

Chapter 2

China's Energy System

In this chapter we provide an overview of China's energy system and energy flows. We employ Sankey diagrams to graphically illustrate these flows, and discuss the dynamics of China's energy system by analysing key influential factors, including economic growth, energy resources, environmental impacts, and energy management. In addition we highlight the differences between China's provinces using a model that considers not only primary energy flows, but also the energy embedded in products and services that flow between these regions.

2.1 Energy Allocation Sankey Diagrams

The Sankey Diagram is used as the main tool to analyse and illustrate the physical system of energy use in China. This approach was first used by the Irish engineer Riall Sankey in 1898 (Schmidt 2008) and now has become a popular graphical tool for mapping energy flows from the resource through transformations (for example refining crude oil to produce clean diesel) to final consumption. In a Sankey diagram, the quantity of energy is traced by arrows or lines, with the line width being proportional to an energy flow. This simple graphical approach allows easy identification of dominant energy flows (Ma et al. 2012a, b).

The following Sankey diagrams are termed as “Energy Allocation Sankey Diagrams” as they do not exclude any energy or material losses during the individual transformational processes. The Sankey diagram energy or mass balance can be based on the first law of thermodynamics, or the second law of thermodynamics, and expressed in Joules (J) or the mass balance and expressed in Tonnes or Kilogrammes (t or kg). The only difference is the measurement of the amount of each flow. The first law of thermodynamics is based on the measurement of energy content by low heating values (LHV), and the second law of thermodynamics is

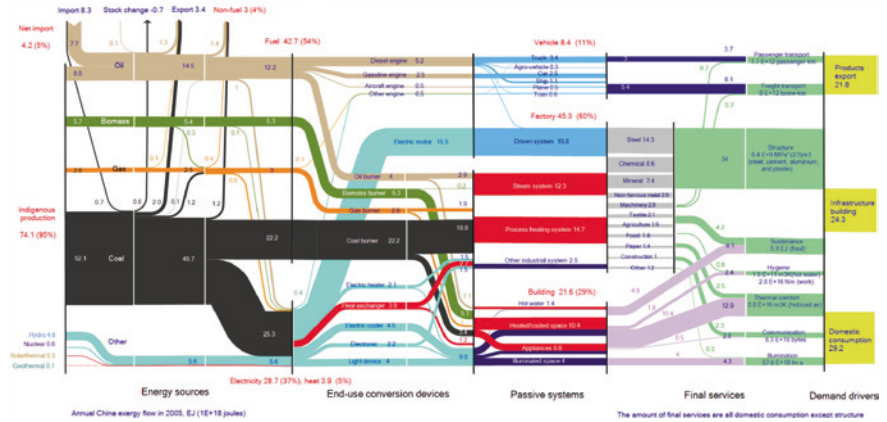


Fig. 2.1 2005 Energy Flows from Primary Sources to Demand Drivers of Chinese Society (Ma et al. 2012a)

based on the measurement of exergy¹ which can be derived from LHV, and the mass balance is based on the actual mass measurement of a fuel.

Using these methodologies, we have mapped the energy allocation Sankey diagram of China’s total energy utilisation, coal flow, oil flow, and natural gas flow whose detailed mapping method and data source will be further introduced.

2.1.1 Total Energy Flows

Before looking at the latest energy data, our first Sankey diagram in Fig. 2.1 traces the total energy flows in China from a decade ago. It is an Energy Allocation Sankey Diagram for 2005, without showing any energy losses and based on exergy measurement. The method and data are explained in detail in a previous academic publication (Ma et al. 2012a). This diagram divides the technical process of energy utilisation into 5 stages, including Energy Sources, End-use Conversion Devices, Passive Systems, Final Services, and Demand Drivers, which were defined in the previous work (Ma et al. 2012a, b).

The Sankey Diagram underlines that the main features of China’s energy system is the dominance of coal as a fuel and the large energy consumption in the heavy manufacturing sector (especially energy-intensive manufacturing industries such as Steel, Chemical, and Mineral). Looking closer at the data, we can see other major insights:

¹In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with its surroundings. Exergy analysis is performed in the field of industrial ecology to use energy more efficiently.

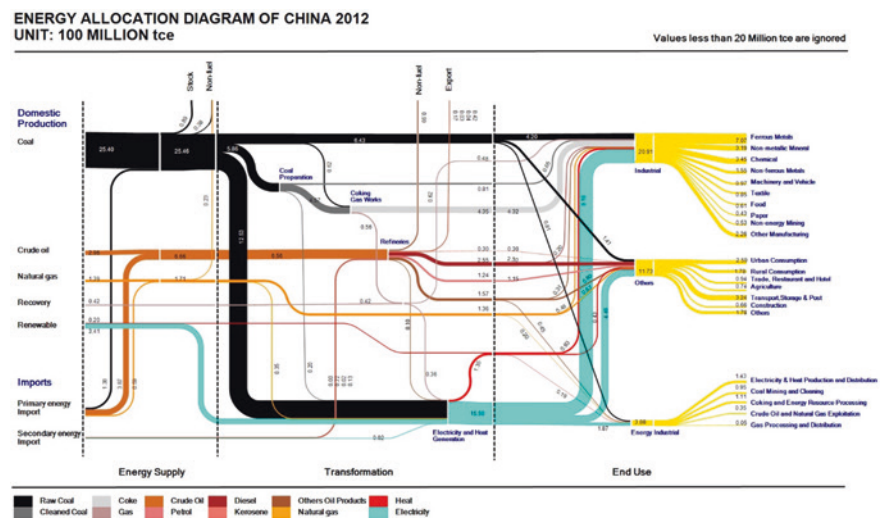


Fig. 2.2 2012 Energy Flows from Energy Supply to End-Use of Chinese Society (Chong et al. 2014)

Demand drivers: about two-third of energy consumption is driven by two major economic activities—product export (about one-third) and infrastructure building (about one-third). The latter is consistent with China’s major investment in infrastructure building for economic development and the former reflecting China’s rise as a global manufacturing powerhouse.

Final services: about 45 % of energy consumption is consumed to provide the final services for construction, e.g. energy-intensive products such as steel, cement, and plastic.

Passive systems: 60 % of energy is consumed by factories, consisting of intensive heat and electricity demand of steel, chemical, and mineral processing.

End-use conversion devices: the main devices consuming energy are coal burners (29 % of energy consumption) and electric motors (20 % of energy consumption). These mainly consume coal as direct fuel or consume electricity derived predominantly from coal power generation.

Energy sources: China’s primary energy consumption is dominated by coal because it is cheap and abundant in China, and readily utilised to power economic growth and industrialisation (as it did in the West).

Figure 2.2 illustrates the updated energy flows of China in the year 2012, which is based on the measurement of LHV and only aggregates the process of energy use into 3 stages: energy supply, transformation, and end-use. The method and data have been published (Chong et al. 2014). Although the method differs from the previous work (Fig. 2.1), it also shows that China’s energy system has not changed appreciably over the years; only the overall consumption has increased. Coal remains dominant (69.7 %) as the fuel of choice. Energy end-use in the economy is dominated by manufacturing (57 %).

2.1.2 Coal, Oil, and Natural Gas Flows

China’s primary energy consumption, like all other major economies, is dominated by fossil fuel, especially coal. In this section we will further analyse the energy flows of coal, oil, and natural gas through the economy.

Figure 2.3 presents the coal flows of China in 2012 (Chong et al. 2014, 2015). It shows that the coal use in China is spread across multiple sectors, but mainly used for power/heat generation (almost 50 %), coking and direct fuel use. Four notable uses in the processing and manufacture of Ferrous metals (iron and steel), Non-metallic minerals (cement, glasses etc.), Chemicals, and Non-ferrous metals (aluminium, copper etc.), add up to circa 50 % of raw coal consumption, from their demand for electricity, heat, and coking products. Therefore, the past and future development of these energy-intensive manufacturing sectors shapes coal demand.

Figure 2.4 presents the oil flows of China in 2010 (the most recent robust data available) (Ma et al. 2012b) and references China’s energy balance in 2010 (NBSC 2012). It shows the crude oil supply of China is heavily dependent on imports and crude oil is mainly used to produce transport fuels such as diesel and gasoline. Transportation shapes oil demand, and to a lesser extent feed stocks for the chemical industry.

Figure 2.5 presents the natural gas flow of China in 2012 (Geng 2015). It shows that the natural gas supply of China is also dependent on imports, just over 33.5 % of the total natural gas consumed in China. LNG imports are greater than pipe-line imports in 2012. Though conventional natural gas production is still the main source of domestic gas production, unconventional natural gas has become an important source of gas production, 41.7 % of total natural gas produced in China. This locally produced gas includes tight gas (30 % of total production), coal bed methane (11.7 %), and very little shale gas. The natural gas supplied is mainly used as fuel for industry and building space heating (residential and commercial use).

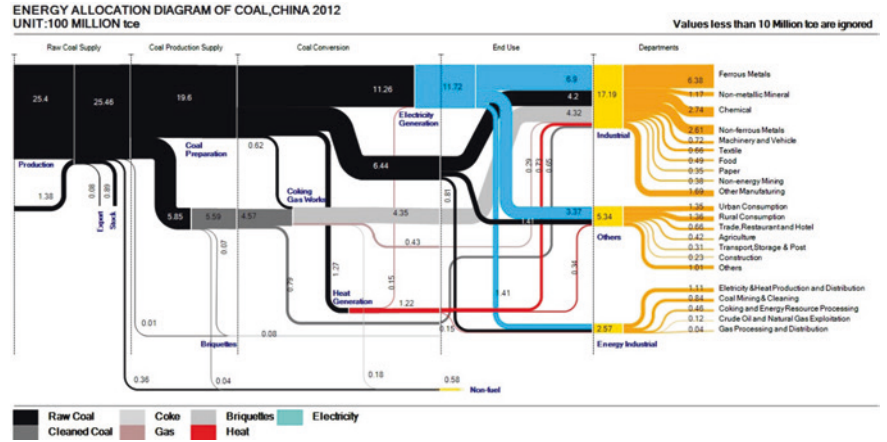


Fig. 2.3 2012 Coal flows of China

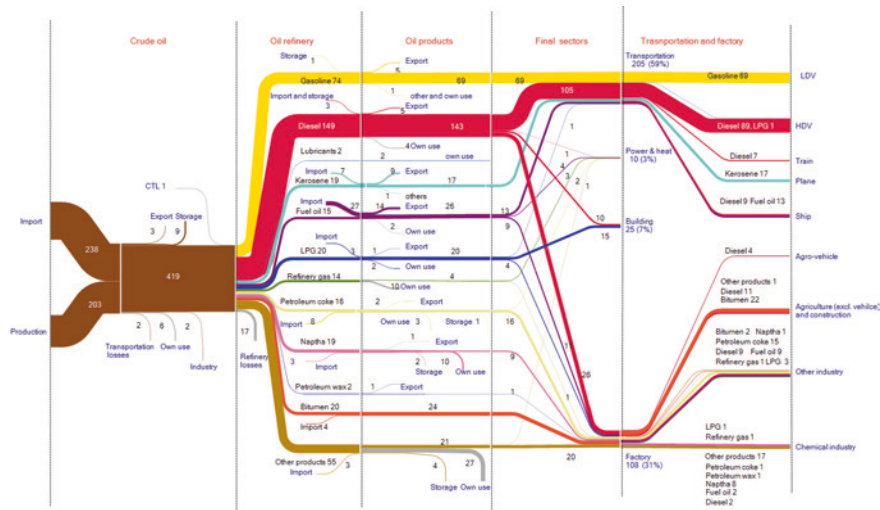


Fig. 2.4 2010 Oil flows of China

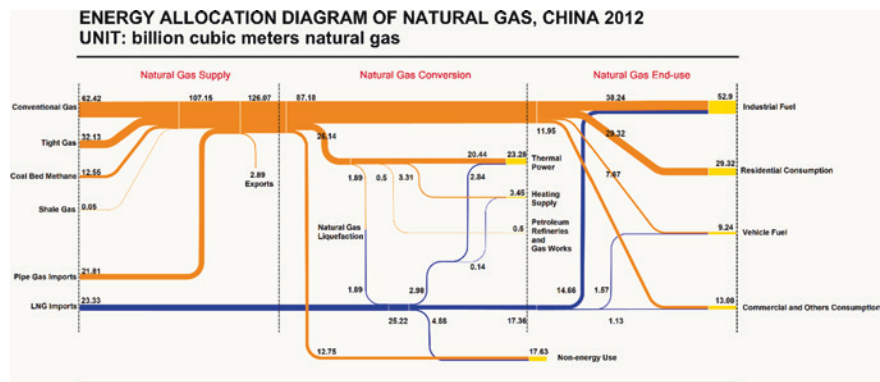


Fig. 2.5 2012 Natural gas flows of China

2.2 The Key Influencing Factors on China's Energy System

2.2.1 Economic Growth and Energy Demand

After 2000, China's economic growth entered a special stage in industrialization called "accelerated industrialization". Its main feature is the rapid expansion of heavy and chemical industry together with rapid urbanisation and motorisation. This economic growth comes with high energy intensity [energy consumption per unit of GDP (Gross Domestic Product)]. Figure 2.6 (Li et al. 2012) shows the

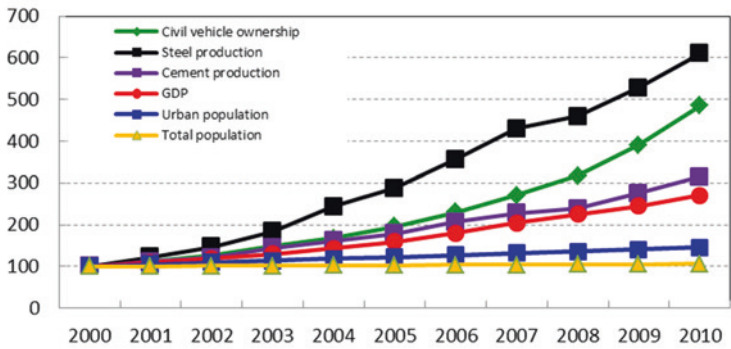


Fig. 2.6 Rapid urbanisation, motorization, and industrialization of China (all above curves are based on the data of 2000 as a relative index of 100)

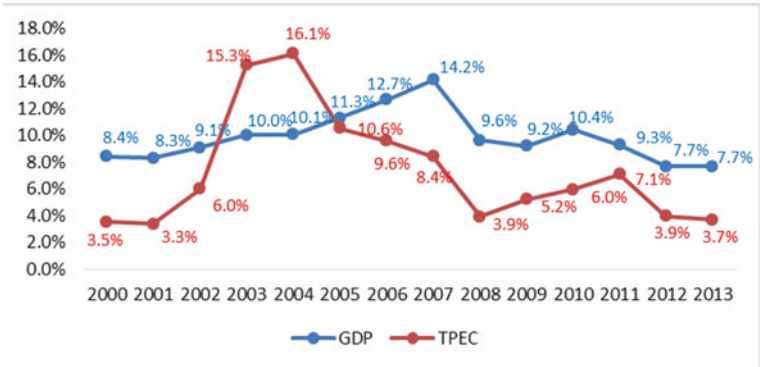


Fig. 2.7 China’s growth rate of GDP and TPEC (2000–2013)

rapid increase of steel and cement production, civil vehicle ownership and urbanisation ratios over the first decade of this century.

Referring to Fig. 2.7, from 2000 to 2011, the average annual growth rates of GDP and TPEC (total primary energy consumption) in China were over 10 % and around 8.4 % respectively. However, after that in 2012 and 2013, the GDP growth rate decelerated to 7.7 %. Meanwhile, the TPEC growth rate of 2012 and 2013 fell below 4 % (NBSC 2014a, b).

The trend of lower GDP and TPEC growth is very likely to continue based on China’s desire to restructure its economy away from heavy manufacturing; as signalled by 2013 data showing the proportion of tertiary industry (service industry) in GDP overpassed the proportion of secondary industry (manufacturing and construction) for the first time (NBSC 2013), and 2012 data indicates that final consumption expenditure has become the main driving force of GDP growth (NBSC 2014a).

In summary, China has entered a turning point. Politically this has been defined by the Chinese leadership as the “New Normal”. This will mean that the future economic growth will be different and likely much less energy intensive than the past 15 years.

2.2.2 China's Energy Resources and Supply Structure

China is known to have relatively abundant coal resources and limited oil and natural gas resources. Hence it is unsurprising that the energy production in China is dominated by coal production (Fig. 2.8). The indigenous production of oil has been relatively stable since 2000. While coal production has steadily increased over the same period, China has witnessed the emergence of natural gas and renewable energy. Over the period from 2000 to 2013, natural gas production increased from 28.1 to 124.9 bcm (BP 2015).

Meanwhile, the rapid increase of non-fossil renewable and nuclear energy can be observed by the data of power generation capacity (CEC 2008–2013) as illustrated in Fig. 2.9. In 2013, the power generation capacity of non-fossil renewable and nuclear energy has occupied 31.6 % of the total power generation capacity (CEC 2014).

Even with the expansion of its indigenous energy production, China still cannot satisfy its own increasing energy demand, so there has been a steady increase of energy imports, including oil, natural gas and also notably high-grade coal. The phenomenon of coal imports arises from the costs of long distance transportation of coal across China from the producing Northern and Western Provinces to the consuming provinces of the South and East, which makes the import of high-grade coal more competitive in coastal regions.

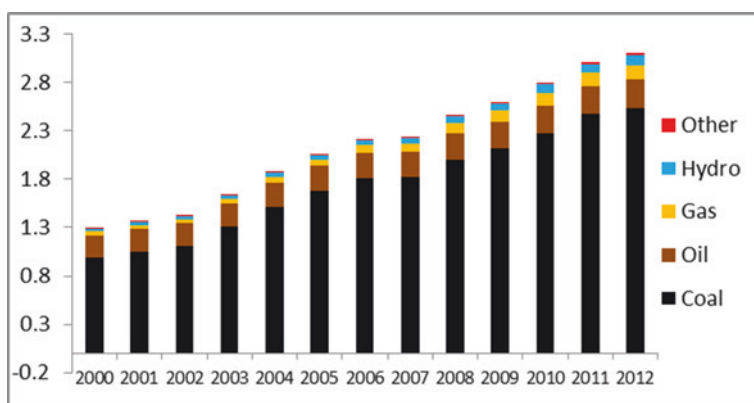
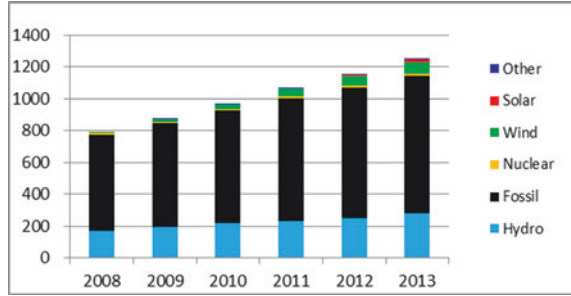


Fig. 2.8 China's primary energy production (2000–2012, unit in billion tce)

Fig. 2.9 China's power generation capacity (2008–2013, unit in GW)



Over the period 2000–2013 (BP 2015), the import dependency of oil, natural gas, and coal has increased from 27.5 to 59 %, –11 to 27.6 %, and –1.9 to 4.4 % respectively.

2.2.3 China's Environmental Challenges

The scale of energy consumption (China is now the second largest economy in the world) and its reliance on coal, contribute to the emissions of major air pollutants and GHG gases. In 2012 (Xinhua Net 2014a, b), coal consumption, including direct coal combustion and activities directly linked with coal utilisation, contributed 93, 70, and 62 % of total emitted SO₂, NO_x, and primary PM 2.5 respectively. The contribution of energy-related CO₂ emissions to total CO₂ emission in China is around 90, and 80 % of energy-related CO₂ emissions came from coal utilisation.

To reduce emissions from energy generation, especially from coal combustion, China implemented much stricter emissions standards for air pollutants from thermal power generation (using coal, oil, and natural gas as fuel). The standard for coal power is listed in Table 2.1.

Moreover, China has endeavoured to reduce the proportion of coal in the total primary energy consumption and in 2013, the coal proportion slipped to 67.6 % (BP 2015).

Statistics from MEPC (Ministry of Environmental Protection of People's Republic of China 2003) (Fig. 2.10), indicated that the total emissions of SO₂ and NO_x from waste gas in China have started to fall in recent years, as a result of improved emission standards and treatment technologies.

Compared to NO_x and SO₂ air pollutants, CO₂ emissions from energy utilisation, especially coal combustion, are more difficult to mitigate and also at quantities several orders of magnitude greater. However, based on energy saving technologies and practices along with and the emergence of renewables, the increasing rate of energy-related CO₂ emissions in China has slowed.

Table 2.1 China’s emissions standard of air pollutants from coal power plants (unit in mg/m³ flue gas)

Emission standard	Dust	SO ₂	NO _x	Mercury and its compounds
GB 13223-2003 (old) ^a	50	400	450–1100 ^c	No standard
GB 13223-2011 (new) ^b	30	100	100	0.03
For key regions	20	50	100	0.03

^aThe standard GB 13223-2003 applied for all projects of construction and retrofit of thermal power plants after Jan 1st, 2004. The data listed applied for most of regions and technologies except some special regions and technologies mentioned in it

^bThe standards GB 13223-2011 applied for all new construction projects of thermal power plants after Jan 1st, 2012 and further for all existing thermal power plants after July 1st, 2014, but the standard for mercury and its compounds only applied after Jan 1st, 2015. The data listed applied for most of regions and technologies except some special regions and technologies mentioned in it, while key regions mean some special regions need to control emissions more carefully

^cThe actual data (450, 650, or 1100) depends on the proportion of volatiles in coal, referring to GB 13223-2003

Fig. 2.10 China’s Emissions of SO₂ and NO_x in Waste Gas Emitted (unit in Mt) (in 2011 there was an adjustment of statistical method and scope, so the data is not so consistent with before)

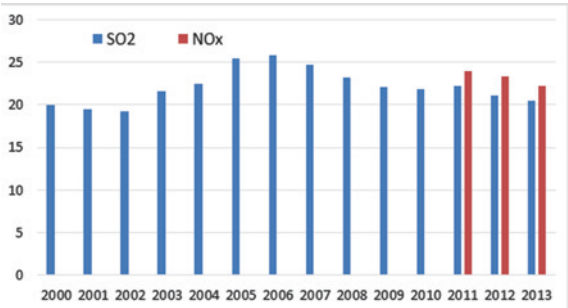


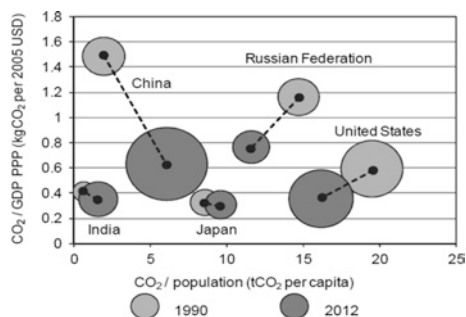
Figure 2.11 compares China to 4 other major countries, and China has delivered the most rapid reduction of the CO₂ intensity per unit of GDP in the period 1990–2012. In 2014, the total energy-related CO₂ emissions of China only increased by 0.9 % relative to 2013 (BP 2015).

2.2.4 China’s Approach to Strategic Planning of Energy

To understand the strategic planning of energy development in China over the past 20 years, we first need to understand the political goals of the central government of China. The series of Presidential reports from 2000 to 2010 to the NCCPC (National Congress of Communist Party of People’s Republic of China) (People’s Net), contained several political goals.

Reports to the 15th and 16th NCCPC by President Jiang Zemin in 1997 and 2002 established the philosophy of ‘opening and reforming’ and the realisation of

Fig. 2.11 Trends in CO₂ Emission Intensities for the Top Five Emitting Countries (the size of the circle represents the total CO₂ emissions from the country in that year.)



rapid economic growth. The key target was to double the GDP in 2010 relative to 2000 and further double it by 2020.

The report to the 17th NCCPC by President Hu Jintao in 2007 again emphasised the importance of rapid economic growth and sticking to the same GDP growth targets, but pointed out that economic growth must be based on the optimisation of economic structure, improvement of economic efficiency, reduction of resource consumption, and protection of environment. A new concept “scientific development” was proposed, which emphasised a more balanced development, not only single-minded economic growth.

Within the framework of these political goals, the main targets of the 10th (2001–2005) and 11th (2006–2010) Five-Year-Plans of economic and energy development are summarised as follows.

The 10th Five-Year-Plan: there was no clear target for energy development in the economic and social development plan, except an aim to reduce the emission of main pollutants by 10 %, which had indirect relationship with energy development. In the special plan of energy development, the emphasis was on energy security, but also mentioned the reduction of coal proportion in TPEC, the improvement of coal power generation efficiency and the reduction of energy intensity.

The 11th Five-Year-Plan: This announced a binding target of 20 % lower energy intensity for the first time in the economic and social development plan. In the special plan of energy development, it further proposed to reduce the proportion of oil consumption in addition to lower coal proportion in the TPEC, by the development of natural gas and non-fossil energy. The plan also emphasised the need to improve energy efficiency.

In the 12th Five-Year period (2011–2015), there were some changes both in political goals and targets:

The political goals announced in the report of President Hu Jintao to the 18th NCCPC: economic growth was still prioritised, as was the target to double GDP in 2020 compared to 2010. However, it was proposed ‘to actively promote the development of an ecologic civilization’ as one of the main missions in the report, to promote a ‘revolution of energy production and consumption’ to ensure energy security and protect the environment.

The 12th Five-Year-Plan also set a binding target of 16 % reduction of energy intensity of GDP, it was also proposed to reduce CO₂ intensity of GDP by 17 % and increase the proportion of non-fossil energy in the TPEC to 11.4 % in the economic and social development plan. It also clearly mentioned controlling the oil import dependency at 61 %, reducing the coal proportion in TPEC to 65 %, and increasing the natural gas proportion to 7.5 %, although these are only expected targets.

2.3 China's Regional Differences

China is too often defined internationally by its national statistics that hide the true heterogeneity of its geographical scale. In reality China consists of over 30 provinces and special regions, some the scale of major countries not only in area and population but also in economic output. It is critical to understand the differences between these regions to fully analyse China's current energy infrastructure and to optimise its future needs and investments. In this section, we begin to explore this in detail using the best available and consistent data, which comes from 2007.

The energy consumption of 30 regions defined by three different metrics is illustrated in Fig. 2.12 (Li et al. 2014). The 30 regions (column) are arranged from left to right by their per capita GDPs (PPP, current international \$) of 2007. The main insights from this data are as follows:

- (1) If we decompose energy consumption by Method 0, which only accounts flow-in and flow-out of energy products, the highest energy-consuming regions are segregated into two classes: those with huge energy (coal) exports (like Shanxi, Inner Mongolia, and Ningxia) and some of the most economically developed regions with large scale manufacturing (like Shanghai and Tianjin).
- (2) If we decompose energy consumption by Method A, which is based on an input-output method and accounts energy embodied in goods and services for final consumption expenditure, gross capital formation and goods and services flow-out (export), we can discern that these high energy consumption regions normally have huge exports of embodied energy.
- (3) If we decompose energy consumption by Method B, which only accounts embodied energy by goods and services flow-in (import) and domestic energy consumption, then the high energy consumption regions are the most highly developed (Beijing for example) and those with significant heavy industries (Liaoning for example).

What our early work on the regional disparities has revealed is how heterogeneous the provinces are. The differences are large. This must be considered in modelling the future and drafting future legislation—one size will not fit all.

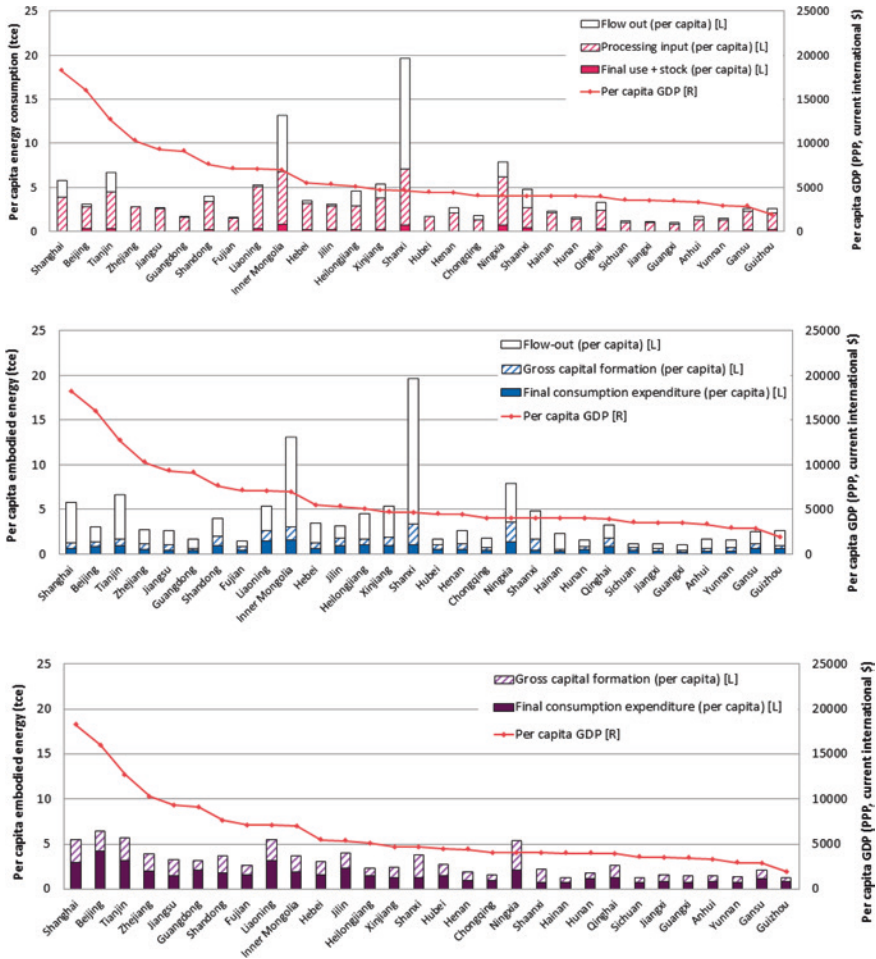


Fig. 2.12 Energy Consumption of 30 Regions by 3 methods (Method 0, A and B from the top to bottom, 2007) (Li et al. 2014) ([L] left vertical ordinate; [R] right vertical ordinate)

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