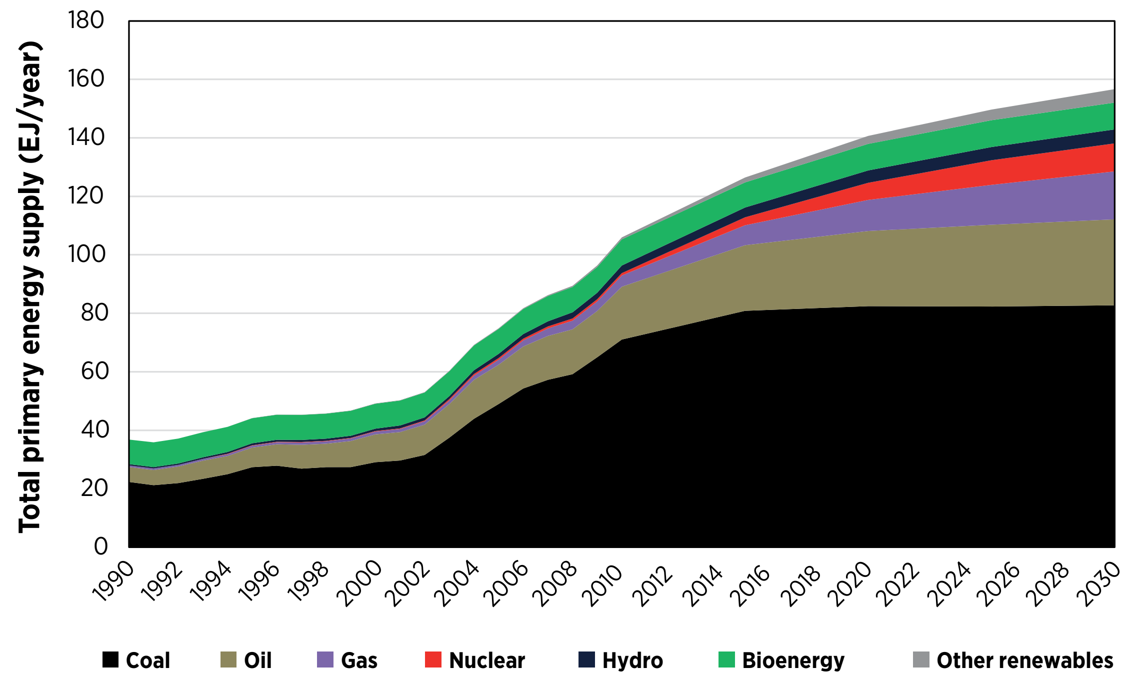
The REmap analysis begins with an assessment of the uptake of renewable energy technology options between 2010 and 2030 based on current policies. IEA (2012a) and CNREC estimates are used to develop the Reference Case for the REmap analysis of China. To put this Reference Case in perspective, this section begins with a brief timeline of China's primary energy demand developments since 1990 (see Figure 8).

The exponential growth in total primary energy supply between 1990 and 2010 will slow down in the following two decades to 2030. Coal consumption will flatten or increase only slightly with most consumption being in natural gas, followed by oil and nuclear power. Growth in other renewables (solar, wind), bioenergy and hydro will follow.

China's TFEC is projected to increase from 57 EJ in 2010 to 92 EJ in 2030 (3,130 Mtce). This is an increase of 60% in 20 years. Total fossil fuel demand is expected to increase at a slower rate of 40%. Much of the shortfall is accounted for by a fourfold increase in natural gas demand over the same period. Demand for coal would only increase by 13%.

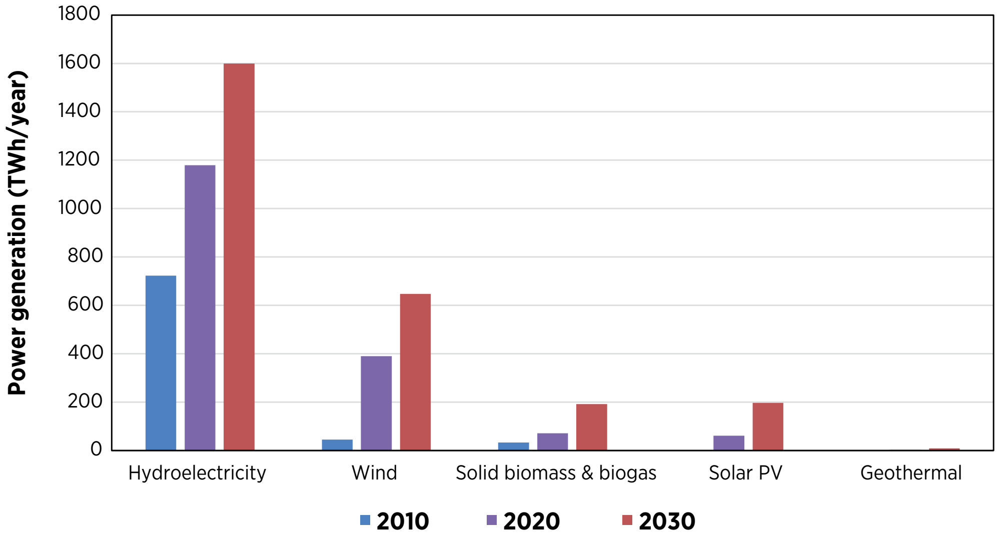
In the Reference Case, total power generation is expected to more than double (by at least 5 000 TWh) from 4 200 TWh/year in 2010 to approximately 9 300 TWh/year by 2030 (Figure 9). Renewable power generation is projected to increase from about 800 TWh to more than 2 600 TWh. By 2030, hydroelectricity generation will total 1 600 TWh followed by wind with 650 TWh, solar PV and CSP 200 TWh and finally biomass with 190 TWh. Hydroelectricity includes an additional 200 TWh that is related to the increased use of electricity-based technologies in end-use sectors sourcing demand from

*Figure 8: Growth of the total primary energy supply in China, 1990-2030*



*Source: IRENA analysis based on IEA (2012a;2013b)*

*Figure 9: Reference Case power generation growth*

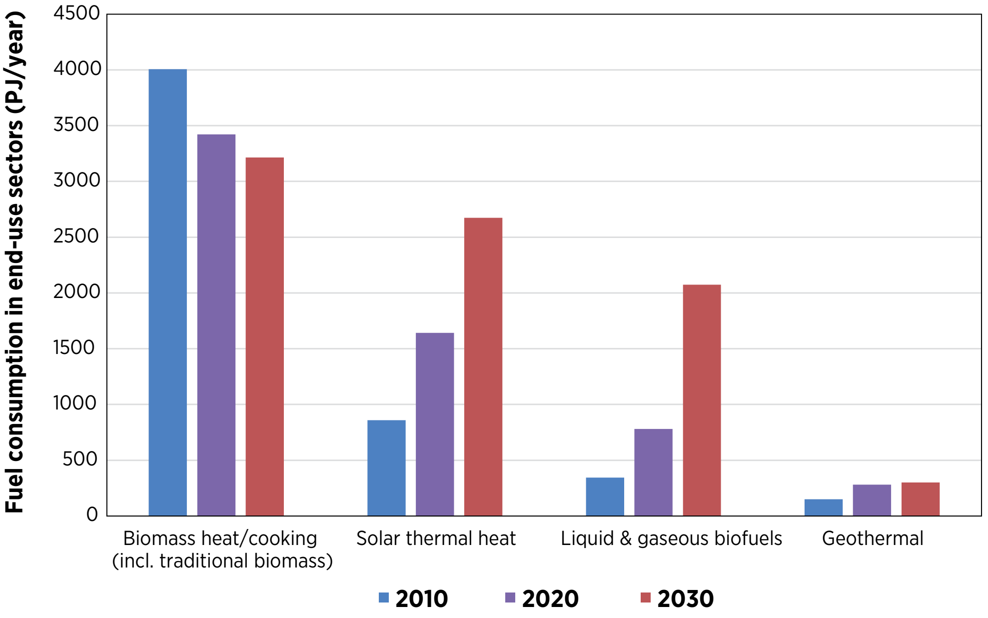


*Source: IRENA analysis based on IEA (2012a) and CNREC*

renewable power according to the Reference Case, such as heat pumps and electro mobility.

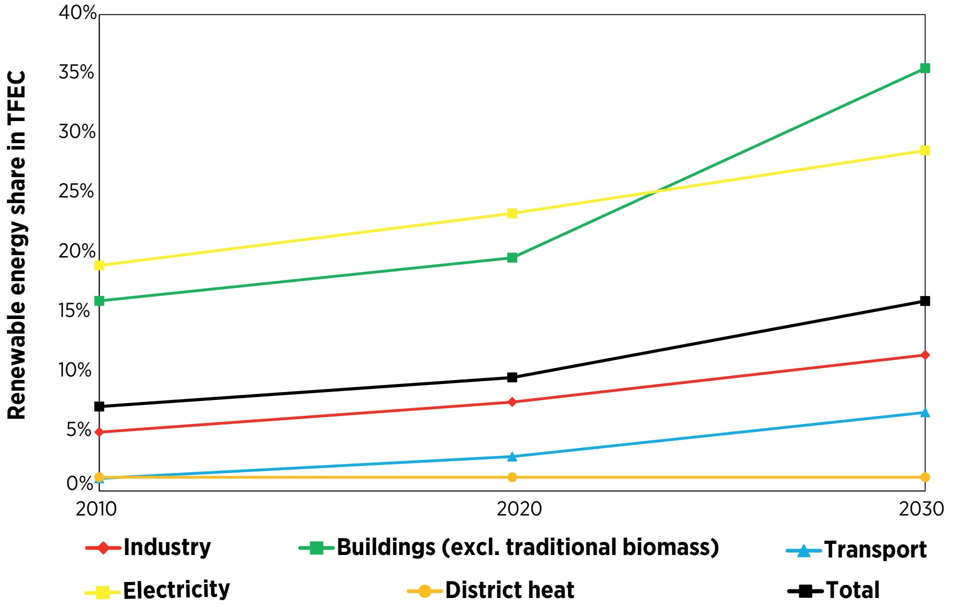
Total renewable energy demand in end-use sectors (excluding renewable electricity and district heat) will see an increase from about 5 EJ/year to 7 EJ/year (Figure 10). This includes developments in the traditional use of biomass where its demand decreases from 3400 PJ/year in 2010 to 1000 PJ/year. As a result of this decrease, total bioenergy demand for heating decreases from 4000 PJ to around 3200 PJ per year. Growth is projected in all other resources as well. Solar

*Figure 10: Reference Case growth of renewable energy in end-use sectors*



*Source: IRENA estimates based on IEA (2012a) and CNREC*

*Figure 11: China Reference Case – Renewable energy in TFEC*



*Source: IRENA analysis based on IEA (2012a) and CNREC*

thermal increases by a factor of more than three in the entire period, from 860 PJ to 2 700 PJ per year. All this growth is accounted for by the building sector. Geothermal heat doubles from 150 PJ to 300 PJ, but its contribution to the total renewable energy share consumption still remains small.

Modern forms of solid biomass use increase by four times, from 500 PJ per year to 2,200 PJ/year. The highest rate of growth is projected for the manufacturing industry sector, from a total use of 100 PJ/year in the pulp and paper sector alone to 700 PJ/year including its other sub-sectors. Solid biomass in the form of briquettes and pellets triples by 2030 compared to with 2010 levels to 1,500 PJ/year. Liquid biofuel and biogas use increases to 2 EJ in 2030.

### *Further electrification of the transport industry will help increase the share of renewable energy used by the sector*

Liquid biofuels use increases from a total of 2.5 Mt to 30 Mt per year in 2030, or from about 2 billion litres to a total of about 23 billion litres in 2030. This is a continuation of the trends between 2010 and 2020 biofuel targets of 12 Mt per year (10 Mt bioethanol and 2 Mt biodiesel) to 2030. The number of electric vehicles (battery and plug-in hybrid) is projected to increase from about 30,000 to nearly 17 million. This represents a 3% share of the total vehicle stock. The number of electric two- and three-wheelers is projected to double to 400 million.

Further electrification is key for the transport sector of China. The renewable energy share of 3.5% in 2030 Reference Case with liquid biofuels only, would increase to 5.2% when electricity use for transportation and the related share of renewable electricity is accounted for.

Modern renewable energy as a percentage of TFEC will increase from 7.1% in 2010 to 15.8% by 2030 (excluding traditional use of biomass) (Figure 11). The increase in the Reference Case renewable energy share will be driven mostly by an increase of renewable power generation from 19% in 2010 to 29% in 2030. The transport sector will see an increase of renewable energy from 1% to 4% by 2030, in the form of biofuels but also partly electrification. The share of modern renewable energy use in the industry sector will increase from 4.9% to 11.4% and in the buildings sector from 15.5% to 35% by 2030, both largely driven by biomass. The rapid growth of renewables in the power sector is balanced by the trends in the end-use sectors. The renewable energy share of district heat generation remains the same across the entire period.

# 5 CURRENT POLICY FRAMEWORK

## Key points

- Renewable energy policy in China has been largely driven by rapidly rising energy demand, reflecting economic growth and related supply-security concerns at a national level.
- Renewables will also play a key role in raising the use of non-coal and non-fossil-fuel sources as a proportion of total energy demand, according to the Action Plan for Air Pollution Prevention and Control.
- At a provincial level, renewable energy targets and the related Renewable Energy Law, which consists of a feed-in-tariff and mandatory grid connection, are key instruments to help increase the use of renewable sources for the power sector.
- Specific support programmes for the expansion of the domestic renewable industry – especially wind and solar PV – focus on research and development (R&D) as well as an increase in manufacturing capacity.
- Mandatory market shares – also known as "renewable portfolio standards" – for utility and grid operators are under discussion, with the possibility of a programme being implemented by 2015.
- Future caps on coal consumption for the whole of China, as well as for specific provinces, may also help the uptake of renewable energy options.
- Grid expansion plans are being implemented, and a smart grid programme is under development. However, there is no concerted power-grid policy for renewable energy yet.
- Renewable heating policy specifically focuses on solar water heating, while transport sector policy is mostly concentrated on direct subsidies for electric vehicles.

China's energy demand has grown significantly over the past decade due to rapid economic development. This section starts with an overview of one of the main drivers in China's renewable energy policy – air pollution, and it continues by providing further insight to the policies across all sectors – power, buildings and transport – but puts a clear focus on the renewable power sector.

To keep the balance between supply and fast-increasing demand while improving security of supply presents a major challenge which it is only possible to overcome with a whole range of different policies. These are discussed later in this report in Sections 8 and 9.

## 5.1 Airborne Pollution Prevention and Control Action Plan

Air pollution and its effects on health and the economy are a serious concern for China. According to some estimates, the total number of mortalities from ambient air pollution (particulate matter and ozone pollution) reached approximately 1.2 million in 2010. China has succeeded in reducing PM levels substantially and slowing the increase in mortalities, but further reductions remain a challenge (OECD, 2014). PM concentration varies across the country; according to 2005 statistics cities in the north have much higher levels (85-160 µg/m$^3$) compared with urban areas in the south (47-125 µg/m$^3$). Based on the analysis of trends between 1975 and 2005, Matus *et al*. (2012) estimate that ozone and PM concentrations resulted in a USD 16-69 billion loss of consumption and USD 22-112 billion loss of welfare in China's economy. Besides the effects on human health, research shows that air pollution has also significant impacts on agricultural production. A global risk assessment shows that local crop loss from sulphur dioxide emissions could be an important issue for countries such as China and India (Marshall, Ashmore and Hinchcliffe, 1997).

In response to these concerns, China's State Council released its Action Plan for Air Pollution Prevention and Control on 12 September 2013. The plan focuses on three key regions, namely the Beijing-Tianjin-Hebei area (Jing-Jin-Ji), the Yangtze River Delta and the Pearl River Delta, and sets targets for the next five years.

The Chinese government recognises that tackling the air pollution crisis will require significant reductions in coal consumption. For the first time, its plans introduce coal consumption caps for provinces. Furthermore, many provinces have been committed since 2013 to reversing the rapid growth in coal use and cutting their overall coal consumption in just four years. No other major coal-consuming country has ever implemented such ambitious targets. If achieved, the measures will not only fundamentally shift the coal consumption trajectory of the world's largest coal consumer, but also significantly re-shape the global $CO_2$ emission landscape.

## *Tackling China's air pollution crisis will require significant reductions in coal consumption. Shandong province alone burns more coal than Germany and Japan combined*

A large share of China's total coal consumption is covered by the targets. Shandong is the largest coal consumer among Chinese provinces and Hebei ranks fourth. Shaanxi is among the ten provinces that consume the most coal. Another two key economic regions – the Yangtze River Delta, comprising Shanghai, Jiangsu, and Zhejiang, with 11% of national coal consumption, and the Pearl River Delta – are aiming for absolute reductions in coal use by the end of 2017. Liaoning and Jilin will also have to limit growth in their coal consumption to less than 2% per year by 2017. Until recently, with the exception of Beijing, all provinces which were covered by the plan have seen coal consumption grow rapidly.

The plan aims to reduce the share of coal in total energy consumption to 65% by 2017, with the share of non-fossil energy reaching 13%. Natural gas will be a key substitute for coal in the generation of power and heat. Twelve provinces which account for 44% of China's total consumption committed to implement measure to control coal consumption. Six provinces have included absolute targets in their plans, with a 50% reduction targeted in Beijing, 13% in Hebei, 19% in Tianjin, 5% in Shandong, 21% in Chongqing and 13% in Shaanxi by the end of 2017. Beijing is also planning to ban the use of coal by 2020 (Huffington Post, 2014).

While the current air pollution plan runs until 2017, further action could be taken in a review scheduled for 2015, as well as the upcoming FYP for the years 2016-

### Box 2: Implications of changes in coal-based power production on water demand

Changes in coal use could have considerable implications for China's water resources. Today, 85% of the country's total power generation capacity is located in water-scarce regions and 15% of this capacity relies on water-intensive technologies. Northern China in particular is suffering from high demand for water from the coal supply sector. Currently, more than half of China's industrial water usage is in coal-related sectors, including mining, preparation, power generation, coke production and coal-to-chemical factories. Coal mining and coal power generation sectors in the north accounted for 15% of China's total freshwater withdrawals (98 billion $m^3$) in 2010 (SA, 2013). National water consumption is projected to increase from 599 billion $m^3$ to 630 billion $m^3$ by 2020. By then, the coal sector will be responsible for 27% of withdrawals, with an estimated 34 billion $m^3$ of water per year used by coal-fired power plants alone.

The coal challenge is exacerbated by the fact that almost all of the collieries are in the northwest, which is also one of the country's driest regions. Coal expansion plans imply that the equivalent of a quarter of the water in the Yellow River would be needed (ca. 10 billion $m^3$/year). This water is not available. Of the planned coal power expansion plans, half are located in high or extremely high water-stressed regions (WRI, 2013b).

Various plans such as water diversion from the south to the north, seawater desalination, east-west pipelines and dry cooling for coal plants (substituting water cooling) are being considered. The South-to-North Water Diversion Project, planned for completion in 2050, will eventually divert 44.8 billion $m^3$/year to the north. The Hami and Tianshan power plants will have air cooling systems by the end of 2014, as will another plant next year in Junzheng Wuhai (PE, 2013). However, dry cooling reduces the efficiency of coal power plants, raising their generation costs. Moreover the quantities involved are too small to make a significant difference to China's overall water consumption.

2020. Coal caps could be introduced to a number of other key provinces, which would also ensure that polluting industries do not simply relocate to areas without coal reduction policies. In addition to these twelve provinces, 17 others announced intentions to cap or reduce coal use.

The change of direction is showing results. New capacity additions in power generation have begun to follow a new trajectory, with coal accounting for only 26% of new investments as of 2012, while non-fossil sources – hydro, wind, nuclear – made up 72%. In 2012, China added 12 TWh of coal, 26 TWh of wind, and 196 TWh of hydro.

This trend is encouraging, but major effects on air pollution levels remain to be seen. Out of the 161 cities monitored in the first half of 2014, only nine of them meet China's new air quality standards. One of those cities which did not meet the targets was Beijing, due to its high levels of $PM_{2.5}$ and other pollutants (NY, 2014). In February 2014, the concentration of $PM_{2.5}$ had reached 505 micrograms per cubic metre, which is sufficient to penetrate into the lungs and the bloodstream (Guardian, 2014).

## 5.2 Renewable energy policy of China

The development of new renewable energy policies can be traced back to 2004, when China announced plans to develop a renewable energy law and to establish a renewable energy development fund[16]. At the outset, 'small-hydro' and small-scale solar PV were identified as key areas for the encouragement of decentralised projects.

The establishment of the CNREC – developed in close cooperation with Denmark – was another national milestone. This institution assists China's energy authorities in renewable energy policy research, industrial management and coordination. China's 12th FYP, which was launched in 2010, was the first time renewables were identified as an emerging strategic industry.

The main components of China's renewable energy policy are as follows (Zhang *et al.*, 2013):

- Mandatory market share for renewables by sector and technology
- Tariff based support mechanisms
- Government financial support for renewable energy projects

Each component is discussed below in more detail.

### Mandatory market share (MMS)

The National Development & Reform Commission (NDRC) introduced mandatory market share (MMS, or "renewable portfolio standards" as they are called in the United States) in 2007 in China, linked to the country's mid-term (2007-2010) and long-term (until 2020) development plans for renewable energy. The NDRC is a ministry in the central government that is responsible for planning the economic development of the country, and it has been assigned the responsibility for energy and climate change (Lo *et al.*, 2014).

In regions served by centralised power grids, the share of power generation form non-hydro renewable sources should reach 1% of the total by 2010 and 3% by 2020 according to the plan. Furthermore, power producers with a capacity larger than 5 $GW_e$ must increase its actual ownership of power capacity from non-hydro renewable energy sources to 3% by 2010 and 8% by 2020 (NPC, 2013; Zhang *et al.*, 2013).

Many aspects of the policy have yet to be put into practice, according to Lo *et al*. (2014). As of 2010, none of the six largest generators had met the 3% renewable energy target, partly due to the lack of monitoring and compliance requirements. Furthermore, the focus of MMS is on installed capacity rather than generation. Therefore, there was no incentive for grid companies to act.

To address these problems, the NDRC began to develop an improvement plan in 2011. A four-step programme was developed which introduced changes and additional details to improve the renewable portfolio standard (Lo *et al.*, 2014). These included the following:

Individual targets would be assigned to generators and grid companies, depending on their circumstances and

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[16] At the "Renewables 2004" conference in Bonn, Germany in June 2004, a follow-up to the 2002 World Summit for Sustainable Development (WSSD).

capacities, with the aim of making the RPS more practical as well as clarifying the companies' obligations

- Significantly increased renewable energy targets would be set for grid companies to provide more incentives to purchase renewable electricity. For example, the State Grid, China's largest grid company, is expected to achieve a 4.8% non-hydro renewable energy share by 2015 (The previous target was 3% by 2020),
- The National Energy Administration (NEA) was given the responsibility of monitoring compliance on a monthly basis. Renewable energy certificates would be used to track the fulfilment of targets, but the certificates had not been made tradable
- The failure to meet targets negatively impacts on managers' performance evaluations. All generators and grid companies regulated by the RPS are state-owned enterprises, and their managers are evaluated annually by the State-owned Assets Supervision and Administration Commission (SASAC).

This draft was released in May 2012 for public consultation (Lo *et al.*, 2014). State-owned enterprises have so far resisted these new requirements, which were still under debate in mid-2014. The MMS is expected to be implemented by the end of 2014 or in 2015.

### Tariff based support mechanisms for power generation from renewable energy sources

Since the Renewable Energy Law came into force on January 2006, renewables have been guaranteed grid

### Box 3: Renewable energy targets in China

China's 12th FYP identified renewables as an emerging strategic industry and set overall targets for renewables. Table 9 below lists the different sectorial and/or technology targets for 2015 and 2020.

The Chinese government also released targets for renewable energy use under the current 12th FYP. The overall goal is for total modern renewable energy consumption to reach 14 EJ (478 Mtce), representing 9.5% or more of the overall energy consumption mix by the end of 2015 (this excludes the traditional use of biomass) (CNREC, 2012). In January 2012, as part of its 12th FYP, China published a report on greenhouse emissions control, which establishes goals of reducing carbon intensity by 17% by 2015, compared with 2010 levels, and raising energy use intensity by 16%, relative to GDP.

According to this plan China will meet 11.4% of its primary energy requirements from non-fossil sources by 2015. At the same time coal use is projected to decline, from 67% to 60% by 2020.

China's total installed power generation capacity is expected to nearly double from 968 $GW_e$ in 2010 to 1,786 $GW_e$ by 2020. The installed capacity of renewable energy will reach at least 600 $GW_e$ by 2020, from 250 $GW_e$ in 2010.

In its 12th FYP, finalised in August 2012, China committed about USD 290 billion to clean energy investments. Its goal is to produce 20% of the nation's electricity from renewable sources by 2015. Total installed hydroelectricity generation capacity is targeted to reach 290 $GW_e$, while wind power will total 100 $GW_e$. Solar power capacity will total 21 $GW_e$ in 2015.

In October 2012, China's State Council released its Energy Policy white paper, updating the previous targets that had been outlined in its five-year plan. The new document extended these targets considerably. China now determined that, by 2015, no less than 30% of its electric power capacity would be based on non-fossil fuel sources – mainly hydro, wind and some solar, as well as nuclear. Installed total wind power generation capacity had already reached 100 $GW_e$ by the end of 2013, while solar PV had reached 35 $GW_e$.

*Table 9: Renewable energy targets overview*

| | Status | Targets | |
|---|---|---|---|
| | 2012 | 2015 | 2020 |
| **Power sector** | | | |
| Biomass power | 8 $GW_e$ | 13 $GW_e$, including<br>8 $GW_e$ agricultural and forest residues<br>2 $GW_e$ biogas and<br>3 $GW_e$ urban waste | 30 $GW_e$ |
| Hydroelectricity | 249 $GW_e$ | 260 $GW_e$ | 350 $GW_e$ |
| Pumped hydro | 20 $GW_e$ | 30 $GW_e$ | 70 $GW_e$ |
| Solar PV | 5.4 $GW_e$ | 50 $GW_e$ | 100 $GW_e$<br>(70 $GW_e$ by 2017) |
| CSP | 0.014 $GW_e$ | 1 $GW_e$ | 3 $GW_e$ |
| On-grid wind power | | 100 $GW_e$ onshore<br>5 $GW_e$ offshore | 200 $GW_e$ onshore<br>30 $GW_e$ offshore |
| **Thermal applications** | | | |
| Biogas | 47 million households | 50 million households | |
| Solar thermal | 258 million $m^2$ | 400 million $m^2$ | |
| Solar cooker | | 2 million sets | |
| Geothermal | 4.6 Mtce | 15 Mtce<br>580 million $m^2$ building space (heating),<br>1.2 million households (hot water) | |
| Bioethanol | 2 Mt | 4 Mt | 10 Mt |
| Biodiesel | 0.5 Mt | 1 Mt | 2 Mt |

*Sources: Based on CNREC (2012); Campbell (2014)*

connection in China. The law was amended in 2009 (IRENA, 2013; NPC, 2013).

According to this law, purchase price of renewable electricity generation is determined by the NDRC. The law provides the legal basis of the support to renewable energy based electricity generation, regulations for implementation and administrative practices that determine the electricity pricing. There are a number of obligations for power grid companies when entering into interconnection agreements with certain projects. They need to provide grid-connection services and related technical support. In addition they need to purchase and dispatch the entire amount of electricity generated from renewable energy projects (IRENA, 2013; Zhang *et al.*, 2013).

There is a free connection service provided by the SGCC for distributed solar PV electricity producers which are located close to consumers and for those with installed capacity of less than 6 $MW_e$ from 1 November 2012 onwards. In addition, in February 2013, SGCC expanded its free connection services to all types of distributed electricity sources (Zhang *et al.*, 2013).

Two main methods have been adopted— competitive tendering (government-guided pricing; an auction mechanism) and FiTs (government-fixed pricing) (NDRC, 2006; NPC, 2013; The World Bank, 2014). During the period from 2006 to July 2009, the grid-connected power price of wind power projects was determined by a government-guided price set in accordance with the price selected through a public request for tenders.

Under the concession programme (*i.e.*, auctions), investors and developers are selected for renewable energy projects such as large wind farms or solar plants through a competitive bidding process; the government is committed to coordinating connection to the power grid and purchasing all the electricity generated by the concession projects. Between 2003 and 2007, the NDRC initiated five rounds of concession bids for wind power projects (Cozzi, 2012). Auctions were also implemented for solar PV, offshore wind and CSP. Price was the determinant factor in deciding successful bidders (IRENA, 2013; Zhang *et al.*, 2013).

These auctions were basis for setting the level for the FiT as the government was able to gather cost information from various renewable energy projects (Wang, Barosso and Elizondo, 2014). A categorised on-grid price setting for each individual source of renewable energy generation connected to the grid has been implemented to determine the FiT from 2005 onwards. To set the price the following factors are taken into account (Zhang *et al.*, 2013):

- Techno-economic performance of different renewable energy technologies
- Geographic location
- Availability of renewable energy resources
- The FiT rates evolved over time and have been continuously reduced according to the cost of development (see Table 10 for the rates as of July 2014).

## Government financial support for renewable energy projects

The Chinese government also supports renewable energy projects by providing financial subsidies. In 2009

*Table 10: Overview of the current feed-in-tariffs in China by technology and resource*

| | | | | |
|---|---|---|---|---|
| **Onshore wind** | I area[1] | II area[2] | III area[3] | Other areas |
| | 0.082 | 0.087 | 0.093 | 0.098 |
| **Solar PV** | I area[4] | II area[5] | Other areas[6] | |
| | 0.145 | 0.153 | 0.161 | |
| **Biomass** | Agricultural and forest biomass | Waste | | |
| | 0.121 | 0.105 | | |
| **Offshore wind** | Near shore | Intertidal | | |
| | 0.137 | 0.121 | | |

*Note: Information refers to July 2014 and all values are expressed in USD/kWh with tax included. A currency exchange rate of 1 USD = 6.21 RMB was used referring to 18 July 2014.*

[1] *In addition to other areas of Inner Mongolia Chifeng, Tongliao City, Xing'anmeng Hulunbeir; Urumqi, Yili Kazak Autonomous Prefecture, Changji Hui Autonomous Prefecture, Karamay, Shihezi City.*

[2] *Zhangjiakou City, Hebei Province, Chengde City; Chifeng, Tongliao City, Hing'an, Hulun Buir City; Zhangye City, Gansu Province, Jiayuguan, Jiuquan City.*

[3] *Baicheng City, Jilin Province, Songyuan City; Jixi City, Heilongjiang Province, Shuangyashan, Qitaihe City, Suihua City, Yichun City, Mountains region; Zhangye City in Gansu Province, in addition, Jiayuguan, Jiuquan City than in other regions; Xinjiang addition Urumqi, Yili Kazak Autonomous Prefecture, Changji Hui Autonomous Prefecture, Karamay, Shihezi than other regions; Ningxia.*

[4] *Ningxia, Qinghai Haixi, Jiayuguan, Gansu, Wuwei, Zhangye, Jiuquan and Dunhuang, Jinchang, Xinjiang Hami, Tacheng, Altay, Karamay, except Inner Mongolia Chifeng, Tongliao, Xing'anmeng, Hulunbeier area.*

[5] *Beijing, Tianjin, Heilongjiang, Jilin, Liaoning, Sichuan, Yunnan, Inner Mongolia Chifeng, Tongliao, Hing'an, Hulunbeier, Hebei Chengde, Zhangjiakou, Tangshan, Qinhuangdao, Shanxi Datong, Shuozhou, Xinzhou, Shanxi Yulin, Yan'an, Qinghai, Gansu, Xinjiang and other areas in addition to area I.*

[6] *Tibet autonomous region benchmark price will be forthcoming.*

the Ministry of Finance (MOF) initiated two national solar PV subsidy programmes to support and expand the domestic solar industry:

- An up-front subsidy for building-integrated PV (BIPV) systems and a subsidy of 50% of the bidding price for the supply of critical components are provided (Zhang *et al.*, 2013). Financial support has decreased substantially since the programme's inception, reflecting the declining cost of photovoltaic energy. By 2012, the rate had fallen to 9 RMB/W for BIPV (compared with 20 RMB/W in 2009) and 7.5 RMB/W for rooftop systems (from 15 RMB/W in 2009) (Lo *et al.*, 2014).
- The Golden Sun Demonstration Programme provides direct subsidies for on- and off-grid PV systems: equivalent to 50% of the total cost for on-grid systems and 70% for off-grid systems in rural areas. In 2012, on-grid systems received RMB 5.5/W, while off-grid systems received RMB 7.0/W (Lo *et al.*, 2014).

## 5.3 Transport sector related policies

There are four key policy mechanisms related to passenger cars which aim to reduce energy demand and increase the share of renewable energy use:

- Fuel economy standards and labelling
- Vehicle and fuel taxation
- Subsidies for energy-efficient and electric vehicles

**Box 4: Distributed solar PV in China and new policy developments**

Distributed solar PV in China deserves particular attention. It is important for the country because it is an emerging industry and provides opportunities for new local jobs as well as the chance for users to become producers. In addition, distributed solar PV offers cost benefits compared with utility-scale plants that need to be connected to the grid. Particularly because of these benefits, the government has been encouraging investments since late 2013.

Due to the slow uptake of the technology, it had not been expected that production would reach the government's 8 $GW_e$ target. But by the end of 2013, the total installed distributed solar PV capacity had reached 4 $GW_e$ and, in the first quarter of 2014, more than 3 $GW_e$ capacity was commissioned. This creates hopes that the 8 $GW_e$ target might be achieved in 2014.

In early September 2014, the NEA made its policy updates public which include a range of options (BNEF, 2014b, EnergyTrend, 2014). The policy offers the option to choose between a premium subsidy and a local FiT for solar PV that is connected to a transmission grid. Furthermore, the challenges related to grid connection and payments are also addressed.

The policy update also addresses a number of more specific areas. For example, local governments are encouraged to include distributed solar PV in their planning and to provide guidance and support to both investor and owners, in particular in development zones, on large company rooftops, on public infrastructure and in areas previously not considered for distributed solar PV. Investments in projects outside the current system boundaries for distributed solar PV are also accounted for, such as plants on abandoned land, greenhouses, lakes or ponds.

While all these policy updates are very encouraging, many barriers remain to the growth of a distributed solar PV market for China. These include the need to improve the quality of equipment available, a lack of standards, lack of financing and risks that involve roof ownership as well as technical issues relating to infrastructure.

- Incentives for biodiesel use

The State Council considers electric vehicles to be key to transforming the transport sector. There are three types of subsidies for energy-efficient and electric vehicles (Lo *et al.*, 2014):

- Energy-efficient automobiles with fuel consumption of between 4.8 litres per 100 km to 6.9 litres per 100 km, depending on weight, are supported with 3,000 RMB,
- Electric vehicles:
    - Support ranges from 3,000 RMB to a maximum of 50,000 RMB depending on battery capacity and type of vehicle,
    - Plug-in hybrid vehicles (50,000 RMB),
    - Pure electric vehicles (60,000 RMB)
- Hybrid and electric public vehicles, including buses, taxis, official vehicles and municipal service vehicles (*e.g.*, garbage trucks and mail trucks), are subsidised based on the length and type of vehicle, its fuel-saving potential, and the ratio of electric motor and battery type

China is also aiming for 30% of new government vehicles to be powered by alternative energy by 2016. In addition to subsidies, there were a number of license plate-based policies (*e.g.,* odd-even, end-number) in Beijing to reduce car use. In Beijing there is also a policy to increase the purchase of small passenger cars with fewer than five seats. Another policy in the city restricts driving by one day a week to reduce car use by 20% during week days (Wang *et al.*, 2013).

While in principle the government is keen to encourage the use of biofuels, there are a number of major constraints. A variety of feedstocks can be used for ethanol production, including cassava, sugar cane or sweet sorghum. However, land availability is an important issue for China in view of the demand for food. Rising domestic grain prices have also led to ambitious plans for transportation biofuel production based on food crops being abandoned.

Instead, attention has focused on advanced biofuels and the main policy for biofuel production in China is to avoid competition with crops for human consumption. Since 2008, the government has been tightening controls on the grain processing sector to lower financial support for grain-based ethanol production. By 2015, a value added tax rebate will also be removed and a 5% tax for grain-based ethanol production will be applied. There are nationwide targets to increase the consumption of bioethanol and biodiesel. Each province or city has the authority to implement its own policies. With regard to bioethanol, there are limited incentives for grain-based production and subsidies have been cut. In the case of biodiesel, there are no national or provincial mandates given the small scale of production (USDA, 2013). It should also be noted that, unlike the European car market, in China only trucks use diesel engines. Thus the feedstock for biofuels for domestic consumption in China will differ from other countries.

***The future of the biofuel sector is still under discussion – industry development is therefore insecure***

## 5.4 Solar water heating policy for buildings

China has installed the most solar water heaters in the world, accounting for nearly two-thirds of global capacity. The adoption of solar thermal heating has accelerated without government support; between 2000 and 2012 solar water heater installation increased almost tenfold from 26 million $m^2$ to more than 250 million $m^2$. In 2009, the MOF started a support programme to subsidise solar thermal use for rural consumers in China. This programme provided an allowance equivalent to 13% of the product price, with a ceiling of RMB 5,000 per unit for solar water heaters. In June 2012 a new subsidy programme was initiated by the MOF for urban consumers offering up to 550 RMB per installation (Lo *et al.*, 2014).

## 5.5 Industrial policies for renewable energy

There are important socio-economic benefits of renewable energy deployment such as increased income, industrial development and job creation (IRENA, 2014e). Hence in addition to policies that focus on renewable energy use, China uses specific supply-side tools to support the development of a national renewable energy industry. One of them is financial support for research and development (R&D). The 11th FYP classified the development of energy technologies as a top priority and provides short-term targets and goals for China's R&D and innovation activities as well as listing energy technologies as a key area (Zhang *et al.*, 2013). Three key clean technologies are highlighted:

2–3 MW$_e$ wind turbine commercialisation: Among various publicly funded programmes, the "863" and "973" programmes were the two most important, providing substantial direct funding

- Domestic wind industry across the entire value chain: The Ministry of Finance also established a special fund to support enterprises in their R&D. These enterprises are either controlled domestically or 100% owned and produce wind power machines and equipment
- Solar PV: Several R&D projects have been government-financed, such as polysilicon production. This enabled bodies such as the state-owned Semiconductor Research Institution to transfer knowledge from its R&D to other manufacturers in China

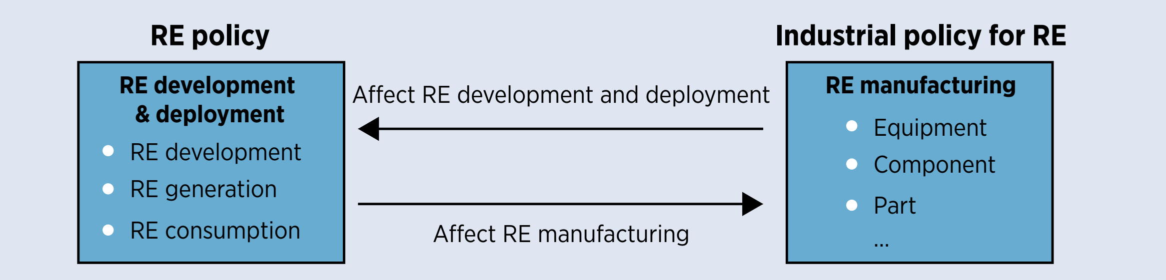
Another key area for financial support is renewable energy equipment manufacturing. In order to achieve self-sufficiency in the supply of such equipment, China offers import tax exemptions for complete sets of

### Box 5: China´s "push & pull" strategy to expand the renewable energy industry

China has used a unique "push & pull" strategy for the expansion of renewable energy over the past decade. The first step occurred in 2006 with the creation of a market for renewable generation based on a FiT programme that drew heavily on the experience of other such schemes elsewhere, particularly in Germany. As a result, a renewable electricity market was developed that created bankable project developments for new wind turbines.

At the same time, China has actively encouraged the establishment of a local wind industry and a solar PV industry. These "push" mechanisms have included R&D programmes, financial support for renewable energy technologies and local content requirements which have driven a significant expansion of the domestic manufacturing base.

*Figure 12: Interactions between renewable energy policy and renewable energy industrial policy*



*Source: Based on Zhang et al. (2013)*

Additionally, a strong export strategy – especially for solar photovoltaic technologies – was established to boost demand for China´s renewable energy manufactured products. The result has been a significant reduction in the cost of solar PV modules and a market in China that installed 13 GW$_e$ of new solar PV in 2013.

Expanding the annual output of renewable energy manufacturers in turn achieves economies of scale which reduce generation costs and lead to cost-competitiveness with conventional forms of power generation. Increased market competitiveness also leads to a decrease in required FiTs. The interaction of lower equipment costs and the resulting lower generation costs provides benefits for all involved. These types of positive feedback loops are possible especially in larger economies.

foreign-made equipment, as well as import tax exemptions for foreign-made parts which are necessary for the development of key equipment for domestic enterprises (Zhang *et al.*, 2013).

***China is encouraging local renewable equipment manufacturers through a range of tax exemptions as well as direct financial support***

State-owned banks and local governments have also provided strong financial support for "strategic emerging industries," which include the renewable manufacturing industry. The China Development Bank (CDB) has provided low-cost loans to the top five PV manufacturers in the country (USD 30 billion in 2010 alone). Solar PV manufacturing is one of the key industries identified according to the Catalogue of Chinese High-Technology Products for Export which was updated in 2006. Solar PV manufacturers are eligible for additional financial support for R&D and for export credits at preferential rates from the Import–Export Bank of China. They are also eligible for export guarantees and insurance through the China Export and Credit Insurance Corporation (Zhang *et al.*, 2013).

## 5.6 Carbon policy

China announced in March 2011 that it would develop carbon-emission trading pilot projects to support its 12th FYP carbon intensity target, signalling its increasing interest in the use of market mechanisms (IEPD, 2014; Baron *et al.*, 2012).

Carbon trading in China has been in development since 2008. As policies around climate change and clean energy were being developed, private exchanges began to be set up that year. The first such institutions were the China Beijing Environment Exchange (CBEEX), the Tianjin Climate Exchange (TCX), and the Shanghai Environment and Energy Exchange (SEEE). These institutions initially focused on the clean development mechanism (CDM) and voluntary carbon credit markets (IEPD, 2014).

In January 2012, the NDRC ordered the seven carbon market pilot regions to set a cap on carbon emissions in preparation for the launch of their trading schemes. This notice also required each region to set up a fund to support the trading scheme and to prepare implementation plans. Guangdong's plan has already been approved by the NDRC where the province aims to reduce its carbon intensity by 19.5% by 2015 compared to 2010 levels and raise its non-fossil-fuel energy share in total energy consumption to 20% by 2015. The $CO_2$ emissions cap is 660 Mt $CO_2$. Compared to the 2007 emissions of 508 Mt $CO_2$, this allows room for continued growth in its emissions (IEPD, 2014).

In June 2014, China announced that it will introduce an absolute cap on emissions from 2016 as its 13th FYP comes into force (Reuters, 2014b). At the same time, the government also launched its seventh pilot carbon market, the last before a national scheme which is expected to be launched in 2018.

China is promoting emissions trading as one way to drive efficiency and carbon emissions cuts across its heavy industry sector, thus boosting air quality and reducing the country's contribution to climate change. The government is discussing how and whether a national cap and trade scheme, a carbon tax or pollution limits will be introduced. Five of the seven provinces today have an absolute cap on emissions which could also be applied to a national scheme. Beijing has an intensity-based target (emissions per unit of GDP) (RTCC, 2014).

In order to develop China's carbon trading system further, all pilot projects will be evaluated. The NDRC developed the following concept for the development of a Certified Emission Reduction trading scheme (Feng, 2014):

- Enhancement of macro policy:
  - The possible development of an emissions trading system (ETS) as one of the key tasks in pushing forward reforms of the economy and establishment of a new ecological cultural system
  - The 12th FYP on Social and Economics Development
  - A working programme on GHG Emission Control, as part of the 12th FYP
  - The decision of the Third Plenary Session of the Eighteen Central Committee

- Related preparation works:
  - CDM cooperation

Table 11: Overview of carbon trading systems in seven provinces of China

| Province / Region | Launch date | Covered Carbon Emissions (Mt) |
|---|---|---|
| Beijing (BJ) | November 2013 | 60 |
| Shanghai (SH) | November 2013 | 136 |
| Chongqing (CQ) | June 2014 | 125 |
| Guangdong (GD) | December 2013 | 388 |
| Tianjin (TJ) | December 2013 | 108 |
| Shenzhen (SZ) | June 2013 | 33 |
| Hubei (HB) | December 2013 | 324 |

- The development of a Chinese Certified Emissions Reductions (CCER) trading scheme

Since 2011, seven emissions trading pilot programmes have been initiated with the purpose of exploring the best approaches and obtaining the necessary experience for the development of a national ETS scheme in China. According to Feng (2014), the following trading methods are applied in the seven provinces/regions:

- Shenzhen, Tianjin and Hubei: enterprises with compulsive responsibility, other approved organizations and individuals are all allowed for trading
- Beijing: enterprises with compulsive responsibility, other approved organisations are both allowed for trading
- Guangdong and Shanghai: Only the enterprises with compulsive responsibility are allowed for trading now but are considering to include organisations and individuals
- Beijing and Tianjin: Over-the-counter is allowed.

Jotzo, de Boer and Kater (2013) undertook a survey from late July to early September 2013, eliciting expectations about the future of China's carbon price from 86 China-based experts on carbon pricing and carbon

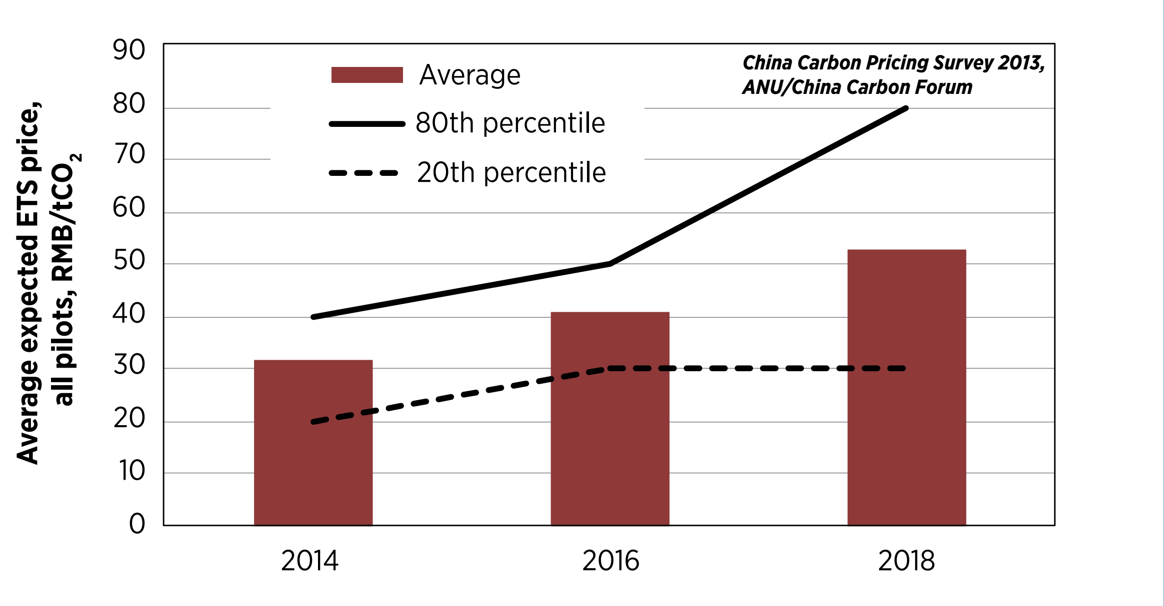
Table 12: China's ETS pilots and performance

| Province / Region | Legislation | | MRV guideline | GHG emission verification | Scope and coverage | Cap set | Allowance allocation | Start trading | Accumulated trading volume of $CO_2$ (tonnes) | Accumulated trading value (RMB) | Average price in total (RMB/t) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Legislation level | Administrative level | | | | | | | | | |
| SZ | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Jun-13 | 328 559 | 23 240 598 | 71 |
| SH | | Yes | Yes | Yes | Yes | Yes | Yes | Nov-13 | 342 955 | 13 097 987 | 38 |
| BJ | | Yes | Yes | Yes | Yes | Yes | Yes | Nov-13 | 86 983 | 4 660 401 | 54 |
| GD | | Yes | Yes | Yes | Yes | Yes | Yes | Dec-13 | 126 181 | 7 594 028 | 60 |
| TJ | | Yes | Yes | Yes | Yes | Yes | Yes | Dec-13 | 109 060 | 3 221 618 | 30 |
| HB | | Yes | | Yes | Yes | Yes | Yes | Apr-14 | 2 819 876 | 68 005 497 | 24 |
| CQ | | Yes | | Yes | | | | 2014 (estimated) | | | |

*Source: Based on Feng (2014)*

*Note: Trading volume until 21 May 2014*

*Figure 13: Expected average carbon price – China carbon trading*



*Source: Based on Jotzo, de Boer and Kater (2013)*

markets. The results indicate confidence that China's seven pilot ETS projects will be implemented, with prices rising over time and influencing investment decisions. However, there remains significant uncertainty about price levels.

There are high expectations that China will introduce national emissions trading in combination with a carbon price. A significant majority of respondents expect that China's 2020 emissions intensity target will be achieved or surpassed, and almost all expect further targets to be adopted in 2025 and 2030, possibly in the form of absolute limits on emissions.

According to the survey by Jotzo, de Boer and Kater (2013), the average carbon price across all the ETS pilot projects that are in operation is expected to be around RMB 32/t in 2014; RMB 41/t in 2016; and RMB 53/t in 2018. However, there is considerable uncertainty about price levels. For the national ETS, the average price expectation (factoring in no scheme and zero price expectations from some of the respondents) rises steadily from RMB 29/t in 2018, to RMB 51/t in 2020, and to RMB 68/t in 2025. As of early September 2014, NDRC indicated the total emissions it could regulate by 2020. These would range between 3 billion and 4 billion tonnes of $CO_2$ emissions and the market will be worth up to USD 60 billion at the carbon prices suggested by the NDRC (RE New Economy, 2014). This would make the market twice as big as the EU, which is currently the world's largest. China plans to start a national market in 2016.

## 5.7 Electricity pricing

Power prices are generally set by the state for both generation and distribution. The State Electricity Regulatory Commission (SERC) was set up in 2002 independent from the price setting NDRC. Its tasks were mainly to establish and monitor an electricity-trading mechanism between power generators and buyers. This trend is reversed in the new structure.

In terms of pricing, thermal power plants pay a fixed uniform tariff irrespective of the time of day. Prices are set a year ahead. Unlike many other markets, China lacks short-term and real-time trading of electricity. China´s electricity pricing system is controlled by the NDRC.

A central renewable energy fund has been established. This is mainly supplied through a fixed surcharge on all electricity purchases. As renewable growth has picked up in recent years, the fund has faced shortfalls. This may have contributed to late or non-payment to generators. In order to ensure that the fund is solvent with more costly solar installations coming online, both revenue streams and subsidy outlays to generators will need to be modified. Historically the high penetration of state-owned energy companies active in the renewable sector have influenced investment decisions. These state-owned companies have traditionally had responsibilities to the state besides turning a profit.

There is a considerable difference between residential and industrial electricity prices. NDRC and the grid companies agree on provincial electricity costs for residential consumers which are kept purposefully low. While a large difference exists between the international average and China's residential electricity prices, industry prices are closer to the global average and much higher than residential sector prices in the country.

The "Increasing block tariff" (IBT) is a common pricing mechanism used to encourage households to conserve electricity. It also divides electricity consumption into several blocks for calculating electricity prices (Lo *et al.*, 2014). The IBT is often used in addition to subsidy programmes for energy-efficient appliances in China to help conserve energy use by rewarding low electricity consumption or by punishing overconsumption. The IBT price of electricity sets a limit beyond which usage is charged at a higher price.

The NDRC approved a shift from the single tariff system in 2010. However, the use of block tariffs was not implemented across China until July 2012 because of the potential negative impacts such as the affordability of electricity and, partly in consequence, social stability (Lo *et al.*, 2014).

China's IBT has a three-block structure:

- The price for the first block (0–240 kWh per month) is subsidised to ensure residents are able to afford basic electricity and is expected to cover approximately 80% of electricity consumption
- The price for the second block (241–4,400 kWh) is set to recover full costs
- Finally, the price on the third block (4,400 kWh) is punitive and considers resource scarcity and pollution externalities. Low-income groups are allowed to consume a certain amount of electricity at no cost (Lo *et al.*, 2014)

***China has a number of electricity pricing mechanisms – both for supply and demand. Were the electricity market to be established, the entire design of the current power sector would require significant changes***

The tariffs paid to generators of wind and solar power were earlier determined by auctions. These auctions were then used as the basis for setting the level for the FiT. Wind and solar power capacity has grown quickly in China. In order to address the issue of solvency of the fund, in August 2013, NDRC doubled the electricity surcharge for industrial customers. Since a large share of China's total electricity demand is consumed by industrial users, this will make a substantial contribution to the fund. Concurrently FiTs for solar were scaled back through instituting a regional system similar to that developed for wind (Davidson, 2013a).

Additionally, on-site distributed solar electricity will receive a RMB 0.42 per kWh subsidy. Any excess electricity sold back to the grid, where grid connections and policy are in place, will be at the prevailing coal tariff, ranging from RMB 0.3 to RMB 0.5 per kWh (USD 5-8 cents per kWh). It is unclear if these adjustments will mitigate the expected large financial demands required to support solar technologies (whose FiT outlays per kWh are still more than double that of wind) (Davidson, 2013a).

# 6 RENEWABLES POTENTIALS

China has significant conventional energy resources. Potentially, it also has considerable renewable energy sources, most of which are still not utilised. Compared with the technical potentials of onshore wind and solar capacity, which are close to 3,000 $GW_e$, current installed capacities are minimal (Table 13). Resources vary by region. The northern parts of China have the best wind resources while the southeastern and central parts of China have high solar irradiation. The potential for hydro lies at 400–700 $GW_e$. By comparison, installed hydro capacity in 2012 was about 250 $GW_e$, about two-thirds of the total potential.

***China is blessed with abundant resources of all types of renewable energy sources, a small proportion of which are used today***

China also has abundant biomass resources, little of which are effectively used today. Biomass resources are related mostly to agricultural and forest logging residues, animal waste and industrial and municipal biodegradable wastes. The straw resource is concentrated in the northeast and lower Yangtse River. Furthermore there are significant wood resources in the northeast and southeast (Sichuan, Shandong, Jilin, Henan).

China produces around 700 Mt straw per year. Some 37% of this total is corn straw, 28% is rice straw and 20% is wheat straw. The remaining 15% includes various other crops. Around half of the straw is used for fodder and fertiliser. This leaves around half (350 Mt/year) for energy. Around 40% of this amount is already used (Zhang, 2014). The livestock industry equates to 135-170 Mt of animal wastes available for biogas production (Delman and Chen, 2008)

Sweet sorghum has the potential to be grown in different parts of China. In northern and southern China it is also possible to grow sweet potato. Cassava has a potential to be grown in the middle areas and lower Yangtze River as well as in southwest China (Qiu *et al.*, 2012).

China has limited forest resources and they are not evenly distributed across the country. The solid forest products industry is therefore dependent on imports where much of the hardwoods logs are brought from tropical sources and softwood logs are imported from Pacific Rim nations and Siberia (Bioenergy Crops, 2013b).

Table 14 shows a breakdown of the total biomass supply potential in 2030 by biomass. With the exception of Batidzirai, Smeets and Faaij (2012), no other study provides a potential for energy crops. The total supply potential of forest products, their residues, agricultural residues and waste according to the four studies range from 9 EJ to 19 EJ (307 Mtce to 648 Mtce) (excluding energy crops) by 2030.

***There is a biomass supply potential ranging from 9 EJ to 19 EJ in China by 2030 but only a limited amount of this is used effectively today***

By 2030, IRENA estimates that the supply costs of biomass will range from USD 3 to USD 12 per GJ. The lower

*Table 13: Renewable energy resource potentials of China*

| | 2012 capacity ($GW_e$) | Technical potential ($GW_e$) |
|---|---|---|
| Hydro | 250 | 400-700 |
| Onshore wind (>50m) | 63 | 1300-2600 |
| Offshore wind (at depth 5-25m) | 0.3 | 200 |
| Solar PV (utility) | 4 | 2200 |
| Solar PV (rooftop) | 1.4 | 500 |

*Source: CNREC (2012)*

Table 14: Breakdown of total biomass supply in 2030

| | Batidziari, Smeets and Faaij (2012) (EJ/year) | Van Sambeek *et al.* (2013) (EJ/year) | IRENA (2014c) (EJ/year) | CNREC estimates (EJ/year) |
|---|---|---|---|---|
| Forest products incl. residues | 0.9-7.8 | 5.6 | 2.1-2.4 | 6.8 |
| Agricultural residues incl. animal waste | 0.4-7.9 | 13.5 | 6.9-13.5 | 7.6 |
| Straw | | 4.1 | | 4.9 |
| Resides after food crop processing | | 0.9 | | 0.9 |
| Livestock manure | | 5.9 | | 0.8 |
| Municipal solid waste | | 0.38 | | 0.4 |
| Municipal sludge | | 0.05 | | |
| Industrial organic wastewater and sludge | | 2.2 | | 0.6 |
| Energy crops | 3.8-11.5 | | | |
| Total supply potential | 5.1-27.3 | 19.1 | 9-15.9 | 14.4 |

end of this range refers to agricultural residues (harvesting and processing) as well as biogas; the higher end refers to forest products and residues, including fuel wood.

# 7 REMAP OPTIONS

## Key points

- Options have been identified that could raise China's renewable energy use in terms of TFEC to approximately 23 EJ (770 Mtce) by 2030 (equivalent to 26% in the share of TFEC). This includes the full substitution of traditional uses of biomass with modern renewables.
- Some 49% of the total renewable energy use in REmap 2030 is related to renewable power options.
- Various forms of biomass (such as power, heat, motor fuel) and solar (PV, CSP, thermal) would account for 60% of the total renewable energy use in REmap 2030.
- 40% of the REmap Options that have been identified in the power sector are related to solar, one-third to biomass and 20% to wind. The remainder is related to geothermal. REmap Options for renewable heating and transportation account for two-thirds of the total.
- Total wind capacity would increase by 13 times compared with 2012. Solar and geothermal capacity would both increase by a factor of six or seven.
- Total biomass use would double from 2012. While traditional use of biomass is fully substituted between 2010 and 2030, modern uses of biomass increase by five times in the same period.
- Additional biomass use potential is concentrated in heating markets (building and industry), including the district heat generation sector.
- The total package of REmap Options identified requires additional costs of USD 5.6 per GJ (RMB 1230 per tce) for consumers and USD 6.9 per GJ (RMB 1480 per tce) for society (USD 55-60 bln/year additional costs; RMB 375-410 billion per year). These costs exclude savings from the benefits of renewable energy from improved human health and reduced $CO_2$ emissions.
- Costs are outweighed by estimated savings due to external effects from air pollution, including a reduction of 1,690 Mt of $CO_2$ per year in 2030.
- There are challenges for wind and biomass related to connecting supply and demand, and costs associated with these. Furthermore, barriers related to permitting, licensing and other regulatory issues need to be resolved in order to build the necessary transmission grid. While a part of the bioenergy demand in end-use sectors could be met with local feedstock availability, domestic logistics for bioenergy trade must be developed to meet demand spread across the country.

The Reference Case (*i.e.* business as usual) analysis for China utilizes an internally developed REmap tool that incorporates the estimates of the IEA *WEO* New Policies Scenario and CNREC for the year 2030. The data, assumptions and approach used have been summarised above in Section 4. The tool allows IRENA to enter additional renewable energy options in the end-use sectors of industry, buildings, and transport, as well as for power and district heat generation. The process for the REmap Options was as follows:

1) Reference Case for the period between 2010 and 2030 was created. The results of this projection are explained in Section 4,
2) Commodities and fuel prices were prepared to reflect the national situation,
3) Technology cost and performance criteria (*e.g.,* capacity factors) were prepared to reflect the national situation,
4) Additional renewable energy options for all end-use sectors and the power sector were analysed based on various study and assessments.

The following studies have been used to identify additional renewable energy options beyond the Reference Case:

a. For power sector: CNREC estimates, historical trends, IEA estimates and IRENA renewable energy industry roadmap and its accompanying data were used (for biomass power generation from CHP) (IRENA, 2014b),
b. For transport sector: IRENA estimates were used,
c. For industry sector: a recent IRENA renewable energy in industry roadmap (IRENA, 2014b) and its accompanying data was used; only renewable energy options for new capacity were considered.

d. For building sector: an internal analysis of Reference Case developments and REmap Options was used in addition to the draft "Roadmap Research of China Solar Thermal Development" (Ruicheng, Tao and Xuan, 2014).

This section is divided into five sub-sections. Section 7.1 focuses on the potentials of different renewable energy technologies in China and also mentions the top regions with resource availability. Section 7.2 provides the REmap Options. In Section 7.3, costs of REmap Options are estimated and Section 7.4 presents the cost-supply curves for the REmap Options. Section 7.5 discusses these findings.

## 7.1 Renewable energy technologies

### Wind

The potential for wind lies mainly in the northwest and northeast, and partly in the east of the country. In these regions, wind speeds easily exceed 8-9 m/s and capacity factors reach between 20% and 40% (IEA, 2011a; He and Kammen, 2014). However, the ability to deliver electricity to consumers in the southern and eastern parts of the country is a challenge given existing grid infrastructure.

A regional approach has been chosen in determining the potential of wind in China by distinguishing between high and low capacity factor regions. More than two-thirds of the total wind potential is assumed in regions with large wind resources, mainly east and west Inner Mongolia as well as Xinjiang, Gansu and Jiangsu (where capacity factors reach up to 35%). The remaining potential is assumed in regions with moderate availability of wind resources (those with capacity factors of around 20%).

A total of 246 $GW_e$ capacity has been assumed as Remap Options on top of the capacity identified in the Reference Case. This results in a total installed capacity of 561 $GW_e$ in REmap 2030, which is much lower than the technical potential of approximately 2,500 $GW_e$. Realising this potential would imply the deployment of all possible installed capacity in Inner Mongolia, Xjiang, Gansu, Hebei, Jilin and Jiangsu (IEA, 2011a). To realise this high wind potential, it is also assumed that some of the coal plants built between 2010 and 2030 are retired early, in particular in western China. The total capacity growth is ambitious requiring about 24 $GW_e$/year of onshore wind capacity deployment, double current levels. For offshore wind, the growth is about 3 $GW_e$/year.

### Solar PV and CSP

In the southwest and to the north of China, solar irradiance levels range from 1,500 to 2,000 kWh/m$^2$/year. So far most solar capacity is also installed in this band, notable in Qinghai. Most of the rest of the capacity is assumed to be deployed in this region as well, but with rooftop solar PV distributed in other parts of China as well. The average capacity factor is estimated as 17% for utility-scale projects, and about 15% for rooftop solar PV. An additional 169 $GW_e$ in the 2010-2030 period (on top of the 139 $GW_e$ in the Reference Case in 2030) was assumed in REmap 2030. In total, by 2030, 309 $GW_e$ of solar PV would be installed (of which 118 $GW_e$ is rooftop), representing an installation rate of around 16 $GW_e$ per year. Most of the utility-scale solar PV will be installed in western parts of China whereas distributed solar PV will be spread across the country, but mainly in the eastern parts of the country.

Solar CSP could also play a further role in China, mainly in parts where solar PV also has potential, such as Xinjiang and Qinghai. Without storage, the capacity factor would be around 17%. An additional 20 $GW_e$ on top of the Reference Case of 12 $GW_e$ is assumed in REmap 2030.

### Geothermal

Geothermal resources are available in many areas, but in most locations the temperatures are moderate, ranging from 30-90° C. Since 1990, the use of geothermal energy for space heating, recreational bathing and spas, and cultivation has evolved rapidly.

High-temperature geothermal resources do exist, but they are limited to a few locations in southern Tibet, western Yunnan and western Sichuan, on the Himalayan Geothermal Belt. Thus far, total installed capacity is 27 $MW_e$. As of 2006, 181 geothermal systems had been found on mainland China, with an estimated generation potential of 1.74 $GW_e$. This is small compared with the overall power demand needs and most of this capacity is assumed to be deployed in the Reference Case. In REmap Options, no additional capacity is assumed.

## Biomass/biogas

As discussed in Section 5, China has considerable biomass potentials which are not utilised to their full extent yet. These include a mix of agricultural residues, waste and forest products. To some extent, straw production is already utilised, so is fuel wood in traditional forms. However, there is also a major potential for the use of modern forms of biomass in the heating sector and partly for power generation, in particular in industrial combined heat and power (CHP) plants.

Central and northeastern parts of China have large stalk and straw potential which accounts for the majority of the total supply in China. The southwest has limited potential for agricultural residues. Fuel wood potential is distributed in the southern and central parts of China. As for animal manure, the main potential is in the southern and central regions as well as in northeastern China (Jingying *et al.*, 2001). Forest-based bioenergy use is in its infancy in China, but there is now a mid-term goal to develop forest-based bioenergy in those southern and eastern parts of China which are in close proximity to ethanol and biodiesel plants (Bioenergy Crops, 2013a).

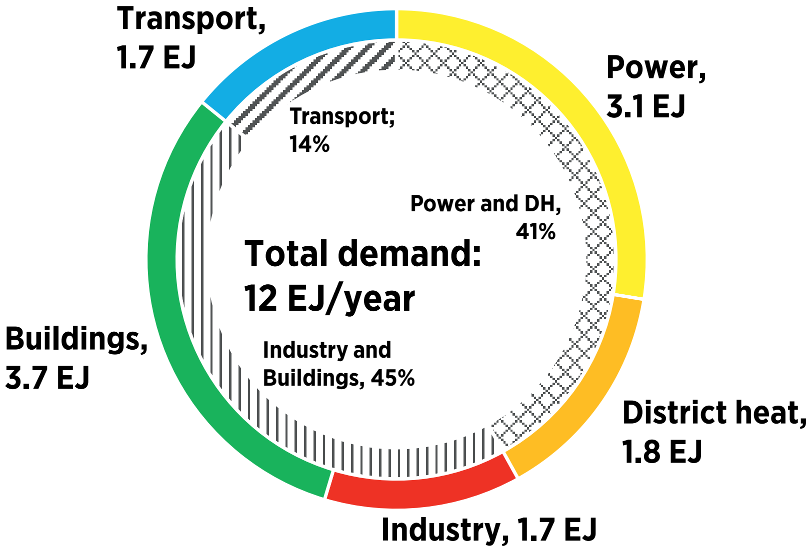
An additional 27 $GW_e$ of biomass power generation (including 6 $GW_e$ CHP used in industry) has been assumed on top of the 38 $GW_e$ identified in the Reference Case, as well as an additional 2.2 EJ of modern biomass for heating in industry and buildings (on top of the 3.1 EJ in the Reference Case). All traditional biomass use in the 2030 Reference Case of 2.9 EJ is substituted.

Figure 14 shows total primary bioenergy demand based on REmap 2030 reaching 12 EJ per year (410 Mtce), which based on the biomass supply literature review would represent two-thirds of the high end of the supply potential (8-19 EJ). Compared with the low-end of the total supply potential, demand could be higher. This implies that a large share of the bioenergy resource potential of China would be used. 30% of this total would be consumed in the building sector followed by a quarter for power generation. The demand for biofuel production and for heating in industry and district heat sectors account for 45% of the total demand.

## Hydro

Of the total potential for hydroelectricity, all the economic potential of 400 $GW_e$ is assumed to be deployed

***Figure 14: Primary biomass demand by sector with REmap Options, 2030***



already in the Reference Case. No additional potential is assumed in REmap 2030.

### Additional potential of renewables in end-use sectors

The analysis can still be expanded to include additional renewable energy options, particularly in end-use sectors where no comprehensive accelerated renewable energy scenarios are available. In industry, retrofits for biomass medium/high temperature process heat (to a large extent increasing the share of biomass and waste in the fuel mix of cement kilns) and solar thermal for low/medium temperature heat could be considered. Assuming about 20% of the total energy demand of the cement industry is provided by biomass and waste by 2030, a total of about 0.6 EJ of fuel would be required. Another 0.5 EJ of biomass for heat production in industrial CHP plants and 0.3 EJ of biomass for steam boilers are assumed that would account for about 2% of the sector's total energy demand for process heat generation (WBCSD, 2009; IRENA, 2014b).

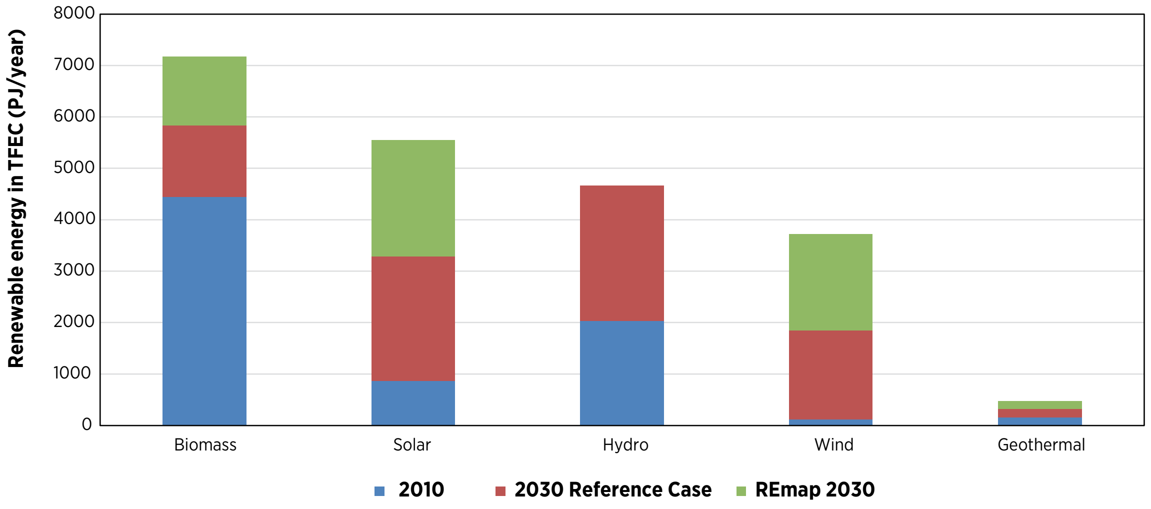
In REmap 2030, total solar thermal capacity in China is expected to reach 1,500 million m$^2$. Hence REmap Options represent an additional potential in 2030 of 700 million m$^2$ compared to the Reference Case of 800 million m$^2$. Building sector accounts for 70% of the capacity installed by 2030 (60% residential and 10% commercial). The remaining 30% is located in the industry sector. The major task is to substitute traditional uses of biomass with modern cooking stoves and to continue to increase the use of solar thermal for water/space heating.

For the REmap analysis it is assumed that that the package of electric two-wheelers, extended metro and broader use of electric buses can replace 20% of the projected car demand in 2030. As for road transportation, a significant amount of the capacity is needed to haul coal from the mines to the centres of demand. The REmap Options could reduce coal demand by around 5%. It is estimated that this will reduce road transportation demand by around 1% in 2030.

## 7.2 Roadmap table and implications for renewable energy

REmap results in a significant increase in the amount of renewable energy consumed as a proportion of the total. In 2010, about 7.4 EJ/year of renewable energy was consumed in China. 60% of that was in different forms of biomass. The only other sizable contributions were from renewable electricity in the form of hydro and renewable heating from solar thermal in the building sector.

*Figure 15: Increases in renewable energy consumption in TFEC by resource*



In the Reference Case for 2030 an additional 7.2 EJ of renewable energy will be consumed, resulting in total renewable energy use of 14.6 EJ. The REmap Options show an additional 8.4 EJ of renewable energy. In REmap 2030, renewable energy use in the TFEC would reach 23 EJ. Compared with 2010 level, this is an addition of 15.6 EJ. Figure 15 shows the anticipated increase for each renewable energy resource. The largest growth in absolute terms is in the use of solar (including both PV and thermal applications), in total approximately 6 EJ between 2010 and 2030. Biomass, wind and hydro additions are each 3 EJ in the same time period.

Biomass may still be the largest source of renewable energy in REmap 2030, but it is actually solar, hydro and wind that show the highest growth rates.

### *There is scope to more than triple 2010 levels of renewable energy consumption to 23 EJ by 2030, with solar PV and solar thermal accounting for 40% of the total potential beyond the Reference Case*

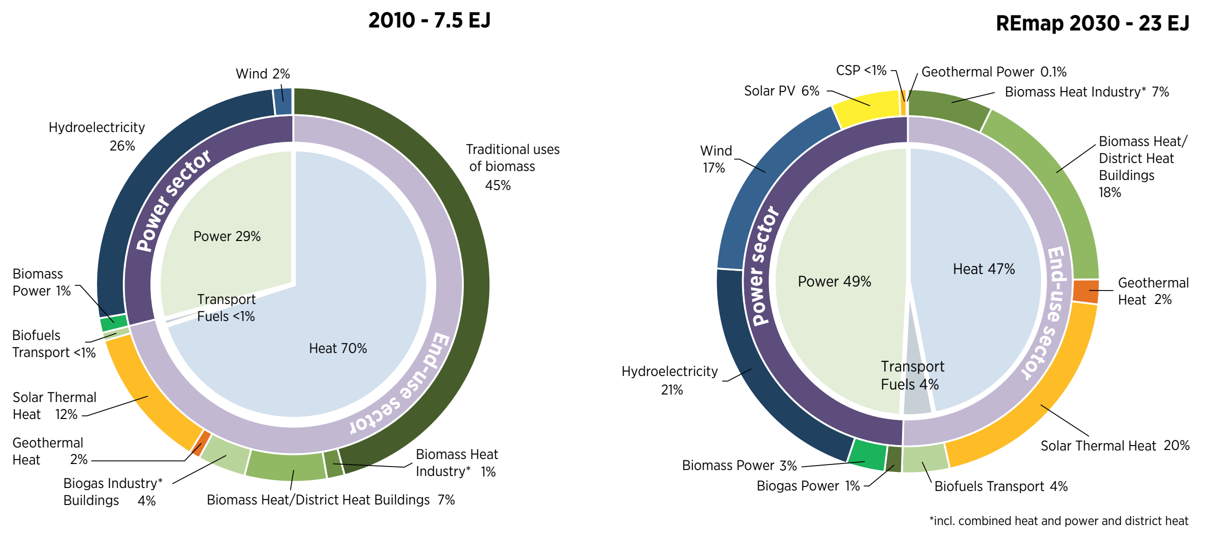
Figure 16 shows the breakdown of renewable energy by consuming sector between 2010 and REmap 2030. Note that biomass as an energy source changes significantly, as its traditional use in the building sector is replaced with modern alternatives. Also, the growth in biomass use is not seen in the power sector, rather in the form of biofuels and residue combustion for heating used in industry.

The other changes include a significant increase in solar thermal use in both the building and industrial sectors. In the power sector, hydroelectricity remains the largest source of electricity, however wind increases its share tenfold over 2010 levels. Solar PV goes from being almost non-existent in 2010 to comprising 6% of all renewable energy use by 2030, becoming the third most important source of renewable electricity in 2030. The power sector gains nearly a 50% share in the total renewable energy market by 2030, compared with 29% in 2010.

### *Renewable power and heating applications each would account for about half of the total renewable energy use in 2030 if all REmap Options are implemented*

Table 15 below shows the results of these increases on the share of renewable energy. When excluding traditional uses of biomass, modern renewable energy use increases from 7% of the total in 2010 (13% if traditional biomass is included), to over 16% in the Reference Case. When the REmap Options are included the share of modern renewable energy in the total mix can be raised to 26%.

*Figure 16: Breakdown of renewable energy use by application and sector, 2010 and REmap 2030*



**2010 - 7.5 EJ**

**REmap 2030 - 23 EJ**

*incl. combined heat and power and district heat

*Table 15: Breakdown of renewable energy share by sector*

|  | Renewable share of: | as % of: | 2010 | 2030 Reference Case | REmap 2030 | RE use REmap 2030 (EJ/year) |
|---|---|---|---|---|---|---|
| Industry | Heat | Heat consumption | 1% | 2% | 10% | 2.6 |
|  | Heat, Electricity & DH | Sector TFEC | 5% | 11% | 21% | 10.5 |
| Buildings | Heat | Heat consumption | 16% | 39% | 64% | 7.3 |
|  | Heat, Electricity & DH | Sector TFEC | 16% | 36% | 54% | 10.5 |
| Transport | Fuels | Fuel consumption | 1% | 5% | 5% | 0.9 |
|  | Fuels & Electricity | Fuel TFEC | 1% | 7% | 8% | 1.5 |
| Power |  | Generation | 19% | 29% | 40% | 13.2 |
| District Heat |  | Generation | 1% | 1% | 36% | 1.4 |
| **Total** | **excl. trad. biomass** | **TFEC** | **7%** | **16%** | **26%** | **22.5** |
| **Total** | **incl. trad. Biomass** | **TFEC** | **13%** | **17%** | **26%** | **22.5** |

The building sector leads in terms of renewable use, largely driven by the high levels of solar thermal use and biomass, followed by industry and transport. Renewable energy in power generation increases to almost 40%, with half of that, or 20% of all generation, coming from solar PV, CSP and wind.

### *Renewable energy use by the manufacturing industry and building sectors (including renewable power consumed in these sectors) would account for 90% of the total renewable energy use in REmap 2030*

Figure 17 shows how the REmap Options would change the primary energy fuel mix in 2030. Renewables become the second largest contributor of energy services in total primary energy demand (TPED)[17] based on both methodologies used to convert renewable energy to primary energy. The "RE high" calculation uses the US Energy Information Agency's partial substitution method while the "RE low" calculation uses the IEA physical energy content method. These do not represent different cases, or levels of renewable energy consumption, rather differences in converting renewable electricity and heat into primary equivalents.

In primary terms, renewable energy increases between 42% and 48% over the 2030 Reference Case. Coal sees the most significant reduction, with 18% fuel savings to about 65 EJ of primary fuel (2 220 Mtce) but remains the largest source of primary energy. Natural gas sees the second largest reduction of 9%, and is the fourth largest energy carrier after coal, oil and renewables. Oil is the third largest contributor of primary energy and sees only a 7% reduction. Finally nuclear remains unchanged and the smallest contributor to primary energy (using the IEA method).

Table 16 goes into more detail about the energy system, including data for 2010 (the analysis base year), the 2030 Reference Case, and REmap 2030 which includes the REmap Options. The renewable energy share in the TFEC, when excluding traditional biomass, increases from 7% in 2010 to 16% in 2030 according to the Reference Case (or from 14% to 17% if including traditional use of biomass).

Implementing all REmap Options can raise the renewable energy share to 26% in REmap 2030. This will result in total renewable energy use of 23 EJ/year (770 Mtce) by 2030. This consists of 0.9 EJ liquid biofuels, 11.5 EJ renewables for heat in end-use sectors and 10.1 EJ re-

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[17] There are different methods applied to estimate the total primary energy demand. The two applied in this study are the "physical energy content" and "substitution" methods. The physical energy content method is used by the IEA and Eurostat where renewable electricity and biofuels are counted as primary energy as they appear in the form of secondary energy, while geothermal, CSP and nuclear are counted using average process efficiencies to convert them into primary energy equivalents. The substitution method is used by the US EIA and BP where renewable electricity and heat are converted into primary energy using the average efficiency of the fossil fuel power and heat plants which would otherwise be required to produce these quantities.

*Figure 17: Changes in total primary energy supply in REmap 2030*

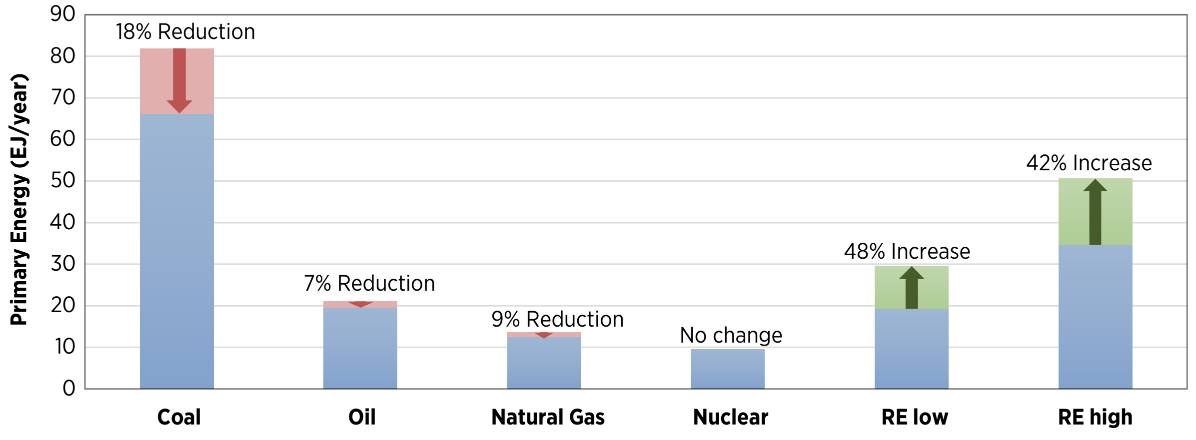


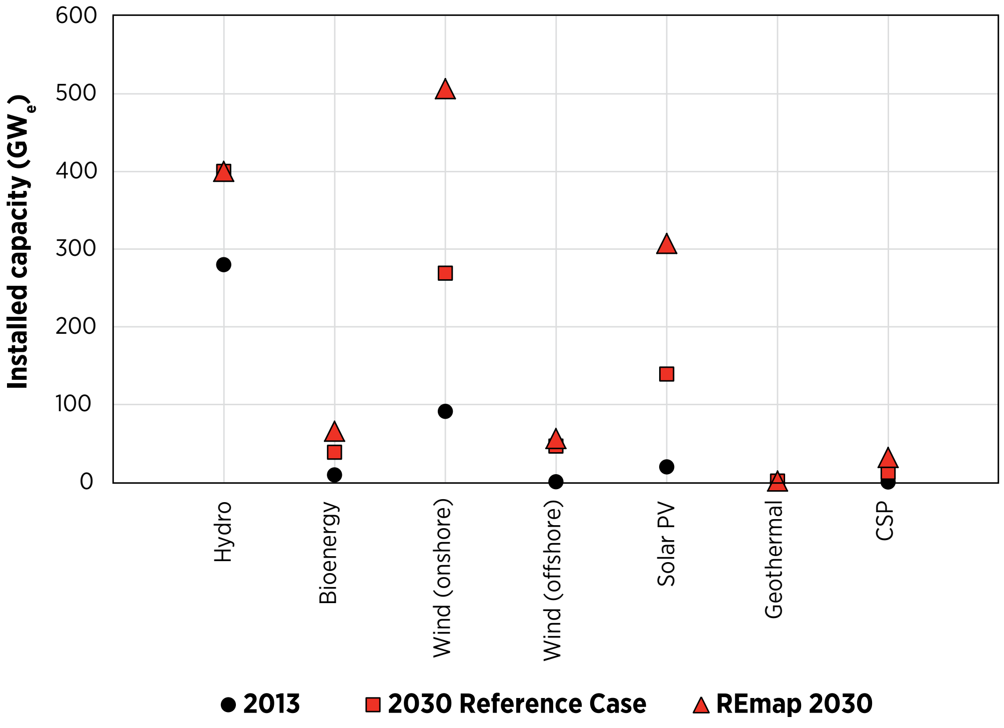
*Table 16: China REmap 2030 overview*

| **1. Electricity generation** | | **Unit** | **2012** | **Reference Case 2030** | **REmap 2030** | **Difference between REmap 2030 and Reference Case** |
|---|---|---|---|---|---|---|
| **Installed Capacity** | **Renewable energy** | $GW_e$ | **345** | **1 005** | **1 467** | **462** |
| | hydroelectricity (excl. pumped storage) | $GW_e$ | 249 | 400 | 400 | 0 |
| | hydroelectricity pumped storage | $GW_e$ | 20 | 100 | 100 | 0 |
| | Wind onshore | $GW_e$ | 63 | 269 | 501 | 232 |
| | Wind offshore | $GW_e$ | 0.3 | 46 | 60 | 14 |
| | Biomass (incl. biogas, industry CHP) | $GW_e$ | 7.7 | 38 | 65 | 27 |
| | Solar PV utility scale | $GW_e$ | 4 | 98 | 190 | 92 |
| | Solar PV rooftop | $GW_e$ | 1.4 | 41 | 118 | 77 |
| | Solar CSP | $GW_e$ | 0.014 | 12 | 32 | 20 |
| | Geothermal & Ocean | $GW_e$ | 0.03 | 1 | 1 | 0 |
| **Electricity Generation** | **Renewable energy** | TWh | **1 006** | **2 643** | **3 660** | **1 109** |
| | Hydropower | TWh | 864 | 1,600 | 1,600 | 0 |
| | Wind | TWh | 100 | 647 | 1,263 | 692 |
| | Biomass | TWh | 38 | 190 | 358 | 168 |
| | Solar | TWh | 4 | 197 | 446 | 249 |
| | Geothermal & Ocean | TWh | 0 | 9 | 9 | 0 |
| **2. Biogas Supply** | | billion $m^3$ | 16 | 60 | 83 | 23 |
| Biogas users | | million households | 47 | 175 | 240 | 65 |
| Mid-size and large biogas plant | | billion $m^3$ | 0 | 40 | 80 | 40 |
| Biogas in tce | | Mtce | 11.0 | 41.5 | 57<br>1.7 EJ | 0.5 EJ |

| | Unit | 2012 | Reference Case 2030 | REmap 2030 | | Difference between REmap 2030 and Reference Case |
|---|---|---|---|---|---|---|
| **3. Heat Supply** | | | | | | |
| Solar water heater | $Mm^2$ | 258 | 865 | 1500 | - | 635 |
| Solar water heater in tce | Mtce | 29.6 | 91 | 149 | 4.4 EJ | 2.0 EJ |
| Geothermal energy for heating in tce | Mtce | 5 | 10 | 15 | 0.5 EJ | 0.2 EJ |
| Heat Supply in tce | Mtce | 34 | 101 | 164 | 4.9 EJ | 2.2 EJ |
| **4. Biofuel** | | | | | | |
| Solid biomass | Mt | 28 | 85 | 133 | 2.3 EJ | 0.8 EJ |
| Traditional biomass | Mt | 225 | 66 | - | - | - |
| Modern biomass industry | Mt | 6 | 40 | 88 | 1.5 EJ | 0.8 EJ |
| Bioethanol | Mt | 2 | 25 | 25 | 31 bln liter | - |
| Biodiesel | Mt | 0.5 | 5 | 5 | 6 bln liter | - |
| Total | Mtce | 148 | 140 | 225 | 4.8 EJ | 1.6 EJ |
| **5. District heat generation** | | | | | | |
| Biomass | Mt | 2 | 2 | 78 | 1.4 EJ | 0.3 EJ |
| **6. Electric vehicles** | | | | | | |
| Electric and plug-in hybrid vehicles | (million) | .03 | 17 | 35 | | 18 |
| Electric two-wheelers | (million) | 200 | 400 | 500 | | 100 |
| **7. Ratio of electricity generation** | | | | | | |
| Total installed capacity | $GW_e$ | 1 203 | 2 306 | 2 602 | | 330 |
| Gross power generation | TWh | 4 980 | 9 315 | 9 543 | | 205 |
| Capacity ratio of renewables | % | 28% | 39% | 53% | | 15 p.p. |
| Generation ratio of renewables | % | 20% | 29% | 39% | | 10 p.p. |
| **8.Ratio of energy consumption** | | | | | | |
| TFEC | Mtce | 2 150 | 3 123 | 3 055 | | -68 |
| TFEC | EJ | 66 | 91.5 | 89.5 | | -2 |
| Renewable electricity (consumed) | EJ | 3.3 | 7.6 | 10.7 | | 3.1 |
| Renewable gas, heat and fuel | EJ | 5.2 | 7.0 | 12.3 | | 5.3 |
| All renewable energy | EJ | 8.5 | 14.6 | 22.5 | | 8.4 |
| Renewable energy in TFEC (in brackets, excluding traditional use of biomass) | % | 14% (7%) | 17% (16%) | 26% | | 10 p.p. |

*Note: p.p. percentage point*

*Figure 18: Power capacity by renewable energy technology*



newable power. Electrification in end-use sectors results in additional power generation of about 280 TWh/year in REmap 2030 compared with the Reference Case, *i.e.* 3% additional electricity demand. Biofuels used in transport will total 0.9 EJ, with 18% coming from advanced biofuels.

The share of renewable power generation grows to 39% in REmap 2030. Half of this, or 18% of the total power generated, is considered variable power which includes solar PV, CSP and wind. Growth in the power sector's renewable energy share is substantial compared with the Reference Case. This is due to growth in wind (more than 617 TWh/year), solar PV (233 TWh/year), and biomass including industrial CHP (168 TWh/year). Hydro and geothermal see no increase compared with the Reference Case.

Figure 18 shows developments in power capacity. If the trends to 2020 targets are extrapolated assuming exponential growth, the capacity for renewables could grow to 1200-1600 $GW_e$ in 2030. This is represented by the REmap 2030 total of 1467 $GW_e$. Wind nearly doubles to 561 $GW_e$ (including 60 $GW_e$ offshore) in REmap 2030, compared with 315 $GW_e$ in the Reference Case. Solar PV increases to 308 $GW_e$, up from 109 $GW_e$ in the Reference Case. Solar CSP increases to 32 $GW_e$, a three-fold increase over the Reference Case installed capacity of 12 $GW_e$. Total hydroelectricity capacity increases by nearly 150 $GW_e$ between 2010 and REmap 2030, from 215 $GW_e$ to 400 $GW_e$.

The increases in renewable power substitute coal capacity. This results in 180 $GW_e$ less coal in REmap 2030 of which 45 $GW_e$ is accounted for the early retirement of existing plants and substitution with wind power. There remains over 850 $GW_e$ of coal power generation capacity in the system, even after the substitution. However, this is less than the total of current installed (750 $GW_e$) and planned coal capacity (350 $GW_e$) as of 2011 (Platts, 2013).

The renewable energy share ranges between 10% and 64% in end-use sectors. This growth is mainly from biomass which accounts for more than half of the total renewable energy fuel use (when excluding electricity). Primary biomass demand for modern and traditional applications in China doubles from 6.1 EJ in 2010 to nearly 12 EJ in REmap 2030 if all REmap Options are deployed (demand in all sectors). This growth is tempered by the substitution of traditional uses of biomass with modern biomass which is by a factor 2-3 more efficient in comparison.

One third-of the total renewable energy use in REmap 2030 is from biomass, and it has a higher share in end-use sector total renewable energy use of 60%. The contribution of non-biomass renewable energy technologies to supply heat in the building and industry sectors is also substantial, with solar thermal at 5 EJ and geothermal at 0.3 EJ. Solar thermal capacity in 2030 would reach 1,050 $\text{GW}_{\text{th}}$ (or 1 500 million $\text{m}^2$). About 40% of the total installed capacity would be in the industrial (30%) and commercial (10%) sectors in 2030. The number of electric vehicles increases to 35 million in REmap 2030. This would represent more than 10% of the total car stock in 2030. The number of two-wheelers would reach 500 million in 2030.

## 7.3 Renewable energy technology cost projections

Table 17 provides an overview of current and projected LCOE for new capacity power plants. In REmap renewable power technologies only substitute coal-based generation. In the absence of a carbon price the cost of new coal power is expected to rise to around USD 50 per megawatt-hour (MWh). Substitution of coal generation includes both new capacity and existing capacity, which produces electricity closer to USD 20 per MWh. Due to China's abundance of coal, renewable technologies do not compete on cost alone, as shown by the USD 16 per GJ substitution cost for the REmap Options in the power sector.

REmap projects that generation costs for wind will remain relatively stable, at USD 78-95 per MWh. Another 'remote' wind onshore option is identified. This refers to wind farms installed in regions which have high capacity factors, but which are more distant from the existing grid and may also require higher capital costs for their construction and equipment transportation.

Contrary to the wind, the cost of solar PV will decrease significantly to around USD 60-120 per MWh by 2030. Utility scale plants have an LCOE of USD 60-75 per kWh compared with distributed solar PV plants, which have an LCOE of USD 90-120 per kWh. However, it should be noted that costs related to the integration of various renewables are outside the scope of this study, and according to the IEA could add between USD 5 and USD

*Table 17: Comparison of LCOE for power sector technologies*

| | BNEF 2012 (USD/MWh) | IRENA 2013 (USD/MWh) | IEA/NEA 2010 (USD/MWh) | GlobalData 2013 (USD/MWh) | REmap 2030 (USD/MWh) |
|---|---|---|---|---|---|
| Discount rate (%): | N/A | 10 | 10 | 5-8 | 8 |
| **Renewables:** | | | | | |
| Wind onshore | 46-124 | 79 | 72-125 | 53-67 | 78-95 |
| Wind onshore (remote) | | | | | 70-88 |
| Wind offshore | 91-240 | | | 95-120 | 125-160 |
| Solar PV (utility) | 99-257 | 191 | 186-282 | 70-86 | 60-75 |
| Solar PV (rooftop) | | | | | 90-120 |
| Solar CSP | | | | | 145-200 |
| Landfill gas ICE | | | | | 42-57 |
| Biomass | 28-132 | 53-67 | | 27-31 | |
| **Conventional:** | | | | | |
| Coal (new) | | | | | 43-57 |
| Coal (existing) | | | | | 15-21 |

*Source: Based on Asia-Pacific Renewable Energy Assessment, BREE 2014, summary of data from BNEF, IRENA, IEA/NEA, GlobalData.*

25 per MWh. These additional costs could have an effect on the ranking of the price of power generation. Landfill gas will remain competitive with new coal power plants.

According to IEA estimates (IEA, 2011a; not shown in the table below), wind power generation costs vary considerably depending on the region and as installed capacity rises. For example, as the installed capacity increases from 45 GW to about 200 GW in West Inner Mongolia, LCOE increases from USD 54 per MWh to about USD 70 per MWh. For the same installed capacity (for 45 $GW_e$), LCOE ranges from USD 50 per MWh in Gansu to USD 74 per MWh in Heibei. To reach 400 $GW_e$ installed capacity by 2030, IEA estimates an LCOE range of USD 64-84 per MWh across the seven regions with the largest wind resources[18]. This is similar to the REmap 2030 estimates for 467 $GW_e$ installed wind onshore capacity.

## *By 2030, onshore wind, utility-scale solar PV and landfill gas/biomass will be the cheapest sources of renewable power generation*

System costs such as transmission can have an important effect on overall estimates. According to the IEA (2011a), by 2020 the estimated average LCOE for wind would be equivalent to USD 56 per MWh, when transmission costs are excluded. When these costs are factored in, the additional cost the LCOE rises to USD 79 per MWh (a 36% increase).

Taking these costs into account, more than 200 $GW_e$ of wind capacity could be implemented in high-resource regions by 2020, which would require the continuation of annual capacity development rates today. By 2030, the LCOE (excluding transmission costs) could increase to 60 per MWh, versus tariffs which include transmission costs of USD 80 per MWh. This would result in a total installed capacity of more than 400 $GW_e$ by 2030. Transmission costs would add 30-40% to the overall sum.

According to the "high renewable scenario" laid out by the WWF (2014), which foresees a 56% share of renewable energy in power generation by 2030 (22% from wind and 18% from hydro, with the remainder a 16% mix of solar PV and biomass), there would be a weighted LCOE of USD 85 per MWh (for all technologies including conventional). The cost of transmission and the costs of demand/peak reduction measures and storage would add USD 46 per MWh, resulting in total generation and system costs of USD 131 per MWh by 2030.

BNEF (2013) estimates total capital investment requirements of USD 3256 billion between 2013 and 2030 to increase the installed capacity from 1124 $GW_e$ to 2867 $GW_e$. Of this total installed capacity, half of it would be renewable energy. Of the total net capacity additions estimated between 2013 and 2030 (1743 $GW_e$), about two-thirds is renewables (1110 $GW_e$) and of that about 900 $GW_e$ is related to wind and solar PV. Additional investment requirements for supporting infrastructure related to these capacity additions are estimated as USD 1,123 billion in that period, adding about a third on top of the total capital investment. About 45% of the estimated infrastructure investments are related to transmission lines, while one-third is related to smart grids; and additional 17% is related to storage while the remainder 5% is related to demand response.

In the building and industrial sectors, the outlook is also challenging for renewable energy technologies due to the availability of cheap coal (see Annex E for an overview of these sector end-use costs). Due to this cheap supply, many types of renewable energy technologies that provide space heating or process heat will find it hard to compete based on price alone, meaning that their substitution costs are a positive factor.

In the transport sector, the outlook for renewable energy is better. Since oil is traded internationally and China is a net importer, the price per barrel of crude in China does not deviate much from increases seen around the world. For REmap a modest price increase is forecast, amounting to a barrel price of around USD 120 by 2030 (based on a lower heating value of 5.4 GJ per barrel of oil equivalent), which translates to a price for petrol that increases from USD 23 in 2010 to USD 32 per GJ in 2030 – an increase of around 50%, assuming no changes in petrol taxes.

Additionally, because China is a rapidly urbanising society and income levels are increasing, the car stock in China is expected to increase from 100 million in 2012 to about 500 million in 2030. If this were to happen, the increased demand for petrol would put even higher pressure on petroleum prices. This would enable many

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[18] The seven regions analysed by the IEA (2011a) are Gansu, Heibei, Jiangsu, Jilin, East and West Inner Mongolia.

types of alternative transport technologies or fuels to compete on a cost-basis. However, because many alternatives exist, ranging from biofuels to electromobility, and because there are infrastructure costs associated with increased uptake, the cost structure of these technologies are still hard to estimate.

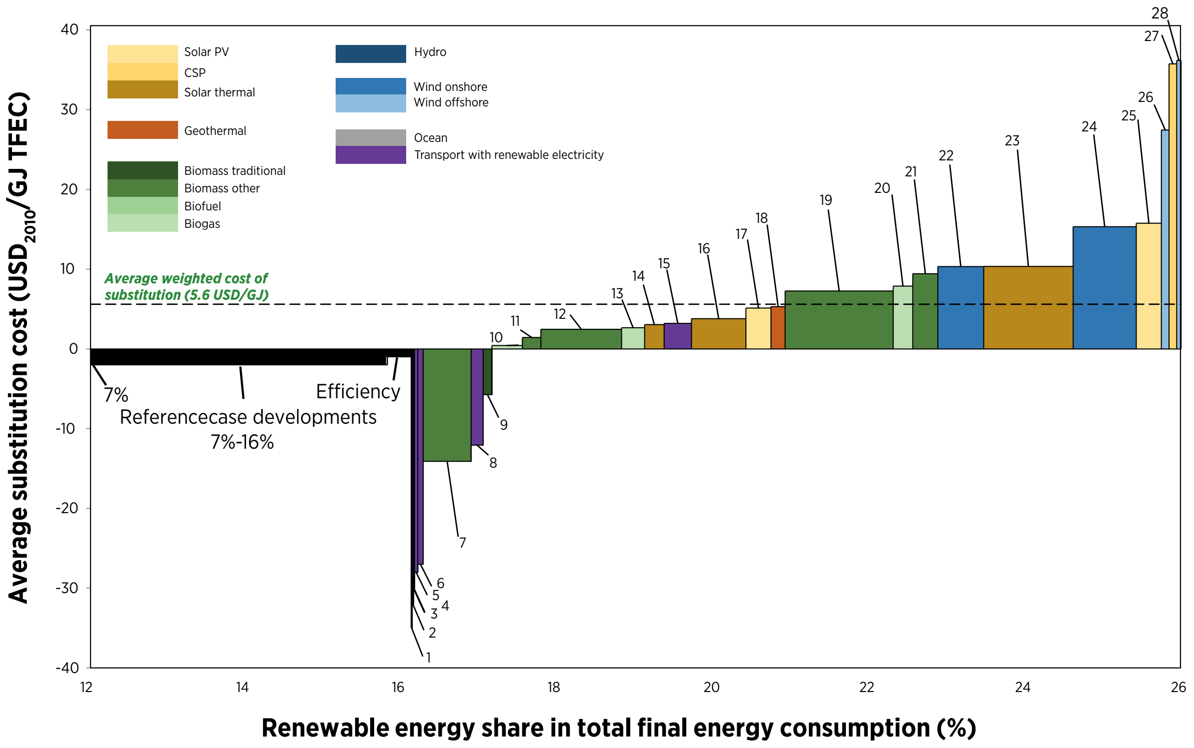
What is clear, however, is that most of these technologies pose a realistic potential to compete with petrol use in transport on a cost-basis, according to the methodology applied and the cost data (capital and operation and maintenance (O&M) costs, energy prices and discount rates) used in this study. This growth also presents an opportunity for China to increase the use of transport modes that consume electricity rather than liquid fuels – so called modal shifts. These include supporting the introduction of local electric bus and tram systems, as well as long-distance rail for both passengers and freight. This is already being pursued aggressively in China; however, REmap assumes more could be done and at significant cost-savings.

## 7.4 Summary of REmap Options: cost-supply curves

The previous sections have discussed the technology options and their costs. In this section, the options are aggregated into an overall potential curve, and they are ranked in terms of their cost effectiveness.

The cost-supply curve displays an approximate representation for the realistic potential of renewable energy

*Figure 19: REmap Options cost supply curve, business perspective, by resource*



*Note 1: See Annex E for the numbered technologies*

*Note 2: The purple bars represent electrification technologies. The substitution costs of these technologies include their annualised capital (e.g., electric vehicle ownership cost), O&M and energy costs vs those of their conventional counterparts (e.g., ICE passenger car running with gasoline). It is also assumed that each additional electrification technology will result in renewable power generation capacity investments; hence, it is assumed they consume electricity from renewable sources only. These costs are included via the electricity prices that account for the changes in China's power generation mix. As opposed to depicting the energy demand technologies (e.g., electric vehicle, heat pumps), bars for electrification technologies could also be represented by the renewable electricity supply technologies which consists of 70% wind and 30% solar PV in the case of the China.*

technologies – the REmap Options – which can be deployed by 2030 in addition to the Reference Case. The cost supply curve is not used to develop the REmap 2030, but it is a representation of the REmap Options which have been selected.

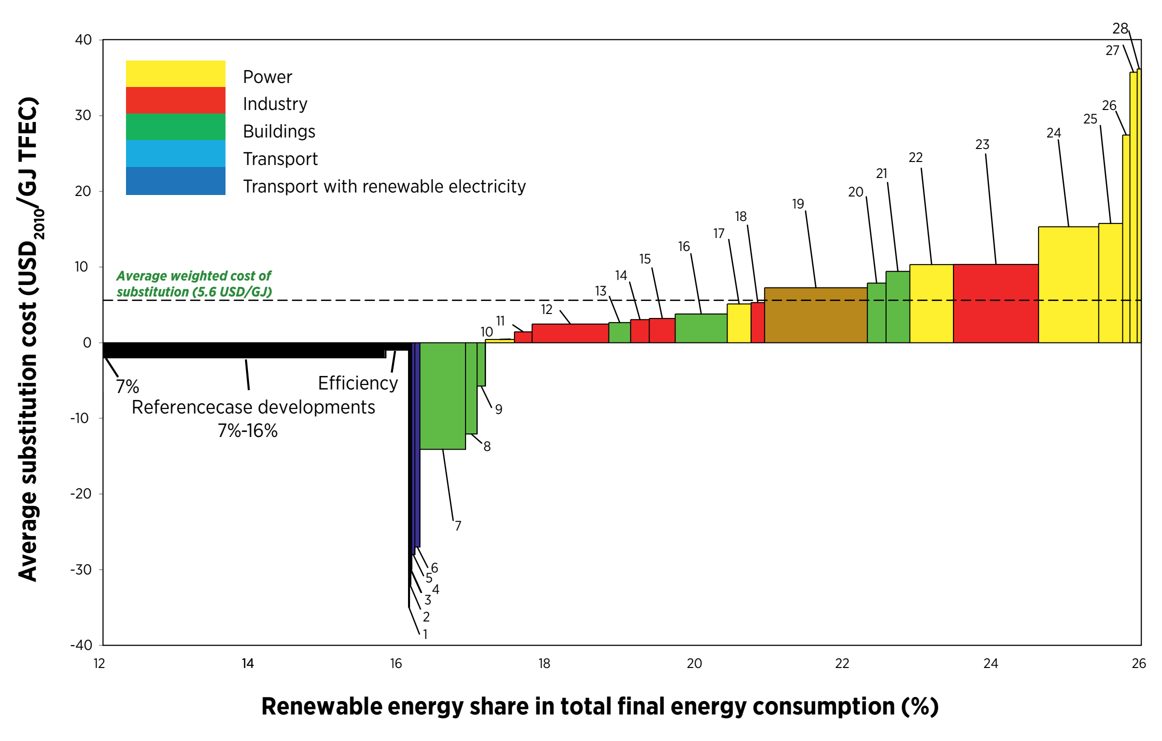
The REmap Options are a portfolio of technologies for accelerated renewable energy deployment in the power, district heat, and end-use sectors of buildings, industry and transport. This portfolio is not an allocation of the global additional potential based on the GDP of China and the other 25 REmap countries, nor does it represent extrapolations. Further technology portfolios can be generated based on the different understanding of the parameters that constitute REmap Options or other studies looking at the specific case of the China.

The results of the analysis are shown in the cost-supply curves in Figure 19 through Figure 22. This includes two sets of curves: one based on national prices (business perspective) that incorporate the national cost of capital (8% discount rate), commodity prices that include national taxes or subsidies, and technology cost and performance characteristics; and another (government perspective) based on standard international commodities costs (with differentiation made for coal and natural gas between export and import countries) and a fixed 10% discount rate.

The former reflects factors likely to influence private investment decisions; the latter is more relevant to government decisions on policy and spending. Each of these two curves is presented twice, once coloured by resource and once by sector. The national cost supply curves are used to examine the economic cost and financial savings potential of increased renewable energy uptake. The standard international curve is used when considering R&D needs, comparing renewable potential and costs across regions or globally as well as providing insight into cost differences between China and global markets resulting from policy decisions such as energy taxation.

Decision makers will be tempted to pick low-cost options, from the left end of the curve, and to skip high-

***Figure 20: REmap Options cost supply curve, business perspective, by sector***



*Note: see Annex E for the numbered technologies*

*Color code: dark blue bars: electrification technologies in transport sector; green bars: building sector; red bars: industry sector; yellow bars: power sector. Dark yellow bars: district heat sector*

*Figure 21: REmap Options cost supply curve, government perspective, by resource*

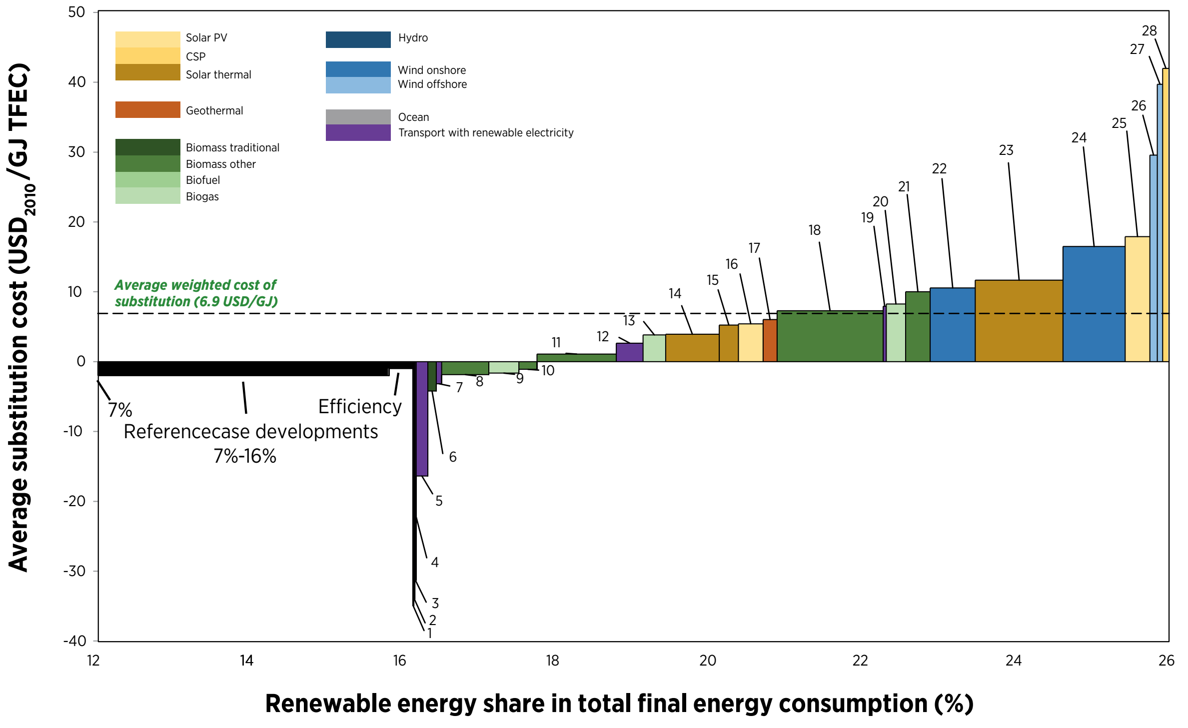
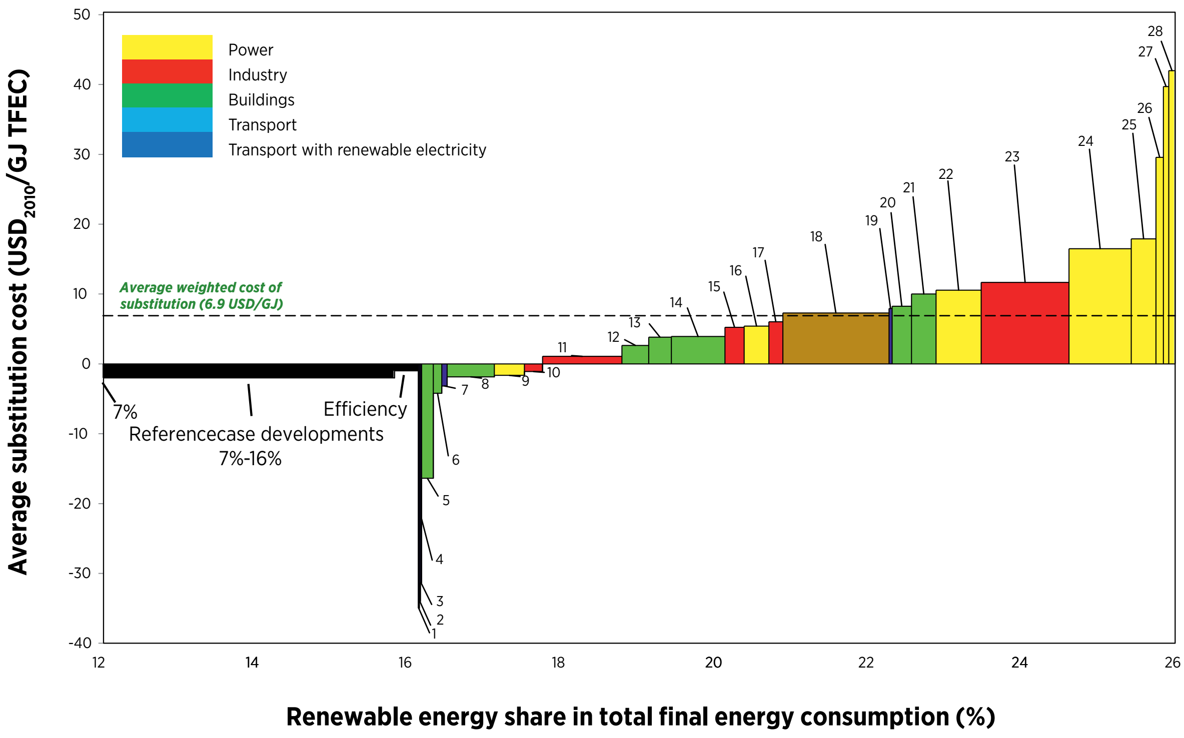


*Figure 22: REmap Options cost supply curve, government perspective, by sector*



cost options, on the right-hand side; however the figure gives a perspective of the entire country. Decision makers may assume that options represented by individual blocks in the supply curve are homogenous in terms of substitution costs. However, the blocks represent averages based on the assumed deployments in the REmap 2030. A focus on the cheapest individual options will not result in the least expensive overall transition; achieving that requires a holistic approach, and only when all of these options are pursued simultaneously can the share of renewables in TFEC of China be raised to 26% by 2030 according to this study.

In Figure 20 (below) the same curve is displayed but with the technologies coloured by sector. This curve shows that the additional potential lies largely in the building, industry and power sectors.

### *Focusing on the cheapest individual options will not result in the least expensive overall transition; a holistic approach is required*

Figure 21 and Figure 22 are the REmap cost-supply curves for China based on standardised international commodity price estimates (which exclude the effects of taxation or subsidy) and a 10% discount rate. The curve is significantly different from the national one, resulting from the changes relating to the discount rate (10% versus 8%), and energy prices. In addition to showing cost differences driven by commodity prices that are locked into a local market (such as natural gas), this curve also shows the effects of price differences resulting from subsidies and taxes on energy and how they can affect technology deployment. This curve is also used to look at regional and international contexts when comparing the results from China.

### *A sector-based cost curve shows that most additional potential lies in the housing, industry and power sectors*

For the REmap cost-supply curves, the Reference Case growth in renewable energy from 2010-2030 is shown by the first horizontal bar, which is coloured based on resource. The resource colouring is consistent with the deployment of renewable energy seen in the Reference Case. The results of the REmap analysis and accelerated deployment of renewable energy (the REmap Options) is plotted in the curve as coloured bars showing the additional potential of each technology (on the x-axis) and the average incremental cost of substitution of deploying that technology in lieu of a conventional variant (on the y-axis). The Reference Case already includes some significant expansion of renewable resources: wind and solar already see growth in the Reference Case and their incremental potential is lower in the REmap Options. In China, modern renewable energy in TFEC according to the Reference Case is expected to grow from 7% in 2010 to about 16% by 2030.

### Cost-curve results by sector and technology

The results presented in these cost supply curves are dependent on projections of technology cost and fuel prices. An overview of the assumptions underlying these projections is available in the Annexes. The technology option mix and costs vary according to sector. Costs associated with the Reference Case are not quantified as they are part of expected energy system developments and outside the boundaries of the REmap analysis.

The results from the REmap cost-supply curves show that some of the REmap Options identified, if viewed from a business perspective (national prices), could be

*Table 18: Overview of the average cost of substitution of REmap Options for the China*

| | **Business Perspective (national prices) (USD/GJ)** | **Government Perspective (international prices) (USD/GJ)** |
|---|---|---|
| Industry | 5.7 | 5.7 |
| Buildings | 0.5 | 2.7 |
| Transport | -11.0 | -3.7 |
| Power | 13.2 | 14.0 |
| **Average of all sectors** | **5.6** | **6.9** |

deployed at a cost-saving when compared with fossil fuel alternatives. Table 15 shows the average cost of substitution for each sector. If viewed from a business perspective, the REmap Options require additional costs of USD 5.6 per GJ. If viewed from the perspective of government (international prices), the cost of substitution increases to USD 6.9 per GJ, assuming the removal of tax on fossil fuels (since biomass is taxed relatively little and other renewable energy technologies that have no fuel demand are not affected by fuel taxes) and a high discount rate of 10% (most renewable energy technologies have higher capital costs). This is higher than the global average of USD 2.5 per GJ estimated based on the analysis of 26 REmap countries (IRENA, 2014a).

The cost-supply curve results from the business perspective show that most of the technologies result in incremental costs when compared with their conventional alternatives. However, to put these incremental costs into perspective, the incremental cost average of USD 5.6 per GJ of final energy is actually equivalent to an increase of around USD 20 per MWh, or around USD 2 cents per kWh. This is also despite China having some of the lowest fossil fuel prices in the world, particularly the extremely cheap coal used in the industry and power sectors. This also explains why most renewable energy options which are cost-effective are those that substitute petroleum products (largely in transport) or fuels used in the building sector (including traditional biomass). However, as shown in Table 21, if externalities are factored into the cost of substitution, the REmap Options as a whole result in cost-savings compared with their conventional alternatives. The cost-supply curves do not display these external costs since both health and environment costs are not internalised into the substitution process – they are apportioned in a later step.

### *Most cost-effective renewable energy options in China are those that substitute petroleum products (mainly in transport) or fuels used in the building sector*

In the power sector all technologies result in incremental costs when compared with conventional alternatives. This is due to low coal prices, and also because some renewables are assumed to replace existing coal power plants. The most competitive renewable energy technology is landfill gas and electricity generated from biomass such as CHP plants that utilise agricultural residues. Utility-scale solar PV, onshore wind and geothermal are next, resulting in incremental costs close to the total average substitution costs of USD 6 per GJ. Solar PV for rooftop applications result in an incremental substitution cost of around USD 17 per GJ. However, it is important to note this is compared with wholesale power cost as for all power generation technologies, not retail electricity. Lastly offshore wind, and wind plants that substitute existing coal plants result in the highest cost of substitution of all technologies.

In the industrial sector results are similar, also due to the availability of cheap coal that does not internalise health or environmental costs. Industrial process heat generated from biomass-fired CHP plants using agricultural residues is the most cost-competitive option. Two novel, yet largely unused technologies, follow in terms of competitiveness: solar cooling, which replaces electric cooling, followed by heat pumps providing process heat for temperatures of up to 150 °C. Both of these technologies compete well, with only around USD 3 per GJ incremental costs. The largest potential is found in solar thermal for low-temperature heat applications; however, the cost of substitution is the highest among all technologies in the industry sector (USD 11 per GJ).

The building sector includes renewable technologies that substitute both fossil fuels and traditional use of biomass. The most competitive is modern biomass-based space heating that substitutes heating oil, mainly due to high oil product prices. Heat pumps also result in cost-savings when substituting natural gas; however, their potential is lower than biomass. Modern renewable-based cooking results in cost-savings when compared with traditional uses of biomass when modern solid biomass is used. Utilising biogas for heating or cooking applications instead of traditional forms of biomass results in only a small incremental cost. The largest potential is in solar thermal heating, as in the case of industry, which is already very prevalent in China. REmap shows this additional potential can be deployed at a relatively low incremental cost. It is important to note that China has a significant district heating network in many cities, and REmap shows that waste-to-energy systems can provide significant additional potential, however at an incremental cost above the average.

The transport sector has the most competitive set of renewable technology options. This is due to the high cost of oil, which mirrors world prices, relative to the lower cost of coal used in the other sectors. Technologies that utilise electricity, which in China is cheap, result in the most cost savings. Developing passenger rail networks that substitute aviation, or urban tram or subway systems that substitute passenger automobiles, result in significant savings. However, China is building significant infrastructure for these technologies, so only limited additional potential is available beyond the Reference Case. Forms of individual electric transit, including various forms of electric vehicles and electric 2-3 wheelers are also cost competitive. However there is significant growth in these technologies already assumed in the Reference Case, so additional potential identified in REmap 2030 is also limited. Electric mobility technologies have high efficiency compared with fossil alternatives, so even though they seem small in energy consumption terms, they provide significantly better performance (in terms of passenger miles, for instance) than a comparable unit of petrol or diesel. No liquid biofuel growth has been assumed for China in REmap 2030 beyond the Reference Case.

## Benefits of REmap Options

In addition to economic arguments for increased renewable energy deployment, there is also a strong environmental case. The REmap Options would result in an estimated reduction of 1.7 gigatonnes (Gt) of $CO_2$ by 2030 (Table 19). The largest decrease would occur in the building sector, followed by the power sector. If all REmap Options were fully deployed, China could reduce its $CO_2$-related emissions from energy combustion by around 17% over the 2030 Reference Case.

Reductions in emissions from China would contribute 21% of the global $CO_2$ emission reductions which could be achieved if all REmap Options required for doubling the global renewable energy share are implemented by 2030 (a total of 1.7 Gt $CO_2$ emission reductions by 2030). Among the 26 REmap countries, China has the largest potential in terms of an absolute reduction in emission volumes. China is followed by the reduction potentials of the USA and India if all REmap Options are to be implemented. These three countries could account for half of the potential reductions in global emissions according to REmap 2030. Deploying renewables and reducing emissions in these countries are essential for a transition in the global energy system and to mitigate climate change.

***China, the USA and India together could account for half of global reductions in emissions by 2030 if all Remap Options are implemented***

These emission reduction estimates assume that all renewable energy sources are carbon-neutral. While this applies to most renewables, it is not the case for biomass due to GHG emissions during bioenergy harvesting, processing and combustion, in particular when land use change emissions are accounted for. In addition, emission estimates are subject to uncertainty originating from the discrepancies in China's energy statistics, mainly related to coal use in coal washing and the manufacturing and industrial sectors. For the year 2010, the margin of error for China's total $CO_2$ output is estimated as 1.4 Gt, which is nearly as high as the total emissions avoided under REmap 2030 (Guan *et al.*, 2014). With better data, total energy use projections and thus $CO_2$ emission saving estimates can be refined.

*Table 19: Development of China $CO_2$ emissions, 2010-2030*

| | 2010 (Mt/year) | Reference Case 2030 (Mt/year) | REmap 2030 (Mt/year) | Total avoided (Mt/year) |
|---|---|---|---|---|
| Power and district heat generation | 3 595 | 5 762 | 4 544 | 1 218 |
| Industry | 2 327 | 2 746 | 2 528 | 217 |
| Transport | 529 | 1 199 | 1 123 | 76 |
| Buildings | 467 | 478 | 298 | 181 |
| **Total emissions from fossil fuel combustion for energy services** | **6 917** | **10 185** | **8 493** | **1 692** |

***If all REmap Options are implemented in 2030, total emissions from the building and power sectors of China can be reduced by 37% and 20%, respectively***

There are also socio-economic benefits to increasing the use of renewables. According to IRENA estimates, about 6.5 million people were already employed in 2013 in the renewable energy industry worldwide, of whom 2.6 million were in China (IRENA, 2014d). By 2010, China had the largest number of people working in the solar PV sector, with 120 000 jobs. In the solar thermal sector the total number of people employed was between 250 000 and 600 000 in the period 2006-2010. The biomass sector also provided about 266 000 direct jobs.

The total number of jobs worldwide could reach 16 million (in cumulative job-years) by 2030 according to REmap 2030. This implies an equivalent of 0.9 million additional jobs which could be created in the global renewable energy sector (IRENA, 2014a). Given that a large share of the global renewable energy use estimated in 2030 would be in China, the country would benefit considerably from these additional jobs created.

The REmap Options identified in China result in incremental system costs of USD 55-60 billion from a government perspective (Table 20). System cost calculations from a government perspective exclude energy taxes and subsidies, and use a standard 10% discount rate for capital investment. Incremental system costs do not include benefits related to reductions of air pollution (health) and $CO_2$ emissions. If such externalities are included, and depending on how these are valued, full deployment of the REmap Options could result in estimated reduced health costs of USD 78-162 billion per year by 2030. These avoided external costs result from a reduction of health complications due to air pollution from fossil power plants, indoor and outdoor air pollution from the traditional use of biomass and other solid fuels as well as fuels used in the transport sector.

If the benefits of the 1.7 Gt of reduced $CO_2$ are taken into account, an additional USD 32-126 billion per year could be saved by 2030 (based on a carbon price of USD 20-80 per tonne $CO_2$). The result of these externalities is a possible reduction in energy system costs of between USD 55 billion and USD 228 billion per year. It is therefore possible to raise the renewable energy share with significant savings if externalities are included, and depending on how these are valued.

For example, today the damage to GDP related to acute mortality (from PM and sulphur dioxide) is equivalent to between 0.65% and 3.81% of China's total GDP, with premature mortality of 62 000-125 000 per year. Chronic mortality related to particulate matter alone resulted in 561 000 cases of premature mortality annually with a total health damage to GDP of 4.36% (Ho and Nielsen, 2007). With total reductions in coal use of about 16 EJ (or a 18% reduction), total savings could be equivalent to 0.78% of GDP. This would mean

*Table 20: Financial indicators of REmap Options, based on government perspective*

| | **(USD bln/year)** |
|---|---|
| **Changes in costs of the energy system (in 2030)** | |
| Incremental system cost | 55-60 |
| Reduced human health externalities | from -78 to -162 |
| Reduced $CO_2$ externalities | from -32 to -126 |
| Net cost-benefits | from -55 to -228 |
| Incremental subsidy needs in 2030 | 60 |
| **Investments (average between today and 2030)** | |
| Incremental investment needs | 40 |
| Total investment needs (REmap Options) | 54 |
| Total renewable energy investment needs (REmap Options and Reference Case) | 145 |

a total saving of up to USD 200 billion per year, assuming China's total GDP doubles by 2030 to USD 25 trillion.

Table 20 shows that the total investment needs of the REmap Options would be USD 54 billion per year. The table also shows that in addition to investment, an annual subsidy of USD 60 billion would be required to make REmap Options technologies with positive substitution costs "competitive" with fossil technologies. Technologies which require a subsidy lie mainly in the end-use sectors rather than power generation, namely for heating in buildings and industry (solar thermal) and electric vehicles.

This cost would likely be borne by consumers in the form of increased energy costs or taxes. It is important to note that by 2030 many renewable energy technologies should not require a subsidy, and should actually result in lower energy costs, so a better metric for energy prices might be the incremental system cost, which shows that energy prices would increase slightly.

## 7.5 Discussion of REmap 2030 Options

### Technology development challenges

Among the different REmap Options, four technologies need to grow substantially if the estimated potential of renewables in REmap 2030 are to be realised. Onshore wind power needs to grow by about 24 $GW_e$/year, solar PV by about 17 $GW_e$/year (40% of that related to rooftop installations) and solar thermal by about 48 $GW_{th}$/year (40% related to industrial process heat and other commercial applications). Given that there is very limited deployment of offshore wind today, development of 3 $GW_e$/year is another substantial addition. Biomass as a source of energy for both the power and end-use sectors will also need to grow substantially and its traditional uses will need to be fully substituted according to REmap 2030.

While the growth rates envisioned are slightly higher than current trends, another major issue lies in expanding grid transmission capacity. This will require substantial investments. Estimates of other studies show that additional infrastructure related to the power sector (transmission, variable renewable energy measures) can add between 30% and 50% in addition to the total investment costs of power plants. Other grid constraints (*e.g.,* institutional barriers, see Section 8) need to be resolved in the short-term as well to avoid today's situation of capacity being installed but not necessarily connected to the grid.

In addition, inter-provincial transmission infrastructure needs to be built to allow power from the northern, northeastern and northwestern regions to be supplied to central and coastal demand areas. Inter-regional connections need to be strengthened and electricity trading markets will need to be developed. Some of the solar PV and wind development can be pushed to lower resource regions to ease the long-term challenge of building transmission grids. There will also be a focus on southwestern hydroelectricity in the future, given the distribution and development of water resources; however, here too there is a shortfall in planning for long-distance transmission lines. With regard to solar PV, the quality of equipment needs to be improved to ensure long project lifetimes.

In the case of offshore wind, the main challenge will be to increase connection to the mainland grid. China has limited experience in this area so far, particularly when it comes to connecting farms further from the shore. Hence, the challenge will be to develop solutions by 2020 to cope with the potential growth in offshore wind such as the development of offshore substations and sub-sea cabling as well as improving gearbox reliability. In parallel, offshore wind-related equipment manufacturing output will need to grow to meet the growing demand (Carbontrust, 2014). Furthermore, China needs to focus on developing technologies that can deal with the corrosive effects of seawater on offshore installations as well as typhoon-resistant models.

In addition to technical challenges, costs may also be a problem for solar and wind since, as capacity increases, spatial constraints in certain regions may create issues. Hence today's economically competitive locations may be less cost-effective in the longer term as their potential is realised.

***As solar and wind capacity increases, the most favourable locations may become less cost-competitive due to spatial constraints***

Solar thermal heat use in the building sector is already high in China and this is estimated to nearly quadruple by 2030, from 258 million $m^2$ to 900 million $m^2$. While this is already a challenge in its own right, the main effort will need to focus on deploying 600 million $m^2$ solar thermal in the industrial (450 million $m^2$) and commercial (150 million $m^2$) sectors, where installed capacity today is nearly zero. Assuming 10 megawatts-thermal ($MW_{th}$) of installed capacity per solar thermal facility, this would mean more than 30,000 manufacturing industry plants would be equipped with such technology.

China has a manufacturing industry that is diverse in terms of its energy demand and process heat temperature levels. Although much of industry comprises medium- and high-temperature sub-sectors such as cement, chemicals and iron and steel, many food processing and textile manufacturing plants exist which utilise low temperature heat. Given the highly cost-competitive solar thermal equipment available in China, such sectors can benefit from solar thermal if the right policies and targets are put in place for 2020 and 2030.

Bioenergy is estimated to have a potential across all sectors. However, the residential and industrial sectors pose particular challenges. In the residential sector, traditional uses of biomass are decreasing, and being substituted with modern forms of fossil fuels such as liquid petroleum gas (LPG). This change in fuel sources needs to be steered towards modern renewables, including modern forms of biomass. This requires the availability of reliable and affordable modern cook stoves. Earlier experiences showed that such equipment may not necessarily be accepted and used. Thus the challenge here concerns aspects of policy and public awareness as opposed to technical barriers.

Given the focus of China on non-food based liquid biofuels, the majority of production will need to be provided by advanced biofuel plants. So far production capacity is limited which means that substantial investments will be required to meet the potential demand. The capital costs of these plants are currently higher than conventional liquid biofuel plants. This capacity needs to be deployed already by 2020 to meet the assumptions of the Reference Case. Meeting all demand locally would require about 200 advanced biofuel plants, each with a total production capacity of 230 million litres ethanol per year.

The China biodiesel industry needs to compete for feedstock supply with gutter oil. According to Van Sambeek *et al*. (2013), 200-300 million tonnes of gutter oil is produced and sold back to market as edible oil each year.

As with solar thermal, biomass is not a fuel of choice for process heat generation in industry. However, a considerable share of up to 20% of the total demand from cement kilns, which comprise one of the largest manufacturing sectors in China, can be provided by biomass, waste and other fuels without any process modifications. In addition, biomass-fired CHP is an alternative to any fossil fuel-based heating systems and can be considered in investments for new production plants.

Water could be a major challenge with regard to a number of renewable energy technologies, in particular bioenergy and CSP, as is the case today for the coal supply chain. Among the different renewable power generation options, CSP is one of the most water intensive options. In particular, areas where CSP can be deployed (Qinghai, Gansu) are also arid. Water for bioenergy cultivation is another important consideration. Although the liquid biofuel market in China is not as developed as in the USA or India, about three-quarters of the total is assumed to originate from conventional feedstocks which also rely on water. For example, sorghum-based ethanol production is the most water-intensive route, followed by corn- and cassava-based ethanol.

Deployment of the full potential for biomass will depend on the availability of bioenergy supplies. In the high case of biomass supply, demand could utilise up to two-thirds of total available. But if supplies are limited, demand is likely to exceed the domestically available biomass in China. As part of the demand may need to be met from land- and fertiliser-dependent energy crops, improving yields and using marginal land will be important.

Focusing on the energy-land-water nexus and optimising the key routes will be very important if China is to realise its bioenergy potential. China also needs to start now on developing collection and logistics systems to increase the availability of scattered agricultural and forestry bioenergy to end-users. Conversion of feedstock to higher energy density biomass and related technologies (*e.g.*, torrefaction) will gain importance. Another option to reduce increasing dependency on bioenergy will be to reduce total demand by improving energy efficiency.

Overcoming these development challenges will require target setting, the development of finance mechanisms and in particular efforts to address transmission-related issues. China is currently putting much effort into these issues, but this effort needs to be sustained in the long term to 2030 and beyond.

## The case for electrification

The analysis shows that biomass resources in China account for around 30% of the identified options in REmap 2030. However, affordable and sustainable sourcing of biomass remains an important issue. The concurrent deployment of alternative and complementary renewable energy resources can help to reduce the potential dependence on biomass.

Electrification offers the potential to reduce fuel use for heating and transport. To further explore and clarify the renewable electricity potential, we have created an additional set of REmap options expressly for this case, Remap-E, which considers a more radical electrification scheme than REmap 2030. It essentially replaces most biomass and some fossil fuels with electricity from renewables. In REmap-E, we assume the deployment of three technology strategies to reduce biomass dependency and increase the share of electricity in end-use sectors. In the building sector, heat pumps deliver the required heat in the building and industry sectors instead of biomass (but only for low temperature heat). In the transport sector, modal shifts (public trams, electric buses and trains) can replace liquid biofuel use. Increased electricity demand from these end-use sectors would be supplied by additional solar PV and wind capacity.

### *A more radical electrification plan (REmap-E) could raise the share of renewables in power generation and total final energy consumption*

In industry, the options for heating are limited, especially in the case of high-temperature process heat generation in the manufacturing sector, which can only be generated from biomass (or fossil fuels). However, for low and medium temperature applications, heat-pumps could be deployed. In the manufacturing industry an increase in electricity demand resulting from a switch from biomass fuels to heat-pumps results in around 470 TWh/year of additional power demand.

For the transport sector, the additions in biofuel consumption identified in REmap 2030 are replaced by a shift from passenger automobile to electric public transport. For this around 20% of this passenger traffic is met by better utilisation of existing public transport lines, and the remaining 80% met through new electric transport infrastructure. In total 38 TWh of additional electricity is needed to power these electric transport systems.

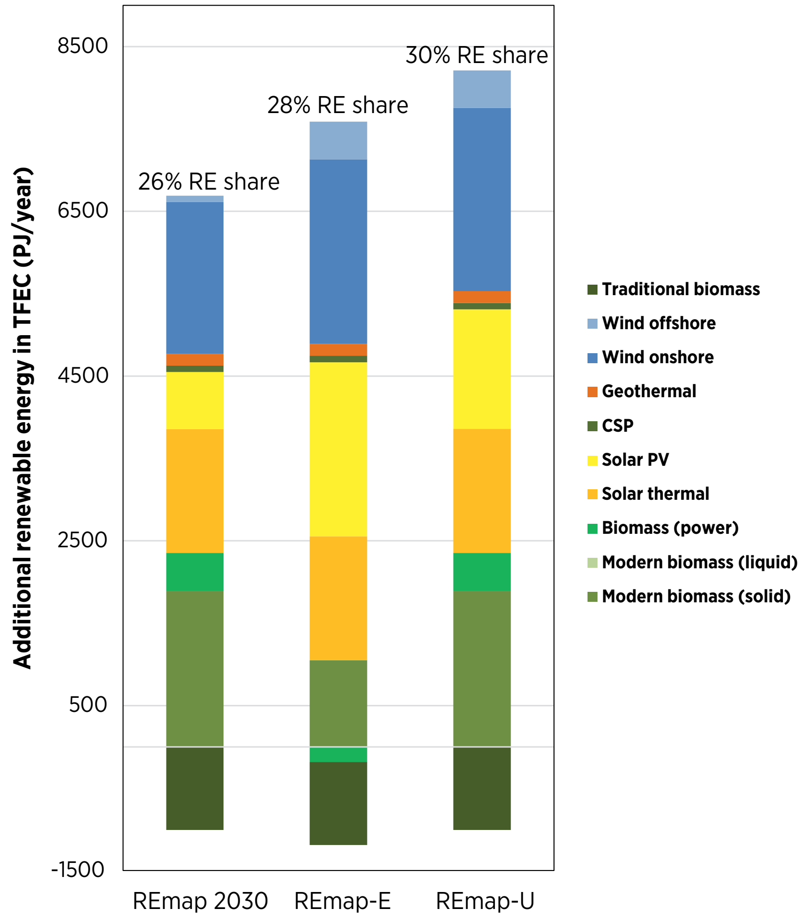
In the power sector, there are plenty of alternatives to substitute biomass use in power production. In REmap-E, 230 TWh of power production from biomass is reduced compared with REmap 2030, or a 66 TWh reduction over the 2030 Reference Case level. It was assumed that this reduction is met by increases in solar PV generation. Additionally, the increased electricity demand resulting from electrification in the end-use sectors of 415 TWh is met with 50% solar PV, 25% of onshore wind and 25% offshore wind.

Figure 23 compares the breakdown of the additions identified in the various REmap cases, as well as the renewable energy share in the energy mix of 2030: REmap 2030 and REmap-E and REmap-U, which shows how a 30% or great renewable energy share could be achieved on a global basis. Note that the share of renewables in TFEC would be slightly higher with electrification technologies replacing biomass, increasing from 26% in REmap 2030 to 29% in REmap-E.

Biomass demand in China is assumed to increase in primary terms to 6.8 EJ by 2030 in REmap-E instead of 11.9 EJ in REmap 2030. This translates to almost no growth in biomass demand compared with today's levels. Compared with REmap 2030, this is halving the demand for total biomass use.

The effect on the power sector in terms of installed capacity is dramatic. The total capacity of solar PV doubles from just over 300 $GW_e$ REmap 2030 to over 600 $GW_e$ in REmap-E. For wind, including both offshore and onshore, around 100 $GW_e$ of additional capacity is added, resulting in around 630 $GW_e$ in REmap-E. Biomass power capacity decreases to about 25 $GW_e$, or around two-thirds the 2010 level. The share of renewable energy in power increases from 39% in REmap

*Figure 23: Renewable energy technology options in the cases of REmap 2030, REmap-E and REmap-U, 2030*



*Note: All cases result in a reduction of traditional uses of biomass and REmap-E results in a reduction of biomass use for power generation, these are shown with the negative values in the graph*

2030, to 43% in REmap-E. These have the effect of raising the share of variable renewables in generation from 19% in REmap 2030 to 26% in REmap-E, implying that even more efforts will be required to ensure grid stability compared with the REmap 2030 case.

Another important finding is that REmap-E results in a lower TFEC in 2030 of 83 EJ compared with 90 EJ in REmap 2030, a saving of 8%. The main reason is the higher energy efficiency of electrification technologies over combustion energy systems when viewed in final energy terms. As a result, even with a smaller increase in EJ from the REmap Options in REmap-E, a similar share of renewables can be achieved as in REmap 2030.

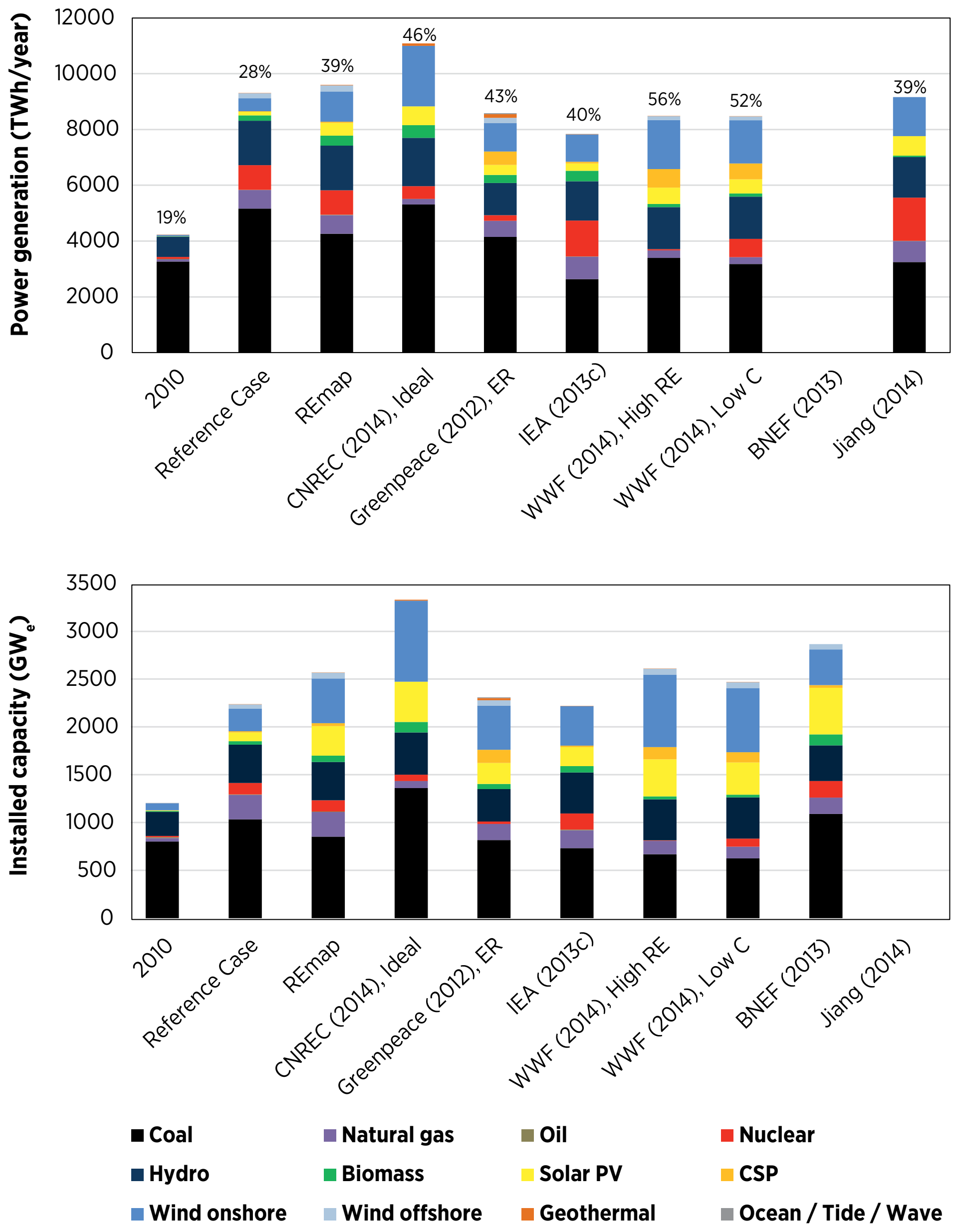
Another strategy for doubling the global renewable energy share is represented by the case of REmap-U (also shown in Figure 23). In this case, all countries are assumed to reach at least 36% renewable energy share by 2030 regardless of where they stand today, using a generic mix of different renewable energy technologies. While some countries would need to substantially increase their renewable energy shares from today's very low levels to 30%, others would meet, or even surpass, this level according to their Reference Case developments.

A number of technology options and strategies are required to ensure that all countries reach at least 30% by 2030. According to REmap-U, the first strategy for all countries is to reduce energy demand by implementing energy efficiency measures. The reduction potential would differ for each country, varying with the growth of energy consumption and the current level and distribution of energy intensity. For China an energy efficiency improvement of 5% was assumed.

The second strategy involves using increased electrification technologies for countries that do not achieve a 30% renewable energy share after the REmap Options and energy efficiency improvements are considered. This includes China, which only achieves slightly more than 28% in REmap-U when only energy efficiency improvements are taken into account. The electrification technologies chosen for China are those used in REmap-E, with the exception of industry relocation, which is not considered. As shown in Figure 23, REmap-U takes China's renewables share to 32%.

There are increased costs associated with both of these cases. These increased costs are in addition to the substitution cost already incurred when deploying biomass

*Figure 24: Comparison of REmap 2030 with the findings of other studies for power sector, 2030*



technologies. In REmap-E, for the building sector, the increase amounts to only around USD 1 per GJ to the substitution cost. For the transport sector this increase rises to around USD 10 per GJ for the impacted technologies. In industry the use of heat pumps adds around USD 2 per GJ to the substitution cost. For REmap-U, similar costs are associated with increased electrification, the assumed energy efficiency improvements yielding cost savings since less renewable energy capacity is required. As a result, the cost impact of REmap-U is lower than REmap-E.

## Comparisons with other studies

Figure 24 provides a comparison of the REmap 2030 findings for the power sector with those of a number of other scenario studies. The most ambitious renewable energy scenario has been chosen from these studies for comparison with the REmap 2030.

IRENA's total power generation estimates of 9 595 TWh/year are in the middle of the range found by other studies, which span from about 8 000 TWh/year to 11 000 TWh/year in 2030. In terms of the renewable energy share in power generation, REmap 2030 estimates are 5-15 percentage points lower than others. This is partly due to higher forecasts for coal-based power generation of around 4 300 TWh/year in REmap 2030, compared with between 2 600 TWh and 3 400 TWh/year in other studies.

Hydroelectricity generation is among the highest in REmap 2030, with about 1 600 TWh/year compared with total installed capacity of around 400 $GW_e$ in most other studies. The difference is explained by the higher capacity factors of 4 000 hours assumed in REmap 2030.

Total power generation from wind of 1 300 TWh/year is lower than other studies. With regard to biomass and geothermal power generation, REmap 2030 is comparable to projections in other studies. Greenpeace (2012) projects much higher generation for offshore wind, geothermal and ocean technologies compared with any other studies.

A comprehensive review of various modelling tools looking into China's energy future has been carried out by Mischke and Karlsson (2014). According to the review of 10 energy models, the total energy demand of China could grow by anywhere between 50% and 125% by 2030 compared with 2010 levels. In the Reference Case of this study, total final energy consumption grows by about 60%, which falls in the middle of this range.

***Forecasts of China's energy demand growth by 2030 vary widely; projections in the Reference Case of this study fall in the middle of the range***

# 8 BARRIERS AND OPPORTUNITIES FOR RENEWABLE ENERGY TRANSITION

## 8.1 Barriers and opportunities in the power sector

### Conventional fuels

As a result of its coal dependence and size of the economy, China has the highest $CO_2$ emissions of all countries. Moreover China currently accounts for 70% of new $CO_2$ emissions each year. Burning coal also results in massive local and regional air pollution problems. The record air pollution in January 2013 resulted in increased efforts to limit coal use, especially in the populated and industrial areas of eastern China. The government has recognised these environmental problems and is trying to diversify its energy mix.

Around 95% of the total power generation capacity in China has been built since 1990 and will still be operational in 2030. Therefore replacement investments play a secondary role in the transition to renewables unless the costly early retirement of some coal-fired plants is considered, as has been addressed in the case of onshore wind power in this study. However, demand growth is projected to continue and double between 2010 and 2030. This translates to about 1 000 $GW_e$ of future coal power generation capacity. Overall, more than 500 GW of capacity additions are planned of which 70% are coal-based (Platts, 2013).

### Transmission and grid infrastructure

The distribution of energy resources in China is diverse. More than 80% of the potential energy resources, such as coal, oil, natural gas, hydroelectricity, wind power and solar energy, are distributed in the northern and western parts of China. Around 80% of onshore wind energy capacity is distributed in the "3-North" regions (North, Northeast and Northwest). Two-thirds of hydroelectricity is located in the southeast. The spatial distribution of supply and demand creates challenges. Significant transmission capacity is planned, but not yet in place. Moreover, renewable power competes with coal power for the same transmission capacity.

By contrast, 70% of the total demand is in central and coastal parts of China (Hammons, 2011). The distance between the best resources for renewable energy generation and the main areas of demand is a major obstacle because of the large investment needs for new transmission and distribution capacity.

This has already constrained the rapid expansion of renewables. There is a considerable lag between additions in wind power capacity and the proportion that has been connected to the grid (DB, 2012; Zhang *et al.*, 2014). In 2012, 22% of installed wind power was running idle, mainly due to the fact that coal-fired power plants have, in practice, priority grid access and grid capacity is limited. As of the same year, 20% of China's wind farms were not connected to a power grid. This is caused by a combination of factors that include, rapid capacity expansion, limited coordination between project developers and grid planners, lack of transmission capacity and technical concerns of regional utilities that the intermittency of wind power could be disruptive to normal operations[19] (Zhang *et al.*, 2014).

Restrictions to inter-regional grid connections mean that cross-regional trade represented 4% of total production in 2009. Much of this is due to the fact that coal power plants still have priority (IEA, 2011b; Davidson, 2013b). The effect might be small in Liaoning, Ninxiang, Yunnan and Xinjiang but it falls 1-3 percentage points off capacity factors in Jilin, Inner Mongolia, Gansu, Heilongjiang and Hebei. The effective capacity factor of Chinese wind is 22-23%, compared with 31-32% for the United States (2013 data). Curtailment rates ranged from 13% to 25% in 2012, although these restrictions are falling. Between January and June 2014, the nationwide curtailment rate was 8.5%. According to China's renewable energy policy, wind farm owners should be compensated for curtailment, but in reality no economic compensation is paid.

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[19] Different accounting systems for annual wind market statistics have led to different information about the status of wind farm connection to the grid; thus different values are found in the literature.

Grid is a key enabler and the future of wind energy is closely connected to the future development of grid policies. So far, high curtailment rates related to problems with grid connections, the lack of priority dispatch and missing power grid capacity have led to uncertainty and financial losses. In 2013, wind saw a capacity increase, possibly as a result of improved measures to reduce curtailment. In addition to curtailment, the second other big system challenge which China's wind sector is facing today is grid interconnection, but China made considerable progress related to that as well since both new installations grew and the percentage of non-connected capacity fell.

With regard to solar PV, curtailment in the first half of 2014 reached up to 30% for many plants, and in particular in provinces where solar PV capacity is high. Some 70-80% of the overall capacity comprised utility-scale plants facing significant grid curtailment constraints (notably in the northern and northwestern regions).

Despite the improvements in wind power, a number of institutional barriers continue to stand against increased transmission. These include disagreements on the engineering and economic merits of AC vs DC lines, fragmented transmission authorities (implying the need for centralisation of dispatch and transmission), and non-market and semi-transparent transmission pricing (Davidson, 2013b).

Each of the three independent grid companies in China, namely SGCC, China State Grid Corporation (CSGC) and the Western Inner Mongolia Grid Corporation, is responsible for its own profit and loss. This limits incentives for inter-company co-operation. Furthermore, the current electricity trading structure is an obstacle. Without changes to the current system, the expansion of grid transmission capacity may not be a solution. Spot market electricity trading is small (14% of the total power generated in 2009); otherwise inter-regional and provincial trading is determined by multi-year contracts, both in terms of the volume and price (IEA, 2011b).

## Solar photovoltaics

China had 21 $GW_e$ of solar capacity installed as of the end of 2013. In the same year, a distributed FiT was introduced. For solar PV, the deployment strategy has changed in recent years. Before 2013, the focus was on large-scale solar PV installations. There has been movement on this front and since then the focus has begun to shift towards distributed solar PV applications. NEA recently approved 1.8 $GW_e$ of distributed industrial/commercial solar PV demonstration projects, and more than 3 $GW_e$ of capacity was commissioned in the first half of 2014, with cumulative distributed PV capacity reaching 4 $GW_e$ by the end of June 2014 (CREIA, 2014b). This is a considerable increase compared to end of 2013 where only 800 $MW_e$ capacity was installed. But current solar PV leasing models have encountered a number of issues related to uncertainties about ownership of a property over the contract period. Such uncertainties could put developers into a situation where the contract might not be respected if the business owner has changed. Moreover, although the saved tariff and received subsidies should be shared between the developer and roof owners, the developers might face difficulties in receiving their share timely or fully as agreed in the contract.

Execution of projects has so far also been hampered by a number of other factors. These include financial returns determined by FiTs which are less attractive as current policy prefers a 100% self-generation and self-consumption model instead of selling self-generated power to the grid. In addition, multi-point grid connections are not allowed, while residential power prices are

**Box 6: Inner Mongolia case study: The need for connection**

In 2010, Inner Mongolia had total power generation capacity of 34 $GW_e$. In comparison, demand is only 18 $GW_e$. Of the remaining 16 $GW_e$, only 4 $GW_e$ can be exported to the northern China grid. This means there is an overcapacity of 12 $GW_e$. This problem will grow as more wind farms are built. In the 12th FYP, Inner Mongolia requested the following grid expansion: seven 600 kV AC lines, one 660 kV DC line, and one 800 kV Ultra High Voltage Direct Current (UHVDC) line which can bundle hydro, thermal and wind power and transmit 30 $GW_e$ outside of the province (Lu, 2010).

much lower than the industrial and commercial rates. This makes residential schemes comparatively unattractive: there is an unguaranteed stability of the load, and as discussed above no standardised roof leasing contracts are available, and the ownership and poor structural stability of roofs is often unclear. All of these risks help to limit the confidence of banks in providing loans to distributed solar PV investors. Quality of equipment (affecting lifetime, return on investments, etc.) and standards are also key issues.

To address these issues, Chinese authorities released a number of policy updates in September 2014 to ensure that the installation target of 8 $GW_e$ of distributed generation can be reached.

Standardised grid connection regulation for solar PV electricity generators with a capacity below 2.5 $MW_e$ can guarantee private investors access, connection and priority dispatch for the distribution grid one month after the completion of construction. In combination with standardised building regulation, this should help to achieve the 2020 distributed solar PV targets. Public buildings might get permission to lease rooftops to investors, benefiting both parties.

## Wind offshore

While offshore wind today is more expensive in China than onshore wind, it is a technology of high strategic importance. The cost reduction potential for offshore wind installations is significant. The majority of China´s mega cities are close to its long coastline and relatively short distances for new power lines are required to connect offshore wind farms with cities and industrial areas. However, current offshore wind targets are low and a mid-term programme to accelerate installation rates would help to boost the industry.

## Bioenergy

Bioenergy for power generation is a mature market, but today feedstock collection and the unstable prices of feedstock are major problems to its deployment. Residues have a large potential, but agricultural production is mostly small-scale and geographically scattered. Supply chains are not yet established to collect and deliver the required quantities to end-users. Despite the large availability of straw, for example, its harvest period is short (six weeks), meaning large-scale storage is required, as are distribution networks to make the most of the resource.

As a result, the growth of biomass power generation capacity has been very moderate. Waste-to-energy technologies exist, but problems arise over the pricing of waste treatment services and the allocation of energy recovery benefits. Related environmental impacts are another issue limiting the further use of waste for power generation.

## Feed-in Tariffs

China has chosen to use FiTs to support the deployment of renewable energy. So far the experience has been good in general, despite problems with long delays in reimbursing producers. But the total costs of the FiT system are growing rapidly and the Chinese government aims to gradually reduce the amount of tariff spending with the aim of stopping FiTs for new installations by 2020. A smooth transition is required in order to secure the future development and growth of the renewable energy industry. Parallel to the phasing out of FiTs, the current “FiT” – a guaranteed price per MWh which is set by the NDRC for thermal plants – should be phased out at the same time in order to achieve a level playing field.

It is not only the FiTs, but grid regulations which could be the backbone of the renewable energy sector in the future. If that would be the case, renewable energy sector will need more regulatory support after 2025 and less monetary support. Priority dispatch and mandatory grid connections will be key policy instruments as they are expected to enter full competitiveness with conventional power generation technologies between 2020 and 2025. A minimum tariff for all renewable energy generators – based on the annual average generation costs of the previous year – could remain as a fall-back-option in order to lower the risk to investors.

## Renewable energy equipment manufacture

China has a large wind turbine and solar PV production capacity. The massive scale-up of solar PV production in the country has contributed significantly to the rapid decrease of solar PV investment costs. Some two-thirds of all solar water heaters and 90% of biogas installations are also located in China. A combination of market size, industrial capacity and the application of policies to specific areas of renewable energy use has enabled this development.

While it may not be the case today, China might face several challenges to developing its renewable energy industry further over the coming decades, including the increasing export orientation of the wind industry and increased imports related to the domestic solar PV market. Targets for equipment manufacturing capacities (solar PV and wind) in terms of GW/year, which take into account the medium and long-term goals for the domestic market, require re-powering needs. The overall assumed development of the global market size could be useful in this respect. Long-term certainty helps to achieve cost stability for renewable energy policies as well.

Improving the quality of products is important for a number of reasons. Better products enhance the lifetime and durability of plants, thereby ensuring a higher return on investments. As a consequence, this creates more confidence for both investors and financiers. Furthermore, there is a need for continuous innovation and R&D to improve the efficiency of plants.

## 8.2 Power market reform

Power market reforms have been on the Chinese government's agenda since 2002, and several local tests have been conducted. On the national level, however, there is only limited progress. Power market reforms on the wholesale and retail side are closely linked to power sector restructuring with more transparent pricing of grid services and clearer division of roles regarding grid development and system operation.

In essence, the power sector can be broken down into three independent areas: power production, transmission and distribution. Transparent regulation for grid access, grid services and dispatch and wheeling fees/regulations enable private and public investors to enter the power market. Unbundling the sector from a transmission grid operator (TSO) and distribution grid operator (DSO) is possible both with private and state-owned ownership structures. Liberalisation of the power sector in Europe over the past 20 years has shown that state-owned grids can still provide access to private investors. Each entity must be independent, with a legal framework which guarantees a level playing field without the discrimination of third parties. The lack of progress in that regard creates challenges for the renewable energy sector.

Firstly, delays in power sector reform create serious problems for the integration of renewable energy. The state-owned power generation companies have their power production prices set by the government; operating hours are set on a yearly basis for coal plants that represent the bulk of generation capacity. This makes it difficult to ensure that the electricity system is efficient. The power uptake of renewables is regulated through state-regulated hydro expansion and portfolio standards combined with FiT for solar, wind and bioenergy, and it has been difficult to coordinate the deployment of these technologies with plans for local grid development.

## 8.3 Barriers and opportunities in end-use sectors

In 2030, power consumption would only account for 30% of China's total final energy consumption. 70% would be related to fuel use in end-use sectors for heating and transport. This means efforts in end-use sectors to overcome related barriers, thereby accelerating the use of renewables will be essential.

Heating demand can be divided into four components. Heating in buildings is for cooking as well as space and water. In the manufacturing industry, it is process heat for production in the form of steam, hot water or direct use.

So far, most policy attention has been related to improving efficiency, but some renewable technologies achieved considerable success. Today there is a support programme which covers both urban and rural consumers regarding the increased use of solar thermal for water heating. However, its capacity in the industry sector is negligible. Biomass also plays a negligible role in industry, with the exception of some non-metallic mineral production processes that use charcoal or briquettes as well as the use of black liquor in the pulp and paper industry. There is no policy focus to accelerate the use of renewables in the sector.

District heating plays an important role in urban areas of northern China. The heat is however predominately produced from coal-fired CHP. Biomass-fired district heat generation and other non-biomass renewables are alternatives. Some of the solar heating and geothermal related targets of the 12th FYP may create synergies for the district heat sector. To date, there are a number of solar thermal pilot projects for district heat generation.

China's biogas programme has resulted in the rapid expansion of biogas digesters; today around 100 million rural people benefit from such systems. In view of the changing socio-economic landscape (*e.g.,* decreasing rural population), policies need to be adapted to ensure continuity in growing biogas use.

One of the key challenges in the residential sector is the traditional use of biomass. The first priority is improving knowledge about the actual use of traditional biomass, hence measuring current demand. There is a wide range in statistics about the number of people relying on biomass for cooking in rural areas. The Chinese government provided 180 million improved cooking stoves to households across the country that use biomass, however, their status is unknown. Without better data, it is not possible to set targets and develop policies. The second priority is to create a market for efficient, reliable and affordable cooking stoves and ensure their acceptability.

***In order to draw up appropriate policies for traditional biomass use, the priority is to acquire better data on the sector and measure current demand***

For the transport sector, the policy focus is on improving efficiency through fuel economy standards, labelling, improving the quality of fuels, as well as subsidies and taxation of vehicle and fuels. There are subsidies which are specific to electric vehicles, the amounts depending on the vehicle type and battery capacity. Regarding biofuels, targets exist for 2020, and the government encourages the use of marginal land and non-food feedstock for their production. However, mandates and market support for ethanol only covers nine provinces so far and the government does not support and/or incentivise specific biodiesel mechanisms.

# 9 SUGGESTIONS FOR ACCELERATED RENEWABLE ENERGY UPTAKE

The development and use of renewable energy is a high priority for China in order to address growing environmental challenges and the need to enhance the security of energy supply. Reaching higher shares of renewable energy use also has an important role to play in meeting China's policy objectives in respect to job creation, new economic activity and a better trade balance. In the beginning of the 2000s, China decided to boost the development of renewable energy through energy policies as well as industry policy measures. As a result, China is today a global leader in renewable energy.

This study showed that there is a potential to increase this growth further which can lead to 26% renewable energy share in China's total energy mix. At the same time, there remains a number of challenge and barriers which must be overcome to realise this potential. Based on the discussion in this study, the following high level policy recommendations have been identified to help accelerate the deployment of modern renewables in China from 2010 to 2030 and to account for some of the requirements during the transition period:

### Renewable energy policy:

- Develop a comprehensive national energy plan that accounts for the needed infrastructure for transmission and distribution of electricity, heat and gas
- Introduce taxation, caps, and/or $CO_2$ trading systems to account for the damage of $CO_2$ emission and other air pollution from coal combustion
- Assess the socio-economic, energy security, health, land and water use impact of various technologies
- Set targets for renewables in manufacturing, buildings and transport

### Power market design:

- Establish national power market, creating incentives for flexible operation, and bringing in new investors
- Develop the grid to better integrate renewable energy, enhance trade and deal with variability

### Technology focused policies:

- Enhance government support for innovation, research and development to reduce renewable energy costs
- Support development of next-generation renewable energy technologies
- Improve knowledge and data collection on biomass and develop a working biomass feedstock market

In addition to these high-level policy recommendations, the rest of this section provides more detailed recommendations grouped under five areas of policy action. These recommendations emerge from the outcomes of the China REmap 2030 analysis. The policy action areas are defined based on IRENA's country analysis in consultation with the national experts.

### Planning transition pathways:

- Diversify technology deployment to include options which are being deployed slowly today, including offshore wind, CSP, large biogas and waste to energy
- Target cost reductions and power system market re-design for the short term, and integration of large shares of renewables into the system for the long term
- Ensure grid development as part of the development strategy for renewables
- Cooperate with neighbouring countries in grid integration to allow renewable electricity trade

(*e.g.*, wind and solar with Mongolia, hydro with Siberia and South East Asia)

- Continue to focus on renewable energy use for end-use sectors, and expand target setting

## Creating an enabling business environment:

- Allow prices to reflect the marginal cost realistically (*i.e.*, spot markets, day/hour ahead markets)
- Continue using subsidy schemes until technologies reach a mature level, in a way that supports cost reduction and efficient use of renewable energy
- Revise renewable power subsidies to enhance effectiveness by rewarding both construction and operation, reach power generators in a timely manner, and avoid delays in reimbursements

## Ensuring smooth integration of renewables into the system:

- Ensure economic incentives for flexible operation of thermal power plants and grids
- Develop solutions for pumped hydro business as part of the power sector market reform
- Strengthen decentralised solutions, notably for rooftop solar PV, including leasing models and policies such as net metering and smart grids
- Improve planning and organisation to stabilise biomass feedstock supply and improve feedstock logistics
- Improve planning for effective utilisation of straw residues as an energy source

## Creating and managing knowledge:

- Support the building of qualified human and institutional capacity for deployment of renewables and related infrastructure
- Improve data collection as well as the quality of biomass statistics (modern, traditional)
- Increase the availability of provincial level data and improve access to data through the internet for load and production of electricity and heat

## Unleashing innovation:

- Assess best practice technology and policies abroad and evaluate their applicability to China conditions
- Consider biomass co-firing and waste use in coal-fired power plants and co-combustion in cement kilns
- Refurbish small-hydroelectricity dams with a view to increase efficiency of power generation
- Explore options for advanced biofuels from lignocellulosic feedstock, and develop innovative solutions for energy-intensive industries that account for large industrial energy use share
- Develop solar heat for industrial process heat generation and solar absorption cooling for commercial buildings
- Strengthen electric vehicle and modal-shift programmes in tandem with an increasingly large share of renewables in power generation
- Strengthen renewable energy use in newly constructed buildings in cities

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AC | alternating current |
| BEV | battery-electric vehicle |
| BIPV | building integrated photovoltaics |
| CBEEX | China Beijing Environment Exchange |
| CC | combined cycle |
| CCS | carbon capture and storage |
| CCER | China Certified Emissions Reductions |
| CDB | China Development Bank |
| CDC | China Datang Co. |
| CDM | clean development mechanism |
| CEC | China Electricity Council |
| CGC | China Guodian Co. |
| CHDC | China Huadian Co. |
| CHNG | China Huaneng Group |
| CHP | combined heat and power |
| CNREC | China National Renewable Energy Centre |
| CNPC | China National Petroleum Corporation |
| CNOOC | China National Offshore Oil Corporation |
| $CO_2$ | carbon dioxide |
| CPIC | China Power Investment Co. |
| CSG | Southern Power Grid Corporation |
| CSGC | China State Grid Corporation |
| CSP | concentrated solar power |
| DC | direct current |
| EJ | exajoule |
| ETS | emissions trading system |
| EU | European Union |
| FiT | feed-in tariff |
| FYP | five-year plan |
| Gcal | gigacalories |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| GJ | gigajoule |
| Gt | gigatonne |
| GW | gigawatt |
| $GW_e$ | gigawatt-electric |
| $GW_{th}$ | gigawatt-thermal |
| HHV | higher heating value |
| IBT | increasing block tariff |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| IPP | independent power producer |
| IRENA | International Renewable Energy Agency |
| km | kilometre |
| kt | kilotonne |
| kV | kilovolt |
| kW | kilowatt |
| kWh | kilowatt-hour |
| $kW_e$ | kilowatt-electric |
| LCOE | levelised cost of electricity |
| LHV | lower heating value |
| LNG | liquefied natural gas |

| | |
|---|---|
| LPG | liquid petroleum gas |
| MMS | mandatory market share |
| MOF | Ministry of Finance |
| Mt | megatonne |
| Mtce | million tonnes of coal equivalent |
| MW | megawatt |
| MWh | megawatt-hour |
| $MW_e$ | megawatt-electric |
| $MW_{th}$ | megawatt-thermal |
| NDRC | National Development & Reform Commission |
| NEA | National Energy Administration |
| $NO_x$ | mono-nitrogen oxide |
| O&M | operation and maintenance |
| OECD | Organization for Economic Co-operation and Development |
| PJ | petajoule |
| PM | particulate matter |
| PV | photovoltaic |
| R&D | research and development |
| RD&D | research, development and deployment |
| RMB | renminbi |
| SASAC | Supervision and Administration Commission |
| SE4All | Sustainable Energy for All |
| SEEE | Shanghai Environment and Energy Exchange |
| SERC | State Electricity Regulatory Commission |
| SGCC | State Grid Corporation of China |
| $SO_2$ | sulphur dioxide |
| tcf | trillion cubic feet |
| TCX | Tianjin Climate Exchange |
| TFC | total final consumption |
| TFEC | total final energy consumption |
| tce | tonnes of coal equivalent |
| TPED | total primary energy demand |
| TWh | terawatt-hour |
| UHV | ultra high voltage |
| UN | United Nations |
| USA | United States of America |
| USD | US dollars |
| WEO | World Energy Outlook |
| WHO | World Health Organisation |

# ANNEX A:

## Technology cost and performance data assumptions

| | Capital costs (USD/kW) | O&M Costs (USD/kW/ year) | Conversion efficiency (%) | Capacity factor (%) |
|---|---|---|---|---|
| **Power** | | | | |
| Renewables: | | | | |
| Wind onshore | 1 300 | 52 | 100 | 22 |
| Wind onshore (remote) | 1 500 | 80 | 100 | 30 |
| Wind offshore | 3 000 | 150 | 100 | 32 |
| Solar PV (rooftop) | 1 400 | 14 | 100 | 15 |
| Solar PV (utility) | 1 000 | 10 | 100 | 16.5 |
| Solar CSP (no storage) | 2 700 | 27 | 100 | 16.5 |
| Landfill gas | 2 250 | 57 | 100 | 80 |
| Wind onshore (remote) | 2 000 | 80 | 100 | 25 |
| Wind offshore (remote) | 4 050 | 200 | 100 | 32 |
| Conventional: | | | | |
| Coal | 1 300 | 52 | 30 | 57 |
| **Buildings** | | | | |
| Renewables: | | | | |
| Air-to-air heat pumps | 500 | 13 | 350 | 50 |
| Solar water heating | 220 | 6 | 100 | 14 |
| Biogas boiler | 1 000 | 25 | 80 | 50 |
| Pellet burners | 300 | 8 | 85 | 30 |
| Cooking (solid biomass) | 15 | 1 | 30 | 10 |
| Conventional: | | | | |
| Coal boiler | 175 | 6 | 90 | 85 |
| Oil boiler | 175 | 6 | 85 | 85 |
| Traditional biomass cooking | 30 | 0 | 10 | 10 |
| **Industry** | | | | |
| Renewables: | | | | |
| Solar thermal | 400 | 6 | 100 | 10 |
| Geothermal | 1 400 | 35 | 100 | 55 |
| Air-to-air heat pumps | 400 | 10 | 350 | 50 |
| Biomass CHP | 1 000 | 24 | 80 | 50 |
| Conventional: | | | | |
| Coal boiler | 400 | 10 | 90 | 85 |

| | Capital costs | O&M Costs | Conversion efficiency | Activity per year |
|---|---|---|---|---|
| | (USD / vehicle) | (USD / vehicle / year) | (MJ/p or tkm) | (p or tkm / year / vehicle) |
| **Transport** | | | | |
| Renewables: | | | | |
| Liquid biofuel passenger car | 28000 | 2800 | 1.64 | 15000 |
| Biodiesel truck | 120000 | 12000 | 1.15 | 110000 |
| Plug-in hybrid (passenger road vehicles) | 30000 | 3000 | 0.98 | 15000 |
| Battery electric (passenger road vehicles) | 32000 | 2880 | 0.69 | 15000 |
| Battery electric two-wheeler (passenger road) | 4000 | 10000 | 0.07 | 5000 |
| Conventional fuels: | | | | |
| Petroleum passenger car | 28000 | 2800 | 1.6 | 15000 |
| Petroleum truck | 120000 | 12000 | 1.16 | 110000 |
| Petroleum two-wheeler | 3750 | 375 | 0.6 | 5000 |

# ANNEX B:

## Energy price assumptions

| | National energy prices in 2030 (USD/GJ) |
|---|---|
| Crude oil | 21.9 |
| Steam coal | 1.5 |
| Electricity Household (USD/kWh) | 0.055 |
| Electricity Industry (USD/kWh) | 0.039 |
| Natural gas Household | 18.2 |
| Natural gas Industry | 16.8 |
| Petroleum products | 29.0 |
| Diesel | 43.5 |
| Gasoline | 50.9 |
| Biodiesel | 43.9 |
| Conventional ethanol | 53.9 |
| Advanced ethanol | 46.8 |
| Primary biomass 1 – fuelwood | 11.9 |
| Primary biomass 2 – biogas | 2.8 |
| Biomass residues 1 – ag. residues | 3.9 |
| Biomass residues 2 – forest residues | 12.2 |
| Traditional biomass | 3.5 |
| Municipal waste | 1.2 |

# ANNEX C:

## Details of REmap cost methodology

Two examples are provided to explain how the substitution costs are estimated:

- Biomass boiler substituting LPG-based boiler: The difference between the annualised capital, operation and maintenance and energy costs of the two boiler systems to deliver the same amount of heat are estimated, thereby taking into account the conversion efficiency, size of capacity, lifetime, capacity factors, etc. This is divided by the total final biomass demand of the boiler required to deliver that heat.
- Wind power substituting existing coal-based power: The difference between the annualised capital, operation and maintenance and energy costs of the two power systems to deliver the same amount of electricity are estimated, thereby taking into account the conversion efficiency, size of capacity, lifetime, capacity factors, etc. In the case of existing coal-based power, there are no capital costs as the capacity is assumed to be depreciated already. This difference is divided by the total renewable electricity generated from the wind power capacity.

For the business case, energy prices were estimated based on a number of methods. For some multipliers, expected developments in energy prices for the period between 2010 and 2030 were used based on the IEA projections and these were applied to national 2010 prices (IEA, 2012a). For the case of coal, import prices were used; for natural gas, Asian regional import prices were used; for oil products, IEA crude oil import price projections were used. For conventional liquid biofuel prices, growth in price was matched to expected development in petroleum prices; advanced biofuel estimates originated from IRENA's own estimates. All biomass feedstock prices are based on IRENA bottom-up analysis (IRENA, 2014c). Electricity prices were assumed to increase 30% over 2010 levels, which is based on the average price increase of conventional energy carriers, but also taking into account the changes in the fuel mix of the power sector with renewables.

In the government case, for coal, China was assumed to largely remain a domestic producer, therefore the lower price option was used. Electricity prices are based on national prices as described in the business case, but with the effect of taxes removed. For natural gas China was assumed to be an importer of natural gas and the higher price was used. Natural gas and coal prices were based on import/export price estimates from the IEA (2012a). Petroleum prices are standardised for the world and indexed to expected developments in the price of crude oil based on IEA (2012a). Liquid biofuel prices are IRENA estimates with the effect of taxes or subsidies removed. Biomass fuel prices are regionalised to the Asia (non-OECD) region.

# ANNEX D:

## Reference Case

| Sector | Renewable energy deployment in Reference Case in 2030 | |
|---|---|---|
| Power sector (incl. CHP) (TWh/year) | Total electricity production | 9312 |
| | Hydro | 1600 |
| | Geothermal | 9 |
| | Solar PV | 197 |
| | CSP | 18 |
| | Wind | 648 |
| | Solid biomass | 192 |
| | Liquid & gaseous biofuels | 0 |
| | Solar thermal | |
| District heat sector (incl. CHP) (PJ/year) | Total heat production | 5884 |
| | Geothermal | |
| | Solid biomass | 805 |
| | Liquid & gaseous biofuels | |
| | Solar thermal | |
| Industry (PJ/year) | Total consumption | 46027 |
| | Electricity consumption | 18255 |
| | Solid biomass | 875 |
| | Liquid & gaseous biofuels | |
| | Solar thermal | |
| Transport (PJ/year) | Total consumption | 18171 |
| | Electricity consumption | 1256 |
| | Liquid & gaseous biofuels | 600 |
| Buildings (PJ/year) | Total consumption | 20996 |
| | Electricity consumption | 7052 |
| | Solid biomass | 2516 |
| | Liquid & gaseous biofuels | 1130 |
| | Solar thermal | 2675 |

# ANNEX E:

## Data for cost-supply curve, from the business perspective and the government perspective

### Business Perspective

| | Technology | PJ TFEC | Substitution cost (USD2010/GJ TFEC) |
|---|---|---|---|
| 1 | High speed train for passenger aviation | 8 | -35 |
| 2 | City tram for passenger road vehicles | 8 | -32 |
| 3 | Battery electric (public road vehicles) | 4 | -30 |
| 4 | Battery Electric Two-wheeler (passenger road) | 6 | -30 |
| 5 | Battery electric (passenger road vehicles) | 34 | -28 |
| 6 | Plug-in hybrid (passenger road vehicles) | 54 | -27 |
| 7 | Space heating: Pellet burners | 500 | -14 |
| 8 | Space heating: Air-to-Air heat pumps | 127 | -12 |
| 9 | Cooking biomass (solid) | 92 | -6 |
| 10 | Landfill gas ICE | 316 | 0 |
| 11 | Autoproducers, CHP electricity part (solid biomass) | 196 | 1 |
| 12 | Autoproducers, CHP heat part (solid biomass) | 838 | 2 |
| 13 | Space heating: Biogas (replace trad. Biomass) | 244 | 3 |
| 14 | Solar cooling | 200 | 3 |
| 15 | Space heating: Air-to-Air heat pumps (LT Industry) | 290 | 3 |
| 16 | Water heating: Solar (thermosiphon) | 570 | 4 |
| 17 | Solar PV (Utility) | 268 | 5 |
| 18 | Geothermal | 145 | 5 |
| 19 | Biomass waste-to-energy | 1124 | 7 |
| 20 | Space heating: Biogas (coal rural) | 200 | 8 |
| 21 | Space heating: Pellet burners | 258 | 9 |
| 22 | Wind onshore | 482 | 10 |
| 23 | Solar thermal | 935 | 10 |
| 24 | Wind onshore (remote, existing) | 656 | 15 |
| 25 | Solar PV (Residential/Commercial) | 268 | 16 |
| 26 | Wind offshore | 77 | 27 |
| 27 | Solar CSP PT no storage | 79 | 36 |
| 28 | Wind offshore (remote, existing) | 59 | 36 |

## Government Perspective

| | Technology | PJ TFEC | Substitution cost (USD2010/GJ TFEC) |
|---|---|---|---|
| 1 | High speed train for passenger aviation | 8 | -35 |
| 2 | City tram for passenger road vehicles | 8 | -34 |
| 3 | Battery Electric Two-wheeler (passenger road) | 6 | -31 |
| 4 | Battery electric (public road vehicles) | 4 | -22 |
| 5 | Space heating: Air-to-Air heat pumps | 127 | -16 |
| 6 | Cooking biomass (solid) | 92 | -4 |
| 7 | Plug-in hybrid (passenger road vehicles) | 54 | -3 |
| 8 | Space heating: Pellet burners | 500 | -2 |
| 9 | Landfill gas ICE | 316 | -2 |
| 10 | Autoproducers, CHP electricity part (solid biomass) | 196 | -1 |
| 11 | Autoproducers, CHP heat part (solid biomass) | 838 | 1 |
| 12 | Space heating: Air-to-Air heat pumps (LT Industry) | 290 | 3 |
| 13 | Space heating: Biogas (replace trad. Biomass) | 244 | 4 |
| 14 | Water heating: Solar (thermosiphon) | 570 | 4 |
| 15 | Solar cooling | 200 | 5 |
| 16 | Solar PV (Utility) | 268 | 5 |
| 17 | Geothermal | 145 | 6 |
| 18 | Biomass waste-to-energy | 1124 | 7 |
| 19 | Battery electric (passenger road vehicles) | 34 | 8 |
| 20 | Space heating: Biogas (coal rural) | 200 | 8 |
| 21 | Space heating: Pellet burners | 258 | 10 |
| 22 | Wind onshore | 482 | 11 |
| 23 | Solar thermal | 935 | 12 |
| 24 | Wind onshore (remote, existing) | 656 | 16 |
| 25 | Solar PV (Residential/Commercial) | 268 | 18 |
| 26 | Wind offshore | 77 | 30 |
| 27 | Wind offshore (remote, existing) | 59 | 40 |
| 28 | Solar CSP PT no storage | 79 | 42 |

# ANNEX F:

## Levelised costs of renewable and conventional technologies in end-use sectors in 2030

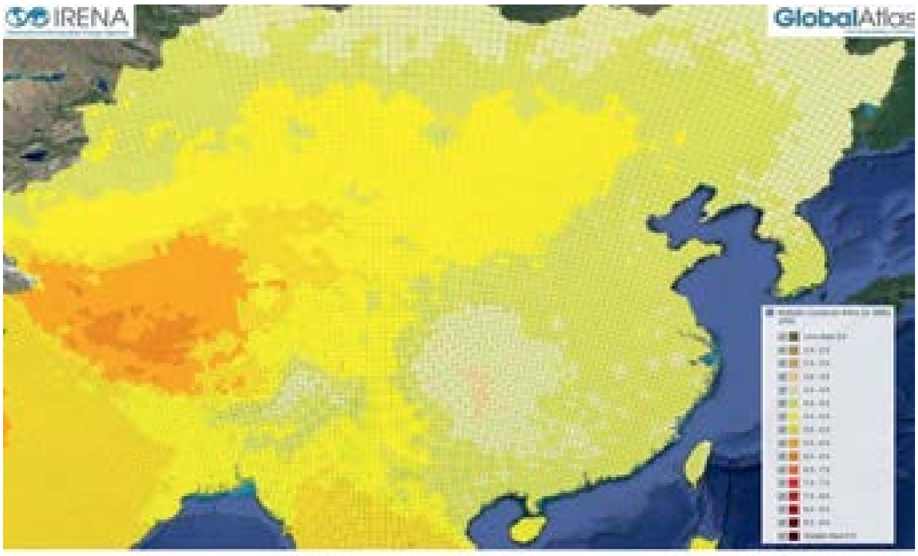
| | | USD/GJ | | USD/GJ |
|---|---|---|---|---|
| **Industry** | Autoproducers, CHP electricity part (solid biomass) | 17 | | |
| | Autoproducers, CHP heat part (solid biomass) | 17 | Coal (steam boiler) | 5 |
| | Solar thermal | 14 | Coal (steam boiler existing) | 3 |
| | Geothermal | 9 | | |
| | Heat Pumps (LT Industry) | 8 | | |
| **Buildings** | Water heating: Solar | 6 | Space heating: coal (boiler) | 3 |
| | | | Space heating: petroleum products (boiler) | 35 |
| | Space heating: Pellet burners | 9 | Heating/cooking traditional biomass | 24 |
| | Space heating: biogas | 14 | | |
| | Space heating: Air-to-Air heat pumps | 9 | Space heating: Natural gas (boiler) | 21 |
| | Cooking biomass/gas | 41 | | |

| | | USD/p or t-km | | USD/p or t-km |
|---|---|---|---|---|
| **Transport** | First generation bioethanol (passenger road vehicles) | 0.52 | Petroleum products (passenger road vehicles) | 0.52 |
| | Second generation bioethanol (passenger road vehicles) | 0.52 | Petroleum products (freight road vehicles) | 0.31 |
| | Biodiesel (freight road) | 0.25 | Petroleum products (two-wheeler) | 0.23 |
| | High speed rail for aviation | 0.01 | Petroleum products (passenger aviation) | 0.29 |
| | City trams | 0.4 | | |
| | Plug-in hybrid (passenger road vehicles) | 0.5 | | |
| | Battery electric (public road vehicles) | 0.48 | | |
| | Battery electric (passenger road vehicles) | 0.51 | | |
| | Battery electric (two-wheeler) | 0.23 | | |

# ANNEX G:

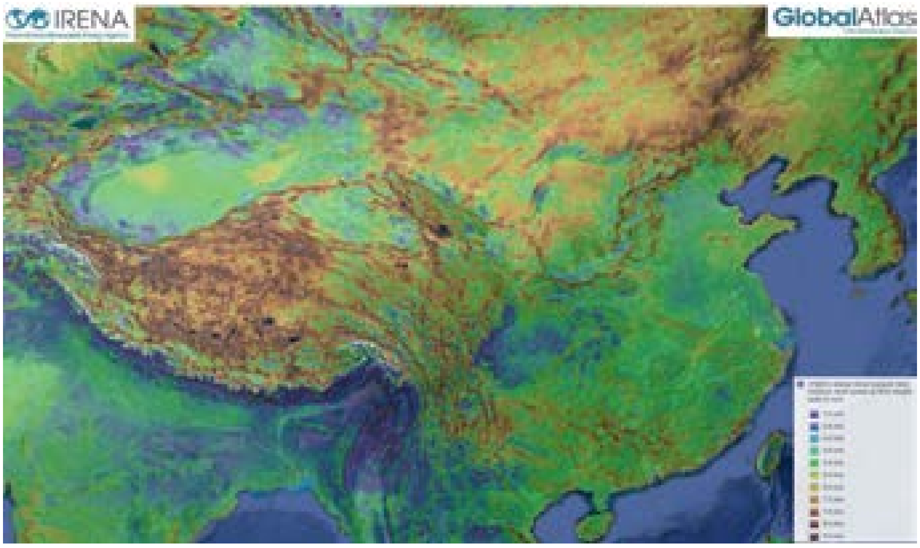
## Resource maps

### Solar



Source: *NREL (2006)*

### Wind



Source: *3TIER (2009)*

# ANNEX H:

## Detailed roadmap table

| **Total primary energy supply (PJ/year)** | **2010** | **Reference 2030** | **REmap 2030** |
|---|---|---|---|
| Coal | 61 561 | 81 944 | 67 400 |
| Oil | 11 460 | 21 083 | 19 552 |
| Natural gas | 2 863 | 13 633 | 12 454 |
| Nuclear | 806 | 9 575 | 9 575 |
| Hydro | 2 600 | 5 760 | 5 760 |
| Traditional biomass | 3 400 | 1 008 | 0 |
| Modern bioenergy (incl. biogas, biofuels) | 1 357 | 6 429 | 11 246 |
| Solar thermal | 860 | 2 674 | 4 482 |
| Solar PV | 3 | 709 | 1 602 |
| Wind | 161 | 2 332 | 4 804 |
| Geothermal | 156 | 353 | 643 |
| Ocean / Tide / Wave / Other | 0 | 0 | 0 |
| Total | 85 229 | 145 500 | 137 519 |
| **Total final energy consumption (PJ/year)** | | | |
| Coal | 24 945 | 25 874 | 22 800 |
| Oil | 11 082 | 20 676 | 19 145 |
| Natural gas | 2 006 | 7 501 | 6 322 |
| Traditional biomass | 3 400 | 1 008 | 0 |
| Modern biomass (incl. biogas) | 607 | 3 424 | 5 312 |
| Modern biomass (liquid) | 343 | 858 | 858 |
| Solar thermal | 500 | 2 667 | 4 365 |
| Geothermal | 140 | 293 | 439 |
| Other renewables | 0 | 0 | 0 |
| Electricity | 11 338 | 26 563 | 27 099 |
| District Heat | 2 424 | 2 918 | 2 918 |
| Total | 56 785 | 91 780 | 89 257 |
| **Gross electricity generation (TWh/year)** | | | |
| Coal | 3 262 | 5 099 | 4 269 |
| Natural gas | 83 | 663 | 663 |
| Oil | 13 | 12 | 12 |
| Nuclear | 74 | 878 | 878 |
| Hydro | 722 | 1 600 | 1 600 |
| Biomass | 33 | 192 | 358 |
| Solar PV | 1 | 197 | 445 |
| CSP | 0 | 18 | 46 |
| Wind onshore | 43 | 465 | 1 105 |
| Wind offshore | 0 | 182 | 158 |
| Geothermal | 1 | 9 | 9 |
| Ocean / Tide / Wave | 0 | 0 | 0 |
| Total | 4 233 | 9 315 | 9 543 |

| | | | |
|---|---|---|---|
| **Electricity capacity (GW)** | | | |
| Coal | 671 | 1 020 | 854 |
| Natural gas | 35 | 257 | 257 |
| Oil | 15 | 5 | 5 |
| Nuclear | 11 | 119 | 119 |
| Hydro (excl. pumped hydro) | 213 | 400 | 400 |
| Biomass | 6 | 38 | 65 |
| Solar PV (utility) | 1 | 98 | 190 |
| Solar PV (rooftop) | 1 | 41 | 118 |
| CSP | 0 | 12 | 32 |
| Wind onshore | 45 | 269 | 501 |
| Wind offshore | 0 | 46 | 60 |
| Geothermal | 0 | 1 | 1 |
| Ocean / Tide / Wave | 0 | 0 | 0 |
| Total | 999 | 2 306 | 2 602 |
| **$CO_2$ emissions (Mt $CO_2$)** | | | |
| Total emissions from fossil fuel combustion | 6 917 | 10 185 | 8 493 |
| **Renewable energy indicators (%)** | | | |
| Renewable energy share electricity - generation | 19% | 29% | 40% |
| VRE share electricity - generation | 1% | 9% | 18% |
| Renewable energy share electricity - capacity | 28% | 39% | 53% |
| VRE share electricity - capacity | 5% | 20% | 35% |
| District heat | 1% | 1% | 36% |
| Industry | 0.5% | 2% | 10% |
| incl. renewable electricity and DH | 5% | 11% | 21% |
| Transport | 1% | 5% | 5% |
| incl. renewable electricity and DH | 1% | 7% | 8% |
| Buildings (excl. trad. biomass) | 16% | 39% | 64% |
| incl. renewable electricity and DH | 16% | 36% | 54% |
| TFEC (excl. trad. biomass) | 7% | 16% | 26% |
| TPES (excl. trad. biomass) | 6% | 13% | 21% |
| **Financial indicators (in $USD_{2010}$)** | | | |
| Substitution Cost - Business Perspective (USD/GJ) | | | 5.6 |
| Substitution Cost - Government Perspective (USD/GJ) | | | 6.9 |
| Incremental system cost (bln USD/year) | | | 55-60 |
| Reduced human health externalities (bln USD/year) | | | -78 to -162 |
| Reduced $CO_2$ externalities (bln USD/year) | | | -32 to -126 |
| Incremental subsidy needs in 2030 (bln USD/year) | | | 60 |
| Incremental investment needs (bln USD/year) | | | 40 |
| Investment needs Reference Case (bln USD/year) | | | 91 |
| Investment needs REmap Options (bln USD/year) | | | 54 |
| Total investment needs RE (bln USD/year) | | | 145 |
| **Biomass supply (PJ/year)** | | | |
| Total supply potential | | | 8000 - 19000 |
| Total demand | | | 12004 |

# ANNEX I:

## Traditional use of biomass in China

While studies provide indications of the total population relying on biomass in China, it is not entirely clear how much traditional biomass is actually used according to the energy statistics available.

There are, however, a number of organisations which look into the total biomass demand by sector. The time series for the years between 1990 and 2013 based on the IEA (2013a), LBNL (2013) and FAOSTAT (2014) are provided in Figure 29. The main findings based on these three sources are discussed below:

(i) According to the IEA (2013a), in 2011 the residential sector used around 8 EJ of solid biomass; this was followed by the power generation sector where demand was 0.45 EJ. The residential sector also used a total of 0.3 EJ of biogas. Solid biomass use in the residential sector is decreasing whereas the demand for other applications is increasing. From these statistics it is not clear which part of the total solid biomass use in the residential sector is actually traditional. According to the IEA definition, all biomass use in the residential sector of the non-OECD countries should be traditional unless otherwise stated. If this definition is followed, the total traditional use of biomass in China in 2011 was 8 EJ. The IEA states in its methodology that data collected for biofuels and waste are estimates based on per capita average consumption according to various surveys and studies.

(ii) The FAO provides figures for fuel wood production and trade statistics by country. According to the organisation, the total fuel wood consumed (equivalent to production) in China has decreased from 3 EJ in 1990 to 1.9 EJ in 2010 (FAOSTAT, 2014)[20]. This decrease is a strong indication that much of this demand is related to traditional uses of biomass in rural areas since an increasing share of China's population is moving to urban areas; in addition, fuel mix changes in the residential sector are increasing the availability of LPG from urban to rural areas. According to the FAO, fuel wood includes all demand for power generation, heating and cooking. Excluding biomass demand related to power generation, we estimate the total wood fuel used for heating and cooking in the residential sector to be 1.6 EJ in 2011. However, it is not possible to provide a further breakdown about how much of the demand is traditional and how much is modern.

(iii) Another source which provides bioenergy use data is the LBNL China Energy Databook (LBNL, 2013). This source provides a breakdown of bioenergy use for three types of biomass, namely crop stalk, firewood and biogas. The source states that biomass data for rural household consumption should be treated with caution, saying that "…since sources vary, official estimates of biomass use for various years may not be comparable"[21]. According to LBNL, in 2007 the total demand for solid biomass had reached 7.4 EJ, which is similar to what is reported by the IEA (2013a) for the residential sector in the same year. Biogas data is identical to the IEA statistics. Crop stalks (5.2 EJ) accounted for two-thirds of the total demand for rural biomass household consumption with the remaining third coming from firewood (2.8 EJ) in 2007. Firewood data provided by the LBNL databook show strong similarities with the fuel wood data from the FAO.

In addition to these energy statistics, a number of other studies provide estimates for the total use of traditional biomass in the rural residential sector. According to Chen, Yao and Li (2010), rural residential energy con-

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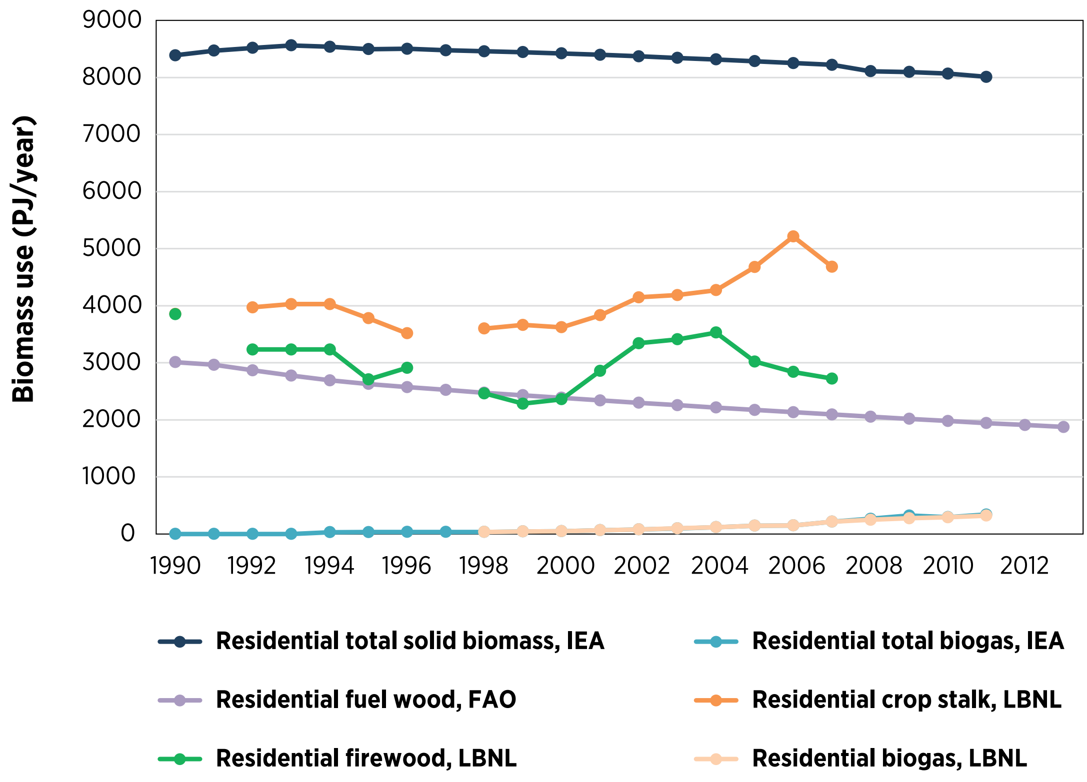
[20] The FAO reports wood fuel used in traditional form separately, if countries report the related quantities. This was not the case in China.

[21] The following sources have been quoted for the energy data in the statistics: EB, National Rural Energy Planning, 1990; SPC, Energy Conservation in China, 1997; NBS, China Energy Statistical Yearbook, various years; NBS, China Statistical Yearbook, various years; EB, China Rural Energy Statistical Yearbook, 1998-1999.

*Figure 28: Comparison of China total biomass use based on different sources, 1990-2013*



*Source: IEA (2013a); LBNL (2013); FAOSTAT (2014)*

sumption has shown a considerable shift from traditional to modern biomass use. The share of traditional biomass decreased from 82% in 2001 to 71% in 2008 of the total non-commercial energy use. The absolute volume of traditional use of biomass is shown in Table 18. In 2008, about 5.1 EJ of traditional biomass was used in China, according to the study. This is much lower than the data provided by the IEA statistics and LBNL databook, but higher than the values according to the FAO.

Xia (2013) reports that rural biomass energy use for the residential sector in China in 2011 was 127 million tonnes of coal equivalent, or 3.7 EJ per year.

Another source of data is the CNREC, which provides a breakdown of total biomass demand for power generation, as briquettes in heating, biogas and finally liquid biofuels. According to the CNREC, total demand for biomass was 0.7 EJ and 1 EJ per year in 2010 and 2012, respectively. CNREC data for power generation, liquid biofuels and biogas are very similar to the values according to the IEA statistics and the LBNL databook. However, data for solid biomass (88 PJ) is much lower than what is reported by other sources.

According to Mainali, Pachauri and Nagai (2012), household energy consumption in China ranged between 3.1 GJ and 10 GJ per capita per year (GJ/cap/year) in 2005. About 2-4 GJ/cap/year was related to biomass for cooking and heating. Based on a total rural population of about 670 million people, the study estimates total biomass demand for cooking was 2.1 EJ/year in 2005.

According to the data provided by Zhou, McNeil and Levine (2009), we estimate the total per capita energy demand in China for cooking and space/water heating as 2.2 GJ/cap/year in 2010. Half of this is for water heating and the other half is split between 80% space heating and 20% cooking.

Other studies also provide values for similar indicators. According to Daioglou, van Ruijven and van Vuuren (2012), total annual rural energy use per capita in 2007 was 12 GJ. Of this total, about 8.5 GJ/cap/year was related to cooking and 3 GJ/cap/year was related to space and water heating, of which space heating accounted for a considerably larger share.

Based on these per capita demand estimates and depending on the share of the total rural population relying on traditional uses of biomass, total demand in 2010 would be 0.8-4.2 EJ in China.

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