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The energy situation and its sustainable development strategy in China

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ABSTRACT

The paper briefly summarizes China's energy situation and sustainable development strategy as they were by 2009. The energy consumption in 2009 is reported to be 3.1 billion tons standard coal equivalent, 1/7 of the world total, 6.3% higher than in the year 2008, and its share of world CO_2 emissions increased rapidly to 20.3% in 2006. These trends are most likely to continue with China's plan to accomplish its social and economy development goals. To address these problems and also respond to increasing world pressure for reduction of greenhouse gas emissions, the Chinese government plans and has legislated promotion of energy conservation, efficiency, renewable energy technologies and use, and reduction of energy-related environmental impacts to reduce energy intensity by 20% during the 2006–2010 period, and to reduce the CO_2 emission/GDP ratio by 40–45% by 2020 relative to 2005. China is facing severe energy-related challenges that conflict resources shortages with the planned rapid economic development, energy use with the related environmental pollution, and new technology with the old production/consumption patterns. It is recognized that energy development must, however, follow a sustainable path to coordinate economy growth, social development, and environmental protection.

1. Introduction

Energy is one of the most important fundamental elements for human development and even survival. In the path towards the establishment of a more affluent society for China's 1.3 billion people, energy is thus of significant importance to economic and social development. It is a long-term and formidable task to accomplish sustainable development of the economy alongside the sustainable development of energy, further noting that sustainable development in China will play an important role in that of the world [1].

From the 1970s, China has rapidly achieved significant progress in its economy and society. The average growth rate of the Gross Domestic Product (GDP) was 9.8% from 1978 to 2008 [2]. In 2009, despite the global economic turndown, China's GDP still stayed at a high growth rate of 8.7%, and reached *RMB* (Chinese currency) 33.53 trillion [3]. Meanwhile the energy consumption increased from 571.4 million *tce* ("standard" tons coal equivalent, where 1 *tce* = 29.3076 GJ) in 1978 to 2850 million *tce* in 2008 [2], with an annual growth rate of 5.6%. According to the National Bureau of Statistics of China, the total energy consumption in 2009 amounted to 3.1 billion *tce*, increasing by 6.3% compared to year 2008 [4,5].

As China is in the process of rapid industrialization, urbanization and modernization, it is expected that energy consumption will continuously increase. The coal-based energy production and consumption energy system, however, faces many significant problems, such as shortages of resources, low energy efficiency, high emissions and environmental damage, and lack of effective management systems [6]. From 1990 to 2006, the CO_2 emission in China increased rapidly at the rate of nearly 6% annually and ended in 5.65 billion tons CO_2, accounting for 20.3% of the global amount in 2006 [7]. It is thus a long journey for China to optimize the energy consumption structure, increase energy efficiency, improve environmental and social protection, and strengthen the energy management to meet the requirement for sustainable development.

Based on collecting, analyzing and comparing statistical data and information from reliable Chinese and international information sources as well as archival journal papers, this paper presents the current energy status in respect to the resources, structure, production and consumption; and analyzes the challenges faced by the energy development. With focus on the strategy of energy development, the major elements of the strategy are emphasized, including energy conservation, diversified development, environmental protection, technology R&D and international cooperation.

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The new policy priorities for energy conservation and efficiency improvement, and development of non-fossil energy are also described in some detail.

2. The current energy situation in China

In the past several decades, especially after the reform and opening up in 1978, the energy industry in China has experienced great growth. It is reported that the energy consumption in 2009 amounted to 3.1 billion *tce* [4,5]. The domestic energy supply reliance is over 90% [8], as the Chinese government holds firmly to the principle that its energy supply must rely mainly on domestic resources, and coal-dominance in the primary energy mix remains unchanged [9]. China has by now established a comprehensive energy industry system including the entire chain from energy exploration, exploitation, transportation, storage, processing and conversion, research and development, design, equipment manufacturing, construction and engineering services.

The current energy situation in China can be described as that of [10] multiform energy resources with low per capita possession quantities; rapid growth of energy consumption with relatively low energy efficiency and heavy environmental impacts with coal as the main primary energy source.

2.1. Natural energy resources

China has diverse energy resources, and is especially rich in reserves of coal and hydropower, which take the third and the first place in the world, respectively. It is, however, relatively short of oil and natural gas. Although with abundant energy resources in whole, the per capita availability of resources is remarkably lower than the world average. For example, the per capita energy resources of coal and hydropower are only 50% of the world average level, and the per capita oil and gas resources are only 1/15 of the world average [11]. In addition, the economic development and the energy resource distribution are highly uneven across the country, energy transportation, especially for coal, lays a heavy burden on the national transportation network, and transportation-related cost and pollution increase considerably the end-use energy cost and environmental impact.

2.1.1. Fossil fuel energy resources

At the end of 2008, the total proven coal reserves were 114,500 million ton, accounting for 13.9% of the total world reserves. Of that, 62,200 million tons are anthracite and bituminous coal, and 52,300 million tons are sub-bituminous and lignite. The ratio of reserves to production is estimated to be 41 years, compared with the 122 years of the entire world [12,13]. The distribution of coal is very uneven across China's regions. Most of the coal reserves (over 100 billion metric tones) are located in Shanxi Province [13]. Other major deposits are found in the North (Inner Mongolia), Southwest (Guizhou and Yunnan), and Northwest (Shaanxi).

As to the petroleum reserves, the proven and exploitable reserves show a continuing decline. There were 17,300 and 17,400 million barrels at the end of 1988 and 1998 respectively, which declined to 16,100 million barrels in 2007 and 15,500 million barrels in 2008. At the end of 2008 it accounted for 1.2% of the world total, and the ratio of reserves to production is 11.1, much lower than the global average level of 42 [12]. Similarly, oil reserves are not evenly distributed either, and major oil fields are in the Northeast (Heilongjiang), east (Jiangsu) and Northwest (Xinjiang) [13].

The proven reserves of natural gas in China are small, about 1.3% of the world total, though China's overall natural gas resources are estimated to be larger and keep increasing during the last several decades. For example, there were 0.92 trillion cubic meters in 1988, they increased to 1.37 and 2.26 trillion cubic meters respectively in 1998 and 2007, and to 2.46 trillion cubic meters in 2008 with the ratio of reserve to production of 32.3 in the same year [12]. Natural gas reserves are mainly located in the Southwest (Sichuan), West (Shaanxi), North (Inner Mongolia) and Northwest (Xinjiang) [13].

2.1.2. Nuclear power

During China's 8th 5-Year Plan period (1991–1995), two nuclear power plants containing 3 nuclear reactors have been built and placed in operation. The total installed capacity was 2100 MWe, and generated 16 TWh of electricity in 2000, accounting for 1.2% of the country's total electricity generation. Four more plants with 8 reactors totaling 6600 MWe have been added during the 9th 5-Year Plan period (1996–2000). The total installed capacity increased to 8860 MWe [9,14,15]. In 2009, the annual nuclear electricity generation has reached 69.3 TWh, accounting for only 1.9% of the total electricity generation, much lower than the world average level of 16% [16].

Currently 20 reactors with total capacity of 21.9 GWe are under construction, which is the highest worldwide [16]. Several others are planned to be constructed. *The Medium- and Long-Term Nuclear Power Development Plan* (2005–2020) [17] outlines the plans to increase the nuclear capacity to about 40 GWe by 2020, 4% or the nation's total installed electricity generation capacity [18,19].

2.1.3. Renewable energy resources

Introduced on February 28, 2005, and having taken effect on January 1, 2006, China's *Renewable Energy Law* [20] has identified the key role of the renewable energy as "increasing energy supply, improving energy structure, guaranteeing energy safety, protecting environment and realizing the sustainable development of economy and society" [21]. In the year of its implementation, the proportion of the installed capacity of renewable energy from the total installed capacity stopped descending and began to climb. In 2009, the cumulative installed capacity of renewable energy reached 212.9 GWe [5], and accounted for 24.4% of the total installed capacity for electricity generation [5].

China has abundant renewable energy resources, and is especially rich in hydropower potential. The hydropower resources are 676 GWe [22], ranking as the largest in the world. The exploitable hydropower potential is estimated to be 400 GWe, of which 128 GWe is from small hydropower plants with an installed capacity below 50 MWe each [23]. The exploitation rate was, however, only 29.9% at the end of 2008, much lower than the average level of 60% in the advanced countries. 66.7% of the total exploitable potential resources are located in the Southwest (Sichuan, Chongqing, Yunnan, Guizhou, Tibet) with an exploitation rate of only 14.4% [24], thus leaving a great potential for further exploitation. The total installed capacity of hydropower was more than doubled in the last decade. It has increased from 77.1 GWe in 2000, to 116.5 GWe in 2005, and to 196.8 GWe in 2009, which is 22.5% of the total installed capacity [16,25]. Electricity generation from hydropower reached 554.5 TWh, that is 15% of the total electricity generation in 2009 [16].

The country's annual solar energy flux ranges from 3360 to 8400 MJ/m^2, and two thirds of China's surface receives a solar radiation flux that is above 5020 MJ/m^2 with annual sunshine for more than 2000 h [23]. The annual solar radiation energy on land is about 1700 billion *tce* [21]. The highest solar energy is available in the Northwest (Tibet, Qinghai, Xinjiang, western Inner Mongolia and Gansu) [24]. By the end of 2005, the installed capacity of photovoltaic power generation had reached 70 MWe. The installed area of solar water heaters had exceeded 70 million m^2, which was 77% of the world total amount and China has taken the leading place in the world in terms of solar water heater production, sale and ownership [21]. The PV installed capacity exceeded 100 MWe in 2007 and increased to 150 MWe in 2008 and 200 MWe in 2009 [12,16]. The solar water heater installation also experienced rapid increase: it was 97 million m^2 in 2006, and 120 million m^2 in 2007, accounting for 67% of the world total [12].

China's wind energy resource is rather rich, too. The development potential of on-shore wind resource is estimated to be as much as 253 GW at a 10 m height with an annual electricity generation of more than 50 billion kWh [23]. Developable offshore wind resources are about 3-fold larger than those on land, i.e. around 750 GW [21]. Up to the year 2005, a total of 61 wind power plants have been completed, with a total installed capacity of 1266 MW [21]. Currently the wind fields are mainly located in the North (Inner Mongolia), Northeast (Liaoning, Jilin, Helongjiang), East (Hebei, Jiangsu), West (Gansu), and Northwest (Xinjiang). Several more wind power bases would be constructed in Xinjiang, Gansu, coast area of Jiangsu and Shanghai, Inner Mongolia, Hebei and Jilin provinces [26].

Potential for biomass energy in China includes mostly crop stalks, firewood, animal and human wastes, domestic garbage, industrial organic wastes and waste water [13]. It is estimated that the total exploitable biomass energy in China is around 700 million *tce*, more than half of which are crop stalks [21]. According to Zhang et al.'s estimation [21], the biomass energy that could be used as energy could reach at least 450 million *tce*. Utilization of biomass energy includes biological chemical conversion (marsh gas and fuel alcohol), biomass gasification (power generation and fuel alcohol), biomass liquefaction (bio-diesel) and direct burning. By the end of 2006, the biomass energy power generation was 2 GWe, the annual marsh gas generation is 8.7×10^9 m^3 [27], the annual production of bio-ethanol reached 1.02 million ton/year, and of bio-diesel 50,000 ton/year [21,28].

2.2. The energy supply and consumption mix

Fig. 1 shows the aggregate energy production and consumption in China over time. Both production and consumption of energy in China have kept increasing to underpin the rapid growth of the economy. The total primary energy production increased from 627.7 million *tce* in 1978 to 2600 million *tce* in 2008 [2]. The energy consumption also experienced fast increase, with the total energy consumption of 571.44 million *tce* in 1978 and of 2850 million *tce* in 2008 [2].

Seen from Fig. 1, there appear to be three distinct periods of energy consumption. From 1978 to 1996, the energy consumption increased steadily with an annual growth rate of 5.1%; this was followed by a stagnation period from 1996 to 2001, and a soaring growth period, of 9.9%/year, from 2002.

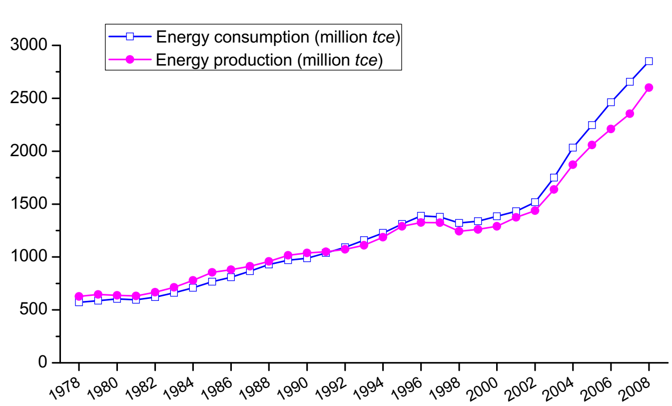

Fig. 1. Energy production and consumption (1978–2008). Data source: [2].

Table 1
Energy production and consumption (million *tce*).

Year	Aggregate production	As percentage of total energy production			
		Coal	Crude oil	Natural gas	Hydro, nuclear, wind power
1978	627.7	70.3	23.7	2.9	3.1
1980	637.4	69.4	23.8	3.0	3.8
1985	855.5	72.8	20.9	2.0	4.3
1990	1039.2	74.2	19.0	2.0	4.8
1995	1290.3	75.3	16.6	1.9	6.2
2000	1289.8	72.0	18.1	2.8	7.2
2001	1374.5	71.8	17.0	2.9	8.2
2002	1438.1	72.3	16.6	3.0	8.1
2003	1638.4	75.1	14.8	2.8	7.3
2004	1873.4	76.0	13.4	2.9	7.7
2005	2058.8	76.5	12.6	3.2	7.7
2006	2210.6	76.7	11.9	3.5	7.9
2007	2354.2	76.6	11.3	3.9	8.2
2008	2600.0	76.7	10.4	3.9	9.0
Year	Consumption	As percentage of total energy consumption			
		Coal	Crude oil	Natural gas	Hydro, nuclear, wind power
1978	571.4	70.7	22.7	3.2	3.4
1980	602.8	72.2	20.7	3.1	4.0
1985	766.8	75.8	17.1	2.2	4.9
1990	987.0	76.2	16.6	2.1	5.1
1995	1311.8	74.6	17.5	1.8	6.1
2000	1385.5	67.8	23.2	2.4	6.7
2001	1432.0	66.7	22.9	2.6	7.9
2002	1518.0	66.3	23.4	2.6	7.7
2003	1749.9	68.4	22.2	2.6	6.8
2004	2032.3	68.0	22.3	2.6	7.1
2005	2246.8	69.1	21.0	2.8	7.1
2006	2462.7	69.4	20.4	3.0	7.2
2007	2655.8	69.5	19.7	3.5	7.3
2008	2850.0	68.7	18.7	3.8	8.9

Data source: [2].

The aggregate primary energy production followed a similar pattern. Importantly, Fig. 1 also shows that from 1992 the aggregate energy consumption surpassed the energy production, and the gap between production and consumption kept increasing post-2002.

Table 1 summarizes the energy production and consumption with a breakdown by type of energy [2]. Coal remains the main primary energy source, although its ratio in energy consumption dropped from 76.2% in 1990 to 66.3% in 2002, and it increased somewhat in recent years, to 68.7% in 2008, as compared with 20–30% in the developed countries [12]. The share of oil remained stable around 20% with some fluctuations. The percentages of natural gas and non-fossil energy show steady increase, for natural gas it increases from 2.1% in 1990 to 3.8% in 2008. As for the non-fossil energy, it was 3.4% in 1978, rose to 5.1% in 1990 and to 8.9% in 2008. This ratio is still well below the 18.2% for the OECD [29].

The relative share of the primary energy production sources hasn't changed much. One feature is that the share of coal is quite stable; it remains at 76% after 2004. The other distinct feature is

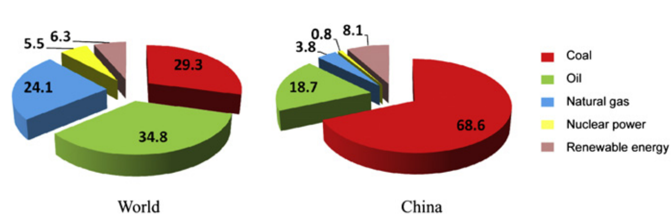

Fig. 2. Structure of primary energy consumption in 2008. Data source: [2,12].

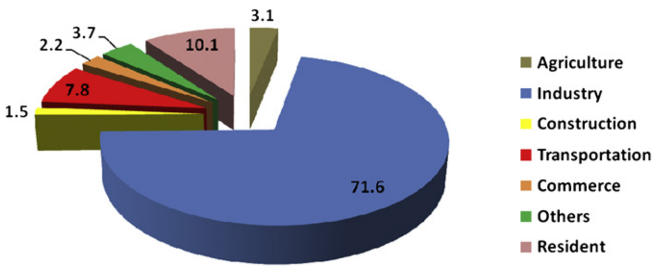

Fig. 3. Energy consumption in sectors (2007). Data source: [2].

that the share of oil production has declined over time, with the decline accelerating in the last decade [13], dropping by 7.7%-points in the period of 2000–2008 (Table 1).

Fig. 2 shows the comparison of the primary energy consumption between the world average and China in 2008.

2.3. Energy consumption by sector

Fig. 3 shows the proportions of energy consumption by different sectors in 2007. Ma et al. [13] analyzed the share change in different sectors over time. As can be seen, more than 70% of the energy is consumed by industry, making it the largest energy consumer. Its share, however, shrank somewhat relative to the nearly 80% in the 1980s. The share of agriculture also declined during the same time period, from 7.7% in 1985 to 3.1% in 2006.

The residential sector has become the second largest energy consumption sector. Its share was only 5.4% in 1985, increased sharply to 16% in 1990, and since then remained stable at about 10% [13].

In the last two decades the transportation and commercial sectors have experienced rapid expansion. In 1985, transportation was only a very modest energy consumer with a small share of 1.5%. It grew sharply to 4.6% in 1990 and jumped to 7.8% in 2007. At the same time, the share of the commercial sector has increased from barely 1% in 1985 to 2.2% in 2007 [13].

2.4. Growth of the electricity generation industry

With the rapid development of the electric industry, capacity building increased rapidly. The newly added capacity in 2009 is 89.7 GWe. By the end of 2009, the total installed power capacity reached 874 GWe, higher by 10.2% than that in 2008 [16]. The total power generation capacity ranks in the second place in the world, only after the United States. The annual electrical energy generated reached 3650.6 billion kWh in 2009, increased by 7.0% compared with that in 2008, but indicating a rather low capacity factor of about 48% that confirms the need for power generation and distribution system improvement. 2981.4 billion kWh and 554.5 billion kWh were generated from fossil fuel and hydropower, respectively [16].

The electricity industry structure optimization in recent years has four features [16] (Fig. 4):

(1) Drop of the share of the power generated by fossil fuel and increase of that generated by renewable energy

From the total installed power capacity, fossil fuel accounted for 74.6%, higher by 8.16% than the year before, but its share dropped by 1.45 %-points from that in 2008. 22.5% of the total capacity came from hydropower, with its share increased by 0.74%-points over the past year.

(2) Fossil fuel power moves to bigger unit capacities and lower environmental impact

By the end of 2009, the fossil fuel power plants with single unit capacity higher than 300 MWe accounted for 64.6% of the total, which is higher by 21%-points than that at the end of 2005. Totally 21 units of ultra super-critical plant type (unit capacity higher than 1000 MWe) are in operation and 12 more are under construction.

(3) Acceleration of nuclear power construction

As mentioned above, 20 nuclear power plants with total capacity of 21.9 GW are under construction by the end of 2009, which is the biggest nuclear power generation capacity increase in the world in that year.

(4) Scaleup of wind power

In 2008, the newly installed wind power was more than 5130 units, with a capacity of 6246 MW. It is estimated that this number increased to 12,000 MW in 2009 and ranks in the first place in the world in terms of new installations. The grid-connected wind power capacity reached 16.1 GW, 9.0 GW was added in 2009 alone. The total wind power installed capacity exceeded 20 GW and took the third place in the world; the percentage of grid-connected wind capacity is about 80%. Construction of the nation's first 10,000 MW wind power demonstration base started in Jiuquan, Gansu.

3. Challenges in energy development

3.1. The substantial increase in energy demand and shortage of domestic resources

China is in the stage of industrialization and still has a long way to go if compared with the industrialization level in developed

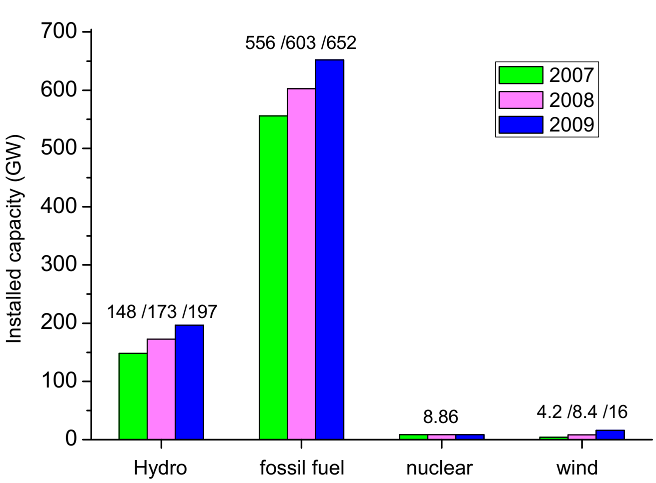

Fig. 4. The installed power generation capacity (2007–2009). Data source: [12,16].

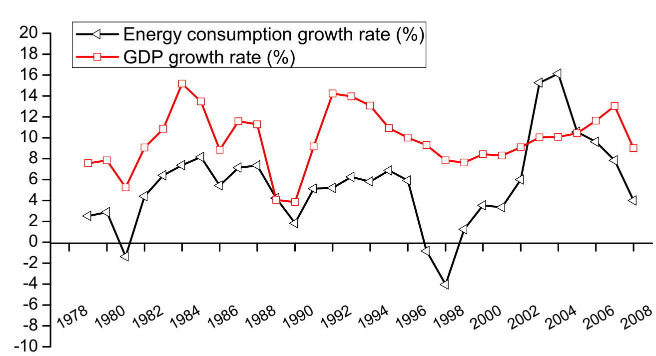

Fig. 5. The growth rates of energy consumption and GDP (1978–2008). Data source: [2].

Table 2
Ratios of reserves to production of fossil fuel.

	USA	China	Brazil	India	world
Coal	224	41	>500	114	122
Oil	12.4	11.1	18.2	18.7	42
Natural gas	11.6	32.3	–	35.6	60.4

Data sources: [12].

countries. The last two decades witnessed rapid growth of the nation's economy [2]. As shown in Fig. 5, from 1978 to 2008, China's economy has experienced rapid growth, with the GDP growing from 364.5 billion Yuan in 1978 to 30,067 billion Yuan in 2008 [2], at an average annual growth rate of 9.8% (taking into consideration the time change of the value of money). Meanwhile the energy consumption increased from 571.4 million *tce* to 2850 million *tce* in 2008 [2], with an annual growth rate of 5.6%. The economy increased especially rapidly in the recent years, with the average growth rate during 1991–2008 being 10.3%. China has become the world's third largest economy in terms of the nation's nominal GDP in 2008 [30]. The Chinese government has worked out a "Three Stage" development strategy to accomplish the modernization and establishment of a well-off society by 2050, and proposed to raise the GDP to the level of the middle-developed countries, with the per capita GDP reaching US$ 14,000–28,000 [7]. While increasing GDP does not necessarily have to be accompanied by commensurate growth in energy demand under certain initial conditions and proper planning, (as shown for example for Denmark [31]), the conditions in China seem to indicate that it has not yet found the way to grow the economy rapidly without rapid growth of energy consumption. Although the aggregate energy consumption is large, the energy consumption per capita is pretty low, 1.6 *toe* (tons oil equivalent)/person, about 1/5 of that of the USA [32]. The electricity consumption per person is 2040 kWh, lower than the world average of 2659 kWh, suggesting that China's total energy demand is likely to increase as the economy grows and the living standards rise.

On the other hand, China is short of resources both in total and per capita terms. At the end of 2008, the ratios of reserves to production of fossil fuels are far below the global average level, especially for oil (Table 2).

3.2. The growing dependence on foreign energy resources

Throughout the 1980s and the first half of 1990s, China was self-sufficient in primary energy supply. The domestic production of hydropower and natural gas continued to rise, and coal remained a relatively stable supply. The growth rate of the oil industry has remained at the low level of 1–3%/year since the mid-1980s, but the consumption has been rising at annual rates of 5–8% [33]. For example, the indigenous oil production has increased slowly from 138.3 million tons in 1990 to 197.8 million tons in 2008, while the oil consumption has grown rapidly from 114.9 to 396 million tons in the same period [30]. Due to the serious disparity between the domestic natural resources and the economic development, import of a large amount of energy resources is needed to meet the demand of the rapid economy growth.

China has become a net oil product importer from 1993, net crude oil importer from 1996, and net primary energy importer from 1997. The net imported primary energy amount has increased continually from 23 million *tce* in 1997, to 201 million *tce* in 2006, correspondingly the energy import reliance increased from 1.7% to 8.2% from 1997 to 2006 [13].

Table 3 shows the trade of coal and oil. China is always self-sufficient in coal and remains a net exporter, but the surplus is declining over the recent years due to the increase of the imported amount, and the net coal trade amount is a very small percentage of the total domestic coal consumption. The picture is however, different for the oil trade. The net import of petroleum has increased rapidly from 12.2 million ton in 1995 to 76 million ton in 2000 [13], and to nearly 200 million in 2008 [30]. The share of the imported petroleum was only 7.6% in 1995 [13], and exceeded 50% from 2007 [30], posing a threat to China's energy security, and the situation has deteriorated due to the rapid expansion of the transportation sector [34]. To reduce the growth rate of demand for oil in the transportation sector, the government takes measures to raise fuel consumption standards for vehicle and to introduce alternative fuels and to develop new engine technologies. Based on the Chinese energy resource conditions, production of alternative liquid fuel from coal is considered to be an important measure to alleviate the pressure from the oil deficit between production and consumption. Coal-based fuel as an expedient alternative can hopefully substitute oil in large scale in the near term, but the accompanying environmental impacts and low energy conversion efficiencies will need careful assessment.

3.3. Low energy efficiency

Seen from Fig. 5, the energy consumption growth and economy growth generally had the same trend. The energy consumption growth is generally lower than that of the GDP, except for the 2003–2005 period.

Both the energy intensity and the energy consumption elasticity coefficient (ECEC) are important indicators of energy efficiency, as they are related to energy consumption and economy growth. Energy intensity is measured as the ratio of energy consumption to GDP output, and the ECEC is calculated as the ratio of energy consumption growth rate to GDP growth rate. Figs. 6 and 7 show the variation of

Table 3
Exported Coal and imported Oil.

	Coal				Oil			
	Import Mt	Export Mt	Balance Mt	Reliance %	Import Mt	Export Mt	Balance Mt	Reliance %
1990	2.0	17.3	−15.3	−1.44	7.6	31.1	−23.5	−20.5
1995	1.6	28.6	−27.0	−2.02	36.7	24.5	12.2	7.6
2000	2.1	55.1	−52.9	−4.25	97.5	21.7	75.8	33.8
2001	2.5	90.1	−87.6	−6.78	91.2	20.5	70.7	31.0
2002	10.8	83.8	−73.0	−5.28	102.7	21.4	81.3	32.8
2003	11.1	94.0	−82.9	−5.06	131.9	25.4	106.5	39.3
2004	18.6	86.7	−68.1	−3.54	172.9	22.4	150.5	47.5
2005	26.2	71.7	−45.6	−2.11	171.6	28.9	142.8	43.9
2006	38.1	63.3	−25.2	−1.07	194.5	26.3	168.3	48.2
2007	51.0	53.2	−2.2	−0.09	211.4	26.6	184.8	50.4
2008	40.4	45.4	−5.0	−0.19	–	–	197.2	50.0

Negative values mean net positive export. Data sources: [2,13,30].

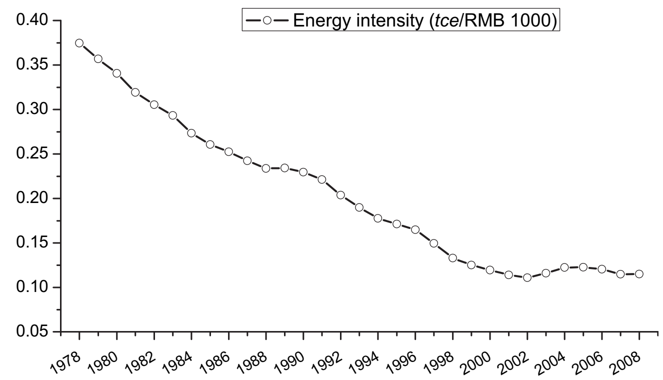

Fig. 6. Energy intensity (1978–2008) (2005 price). Data source: The GDP and energy consumption data are from [2].

energy intensity and ECEC over time. From 1978 to 2008, the energy intensity has decreased from 0.375 *tce* to 0.115 *tce* per 1000 RMB GDP (2005 price), a drop of 69%. In the same time period, the energy intensity of industry has dropped by 75% [6]. From 1990 to 2007, the specific energy consumption of per ton produced cement dropped by over 30%, the energy consumption for copper metallurgy dropped by 64%, and the specific energy consumption for power generation dropped by 16% [35] (Fig. 8). Though these improvements have been remarkable, the original energy intensity was extremely poor and the energy efficiency is still much lower than international values. The energy intensity in 2006 was 2.5-fold higher than that of the world average and 7.2-fold higher than that of Japan [6]. According to Jiang et al. [7], China's current average energy efficiency is about 33%, which is about 10% lower than that of the developed countries. Compared with the advanced international level, the specific energy consumption for producing a unit of steel, cement, ethylene, synthetic ammonia is higher by 17%, 20%, 57% and 31%, respectively, and the specific coal consumption for electricity generation is higher by 18%. The average energy consumption is 40% higher than the international advanced value in the categories of power generation, petrochemical engineering, building materials, chemical engineering, and the steel, non-ferrous metals, light duty, and textile industries. The motor vehicle fuel consumption per km is 25% higher than that of Europe and 20% higher than that of Japan. The building energy consumption per unit heated area is two or three times of that in the developed countries having similar climate conditions.

The energy efficiencies are also very different across different regions in China. In 2008, Beijing had the lowest energy intensity, followed by Guangdong and Zhejiang. Ningxia Province has the highest energy intensity, followed by Qinghai and Guizhou [6].

If inspected by sectors (Fig. 9), it is very easy to identify the consistency between the industrial energy intensity and the aggregate energy intensity, as both industrial energy consumption and industrial GDP contribution comprised most of the aggregate economy [13]. The energy intensity has steadily declined to the year 2001, and after that the pattern has reversed. The energy intensity is also very high in the transportation sector, and similar rising pattern can be found in this new century, from 0.15 *tce*/(RMB 1000) in 2001 to 0.18 *tce*/(RMB 1000) (all in year 2005 RMB value) in 2006. Many studies have analyzed the energy intensity trend changes in the past decades [13,33,35–41]; some of the viewpoints expressed in [33] are summarized below:

3.3.1. From 1978 to 2001

The period to 2001 was characterized by falling energy intensity. This was accompanied by a decline in carbon dioxide emission per unit GDP, although total CO_2 emissions and per capita emissions rose as the energy consumption grew. During this time period, the average growth rates of GDP and energy consumption were 9.64% and 4.12%, respectively. The energy consumption increased 2.5-fold while supporting an 8.2-fold increase of GDP. We note that it was somewhat encouraging for sustainable development that the energy growth rate was significantly lower than the GDP growth rate. The energy consumption elasticity coefficient remained around 0.5. Especially from 1997 to 1999, the nation's economy increased, while the energy consumption dropped, resulting in negative energy consumption elastic coefficients (Fig. 7).

Econometric analyses suggested that energy efficiency improvements within industries during the last two decades of last century are the major contributor to the energy intensity decline. Since the mid-1990s, remarkable efficiency improvements have been achieved in energy-intensive industries such as cement, paper, textiles, metallurgy, power generation, and oil and coal processing [33]. The industrial energy intensity is 1995 was 0.21 *tce*/RMB1000 in 1995, with is half of the value in 1985, and it again dropped by half in the following 5 years, to 0.105 *tce*/RMB1000 in 2001. Andrews-Speed [33] attributed this sustained improvement of energy efficiency to systematic policy measures launched in 1980s to enhance energy efficiency and to the gradual mercerization of the economy, especially since 1993, but we also note that significant reduction were relatively easy because of the very poor original energy intensities.

The structure change in energy supply also played a role. During 1990s, the proportion of coal in the primary energy supply exhibited continuous decline.

3.3.2. Since 2002

The favorable downward trend in energy intensity was reversed in the year 2002. The years 2002–2008 were marked by a boom in economic growth, and so did the energy consumption grow. The average growth rates of GDP and energy consumption were 10.5% and 9.9%, respectively. Especially during the years 2003–2005, both

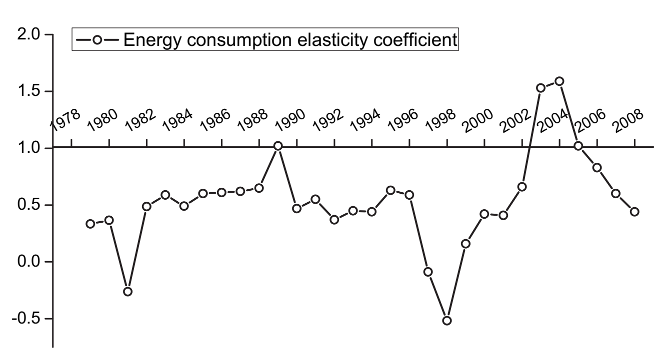

Fig. 7. The energy consumption elasticity coefficient (1978–2008). Data source: [2].

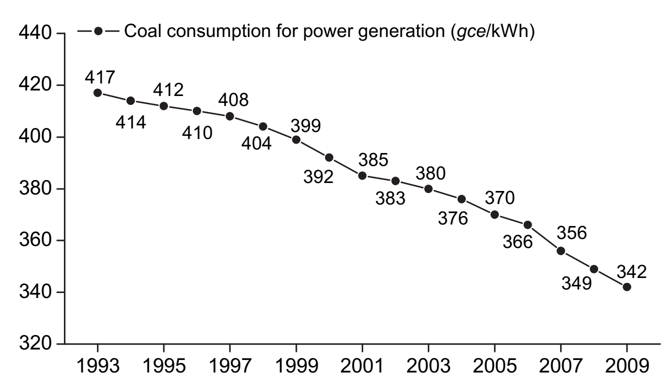

Fig. 8. Coal consumption for power generation. Data source: [2,43].

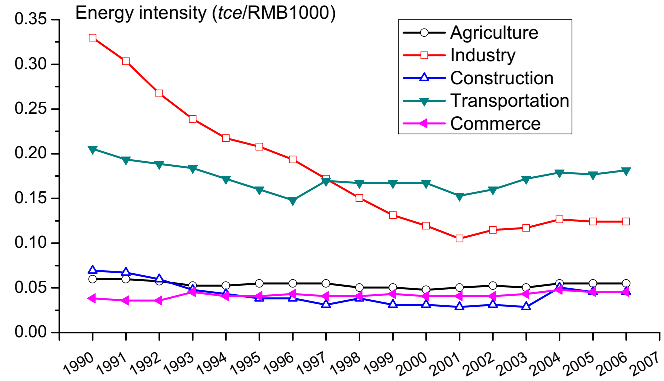

Fig. 9. Energy intensity by sector (1978–2006). Data source: [13].

growth rates were over 10%, and the energy consumption growth rate were as high as 15.3%, 16.1% and 10.6% in consequent years, surpassing the corresponding growth rate of GDP in the same years and thus leading to the high energy consumption elastic coefficients, as shown in Fig. 7.

The major driving force of the energy intensity is the rapid increase of investment, and increase of the percentage of heavy industries, including steel, cement, and chemical and electricity industries. The total investment in fixed assets jumped form 36% of GDP to 47% over the time period 2002–2005, prompting an extreme boom in energy-intensive sectors, such as steel, cement, and construction materials. China became the world's largest producer of steel (35% of world output in 2006), cement (48% of would output), and flat glass (49% of world output) [33]. At the same time, the exportation of the energy-intensive products including aluminum, paper, copper, steel and cement, also soared.

China's energy-intensive industries continue to keep a disproportionately high ratio of small scale plants which are both inefficient and highly polluting. The problem of scale and efficiency exists in energy-intensive industries such as cement, power generation, steel, non-ferrous metals, glass, paper and chemicals. In the case of cement, more than 5000 small plants were in operation in 2005, while the top ten producing enterprises accounted for just 13% of the national cement production. The energy-efficient rotary-type kilns accounted for only 40% of the production [33].

Low energy efficiency not only increases the energy consumption and environmental pollution, but also increases the burden of energy imports. After the implementation of the national energy saving strategy in 2006, the energy consumption elasticity coefficient dropped. In line with 4 years of consecutive decline, it dropped in 2008 to 0.4.

3.4. Serious environmental pollution problem

Fossil fuels (coal, oil, and natural gas) have, on the one hand underpinned the development of the economies of the industrial countries around the world, but on the other hand their combustion for electricity generation, transportation and industrial processes and domestic uses is the main contributor to increasing atmospheric pollutant concentration. High energy consumption and low efficiency only worsen the situation.

The pollutant emissions have high correlation with total energy consumption, and especially with coal consumption in China. Coal consumption accounts for around 70% in the aggregate primary energy consumption, as compared to 29% of the world average level (Fig. 2). Emissions of pollutants from coal consumption were the major sources of the pollutions, as 70% of the particulates, 90% of the SO_x, 67% of the NO_x and 70% of the total CO_2 came from coal combustion [42]. The economic damage from air pollution caused by the fossil fuels was estimated at 2–3% of GDP [23] and its longer term damaging effects are unaccounted for yet. Statistics indicated that the total emission of SO_2 increased remarkable from 13.25 million tons in 1985, to 19.95 million tons in 2000, and to 24.68 million tons in 2007. The industrial soot emissions decreased slightly from 12.9 million tons in 1985 to 11.6 million tons in 2000 and to 9.9 million tons in 2007 [7,42].

Since 1999 China's SO_x emissions have been very high, with about half of them emanating from the coal-fired power plants as shown in Fig. 10. 1n 2004, 298 cities in China were affected by acid rain, accounting for about 56.5% of the total surveyed. Furthermore, about 41.4% of the Chinese cities had an annual average precipitation with pH below 5.6 [42]. After the implementation in 2006 of China's energy saving and emission reduction measures, coal-fired power plants had to employ desulphurization equipments, and the situation improved somewhat. Up to the end of 2008, the total installed capacity with desulphurization reached 363 GWe with the percentage of coal power plants using desulphurization increased from 48% in 2007 to over 60%. At the same time, the specific SO_x emission dropped from 4.4 g/kWhe to 3.8 g/kWhe (Fig. 10) [43].

In addition, the volume of CO_2 emission is huge and the growth has been fast in China, posing challenges for mitigation [7,44,45]. The carbon dioxide concentration in the atmosphere is expected to increase continuously along with the growth of energy consumption. As shown in Fig. 11, the per capita CO_2 emissions in 2006 slightly exceeded the global average value, but they are still is 1/5 of that of the US and 1/3 of that of OECD [12]. The increase of China's CO_2 emission constitutes a high fraction of the global amount. From 1980 to 2002 China accounted for 30% of the net growth in global energy-related CO_2 emission; from 2002 to 2005 this share rose to 53% [46]. Fig. 12 shows the share of the CO_2 emission of China and US in the world total CO_2 emission from burning of fossil fuel in 2006 [12]. The total CO_2 emissions still have large potential to increase as the economy and energy consumption grow. Mitigation of CO_2 emission has become a big challenge to China's modernization process. The Chinese central government set a goal of reducing the CO_2 emission per unit of GDP by 40–45% by 2020 compared to the level of 2005, and made determined efforts to adjust the structure of the country's economy away from energy-intensive production [33].

4. Priorities of energy policy

The basic themes of Energy Strategy from *China's Energy Policy White paper 2007* [47] are summarized as: giving priority to energy conservation, relying on domestic resources, encouraging diverse

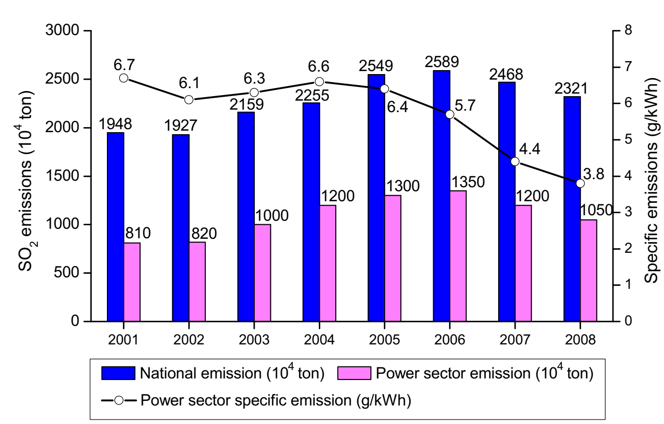

Fig. 10. National and power sector SO_2 emissions. Data source: [43].

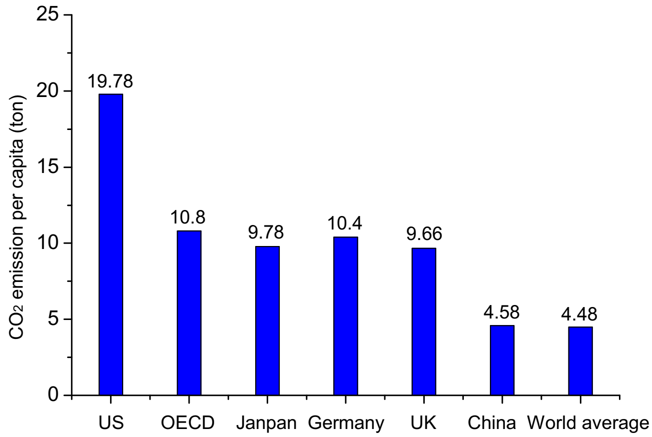

Fig. 11. Comparison of per capita CO_2 emission in 2006. Data source: [12].

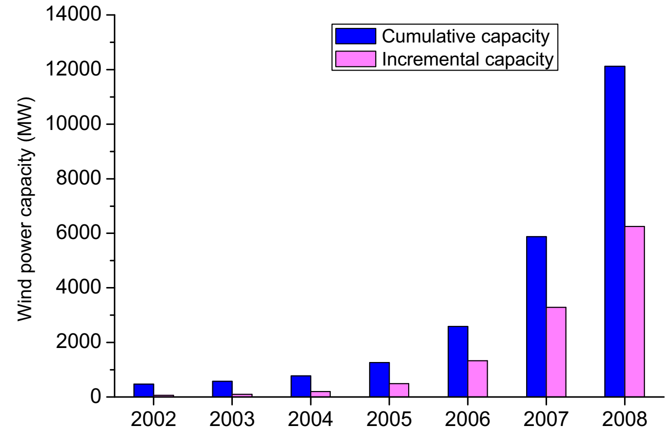

Fig. 13. Wind power cumulative capacity and incremental capacity. Data source: [12].

patterns of development, relying on science and technology, protecting the environment, and increasing international cooperation for mutual benefit. In 2006, China's energy intensity, measured by energy consumption per unit GDP was 2.5 times higher than the world's average [6], it was the second largest CO_2 emitter, and has been under increasing international pressure to reduce its CO_2 emissions. As the energy demand keeps a rapid growth rate, China is currently facing two major energy-related issues, namely the shortage of domestic energy resources and environmental pollution associated with the conventional fossil fuel energy. Reducing the energy intensity and increasing the share of non-fossil fuel energy are the two important remaining ways for China to rely on.

4.1. Energy saving prior developing strategy

In 2004, the National Development and Reform Commission issued the "*Medium and Long Term Energy Conservation Plan*" [48] that placed energy conservation and energy efficiency as the highest priority activities in China's energy policy. During the implementation of the 11th 5-year plan from 2006 to 2010, specific targets have been set to reduce energy intensity by 20% with an annual average reduction rate of 3.6% and to continue the same reduction rate till 2020 [33], and to reduce SO_2 emission and chemical oxygen demand (COD) discharge by 10%, i.e., SO_2 emission from 25.5 million tons in 2005 to 23 million tons in 2010, and COD discharge from 14.1 million tons to 12.7 million tons during the same time period. Due to

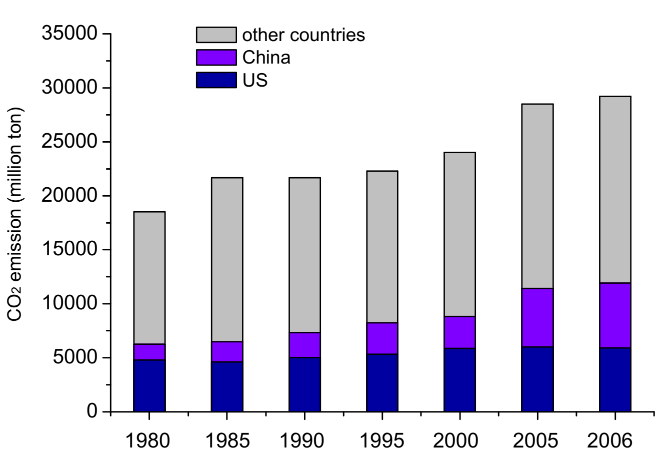

Fig. 12. CO_2 emission from combustion and utilization of fossil fuels in 2006. Data source: [12].

the lag in the publication of statistical data, it still remains unknown whether these targets have been met.

This *Energy Conservation Plan* and subsequent documents have set targets for energy consumption per unit output for the years of 2010 and 2020 for individual energy-intensive industries, including power generation, steel, non-ferrous metals, oil refining, petrochemicals, cement and plate glass, providing proposals for technological, process or management improvements needed to meet these targets. The *Energy Conservation Plan* identified a number of projects with significant potential of energy savings in both short and medium terms, such as industrial boiler retrofit, district cogeneration, and oil substitution in certain sectors [33,48]. The major elements of the *Energy Conservation Plan* were codified by a revised version of the 1997 *Energy Conservation Law of P. R. China* [49], which was approved in October 2007, and put into effect on 1 April 2008. Started from 2006, the *Energy Law* was drafted to include the key aims and shape an integrated energy policy framework. The revised draft of the *Energy Law* is nearly finished, and will be published in one or two years [50].

Industry remains the key focus of energy conservation efforts in China, because it has the biggest energy consumption and big room for energy efficiency improvement. Large potential exists mainly by optimizing industrial structure, increasing the ratio of tertiary industry, replacing the obsolescent capacity, and decreasing energy consumption.

The greatest effort has been put on closing down old, small-scale and inefficient plants, most notably in the power and steel industries. In the second half of 2006, the National Congress issued the "*Opinions of Accelerating Closing of Small-Scale Power Plants*". The Chinese government set a target to close 50,000 MWe of small scale coal-fired power plants during the 11th 5-Year Plan period (2006–2010). Actually 26,170 MWe was closed in 2009 alone, and totally 60,060 MWe was closed during the years 2006–2009 [43], accounting for 42.9% of total small-scale capacity. Consequently 64 million tons of coal can be saved annually, and 128 million tons CO_2 emission can be avoided. Currently there are still 80,000 MWe power plants with unit capacity lower than 200 MWe in the country [43]. In the iron and steel sector, by the end of 2007, 46 million tons of iron smelting capacity and 37 million tons of steel plants had been closed [33] for such reasons. The same was also done in other energy-intensive industrial sectors such as aluminum, glass, and paper manufacturing.

The transportation sector energy consumption accounted for 7.8% of the total in 2007 [2]. Though quite low compared with that of developed countries, a rapid growth of energy demands appears to be unavoidable as many people strive to own motor vehicles without sufficient government restrictions, causing a rapid increase in their number [34]. Proposals to increase energy efficiency include promoting a low carbon consumption and energy saving pattern by further raising fuel efficiency standards in vehicles, replacing old low-efficiency high-pollution vehicles, building more public transportation and railway vehicles, increasing the efficiency of both transportation system and vehicles, improving traffic fleet management, and encouraging the use of alternative fuel and hybrid cars [7,33].

Efforts are also devoted to control energy demand by market measures such as energy consumption tax, augmenting energy savings regulations and standards to improve energy use efficiency, and improving the public's energy saving awareness and understanding through education and dissemination of energy conservation information [7]. For example, a range of financial and fiscal policies such as providing income tax deductions for enterprises making energy saving products, and reduction of value added-tax on specified energy saving technologies, equipments or products, were implemented in the industrial sector. Since 2004 the export taxes has been increased and export tax rebates has been decreased several times to reduce exports of energy-intensive products [33]. Furthermore, the key energy conservation policies and legal regulations have been backed up by a significant increase in financial support. The central government raised the investment in energy efficiency to RMB 21.3 billion in 2007, which is twelve times higher than that in 2006 [33], and a massive increase from RMB 1 billion per yare of the early 2000s [51]. From 2006 to 2008, the Chinese government provided more than 90 billion RMB of financial support for projects aiming at increasing energy efficiency and decreasing environment pollution [52].

4.2. *Diverse patterns of development*

China has maintained rapid economic growth for the last three decades, and will most likely keep this fast growth pace in the future to advance social development. It is predicted that China's annual energy demand would amount to 4.5 billion *tce* in 2020, a 45% increase compared with that in 2009. Under this scenario, the total demand for oil would be 600 million tons with more than 300 million tons relying on imports. Natural gas demand will be 300 billion m^3 with domestic supply deficiency of 100–120 billion m^3. Therefore there would be a large gap between the energy demand and supply capacity, raising significant energy security concerns. A sound and sustainable energy supply should accounts for not only energy demand, but also for the resources mix, energy supply security, and environmental protection. As the Chinese government is determined to follow the principle that energy supply must be based mainly on domestic resources, development of nuclear energy and renewable energy is essential to materialize this domestic resource reliance principle.

In 2008 the usage of non-fossil fuel energy (including nuclear energy and renewable energy such as the hydropower, wind power, biomass power and solar heat power) was over 250 million *tce*, 8.9% of the total primary energy consumption, increased from 5.1% in 1990 [2]. In China 85% of the use of non-fossil fuel energy is for power generation, explained by the major share of hydro and nuclear power. Up to the end of 2009, the installed capacity of non-fossil fuel energy power generation was 222 million kW, 25.4% of the nation's total [16].

Currently, especially because of the concern about global warming generated by use of fossil fuels, nuclear power is increasingly favored worldwide, especially considering potential improvements in its economics, safety, and waste reduction and management. Encouraged by these trends and potential advantages, the Chinese government has decided to accelerate the development of nuclear power in the coastal regions having a more developed economy but short of energy resources. Nine of the 11 units under operation are PWR (Pressurized Water Reactors) [15]. So far, China is able to design and manufacture 300 MWe and 600 MWe PWR-s, and has basically mastered the generation II technology; and meanwhile is trying to import and absorb the generation III technology [15]. One AP1000 nuclear power station (generation III) is currently under construction in Sanmen, Zhejiang Province; the first unit is planned to be put into operation in 2013, which will also be the first AP1000 nuclear plant in the world. Other four AP1000 nuclear plants are under construction.

Foreseeing that the target set in the *Medium and Long Term Nuclear Power Development plan* [17] would be accomplished ahead of schedule, the government recently proposed that by 2020 nuclear power generation capacity will be 60–70 GWe, more than 5% of overall electric power installed [52]. Challenges exist mainly in the development of self-reliant technologies and practices of design, manufacturing, construction and operation of advanced type nuclear reactors.

China's *Renewable Energy Law* [20] identifies the strategic position of renewable energy and provides a set of directives encouraging renewable energy development, including national renewable energy targets, a feed-in tariff, a special fiscal fund, tax relief, technical R&D support, and education and training [23]. Relevant supporting laws and regulations were also legislated to ensure the implementation of the Law. Currently, a total of five sets of supporting laws have been enacted: *Guidance and Content for the Development of Renewable Energy Industry*, *Temporary Method for Managing the Special Capital of Renewable Energy Development*, *Temporary Management for the Price and Cost Sharing in Renewable Energy Power Generation*, *Administrative Regulations on Renewable Energy Power Generation*, and the *Medium and Long Term Plan for Renewable Energy Development* [21]. The *Mid-and-Long Term Development Plan* for Renewable Energy [26] specifies the major target as: accelerating scale-up of applications of non-fossil energy and increasing their proportion of the total primary energy consumption to 10% by 2010 and 15% by 2020 (Table 4). Clearly, a more favorable environment for renewable energy development is emerging in China. In fact, in the first year after the implementation of the *Law* in 2006, China's total renewable energy reached 180 million *tce*, accounting for 7.5% of total primary energy consumption in 2006, a big jump as compared with 63.3 million *tce* and 2.5% in 2005 [21,53]. The use of renewable energy in 2006 alone reduced 3 million tons of SO_2 emissions and saved 1000 million m^3 of water [53].

Hydropower is the most important and mature renewable energy resource in China. The current installed capacity of

Table 4
The major targets of the *Mid-and-Long-Term Development Plan* for *Renewable Energy Development* [26].

	2005	2010	2020
Power generation			
Hydro power (MW)	117,000	190,000	300,000
Biomass power (MW)	2000	5500	30,000
Wind power (MW)	1260	5000	30,000
Solar power (MW)	70	300	1800
Bio-fuel			
Solid fuel (1000 t)		1000	50,000
Bio-diesel (1000 t)	50	200	2000
Bio-ethanol (1000 t)	1020	2000	10,000
Marsh gas (10^6 m^3)	8500	19,000	44,000
Heating			
Solar water heaters (10^6 m^2)	70	150	300
Percentage of the non-fossil energy to total primary energy (%)	7.5	10	15

196.8 GWe accounts for 22.5% of the nation's total installed electric power capacity [16]. The target is to increase the installed capacity by 2020 to 300 GWe, 25% of the total power capacity. China is in a leading place in small hydro technology. The latest report reveals that there are 45,000 small hydropower stations with installed capacity of 55.1 GWe, about 43% of the estimated 128 GWe technological potential. The annual electricity generation from small hydro reached more than 160 billion kWh [5]. The target is to increase the installed capacity to 75 GWe by 2020. Hydropower resources are mainly located in South-West China, far away from the main electricity customers that are mostly located in East China, this leading to the challenges of long distance transmission. The social and environmental impact of its exploitation need to be thoroughly considered and evaluated.

Wind Power is perhaps the most rapidly developing renewable energy. Fig. 13 shows the annual increase and cumulative wind power capacity. The annual increase rate was above 100% since the implementation of the *Renewable Energy Law* in 2006. The wind technology level, however, has fallen behind Europe, as most of the 1–2 MW scale turbines have to be imported from Europe. Imported turbines constitute 75% of the market share [23]. The costs of wind turbines could decrease by 20–30% if major parts such as blades, gear boxes, engines, and hydraulic pressure systems were manufactured domestically [54,55].

The annual increase rate of the installed capacity of solar PV from 2001 to 2008 was 25% [7]. The grid-connected PV is, however, still marginal and mainly in the demonstration stage due to its high cost [23,56]. The target for solar power (both PV and solar thermal power) is to increase its capacity to 0.3 GW by 2010, and 1.8 GW by 2020; it is also planned to increase the solar water heater installed area to 150 million m^2 and 300 million m^2, an increase of 25% and 150% from that in 2007, respectively. China is the world's biggest producer of photovoltaic panels and cells. The total yield of Chinese solar cells in 2007 was more than 1200 MW, accounting for 35% of the world total, and ranks the first in the world, and the total yield increased to 2000 MW in 2008 [56]. Most of the PV products are exported rather than installed domestically, because of the underdeveloped grid-connected applications in China, and the high cost of electricity from a PV system, which is about 2 Yuan/kWh, 4-fold higher than that from the conventional generation sources [57].

Though the promotion of development of nuclear power and renewable energy was given a significant priority in China's energy policy, their development and deployment face challenges related to market barriers, difficulties associated with technological innovation, and public awareness and acceptance [57]. For renewable energy, low availability, low density, small-scale, and high investment cost are the major factors for the high cost, leading to an inferior position for renewable energy when competing with the conventional energy sources, even with governmental subsidies [57]. The power grid managers are often unwilling to accept electricity generated from renewable energy sources, because of the high cost and small-scale compared with that from coal-fired power plants. It is reported that about one-third of the wind generation capacity is not connected to the grid in recent years [28]. In addition, China lags behind in core renewable energy technologies such as wind turbines larger than 1 MW, large scale biogas plants, solar PV cells [23], and therefore has to depend on importing technologies and systems that are priced by the high labor costs in the developed countries that manufacture them. Localizing renewable energy equipment manufacturing is crucial to reduce the overall cost of the renewable energy investment.

To meet these challenges and establish an enabling environment for renewable energy development, Zhang et al. [23] proposed the following additional policy measures for risk management:

1. Improving implementation of China's feed-in tariff;
2. Expediting the formulation of fiscal and taxation measures;
3. Increasing public R&D and information support;
4. Removing market entry barriers;
5. Creating a coordination mechanism for policy formulation and implementation.

5. Conclusion

China is the most populated and most rapidly developing country as well as one of the two largest energy consumer and carbon dioxide emitters in the world, and is thus under great pressure to reduce CO_2 emissions. Such reductions are of benefit not only to China but to the world.

China must follow a sustainable development path so that it can deal in a satisfactory way with the sharp conflict between the inevitable rapid economic growth and environment protection. A long-term development strategy was proposed by the Chinese government with priority on energy conservation, efficient utilization of primary energy and development of clean/renewable energy. As the economy keeps growing and people's living standard keeps improving, it is estimated that energy consumption and CO_2 emission will still be increasing, but based on implementation of the new policies the increase rate will hopefully slow down after 2020, and approach zero by 2050. Sustainable development is the only way to achieve the vitally needed harmony between economic growth, social progress and environmental protection.

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