

# Chapter 1

## China's Energy Transition Strategy in the Context of Global Climate Change



Linwei Ma, Christine Yuan, and Honghua Yang

**Abstract** Worsening climate change has brought grave challenges to global energy development. All countries need to make urgent joint actions to speed up low-carbon transition of the energy sector. China, as the largest energy-related greenhouse gas emitter, plays a crucial part in global low-carbon energy transition. Clear strategic guidance is one of the indispensable factors for the country's successful transition. With the integration of energy system in mind, this chapter builds on the basic concepts of energy transition strategy and framework of system analysis to elaborate on China's energy transition strategy amid global climate change. The chapter contains three sections: energy challenges in China, the history, recent trends and future path of China's energy system, and policy recommendations for energy governance and energy markets. Overall, the challenge of China's energy transition in the context of global climate change lies not only in the call to expedite carbon emission reductions in the energy system, but also in the need to address other energy issues such as energy equity, energy security, and environmental protection. To solve all these issues, it must consider the unique evolution and changing pattern of China's energy system itself, follow the mechanism, and meticulously craft the strategy of energy transition (energy revolution) that suits the national situation. Under the policy objectives of the energy revolution, such as capping total energy consumption, peaking carbon emission, and increasing the share of non-fossil energy, China must accommodate energy system integration relative to coordination between energy and economy, between energy and infrastructure and between energy and regional development. To this end, this chapter envisions the "3+1" energy system integration, and proposes to build a regional smart energy system that features the blend of "smart energy farms—smart energy towns—smart energy industrial parks—smart energy transportation networks". However, this poses new challenges to the existing energy governance system and energy market management. Therefore, it's essential

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L. Ma (✉) · H. Yang  
Department of Energy and Power Engineering, Tsinghua University, 100084 Beijing, China  
e-mail: [malinwei@tsinghua.edu.cn](mailto:malinwei@tsinghua.edu.cn)

C. Yuan  
Corporate Relations, Rio Tinto China, 100004 Beijing, China

for China to empower energy planners, spur bottom-up energy innovation, remove the barriers to cooperation between the energy industry and enterprises, and redouble efforts to strengthen the energy management information system and dedicated think tanks in the energy sector.

**Keywords** Climate change · China's energy system · Energy challenges · Recent trends · Future path · “3+1” energy system integration

## 1.1 Basic Concepts and Analysis Framework of Energy Transition Strategy

Energy transition refers to the paradigm shift in the energy system over time as required by the sustainable development goals. The increasingly severe global climate change has called for more efficiency in energy transition than ever. Driving this process not only involves a higher uptake of energy-saving technologies and renewable energy, but also other spheres such as economy, society, and politics, hence a need to engage the whole society (Singh et al. 2019). In this circumstance, clear strategic guidance is critical.

For this purpose, this paper proposes the basic concepts of energy transition strategy and the system analysis framework to examine China's energy transition strategy. As per the notion of “sustainability-energy system-social governance-market operation” (Ma et al. 2018) coined by the author to study the strategy of regional energy development, energy transition strategy can be perceived as: “a master plan driving the overall revolution of the energy physical system of a specific social organization (global or regional) in order to meet the energy challenges of sustainable development”. The corresponding framework of system analysis is shown in Fig. 1.1.

In this analytical framework, the energy challenge of sustainable development is the background and constraints of the energy transition strategy; the strategy is mainly set by the energy governance system for the energy market system to consciously observe the principle of sustainable development and enable the transition of the energy physical system; the energy market system performs actual operations on the energy physical system, so that the resources input, energy output and emissions of the energy physical system can move towards the strategic goals of the energy system transition and sustainable development.

This chapter would revolve around this framework of system analysis and discuss China's energy challenge, energy system, energy governance and energy market.

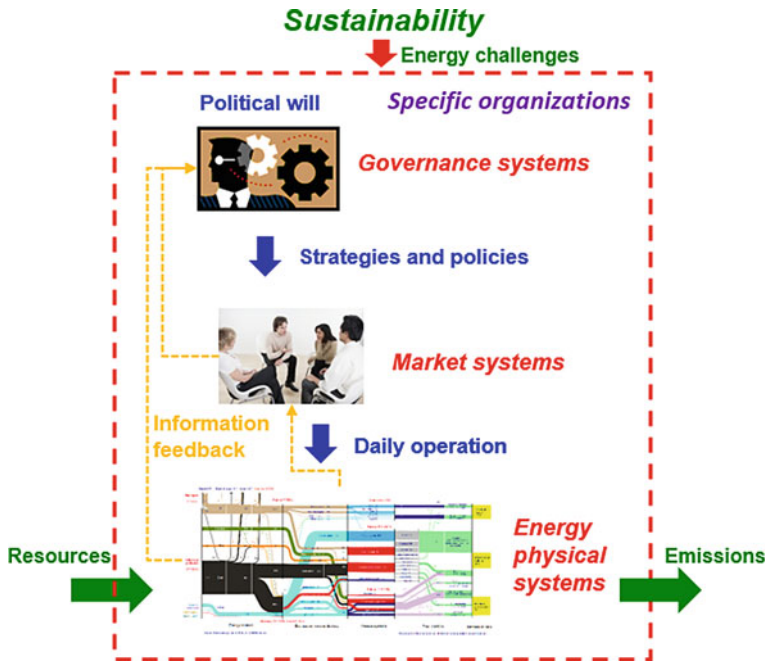


Fig. 1.1 Analysis framework of energy transition strategy

## 1.2 China's Energy Challenge in View of Global Climate Change

### 1.2.1 The Global Climate Change Faces Severe Challenge

To tackle global climate change challenge, the Intergovernmental Panel on Climate Change (IPCC) issued a total of five scientific assessment reports between 1990 and 2014, underscoring the scientificity, urgency, and severity of the issue. The IPCC's fifth report (IPCC 2014a, b) suggested that global warming was beyond all doubt, and that more than half of the observed increase of global average temperature from 1951 to 2010 was "very likely" (over 95% probability) caused by human influence on the climate. Unabated greenhouse gas (GHG) emissions will trigger a warming trend and long-term changes in all components of the climate system, increasing the likelihood of serious, universal and irreversible impacts on humans and ecosystems. Without greater mitigation efforts (reduction of GHG emissions), even with adaptation measures, the severe impacts and high risks of climate change will continue at least by the end of this century.

To deal with global climate change, the Paris Agreement was adopted at the UN Conference on Climate Change in 2015, which set the goal of "keeping global average temperature rise within 2 °C in this century" (UNFCCC 2015). However, the

continued increase in global GHG emissions further enlarges the gap between the target. “Emissions Gap Report” (UNEP 2019) issued by the United Nations Environment Programme (UNEP) in 2019 found that the median global GHG emissions will be about 41 billion tons of CO<sub>2</sub> equivalent per year by 2030 if we want to achieve the 2 °C goal. Meanwhile, the National Independent Contribution (NDC) targets currently submitted by countries in the Paris Agreement indicated that by 2030, the amount of emissions could only be kept between 54–56 billion tons of CO<sub>2</sub> equivalent per year. Given the gravity of the issue, all countries must further accelerate the low-carbon transition to meaningfully reverse climate change.

The energy sector contributes more GHG emissions compared to others, mainly through CO<sub>2</sub> emissions during the combustion of fossil fuels. According to the fifth report of the IPCC (IPCC 2014a, b), if measured in terms of direct emissions, the sector of energy supply (mainly electric heating production) contributed the most, about 35% to global GHG emissions in 2010. It also made up 47% of the annual global anthropogenic GHG emissions from 2000 to 2010. If indirect emissions are taken into account, CO<sub>2</sub> emissions from fossil fuel combustion and industrial processes accounted for 65% of global GHG emissions in 2010 and 78% of global growth in GHG emissions from 1970 to 2020. To mitigate the effects of climate change, the energy sector, as the main source of greenhouse gas emissions, must drive low-carbon transition and create a new system based on non-fossil energy.

### ***1.2.2 The World Faces Multiple Energy Challenges***

Climate change has become a serious challenge for the sustainable development of global energy. Yet sustainable energy development entails multiple objectives. Other energy challenges, alongside climate change, include energy equity and energy security, etc. (IIASA 2012), which are also closely linked to human survival and development. Together with climate change, these challenges constitute “energy dilemmas” for the sustainability of global energy, due to certain trade-offs between other energy challenges and climate change. To illustrate, to rapidly enhance energy equity, energy demand will surge, leading to more potential fossil energy consumption; to ensure energy security, countries tend to prioritize the use of their own rich resources, such as shale gas in the United States and “coal to oil” in China, thus impeding the scale-up of non-fossil energy. To solve the dilemmas, complex and intertwined links between public and private institutions, government and regulatory agencies, economic and social factors, national resources, environmental issues, and consumer behavior should be built, which is not an easy task. The assessment report published by the World Energy Council (WEC) argues that most countries have failed to effectively address the “energy dilemmas”, and there is still a long way to go for the meaningful sustainable development (WEC 2019). Examples for the substance and severity of the challenges could be found in energy equity and energy security listed below:

- **Energy equity:** Energy equity performs the basic mission of energy development by providing affordable modern energy services for all. At present, the world is still haunted by this challenge. For example, in 2016, 13% of the world's population lack electricity and 41% of the population were still using unclean cooking fuels and technologies; only 55% of renewable energy was of modern utilization with the rest coming from traditional biomass fuels such as fuelwood and charcoal. (UN 2018).
- **Energy security:** Currently energy security is not only about oil security, but also about power, natural gas and even end-use energy service security (Wang and Zhou 2017). Influenced by infrastructure and geopolitical factors, global energy security is still not optimistic. Major historic energy security accidents, including multiple oil crises, the power outage in the United States and Canada in 2003 (Zhou 2013), and the three gas disputes between Russia and Ukraine between 2006 and 2014 (Zhou 2014), have highlighted the importance and risks of energy security.

Apart from energy equity and security, other challenges also stand out in many countries, including regional environmental pollution from energy development and utilization, and how to support economic growth through the energy sector, etc.

### *1.2.3 Severe Energy Challenges in China*

The multiple energy challenges in the world are complex in various countries. For China, the magnitude and scale of the problems are unprecedented in human history. The five energy challenges laid out by some scholars (Ni et al. 2008) early on continue to exist, or have even increased, including: (1) huge and dynamically growing energy demand. In 2017, China's primary energy consumption contributed 23.2% to the world's total consumption, averaging an annual increase of 3.9% over the past decade (BP 2019); (2) the rapidly rising dependence on imported oil and gas. From 2007 to 2017, China's foreign dependence on oil rose from 50.7 to 68.5%, and its dependence on natural gas surged from 1.8 to 37.9% (NBSC 2018); (3) severe conventional environmental pollution lingers, including air, water, soil pollution, etc. (Li 2018); (4) lack of clean energy services in rural areas and small towns with acute energy poverty, plus the massive use of inferior bulk coal, serious pollution of coal-burning, backward energy infrastructure, and inadequate use of renewable energy (Ni et al. 2019); (5) enormous and ballooning greenhouse gas emissions. In 2017, China's energy-related carbon emissions accounted for 27.6% of the world's total emission, with a 10-year average annual growth of 3.2% (BP 2019).

In the meantime, as global climate change accelerates and China's economic and social development enters a new phase, the dimensions of China's energy challenge have also undergone notable shift. For instance, the overcapacity at the energy supply side in the new era calls for speedier transition from fossil-based (particularly coal) primary energy utilization to a pattern driven by non-fossil fuels, while meeting the

needs of high quality growth and supply-side reform; a need for transition from mainly centralized energy supply to moderately-sized distributed energy supply; a need for transition from an extensive mode of energy consumption featuring industrial use, especially that of energy intensive industries to a high-quality mode with residential and service usage as the mainstay. These critical issues merit high attention and good solutions during the low-carbon energy transition. The key lies in the collaboration of multiple energy sources and the smooth switch from the old to the new production capacity, which puts higher demand on the level and workload of energy system integration.

In addition to the aforementioned challenges, bigger challenges for China to accelerate the low-carbon transition comes from the “path lock-in” effect caused by the huge energy in-use stocks. For example: (1) Technology and economic lock-in. There is tremendous inertia for the type of energy economy relying on coal and other high energy-intensive sectors. The scale economy of traditional energy technologies and the long-term learning-by-doing development model make for their low cost and high performance, in contrast to new energy technologies that are unable to compete in the short-term (Klitkou et al. 2015). This undermines the motivation of enterprises to pursue low-carbon transition; (2) Social and cognitive lock-in. Stereotypes and living habits make people “selectively blind” to topics such as climate change that seem to bear little impact on their daily life (Nelson 2018). Moreover, user practices and lifestyle have been built upon traditional energy technologies and conventional way of supply and consumption. Triggering a switch would imply a change in the way of living, which faces problems of public acceptance and user participation.

### ***1.2.4 Summary***

The battle against global climate change calls for stronger efforts in low-carbon transition of energy systems in all countries. But the transition is facing multiple “energy dilemmas” including other energy challenges such as energy equity and energy security. China, in particular, is constrained by multifaceted and intertwined energy challenges: (1) vast and rising energy demand, with acute energy security and energy equity issue, heavy conventional environmental pollution from energy use and huge and surging greenhouse gas emissions; (2) the necessity to enable multi-energy synergism and smooth switch between old and new production capacity in the entire value chain of energy production and utilization, putting forward higher requirements for integrating energy systems; (3) the difficult elimination of the “path lock-in” effect from the huge social stocks of coal and high energy-intensive industries. To conclude, China is in an urgent need of exploring a path towards sustainable low-carbon transition based on the reality of its unique energy system.

### 1.3 The Past, Present and Future of China's Energy System

This section begins with a review of the history of China's energy system and its recent development, with a breakdown of historical stages. Secondly, the Sankey diagram tool was adopted to draw a full picture of China's energy flow, followed by analysis of the structural changes of the energy system from 2005 to 2015. Finally, the section explores the future direction for China's energy development, proposing a new concept named as "3+1" for energy system integration.

#### 1.3.1 The History of China's Energy System

Based on the historical data of BP (BP 2019), the changes in China's primary energy consumption and its structure from 1965 to 2018 can be shown in Figs. 1.2 and 1.3. From 1965 to 2018, China's primary energy use increased from 131.47 to 3273.47 Mtoe, growing at 6.25% a year on average; meanwhile, energy-related CO<sub>2</sub> emissions increased from 488.53 to 9428.71 Mt, growing at 5.74% per year; coal had predominated the energy mix during the entire period, yet with decline from 87.0 to 58.3%.

Based on major typical periods and marked changes in the growth of energy consumption and primary energy mix, four stages of energy development can be discerned from 1965 onwards:

- (1) 1965–1978, the first stage with the gradual economic recovery. China's energy consumption experienced a shake-up, hovering at a low range, and then climbing fairly rapidly. This period was characterized by the spike in domestic crude oil

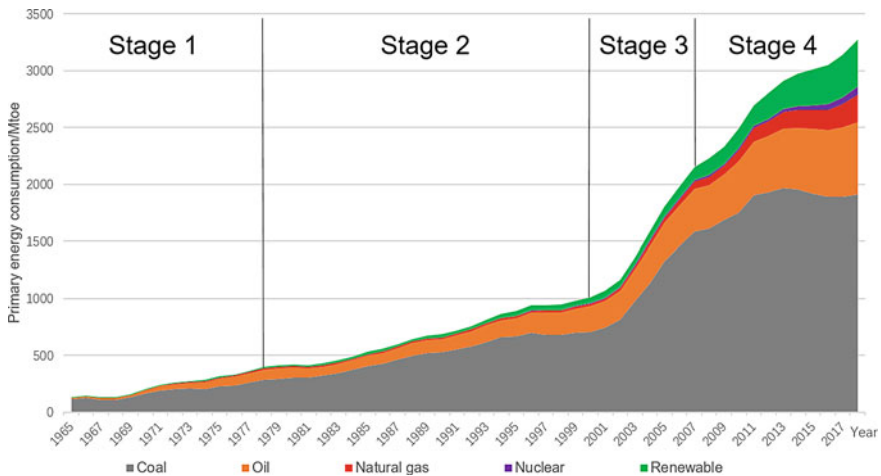
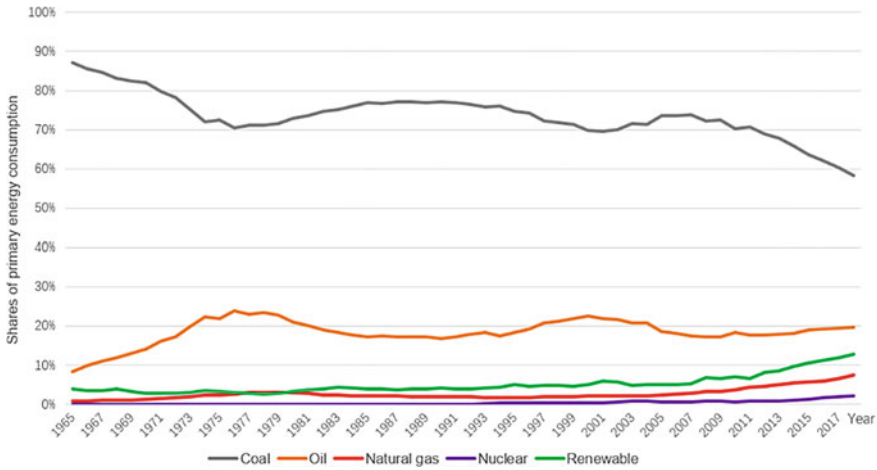


Fig. 1.2 Historical curve of primary energy consumption in China



**Fig. 1.3** Historical curve of primary energy consumption mix in China

production from 11.10 to 92.57 Mtoe, with an average annual growth of 17.72%, pushing up the share of oil in the energy mix from 8.4 to 23.3%, while the ratio of coal dropped from 87.0 to 71.2%.

- (2) 1978–2000 was the second stage with smooth growth in energy use, which saw an increase from 397.07 to 1010.93 Mtoe, growing at only 4.34% annually on average, and the energy structure remained basically unchanged. The smooth growth was mainly attributed to China’s reform and opening up in 1978 and the full recovery of light industry.
- (3) 2000–2007, the third stage, witnessed sharp increase in energy consumption. China’s joined WTO in 2001, and the subsequent opening of the international market to the country led to a surge of investment in energy-intensive sectors, driving up energy consumption from 1010.93 to 2149.64 Mtoe in just seven years, which hit an average annual increase of 11.38%. Energy-related CO<sub>2</sub> emissions from the sector also rose from 3362.70 to 7240.33 Mt, growing at 11.58% per year on average. In 2005, China overtook the United States to become the world’s largest energy-related CO<sub>2</sub> emitter.
- (4) 2007–2018 was the fourth stage when energy transition was progressed. As the extensive development of energy and economic had brought many problems in energy security and ecological environment, China made a hard yet resolute decision to transform the industry. For one thing, energy consumption continued to show an upward trend in order to support the burgeoning economy and society, making China surpass the United States as the world’s largest primary energy consumer for the first time in 2009. On another hand, remarkable progress was made in energy transition during this period. Thanks to the control on total energy consumption, the average annual growth of energy consumption nosedived to 3.89%. The use of renewable energy jumped from 113.30 to



415.59 Mtoe, with an average annual growth rate 12.54%. The share of non-fossil energy grew from 5.9 to 13.9% while coal dropped from 73.7 to 58.3%. The coal consumption realized negative growth in 2014, and energy-related CO<sub>2</sub> emissions also fell for the first time in the same year.

Based on the foregoing, the 2005–2015 period was chosen for research. This decade was featured by a difficult energy transition, which was largely enabled by the government’s strategic guidance. China’s first comprehensive five-year energy development plan—the 11th Five-Year Plan for Energy Development (NDRC 2007a) was unveiled during 2005–2010, followed by the 12th Five-Year Plan for Energy Development (State Council 2013), the Renewable Energy Law of the People’s Republic of China (National Energy Administration 2006), the medium and long-term development plan for renewable energy (NDRC 2007b), the 11th Five-Year Plan for Renewable Energy Development (NDRC 2008), and the “Strengthening Actions to Address Climate Change—China’s National Independent Contribution” (State Council 2015) formulated in the new era to support the Paris Agreement. Identifying the trends of China’s energy system during this period not only helps us understand the actual impact of previous policies on energy transition, but also provides reference for future strategies in this regard.

### 1.3.2 Recent Trend of China’s Energy System

To understand the structural changes in China’s energy system from 2005 to 2015, the 2005 China Energy Allocation Sankey diagram (Fig. 1.4) drawn by Ma et al (2012) was compared with the 2015 diagram (Fig. 1.5) by Yang et al. (2019). The diagrams reveal in details the flow and distribution of energy in various stages of the Chinese energy system, from sources, end-use conversion devices, passive systems

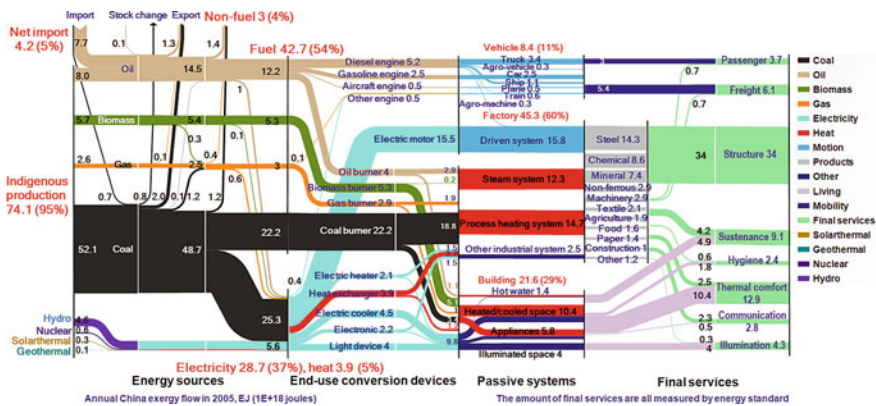


Fig. 1.4 China’s energy allocation sankey diagram in 2005

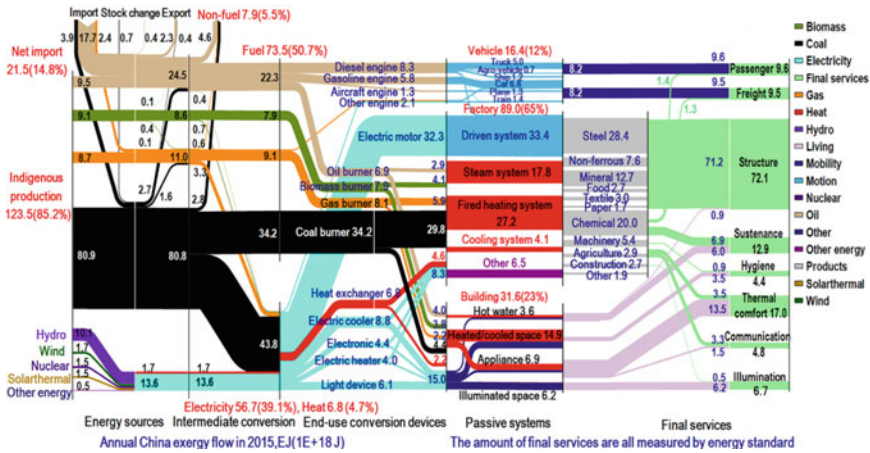


Fig. 1.5 China’s energy allocation sankey diagram in 2015

to final services. In the diagrams, energy flows from left to right, with the thickness of the flow representing the size of energy, and colors showing different energy types and way of utilization. Since the two were drawn in the same format, a comparative analysis of each stage of the two diagrams would provide systematic and in-depth understanding of the recent trends of China’s energy development.

### 1.3.2.1 Energy Supply

Coal Remains the Most Important Primary Energy, yet Its Proportion Saw a Significant Decrease.

A comparison of the two Sankey diagrams found that coal was still the main primary energy in 2015, accounting for more than 60% of the total primary energy supply. However, the biggest change in the structure of energy supply in that decade decreased significantly by 6.4% of the proportion of coal. This is precisely what Chinese government had accomplished in accelerating clean and low-carbon transition of the energy system when the country was challenged by the worsening environment and climate change. Over the ten years, China’s 11th Five-Year Plan for Energy Development and the 12th Five-Year Plan (NDRC 2013) both prompted the reduction of coal consumption by formulating clear binding goals, such as a 20% reduction in energy intensity and a 17% reduction in CO<sub>2</sub> emission intensity, etc. With strong political will and consistent policy guidance, the plans had resulted in notable outcome.

## Natural Gas and Renewable Energy Become Important Supplement

The decreased share of coal was largely due to the substantial increase in natural gas, hydropower and wind. The proportion of natural gas in China's primary energy grew from 3.2 to 7.5%, whose proportion had the largest increase among all primary energy sources. This was attributed to China's vast gas pipelines built during the "11th and 12th Five-Year Plan periods". The relative growth rate of hydropower reached 120%, and its proportion increased by 0.2%. Wind power capacity expanded by as much as 55 times, and its share rose by 1.1%. During the "12th Five-Year Plan" period, wind power was viewed as the second most important priority of renewable energy development.

## Increasing Dependence on Foreign Oil and Gas Undercut Energy Security

The spike in oil and gas consumption had threatened energy security. Although China had made a lot of efforts in domestic oil and gas development, it was still difficult to keep up with the rapid growth of oil and gas demand, which made oil and gas consumption mainly rely on imports. By 2017, foreign dependence of oil had approached 70%, and gas nearly 40% (NBSC 2018). This had posed challenge to China's energy security. Meanwhile, the rapid penetration of renewable energy such as solar and wind had brought about serious wind and solar curtailment.

### 1.3.2.2 Industry

With Rapid Growth of Industrial Energy Consumption and Predominant Steel Industry, It is in Urgent Need to De-capacity.

Industrial passive systems remained the largest energy consumer in terms of end-use. The total industrial energy consumption has maintained sustained growth, with its proportion up from 60% in 2005 to 65% in 2015. The ferrous metal mining and manufacturing, predominant steel industry, contributed the biggest growth, mainly because China was still in the process of industrialization which entailed increasing steel consumption on a per capita basis. In 2008, China offered RMB 4 trillion stimulus package to boost infrastructure construction. Due to excessive expectation of demand increase, plenty of steel production plants were launched and subsequently laid idle, leading to glaring overcapacity in 2015 with great inertia. Thus, achieving de-capacity in the steel sector was a matter of great urgency in facilitating low-carbon transition.

## Chemical and Non-ferrous Industries Should Be New Focus of Energy Saving and Emission Reduction in Future

Chemical product manufacturing was the second largest energy consumer, only after steel production, and was the one with the biggest increase in the proportion of energy use among industrial passive systems (up 3.5%). Despite the energy consumption was relatively small, the non-ferrous metal industry created high growth in embodied carbon emissions due to the large amount of electricity use in its production process, and the share was up by 2.9% (carbon emission data is calculated based on energy flow data and IPCC carbon emission factors, the same below). This was because macro-economic development, growing urbanization and industrial transition provided a fertile ground for chemical and non-ferrous metal sectors. Financial data of industrial enterprises of the National Bureau of Statistics (National Bureau of Statistics 2016) showed that in 2015, despite a fall in total profits of large industrial enterprises, chemical raw materials and chemical products manufacturing saw their profits increase by 7.7%, the biggest growth among all industrial sectors. The considerable profit from the increased demand had brought huge opportunities for chemical companies.

### ***1.3.3 The Growth of Energy Consumption for Non-metallic Mining Slowed Significantly***

On the contrary, the growth of energy use for non-metallic mining dramatically slowed down, with its proportion down 2.1%, the fastest decline among all industrial sectors. This was attributed to the fact that China strengthened rectification of non-metallic mines during the 12th Five-Year Plan period, regulating the mining market, and shutting down nearly 10,000 non-compliant enterprises (Ministry of Natural Resources 2016).

#### **1.3.3.1 Transportation**

##### Road Passenger Transportation Surpassed Road Freight as the Major Transport Energy Consumer

Road passenger transportation and freight transportation remained important energy users in the vehicle passive system, but the ratio of these two had undergone a reversal. The share of energy use by road freight was down from 40.5 to 30.5%, while that of road passenger transport rose from 29.8 to 41.5% and overtook freight to become the biggest energy consumer in transportation. This reversal was partly due to China's constantly improving road traffic network. During the "12th Five-Year Plan" period, national highways had reached 99.9% of townships (towns), the length of expressways totaled 123,500 km, and a nationwide expressway network had taken

shape (Ministry of Transportation 2017). It was also related the change in people's consumption pattern and life style, as could be seen in the popular ownership of private cars. The number of private cars in 2015 was over ten times that of 2005 (Wang 2016). This trend had pushed up oil imports, which posed increasing threat to energy security. Meanwhile, it had led to substantial increase in pollutants and CO<sub>2</sub> emissions (the proportion of carbon emissions rose by 9.5%), worsening urban air pollution, thus becoming a major contributor to carbon emissions.

### The Growth in CO<sub>2</sub> Emissions from Road Freight and Shipping Slowed Down

The growth of energy use from trucks and ships slowed down, with growth rate less than 50% (other transportation modes witnessed over 100% increase in energy consumption), and there was no significant rise in carbon emissions. This was closely associated with economic transition. In 2015, the tertiary industry as a percentage of GDP exceeded 50% for the first time. As the tertiary industry required less physical goods than the other two during that period, the overall demand for freight transport and shipping cooled down.

#### 1.3.3.2 Building

The Proportion of Energy Consumption in Building Fell, Among Which the Energy Consumption of Space Cooling/Heating and Hot Water Systems Increased Significantly

The share of energy consumption from building dropped by 6.0% over a decade, which was a stark contrast to the industrial sector. This was largely due to improved building energy efficiency. In the building passive system, space cooling/heating saw the greatest increase in energy consumption, and occupation ratio of the hot water system showed the highest increase (up by 4.9%). This change was mainly driven by rising living standards of residents, pursuit for quality of life, the need for personal hygiene, and the continuous upgrading of regional hot water supply.

Appliances Saw Lower Proportion in Energy Consumption, but with Surging CO<sub>2</sub> Emissions

Despite only 19% growth rate in energy use, home appliances reported 158% growth rate in CO<sub>2</sub> emissions, with a spike in carbon emissions per unit of energy consumption. This was mainly because during the replacement of traditional home appliances, most of the traditional biomass-based devices ceased to exist (e.g.: wood fire stoves replaced by rice cookers, gas stoves, etc.), while biomass was considered carbon neutral. This accounted for the dramatic rise in carbon emissions despite small changes in total energy use.

### 1.3.3.3 Final Service

#### Demand for Structural Material was the Biggest Driver for Energy Consumption and CO<sub>2</sub> Emissions

At the final service of energy, the structural service was always the most important energy service, making up over half of the total, and rising rapidly. In 2015, it registered a 7.5% growth compared to 2005, resulting in increase in CO<sub>2</sub> emissions as a whopping 2218 Mt. This was, in large part, fueled by China's massive urbanization in the past decade and the booming infrastructure development. From 2006 to 2011, the total output of the construction industry had been growing at over 20% for six consecutive years (Ministry of Housing and Urban-Rural Development 2017), a pillar industry for economic growth.

#### Energy Demand for Thermal Comfort Service and Sustenance Service Slowed Down

Thermal comfort services and sustenance services were marked by the reduction in energy consumption and carbon emissions as the final service, which had been primarily the result of urban central heating pipeline networks, replacement of traditional heating methods, more energy-efficient home appliances and a much smaller primary industry as a percentage of GDP. This also reflected the shift of people's pursuit from trying to make their basic livelihood to aiming for a quality life.

### 1.3.3.4 Summary

China's energy is undergoing transition from high-speed to high-quality growth. Two major trends can be found in the recent development:

1. China is still undergoing rapid industrialization and urbanization. Spectacular infrastructure construction and fixed asset investment have been accompanied by huge and continuously rising demand for structural materials, creating a mushrooming industrial sector (steel and chemical industry in particular) that is often troubled by overcapacity. The high dependence of such industries on coal and electricity presented enormous challenge for China to decoalize and decarbonize its energy system in the short term.
2. People's rising demand for high-quality life has changed the structure of energy end use. For instance, the increased need for passenger transportation, hygiene and communication services has resulted in a marked increase in the energy consumption of hot water supply in passenger cars, aircraft, buildings, and of modern appliances, making them the new driver of carbon emissions.

Therefore, striking balances between economic development and people's needs for a better life and the clean, low-carbon, safe, and efficient goals is crucial for China to achieve the integration and low-carbon transition of its energy system.

### ***1.3.4 Future Path for China's Energy System***

Considering the serious energy challenge, if the current development of China's energy system continues, double challenges would emerge: for one, an inefficient industry burdened by overcapacity with great inertia; for another, a tension between heightened environmental and climate constraints and increasing demand for high-quality energy services. China already has come up with the overall plans and goals for energy transition. However, a deep reflection on the coordinated development of energy and other fields in terms of system integration is required to link the relatively independent goals and requirements under the existing policies to achieve the synergy of all to meet climatic conditions. This section centers on the "three coordinations" of energy and economy, energy and infrastructure, and energy and regions, and to this end, offered a new approach of energy system integration featuring "smart energy farms—smart energy towns—smart industrial parks", paving the way for low-carbon energy transition.

#### **1.3.4.1 Overall Plans and Goals for China's Energy Revolution**

To spur energy transition, China has put in place a relatively clear strategic framework. In China, the term "energy transition" largely equate with "energy revolution". Or rather, "energy revolution" represents the Chinese version of "energy transition". The term "revolution" also signifies the urgency and determination of China's energy transition and its resolve to make it a reality.

The Chinese government has unveiled the overall policy requirements of the energy revolution. The report of the 18th National Congress of the Communist Party of China in 2012 (Hu 2012) first proposed the concept of the energy revolution, requesting "to boost energy production and consumption revolution, cap total energy use, strengthen energy conservation and consumption reduction, support energy-saving low-carbon industries and new energy, renewable energy development to ensure national energy security." Subsequently, General Secretary Xi Jinping further illustrated the dimensions of energy revolution characterized by "four revolutions, one cooperation" in 2014 (Xi 2014), namely: (1) advance the energy consumption revolution and curtail unreasonable energy use; (2) promote energy supply revolution by creating a diversified supply system; (3) facilitate energy technology revolution to upgrade industries; (4) drive energy system revolution to fast-track energy development; (5) step up all-round international cooperation to enhance energy security in an open manner. The report to the 19th National Congress of the Party in 2017 (Xi 2017) also indicated the need to "press ahead with revolution in energy production

and consumption, and build a clean, low-carbon, safe and efficient energy system.” These dimensions and goals of energy revolution had been widely deployed in China, such as in the 13th Five-Year Plan for Energy Development (NDRC 2016b).

It can be seen that the focus of China’s energy revolution has expanded from energy conservation, usage reduction and energy security to consumption, supply, technology, institutions and international cooperation. In recent years, “clean and low-carbon” became the key focus. This means that in the context of global climate change, low carbon is increasingly becoming one of the key goals of China’s energy revolution. With this in mind, the “Energy Production and Consumption Revolution Strategy (2016–2030)” (NDRC 2016a) went further in setting out two milestones: (1) By 2030, the total energy consumption should be capped below 6 billion tons of standard coal; non-fossil energy and natural gas should account for about 20% and 15% respectively; carbon emissions should peak and should do so as soon as possible; (2) By 2050, total energy consumption would stabilize, with over 50% from non-fossil energy.

Despite the aforementioned strategic masterplan and goals of the energy revolution, the task of energy transition involves multi-faceted, multi-layered and intricate interactions between multiple forms of energy and technologies, which goes far beyond the scope of the current policy. To illustrate, though the guideline of “four revolutions and one cooperation” points direction for energy consumption, energy supply, energy technology, energy system and international cooperation, this approach may give rise to separate management of these interconnected workstreams. Therefore, it’s essential to contemplate the means to build linkages between the overarching energy revolution strategy and objectives and the micro-level energy system engineering and technical work. And this would warrant enhanced academic research and policy formulation on energy system integration at the mesoscopic level to match the macro and micro elements.

Aside from the existing goals, the increasing risk of climate change might call for tightening these goals to accommodate new climate requirements. For example, the IPCC’s Special Report on Global Warming of 1.5 °C (IPCC 2018) has imposed more stringent emission reduction requirements on countries to keep temperature rise within 1.5 °C. This means that China needs to continue strengthening energy system integration under the existing policies to attain the set goals, and at the same time envision a more forward-looking approach to create an energy system with higher efficiency and greater uptake of non-fossil energy in order to embrace climate goals.

The following is based on our academic research on energy system integration, and explores the coordinated development of China’s energy transition and other important areas. The “three coordinations”, i.e.: coordination between energy and economy, between energy and infrastructure, and between energy and regions, was examined in detail, together with an illustration of the new solution of energy system integration, i.e. “smart energy farms—smart energy towns—smart industrial parks—smart energy transportation networks” that accommodate the “three coordination” requirements and even harsher emission reduction goals.



### 1.3.4.2 “3+1”Energy System Integration

Energy system integration is an overall strategy that puts together multiple energy sources, technologies, and systems, which involves design, integration, optimization, scheduling, and infrastructure construction and operation of the overall energy system. It aims to synergize various energy sources and sectors through maximizing their complementary strength, thereby achieving the optimization of the overall energy system.

A bridge connecting macro-policy requirements and micro-technical work, energy system integration seeks to address two issues: (1) link energy system integration with macroeconomic and social sustainable development; (2) apply energy system integration to the implementation of specific fields and technologies. As President Xi Jinping pointed out: “Innovation represents a systematic project. The chains of innovation, industry, capital and policy are intertwined and mutually supportive. Carrying out reform in just one or a few processes are far from adequate. It must be done in a holistic approach and advanced with unwavering commitment. Technological innovation should go hand in hand with institutional innovation. We must get “both wheels” in motion (Xi 2016)”. Energy system integration can be perceived as a key component linking the “two wheels” in the energy sector.

Based on the previous research conducted by the author of the chapter on energy system integration, the key of energy system integration in China's energy low-carbon transition involves at least three major issues: energy and economic coordination, energy and infrastructure coordination, and energy and regional coordination. Each of the three coordinations is discussed below, and building on the discussions, a new approach of energy system integration that reinforces the three coordinations is laid out. The three coordinations and one approach are generally referred to as the “3+1” approach for energy system integration.

#### Energy and Economic Coordination—Prioritize and Formulate Sound Plans for Coordinating Energy Supply and Demand

China has experienced a great amount of problems of mismatch between energy and economic development in the past, which is mainly manifested in the frequent disconnection between energy supply and demand during economic development, resulting in either shortages or surplus of energy provision and subsequent huge energy waste, as shown in Fig. 1.6 (Li et al. 2019). The early twenty-first century witnessed acute energy shortages in some parts of China on account of underestimates of energy demand brought by the burgeoning economy, belated construction of coal, oil, electricity and other energy plants, and lack of transportation capacity. In the wake of the world financial crisis in 2008, the “RMB 4 Trillion stimulus package” (ten actions to spur domestic demand for steady and rapid economic growth) was rolled out, leading to a slight increase in energy consumption growth. But overcapacity also occurred in many industrial sectors, including metal smelting, chemical, and energy sector, with plants running below design capacity (Pan 2014). Since 2014, a

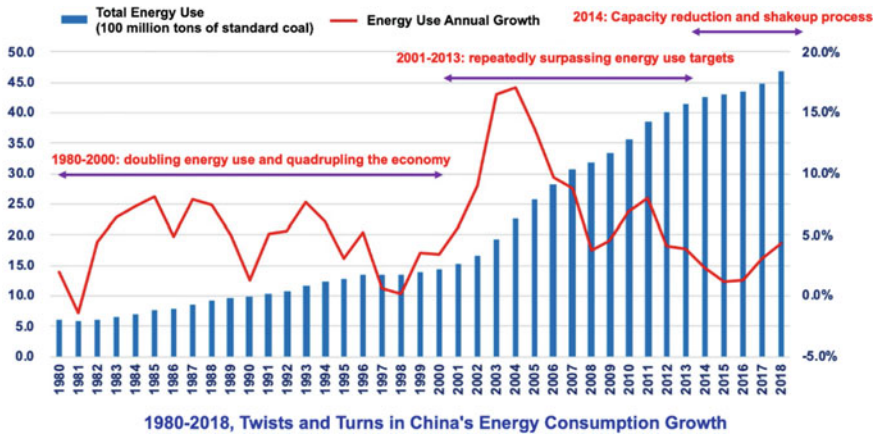


Fig. 1.6 Increase in energy use in China from 1980 to 2018 Li et al. (2019)

slowdown in energy demand growth and the energy mix adjustment had triggered severe overcapacity at coal and coal-fired power plants. At present, China’s economy has shifted gear from the previous high speed to a medium-to-high speed growth, and high-quality development is the call of the time. Concrete steps must be taken to reduce energy waste from the mismatch between energy supply and demand.

Though the energy shortage in the early twenty-first century and the later over-supply appear to be at the opposite ends, the underlying causes are the same, that is, the failure to recognize the inherent relationship and regularity between economic development and energy demand in a timely manner, without forward-looking and proactively accurate adjustment. This underscores the inadequacy and deficiency of theoretical research on energy use control in China, and a severe mismatch between research on control theory, methods and strategies and realities on the ground.

To gain a scientific understanding of the way energy consumption grows in China, the author puts forward a theory of energy consumption growth from the perspective of construction-type energy use. Under this theory, total energy use in the society in any given period can be grouped into three categories: consumption, export and construction use, which correspond to the production or living activities for the purposes of end consumption, export and the fixed assets formation respectively. Among them, consumption and export energy use depend on the final consumption and export of the period, and are determined by the economic and social operation at that time. Though construction energy consumption is included in the total energy use of the society in a given period, the formation of fixed assets takes time, the construction energy consumption is invested in the current period, and the formed assets would lead to new production or service capacity in the future (Fu 2010). Therefore, the dynamic growth of energy consumption during rapid economic development is in fact driven by one-time, impulsive construction energy consumption.

Zhang (2019) Based on China’s energy statistics for 2007, 2010 and 2012, the embedded energy status of final products is calculated, as shown in Fig. 1.7. It can

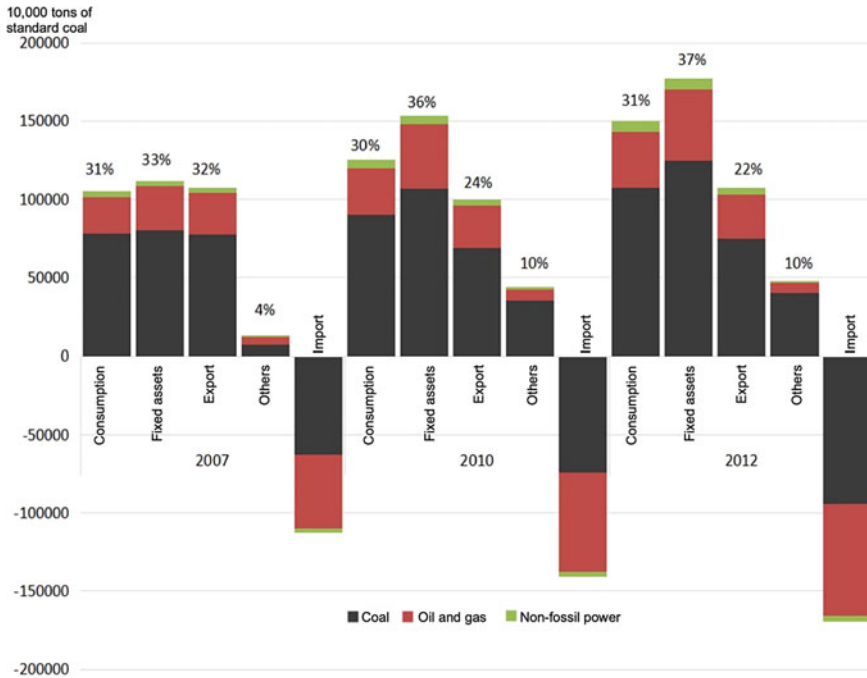


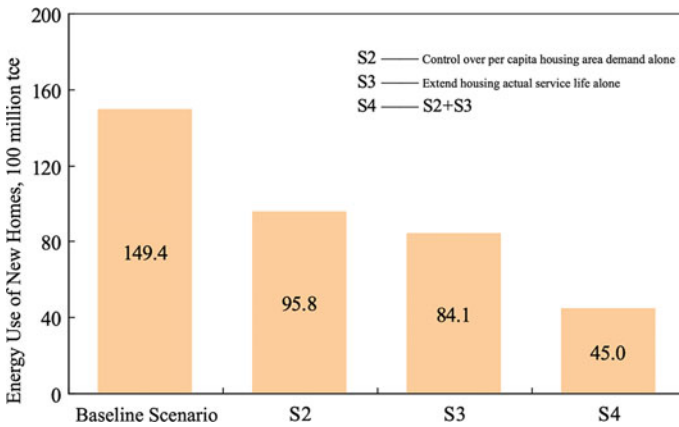
Fig. 1.7 Embedded energy of final products in China for 2007, 2010 and 2012 Zhang (2019)

be seen that during this period, the total embedded energy of all final products keeps increasing, while the embedded energy of fixed asset products always accounts for the largest proportion, which also shows an upward trend. This is largely because the huge investment in new infrastructure and industrial capacity after 2008 led to the production and installation of fixed asset products which consumed vast amount of energy, which was equivalent to large quantities of embedded energy in fixed asset products. By Zhang Xi's further calculation, among all the energy users in this period, the construction sector remained the one with the largest proportion of embedded energy in the final products, and it can be said that the high demand for construction services in China resulted in the great amount of embedded energy in the final products of the construction industry. Thus, if total energy use is to be curbed, a focus on the construction sector is essential.

The construction energy use from the construction sector is not only high in volume, but also considerable in terms of construction energy waste. Statistics show that in recent years, China's floor space has seen exponential growth, but building service life is well below that of developed countries, and the frequent demolition and construction of buildings has also implied tremendous energy waste. To deal with this problem, Fu Feng defined four scenarios with analysis based on the two set values of different per capita housing space demand and actual service life of houses. The key features are shown in Table 1.1(Fu 2010).

**Table 1.1** Key features of the four scenarios Fu (2010)

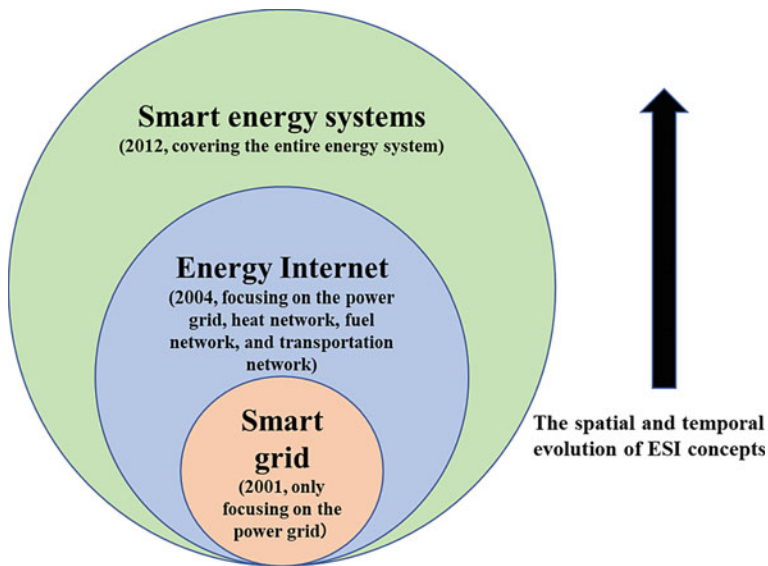
| Scenario definition                  | Baseline scenario       | Policy scenario         |                      |                      |
|--------------------------------------|-------------------------|-------------------------|----------------------|----------------------|
|                                      |                         | S2 scenario             | S3 scenario          | S4 scenario          |
| Increase in per capita housing space | No control              | Control                 | No control           | Control              |
| Actual service life of houses        | No extension (25 years) | No extension (25 years) | Extension (50 years) | Extension (50 years) |



**Fig. 1.8** China’s cumulative construction energy use from new housing space from 2010 to 2050 Fu (2010)

From 2010 to 2050, China’s cumulative energy use in building new housing space is shown in Fig. 1.8 (Fu 2010). Calculation of scenario S2, S3 and S4 finds that curbing the growth of per capita housing space demand and prolonging the actual service life of residential buildings would both slash increase of future energy use from residential housing construction, and the energy saving from extending life of residential buildings is even more promising. Besides residential houses, other fixed assets could also cut energy waste by extending life of assets and upping capacity utilization. These two approaches have become effective tools for energy use control.

The above research suggests that increasing utilization and service life of production capacity should be encouraged in China’s future economic and energy planning. Besides, it’s vital to align energy needs with economic development. More attention should be paid to the changes in the end consumption brought by economic development, as opposed to a sole focus on the current energy supply and efficiency, thereby ensuring a precise match between energy supply and consumption, and reducing construction energy waste.



**Fig. 1.9** Evolution of the notion of energy system integration

### Energy and Infrastructure Coordination—Promoting Energy System Integration in a Cross-sectoral and Holistic Manner

The sound operation of energy system needs to be built upon the coordinated development of energy and infrastructure. Otherwise, the infrastructure would be abandoned prematurely or underutilized, and all range of production capacity connected by infrastructure would not be fully utilized, bringing about enormous energy waste. For instance, inadequate infrastructure in the fields of electricity peak regulation, transmission and distribution has accounted for tremendous curtailment in water, wind and solar in China, with substantial energy losses. Though more of China's non-fossil energy has been fed to the grid in recent years, water and wind curtailment still reached 69.1 billion KWH and 27.7 billion KWH respectively in 2018 (NEA 2019). Given a slew of energy challenges including climate change, China is bound to introduce more renewable energy and advanced energy-saving technologies to its energy system if it were to migrate from coal to non-fossil fuels, and from extensive energy consumption to high-quality and efficient energy use in the future. This puts higher demands for the smooth transition and efficient utilization of energy infrastructure, and requires guidance from new scientific approaches and methods.

With the progress of the third industrial revolution characterized by informationization, the rapid development and spread of information, communication and Internet technologies provide a new approach for integration to enhance the coordination between energy and infrastructure (Zhao 2018). Tracing the evolution of this approach (as shown in Fig. 1.9), one may find that the early concept of “smart grid” focused on the infrastructure optimization of the power system, which sought

to optimize the integration and scheduling among different links of the power system with the aid of information and communication technology (Wang 2012). The subsequent emergence of “energy Internet” enlarged the scope of focus (Zeng et al. 2016). Though smart grid remained the centerpiece of the notion, it built stronger links among energy networks such as heat, fuel and traffic in terms of improved infrastructure integration. However, the energy Internet is mainly about open sharing among various energy networks, the infrastructure of each energy network is still relatively isolated. The notion of “smart energy system” emerged in recent years laid great stress on holistic optimization and cross-sectoral integration (Lund et al. 2017). The notion covers not only all energy networks, but also energy end users, including industry, building, traffic, etc. In terms of infrastructure, it highlights the integrated construction and operation of power grid, heating network and fuel network in the holistic perspective of the best match of all energy sources and end users, and strengthened system flexibility through a variety of energy storage modes. Given the above analysis, it’s clear that the concept of smart energy system is more aligned with the future path of energy and infrastructure coordination, and smart grid and energy Internet can be viewed as the early stage of the path.

In light of China’s unique energy system, the future of smart energy system must possess its own characteristics. According to literature review and reflections on China’s reality, smart energy system in the country can be described as “a safe, flexible, economical, green, shared and coordinated sustainable energy system that enables the synergy of multiple energy forms through the holistic integration of energy supply and such other sectors of industry, building, traffic. It’s grounded on the principle of cross-sectoral integration and systematic optimization, supported by the three pillars of smart grid, smart heating network and smart fuel networks, combined with flexible energy storage”. With this in mind, the core of energy and infrastructure coordination is still the integrated construction and operation of the three core networks of smart grid, smart heating network and smart fuel network (see Fig. 1.10). All kinds of energy supply capacity (Fig. 1.10 above), energy end consumption and distributed energy (Fig. 1.10 below) should build energy hubs primarily for system integration, and achieve the optimal match of supply and demand through the three networks. As the gateway connecting energy production and consumption with the three energy networks, the energy hub guides and assist regional energy production to be fed into the grid, and provides smart energy services for users. Meanwhile, the hub seeks to facilitate multi-energy coordination and optimization of the overall system in a broader scope through the information and energy connectivity among varied hubs. In this model, flexibility of the overall energy system is critical, which brings the need for the flexible construction of varied energy storage facilities (lower right corner of Fig. 1.10). However, these involve the cooperation and coordination among different sectors and industries, and require the removal of barriers between sectors and industries. Thus, higher requirements are put forward for China’s governance system and market mechanism.

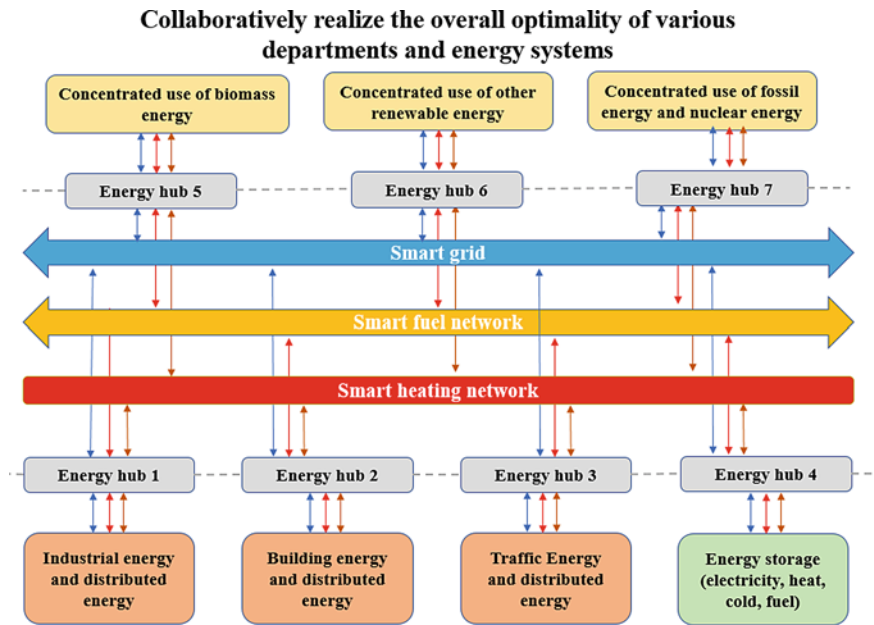


Fig. 1.10 Diagram of smart energy system

### Energy and Regional Coordination—Enhance Regional Footprint and Work Sharing among Regions

Apart from the aforementioned problems at the national level, China's energy systems also vary greatly from region to region. However, existing national energy policies haven't accommodated regional disparities in this regard. During the 12th Five-Year Plan period, for instance, China set a binding target of a 16% reduction in energy intensity for nationwide implementation. A vast majority of provinces have made corresponding targets of 15–17%. But it turned out differently for different provinces. (see Fig. 1.11). This means that policy objectives should not be imposed in a broad-brush fashion. Without adopting a case-by-case approach, national energy policies would not benefit regional energy transition, and the national policy for energy transition might end up nowhere.

In order for the state to introduce region-specific policies to propel regional energy transition, a methodology of analyzing regional energy system with high technical accuracy is needed. The author adopts the EAA-LMDI method (Energy Allocation analysis-log Mean Divisia Index) in drawing the Sankey diagrams of energy distribution in provinces and municipalities in 2016 (as shown in Fig. 1.12), and conducted cluster analysis based on the characteristics of energy systems in each region. The figure reveals three stages from left to right: primary energy supply, intermediate cyclization and energy end use in each province and municipality. The color of the flow indicates the type of energy, and the width of the flow shows the amount of

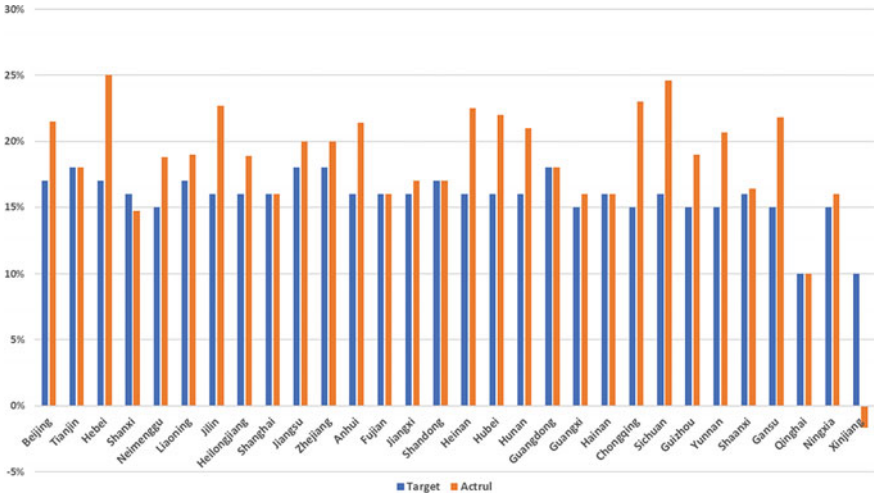


Fig. 1.11 Targets and results of lowering energy intensity in provinces and municipalities during the 12th Five-Year plan period

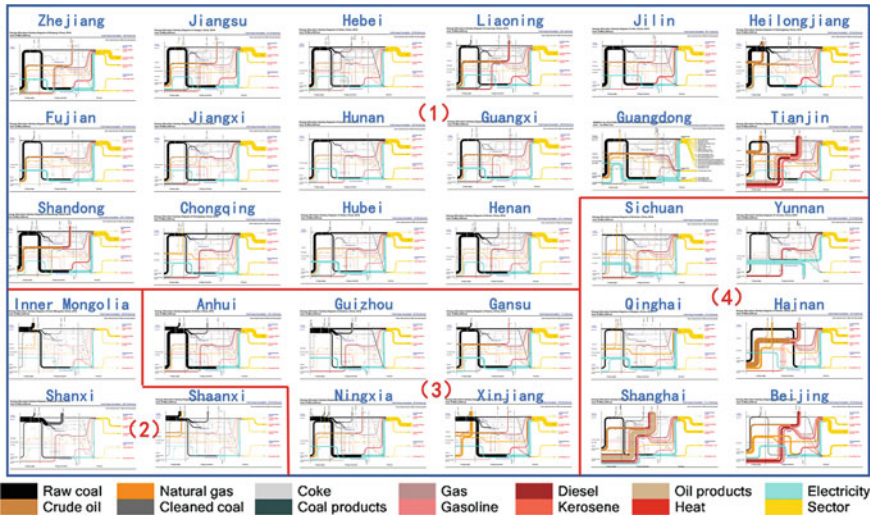
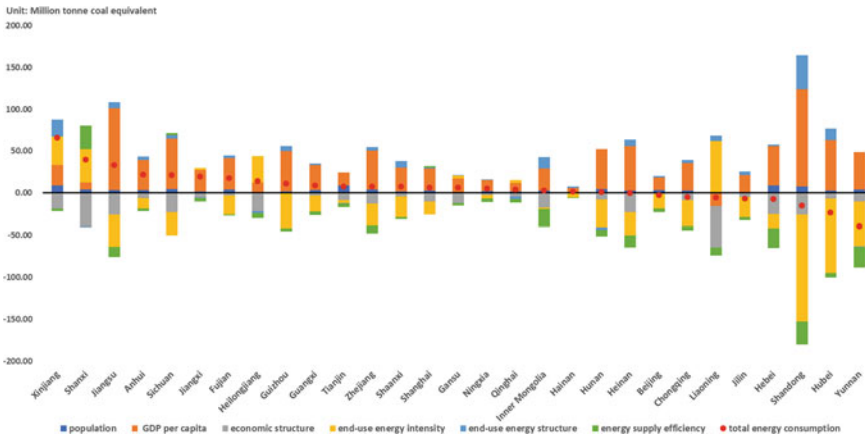


Fig. 1.12 Sankey diagram of energy distribution of provinces and municipalities in 2016

energy. The energy flow data enables analysis and calculation of the energy consumption growth of provinces and municipalities from 2011 to 2016. Based on the above research findings, the following conclusions can be obtained:





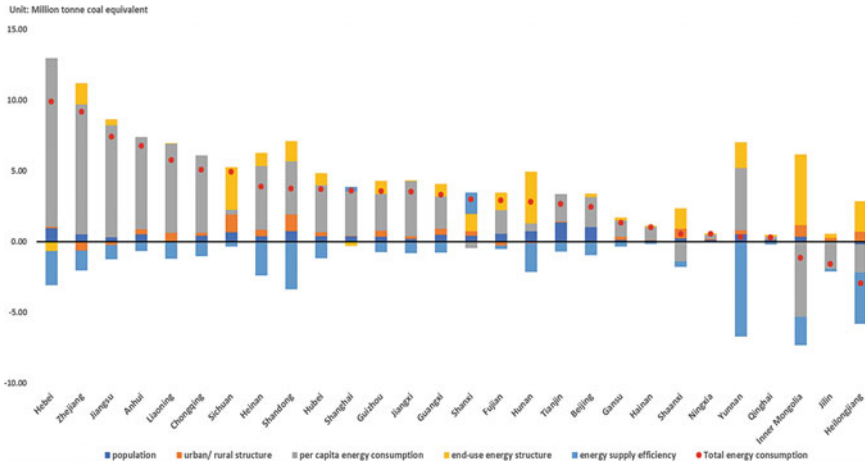
**Fig. 1.13** LMDI decomposition of changes in energy use in the economy of provinces and municipalities from 2011 to 2016

**1. The coal development and utilization structure (shape of coal flow) best mirrors regional disparities in China’s energy systems.**

Energy systems of various provinces and municipalities can be grouped into four categories: (1) in the first category of energy system (Fig. 1.12, upper left), the coal flow resembles the Chinese character “几”, that is, coal is mainly supplied from outside, and is mostly used for electric heating production in energy conversion. 16 provinces and municipalities fall into this category; (2) in the second type of energy system (Fig. 1.12, lower left), the coal flow is shaped as “一”, which indicates vast local production of coal and exports to other regions. The energy systems of three major coal producers fit this description, i.e. Inner Mongolia, Shanxi and Shaanxi; (3) in the third type of energy system (Fig. 1.12, lower center), the coal flow comes in the shape of Chinese character “乙”, which refers to general self-sufficiency of coals in these regions with limited imports or exports. Xinjiang, Ningxia, Anhui, Guizhou and Gansu fit this category. (4) in the fourth energy system (lower right corner of Fig. 1.12), coal flow is not a major part of the energy system. The six regions produce and consume less coal, with other sources dominating the energy mix. For example, Beijing is mostly natural gas and electricity, Shanghai and Hainan see a high percentage of oil, and Sichuan, Yunnan and Qinghai are mostly hydropower.

**2. Per capita GDP constitutes the biggest driver of energy consumption growth in the economy of all regions.**

Between 2011 and 2016, 20 out of the 29 provinces and municipalities saw increase of energy consumption in the economy. The LMDI decomposition analysis of the drivers of energy consumption growth is shown in Fig. 1.13. The red dots represent changes in the total energy consumption in the economic sector of each province over a five-year period, ranked from the highest to the lowest. The bar chart shows the changes in energy consumption caused by different drivers. In most provinces and municipalities, per capita GDP

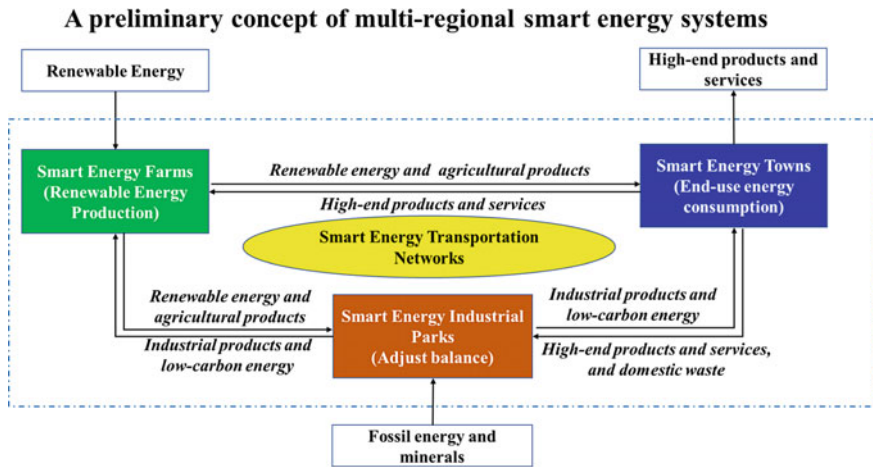


**Fig. 1.14** LMDI decomposition of changes in residential energy use of provinces and municipalities from 2011 to 2016

is the biggest contributor to the growth in energy use, followed by population and end-use energy mix. The main inhibitors of energy consumption increase are economic structure, end-use energy intensity and energy supply efficiency. The adjustment of end-use energy mix is mainly manifested in the switch from coal to electricity. Energy consumption has grown as electricity is more responsible for primary energy consumption than coal. However, exceptions exist in a few regions. For example, the end-use energy intensity in Xinjiang and Shanxi and the energy supply efficiency in Shanghai have not been improved, which may have to do with the transfer of energy-intensive industries and underutilization of production capacity, etc.

- Per capita energy consumption is the most important driver for the growth of residential energy consumption in all regions.** From 2011 to 2016, 26 provinces and municipalities reported increase in residential energy use, as shown in Fig. 1.14. The red dots represent the total change in residential energy consumption in each region over the five years, ranked from the highest to the lowest. The bar chart shows the changes in energy consumption caused by different drivers. The most important driver is per capita energy consumption. Of all the drivers, only improvements in the efficiency of energy supplies have had a positive impact on curbing growth in energy use. It should be noted that although residential energy consumption only represents 1/7 of that in the overall economy, its growth is 3.5 times that of the economy (the national average). Therefore, the increase in residential energy consumption also warrants more attention.

The above research points to great disparities among various regions in China in terms of the status and trend of their energy systems, which calls for specific targets and paths of regional energy transition. In addition, the state should explore



**Fig. 1.15** Diagram of the new approach for energy system integration that accommodates three coordinations

innovations in regional energy governance and market management in light of the administrative segmentation and market characteristics of each region.

**New Approach for China's Energy System Integration as Required by "Three Coordinations"**

The three coordinations of energy and economy, energy and infrastructure, and energy and regions is not isolated from each other, but interconnected and interactive, and should be advanced in a coordinated manner. In this connection, the author proposed the coordinated development notion of "smart energy farms—smart energy towns—smart industrial parks—smart transportation network" under the requirements of the three coordinations (see Fig. 1.15) in an attempt to provide a new solution for energy system integration during low-carbon energy transition.

As far as this approach is concerned, smart energy farms, smart energy towns and smart industrial parks are both energy producers and consumers. Yet they stand to perform different main functions, serving as producer, consumer and regulator of supply and demand in the overall energy system. Specifically, smart energy farms combine renewable energy and agricultural production to supply clean energy and agricultural produce; smart energy towns import large quantities of energy and materials to meet the needs of people's life and work; smart industrial parks are where the production and storage of fossil energy and energy-consuming products are highly concentrated, and seek to balance supply and demand of the energy system. The three share and collaborate with one another in terms of energy and information through the energy hub in the smart energy system:

- (1) Smart energy farms are mainly distributed in remote areas rich in renewable energy, where small populations and relatively low land costs make them suitable for massive development and export of renewable energy and agricultural production (see Fig. 1.15). To ensure the stability of energy output, local industries and energy storage devices that flexibly absorb renewable energy can be developed to generate additional income other than agriculture. Smart energy farms boast pleasant ecological landscape, which meets people's demand for a decent eco-environment;
- (2) Smart energy towns are where population, high-end manufacturing and service industry concentrate, which entail import of vast amount of energy, products and materials from the outside to meet the needs. By promoting electrification and end-use energy saving in cities and towns and improving energy efficiency, some distributed energy storage devices can also assist in the regulation of energy supply and demand. With no polluting industries and imported electricity as the primary form of energy, smart energy towns would be livable places where people enjoy high-end products and services and live out their dreams for a better life;
- (3) Smart industrial parks are mostly located in the proximity of mineral mines and existing industrial parks. Each park gathers many energy-intensive industries on one or more industrial chains. Starting from the production of fossil energy, the smart industrial parks achieve the high-quality and high-density use of materials and energy within a small circle. Through smart management and regulation, the parks oversee the production and storage of fossil energy and energy-intensive products to ensure the balance between energy supply and demand. Smart industrial parks can also receive and dispose of waste from cities and towns. In the park, products of the upstream industry are used as materials for the downstream. The by-products of some industries could be utilized by others. High temperature exhaust gas from power or steel plants can serve as sources of heat for other industries, achieving recycling and co-development of energy and material. Thanks to the smart management and full use of materials and energy, smart industrial parks minimize the negative impact on the environment and protect the living environment of the park residents.

Smart energy farms, smart energy towns and smart energy industrial parks are connected by "smart transportation network", which not only includes the transportation of non-energy products and people, but also transportation of all forms of energy. Smart transportation network requires the integration of passenger and freight transportation network and energy network to realize the optimal design and operation of transportation infrastructure.

The vision of "smart energy farms-smart energy towns-smart industrial parks-smart transportation network" accommodates the "three coordinations": (1) taking into account technology switch in the space of energy, industrial upgrading in the space of economy and eco-environment protection. In particular, a match between energy technologies and local industries is ensured when designing the three "smarts" to satisfy people's quest for better life; (2) sitting on top of the full use of existing

production capacity and resources of each region, stressing clear regional division of labor and cooperation to bring out comparative advantages, and guiding and improving transportation infrastructure network; (3) bearing in mind the status quo and disparities of regional energy development, and putting forward the plan for energy system integration on a case-by-case basis. In theory, the envisioned energy system not only fits in with the current requirements of carbon emission cut and sustainable development, but also future mandates for zero or even negative carbon emission. However, this notion is now a mere scientific assumption and a system-wide proposition, and merits more research and practice to verification.

## **1.4 Requirements and Suggestions for Energy Governance and Energy Market to Fulfill the “3+1” Vision**

With the future path of the energy system proposed in Sect. 1.1.3, a new framework of energy governance is needed to introduce strategy and policy that are to be implemented in the energy market so as to secure low-carbon transition of the physical energy system. In particular, the novel approach of “3+1” energy system integration would pose new challenges to China's existing energy governance and energy market model. The following section would put into perspective the main challenges for the current system in light of the current energy governance and energy market in China, and provide policy suggestions.

### ***1.4.1 Challenges for Energy Governance and Energy Market Brought by “3+1”***

#### **1.4.1.1 Fragmented Authority Renders Integrated Governance Difficult**

The functions of China's energy governance are currently split among a dozen government agencies, which involves consultations among them when it comes to major energy issues. The “3+1” approach would require involvement of more functional agencies to devise energy planning and exercise governance. Therefore, the primary challenge for China's energy governance is to coordinate a range of government authorities in promoting energy system integration, tackling climate change while advancing low-carbon transition of the energy sector.

#### **1.4.1.2 The “Top-Down” Management Approach Hampers Innovation**

A vertical hierarchy has long characterized China's energy management. The drawback of the “top down” approach is: when dealing with such complex and enduring

energy governance issues as the “3+1”, the multiple layers of the organizational pyramid would undercut government enforcement, however strong it might be in the first place. And information and decisions, when passing through the layers, tend to be stalled or lost. Consequently, policies made at the central level might be divorced from the realities on the ground. What’s more, energy consumers, citizens and small businesses find it hard to engage in energy governance. Some localities and enterprises have been constantly at the receiving end of mandates from above, without any incentives to carry out policies of their own accord. Worse still, some promising local innovation, suppressed by the hierarchy, has remained untapped.

#### **1.4.1.3 Sectoral Barriers Impede Collaboration**

China’s energy market was once marked by high monopoly and high market regulation. Despite decades of reform, some market players and industries are still preoccupied with local interests and gains, hindering extensive cross-industry collaboration required by “3+1”. Furthermore, government still maintains the grip on prices of some energy products, and resources could not be best allocated via price lever. In addition, private investment has limited access to certain energy projects, which impedes the development of new energy and distributed energy.

#### **1.4.1.4 Inadequate Information Management System Impairs Cross-Disciplinary Interaction**

The “3+1” model, in governing and managing the emerging sector, could not be materialized through expertise from a single discipline. Rather, it involves cross-disciplinary, cross-industry and cross-sector issues that require tremendous knowledge sharing, interaction and communication, presenting a huge challenge to the coverage and efficiency of existing information management system. This, in part, explains the rapid development of various energy think tanks in China in recent years.

### ***1.4.2 Policy Suggestions on Guaranteeing “3+1” Energy System Integration***

#### **1.4.2.1 Empower Energy Planners and Strengthen Leadership and Cross-Sector Coordination**

Planning and research entities of energy strategy at the central and local governments should be bestowed a level of leadership and authority that can handle such complex, key energy system integration models as “3+1”, in order to coordinate and integrate the current separate functions scattered in various government departments, and

maximize China's institutional superiority of "pooling resources for grand projects". What's more, energy researchers and planners should promptly produce a national strategic plan for coordinated development of energy and economy, energy and infrastructure, and energy and regional development similar to the "3+1" notion, and facilitate the establishment of region-specific smart energy systems and the creation of effective linkage among them.

#### **1.4.2.2 Step up Modernization of Energy Governance System and Capability and Invigorate Synergistic Innovation**

The central government should follow the needs of the "3+1" approach by appropriately decontrolling authority, encouraging local governments, enterprises and the public to actively engage in energy governance, thereby forming a multi-stakeholder consultation mechanism that blends top-down and bottom-up approaches. In doing so, special attention should be paid to address the disconnect between central level decisions and the actual needs of local governments, enterprises and citizens, and enhance the interaction between the central government and various stakeholders. With these steps, local governments, enterprises and the people would be incentivized to proactively drive local innovation in the interest of the whole nation.

#### **1.4.2.3 Expedite Reform of Energy Market and Energy Supply and Build Energy Companies into Comprehensive Service Providers**

The "3+1" approach calls for prompt removal of industry barriers and enhanced cooperation and business integration among sectors in order to pay the way for the development of various smart energy systems. The Chinese government should relax price controls and help industries and enterprises to break down barriers, with an aim to build integrated energy service providers that run a variety of energy operations, both upstream and downstream, and encourage the development of innovative small and micro energy businesses. Key support and encouragement should be offered to enterprises that integrate multiple sources of energy and energy needs, or regional energy hubs.

#### **1.4.2.4 Build Stronger Energy Information Management System to Ensure Open and Smooth Communication**

Align with the "3+1" approach, comprehensively strengthen energy management information systems at all levels and in all sectors, industries and regions to enhance the accuracy, openness, timeliness, transparency of information, and attach greater importance to the dissemination of information. In the meantime, actively promote

various energy-specific think tanks that seek to address climate change and sustainable development, and support their cooperation with local governments, enterprises, civil society and the international community.

## References

- BP. (2019). *Statistical review of world energy*. <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf>. Accessed 3 Mar 2020.
- Fu, F. (2010). *Systems analysis of key issues in China's energy conservation* (Ph.D. Thesis). Tsinghua University, Beijing.
- Hu, J. (2012). *Report for the 18th national congress of the communist party of China*. <http://cpc.people.com.cn/n/2012/1118/c64094-19612151.html>. Accessed 3 Mar 2020.
- IIASA. (2012). *Global energy assessment: Toward a sustainable future*. <https://iiasa.ac.at/web/home/resources/publications/options/Sustainable.en.html>. Accessed 3 Mar 2020.
- IPCC. (2014a). *Climate change 2014: Mitigation of climate change*. [https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc\\_wg3\\_ar5\\_full.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf). Accessed 3 Mar 2020.
- IPCC. (2014b). *Climate change 2014: synthesis report*. [https://www.ipcc.ch/site/assets/uploads/2018/02/SYR\\_AR5\\_FINAL\\_full.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf). Accessed 3 Mar 2020.
- IPCC. (2018). *Special report: Global warming of 1.5 °C*. <https://www.ipcc.ch/sr15/>. Accessed 3 Mar 2020.
- Klitkou, A., Bolwig, S., Hansen, T., & Wessberg, N. (2015). The role of lock-in mechanisms in transition processes: the case of energy for road transport. *Environmental Innovation and Societal Transitions*, 16, 22–37.
- Li, G. (2018). *Report of the state council of the PRC on 2017 environmental status and environmental protection target completion*. [http://www.npc.gov.cn/npc/c30834/201804/9ea27a8b943d4d25bbfc7f74b8fc9f2b.shtml?utm\\_source=UfqiNews](http://www.npc.gov.cn/npc/c30834/201804/9ea27a8b943d4d25bbfc7f74b8fc9f2b.shtml?utm_source=UfqiNews). Accessed 16 Jan 2020.
- Li, X., et al. (2018). Coordinating the dynamic development of energy and industry in composite regions: An I-SDOP analysis of the BTH Region. *Sustainability*, 10, 2093.
- Li, Z., Ma, L., Liu, P., et al. (2019). *Theories, methods and applications to effectively control the growth of energy consumption and support high-quality development*. Sichuan: Tsinghua Sichuan Energy Internet Research Institute.
- Lund, H., Østergaard, P. A., Connolly, D., & Mathiesen, B. V. (2017). Smart energy and smart energy systems. *Energy*, 137, 556–565.
- Ma, L., Cullen, J. M., Allwood, J. M., & Li, Z. (2012). The energy use in China: Tracing the energy flow from primary source to demand driver. *Energy*, 40, 174–188.
- Ma, L., Chong, C., Zhang, X., Song, S., Li, Z., & Ni, W. (2018). *A systems concept to study energy strategy for sustainable development: An integration of sustainability, energy systems, social governance and market operation*. Paper presented at the 11th international conference on sustainable energy & environmental protection. Glasgow: University of the West of Scotland, 8–11 May 2018.
- MNR. (2016). *The status of the development of China's non-metallic mineral industry and the prospect of the 13th Five Year*. [http://www.cgs.gov.cn/ddzt/kydh/2016kydh/mtbb/201609/t20160922\\_405026.html](http://www.cgs.gov.cn/ddzt/kydh/2016kydh/mtbb/201609/t20160922_405026.html). Accessed 3 Mar 2020.
- MOHURD. (2017). *The 13th Five-Year plan for construction industry development*. <http://www.mohurd.gov.cn/wjfb/201705/W020170504041246.pdf>. Accessed 3 Mar 2020.
- MOT. (2017). *The 13th five-year plan for modern comprehensive transportation system development*. [http://www.mot.gov.cn/zhuanti/shisanwujtysfzgh/guihua wenjian/201703/t20170301\\_2170528.html](http://www.mot.gov.cn/zhuanti/shisanwujtysfzgh/guihua wenjian/201703/t20170301_2170528.html). Accessed 3 Mar 2020.



- Ni, W., et al. (2008). Energy challenges and some important strategies in China. *Energy of China*, 30, 5–9.
- NBSC. (2018). *China energy statistical yearbook 2017*. Beijing: China Statistics Press.
- NDRC. (2007a). *The 11th five-year plan for energy development*. <https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/200709/P020191104623138936402.pdf>. Accessed 3 Mar 2020.
- NDRC. (2007b). *The mid-long term plan for renewable energy development*. <https://www.ndrc.gov.cn/xxgk/zc/fb/ghwb/200709/W020190905497518622709.pdf>. Accessed 3 Mar 2020.
- NDRC. (2008). *The 11th five-year plan for renewable energy development*. [http://www.nea.gov.cn/2011-08/22/c\\_131065984.htm](http://www.nea.gov.cn/2011-08/22/c_131065984.htm). Accessed 3 Mar 2020.
- NDRC. (2013). *The 12th five-year plan for energy development*. [http://www.gov.cn/zw/gk/2013-01/23/content\\_2318554.htm](http://www.gov.cn/zw/gk/2013-01/23/content_2318554.htm). Accessed 3 Mar 2020.
- NDRC. (2016a). *Revolutionary strategy of energy production and consumption*. <http://www.gov.cn/xinwen/2017-04/25/5230568/files/286514af354e41578c57ca38d5c4935b.pdf>. Accessed 3 Mar 2020.
- NDRC (2016b) *The 13th five-year plan for energy development*. Available. [http://www.nea.gov.cn/135989417\\_14846217874961n.pdf](http://www.nea.gov.cn/135989417_14846217874961n.pdf). Accessed 13 Jan 2020.
- NEA. (2006). *Renewable energy law of the people's republic of China*. [http://www.nea.gov.cn/2012-01/04/c\\_131260380.htm](http://www.nea.gov.cn/2012-01/04/c_131260380.htm). Accessed 3 Mar 2020.
- NEA. (2019). *Introduction of renewable energy grid-connected operation in 2018*. [http://www.nea.gov.cn/2019-01/28/c\\_137780519.htm](http://www.nea.gov.cn/2019-01/28/c_137780519.htm). Accessed 3 Apr 2020.
- Nelson, R. (2018). Bounded rationality, cognitive maps, and trial and error learning. *Journal of Economic Behavior and Organization*, 67, 78–89.
- Ni, W., Jiang, Y., & Ma, L. (2019). *Analysis of several major problems in the field of rural energy technology*. Beijing: China Science Publishing & Media Ltd.
- Pan, L. (2014). *Dynamic modeling and embodied energy assessment of oil supply chain* (Ph.D. Thesis). Tsinghua University, Beijing.
- Singh, H. V., Bocca, R., Gomez, P., Dahlke, S., & Bazilian, M. (2019). The energy transitions index: An analytic framework for understanding the evolving global energy system. *Energy Strategy Reviews*, 26, 100382.
- UN. (2018). *The sustainable development goals report 2018*. <https://unstats.un.org/sdgs/files/report/2018/TheSustainableDevelopmentGoalsReport2018-EN.pdf>. Accessed 3 Mar 2020.
- UNEP. (2019). *Emissions gap report 2019*. <https://wedocs.unep.org/bitstream/handle/20.500.11822/30797/EGR2019.pdf?sequence=1&isAllowed=y>. Accessed 3 Mar 2020.
- UNFCCC. (2015). *The paris agreement*. <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>. Accessed 3 Mar 2020.
- Wang, Q. (2016). *Energy data of China 2016*. Beijing: China Energy Group.
- Wang, Q., & Zhou, K. (2017). A framework for evaluating global national energy security. *Applied Energy*, 188, 19–31.
- Wang, Y. (2012). *The brief history of the development of the smart grid technology* (Master Thesis). Taiyuan: Shanxi University.
- WEC. (2019). <https://www.worldenergy.org/publications/entry/world-energy-trilemma-index-2019>. Accessed 3 Mar 2020.
- Xi, J. (2014). *Speech at the 6th Meeting of the central leading group of finance and economics*. <http://www.ceec.com.cn/g13385/s25501/t69684.aspx>. Accessed 3 Mar 2020.
- Xi, J. (2016). *Struggling to build a world power of science and technology*. [http://www.xinhuanet.com/politics/2016-05/31/c\\_1118965169.htm](http://www.xinhuanet.com/politics/2016-05/31/c_1118965169.htm). Accessed 3 Mar 2020.
- Xi, J. (2017). *Report for the 19th national congress of the communist party of China*. <http://www.12371.cn/2017/10/27/ARTI1509103656574313.shtml>. Accessed 3 Mar 2020.
- Yang, H., Ma, L., Li, Z., & Ni, W. (2019). A method for evaluating structural changes of energy flow process with the case study of China from 2005–2015. *Chemical Engineering Transactions*, 76, 637–642.

- Zeng, M., Yang, Y., Liu, D., Zeng, B., Ouyang, S., Lin, H., et al. (2016). “Generation-grid-load-storage” coordinative optimal operation mode of energy internet and key technologies. *Power System Technology*, 40, 114–124.
- Zhang, X. (2019). Measurement and forecast method of construction services-related energy consumption in economic and industrial development (Ph.D. Thesis). Tsinghua University, Beijing.
- Zhao, Y. (2018). *A conceptual review of smart grid, energy internet, and smart energy systems. Paper presented at the 11th international conference on sustainable energy & environmental protection*, University of the West of Scotland, Glasgow, 8-11 May 2018.
- Zhou, X. (2013). U.S. blackout loses 30 billion. <http://www.people.com.cn/G/B/paper68/9981/916184.html>. Accessed 16 Jan 2020
- Zhou, X. (2014). Russia has cut off gas supply to Ukraine. [http://news.ifeng.com/a/20140616/40756146\\_0.shtml](http://news.ifeng.com/a/20140616/40756146_0.shtml). Accessed 16 Jan 2020.