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Pathway to an active renewable energy scenario of Jiangsu province 2050

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Abstract: In 2009 Jiangsu province of China supplied 99.6% of its total energy demand with fossil fuels, of which 82% was imported from other provinces and countries. As energy demand soars, the problem of energy shortage worsens, and the degrees of pollution aggravate, it is essential for Jiangsu to put more emphasis on improving its energy efficiency and utilizing its renewable resources in future. This paper presents the integrated energy pathway for the transitional economy and society of Jiangsu by 2050. EnergyPLAN is chosen as the energy system analysis tool, since it accounts for all sectors of the energy system that needs to be considered when integrating large-scale renewable energy. A Current Policy Scenario (CPS) based on current energy policies and an Ambitious Policy Scenario (APS) based on large-scale integration of renewable energy and ambitious measures of energy efficiency improvement are proposed respectively. The energy pathway under these two scenarios are modeled and compared in terms of technology combination, renewable energy percentage, socioeconomic cost, and can provide valuable implications for Jiangsu's future energy policies.

Keywords: renewable; Jiangsu; 2050

1 Introduction

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According to the IPCC Fourth Assessment Report (AR4) in 2007, the worldwide discharge of greenhouse gases (GHGs) must peak as soon as possible no later than 2015, and need to be reduced by 50-85% by 2050 compared with the year 2000 to ensure a maximum of 2 ℃ increase (IPCC, 2007). Some researchers argued on the insufficiency of this standard to avoid irreparable damage and proposed a more challenging reduction to 350 ppm CO_2 in the atmosphere instead of 450 ppm CO_2 referred in AR4 (Hansen et al., 2008; Matthews and Caldeira, 2008; Monastersky, 2009). If climate changes as predicted, China will be one of the worst-impacted regions in the world, including the inundation of lowland coastal areas, frequent extreme events, reduced agricultural output as well as worse ecosystem impacts (Zeng et al., 2008). As the world's largest GHGs emitter, China is confronted with increasing pressures from both domestic and international community on global climate change. Meanwhile, foreseeable high energy demands and import dependency of fossil fuels is another important driving force for the nation to explore a low-carbon pathway (Chai and Zhang, 2010; Li, 2008; Liu and Gallagher, 2010; Zhang, 2010). Specifically, the energy transition from low efficiency coal to oil, gas and renewable sources will be accompanied by a series of socioeconomic transitions: from agriculture to urbanization and industrialization, from heavy industry to light and high tech industry, from low motorization to rapid growth of the motor vehicle population.

Jiangsu is one of the nation's most populous and prosperous provinces with a population density as high as 767 per km^2 (Fig. 1). In 2010, its GDP was 4.09 trillion yuan (US$ 631billion), making it the second largest GDP of all the provinces and an annual growth rate of 12.6%. However, its high speed economic growth is at the cost of large amounts of energy consumption, especially fossil-fuels. Since the province lacks energy sources, it imported approximately 82% of fossil fuels from other provinces and countries in 2009. The current condition of increasing energy demand, low energy efficiency, high energy dependency, soaring energy prices, and an almost 100% fossil fuel based energy mix with large amounts of GHGs emissions have already posed a great challenge to the province's sustainable economic growth in future. Energy strategies are becoming an important part of Jiangsu's five year plan in order to cope with the issues of energy security, pollution control and GHGs mitigation. Even though several policies regarding energy efficiency and renewable energy development have been published; there is a lack of consistent, comprehensive and long-term energy roadmap for Jiangsu. Also there is a lack of studies using coherent energy planning tools for the provincial level planning in China, which are widespread in international studies (Connolly et al., 2011; Mathiesen et al., 2011; Treffers et al., 2005).

As the place undergoing the fastest socioeconomic transformation, Jiangsu suffers the most severe conflicts between energy security and sustainable economic development in China. Therefore, this paper chooses Jiangsu as a typical case to develop and evaluate two future energy scenarios by 2050 under the contexts of its socioeconomic transition trajectory. It is the first time to develop a long-term energy pathway and evaluate its socioeconomic feasibility for a province in China using a coherent energy system analysis tool. The Current Policy Scenario (CPS) is based on current energy policies, while the principle of the Ambitious Policy Scenario (APS) is to promote the large-scale integration of renewable energy and ambitious measures of energy efficiency improvement. The business-as-usual (BAU) scenario hasn’t been considered in this study as it won’t become reality in future. Both the CPS and APS are based on the same assumptions of socioeconomic transition trajectories for Jiangsu by 2050. They are designed in terms of energy consumption, energy intensity and installed capacities of different energy technology projections in future. The analyses include: energy efficiency by sectors, transport, power generation and renewable energy technologies. The paper presents technical energy system analyses using the energy system analysis tool EnergyPLAN with a multitude of interrelated technologies by 2050, while a reference year 2009 and three other intermediate years including 2015, 2020 and 2030 are also analyzed. The methodology enables the design of flexible energy systems with the ability to balance electricity supply and demand through hour-by-hour simulations. Besides, the possibilities to increase the percentage of non-fossil fuels and reduce the emission of CO_2 are analyzed; and related socioeconomic costs and sensitivity analysis are presented as well.

Fig.1 Location of Jiangsu province

2. Characteristics of transitional economy and energy consumption

The social and economic development of Jiangsu can be characterized by high economic growth, industrialization, urbanization and mobilization during the past decades as shown in Fig.2. The average annual economic growth rate was 15.6% from 1995-2009, and the share of GDP of Jiangsu's primary, secondary and tertiary industries were 6.2%, 52.3% and 40.6% in 2009. The economic growth was accompanied by large amounts of primary energy consumption and thus GHGs emissions. In Jiangsu, industry consumes about 85% of the total final energy consumption, with residential, commercial and transport users dividing up the remaining 15% as shown in Fig.3. Jiangsu has seen massive investments in heavy industries that make energy-intensive products such as steel, aluminum and glass for China's domestic market. At the same time, rapid growth in export industries (primarily lighter goods such as electrical and mechanical products and clothes) have also driven GHGs emission growth. So far, consumption of private goods, such as personal cars, by the middle class is not yet the major driver of Jiangsu's emissions. However, the number of private cars has already reached 12.4 million in 2010 with an annual growth rate of 7%. Moreover, around 0.78 million of population migrates annually from rural areas to urban areas during Jiangsu's urbanization process, while the energy consumption per capita in China's urban areas is three to four times that in the rural areas (Ma et al., 2011). Thus, there are great potential of energy consumption increase in the residential, commercial and transport sectors in the future.

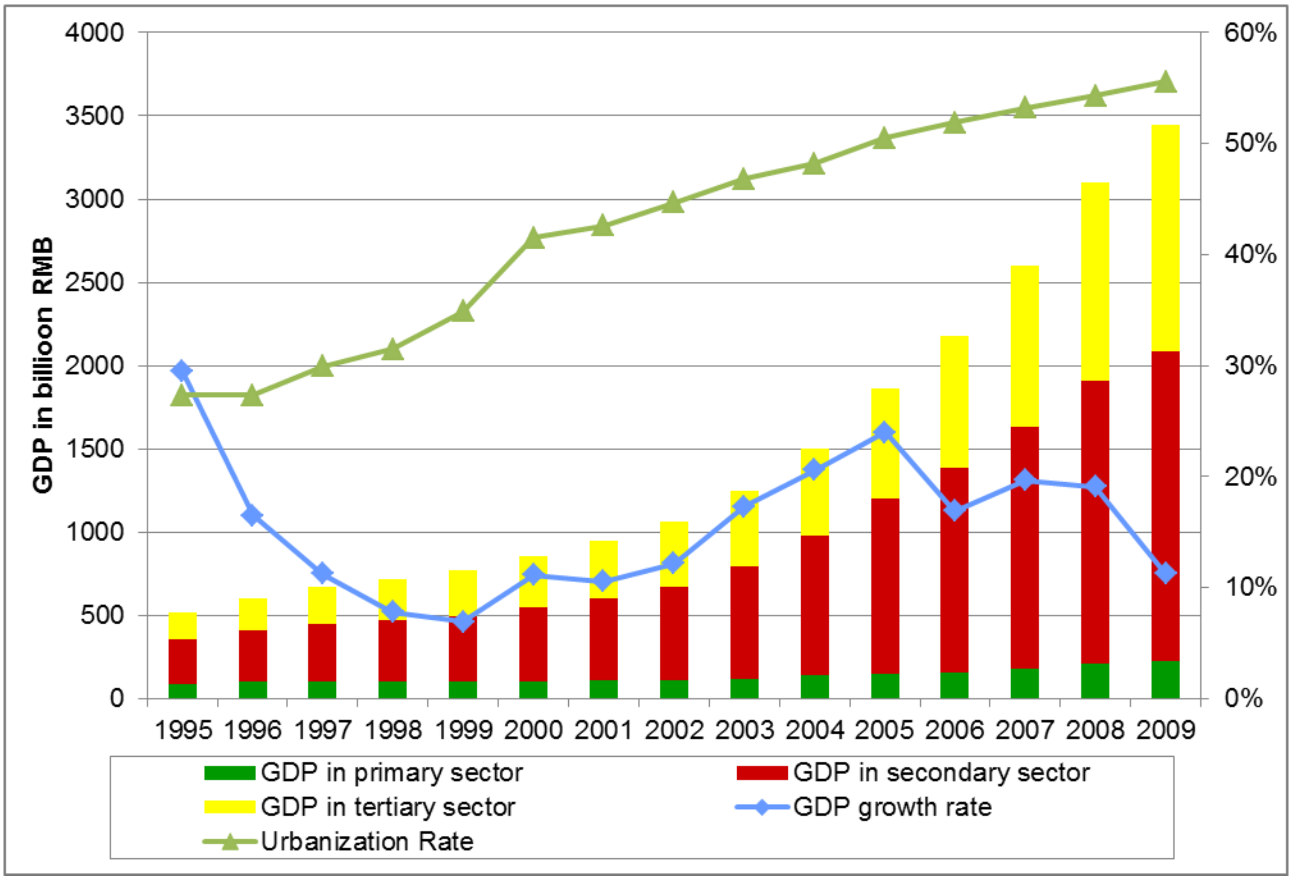

Fig.2 Trends of gross domestic production and urbanization

Source: Statistics Bureau of Jiangsu (1996-2010).

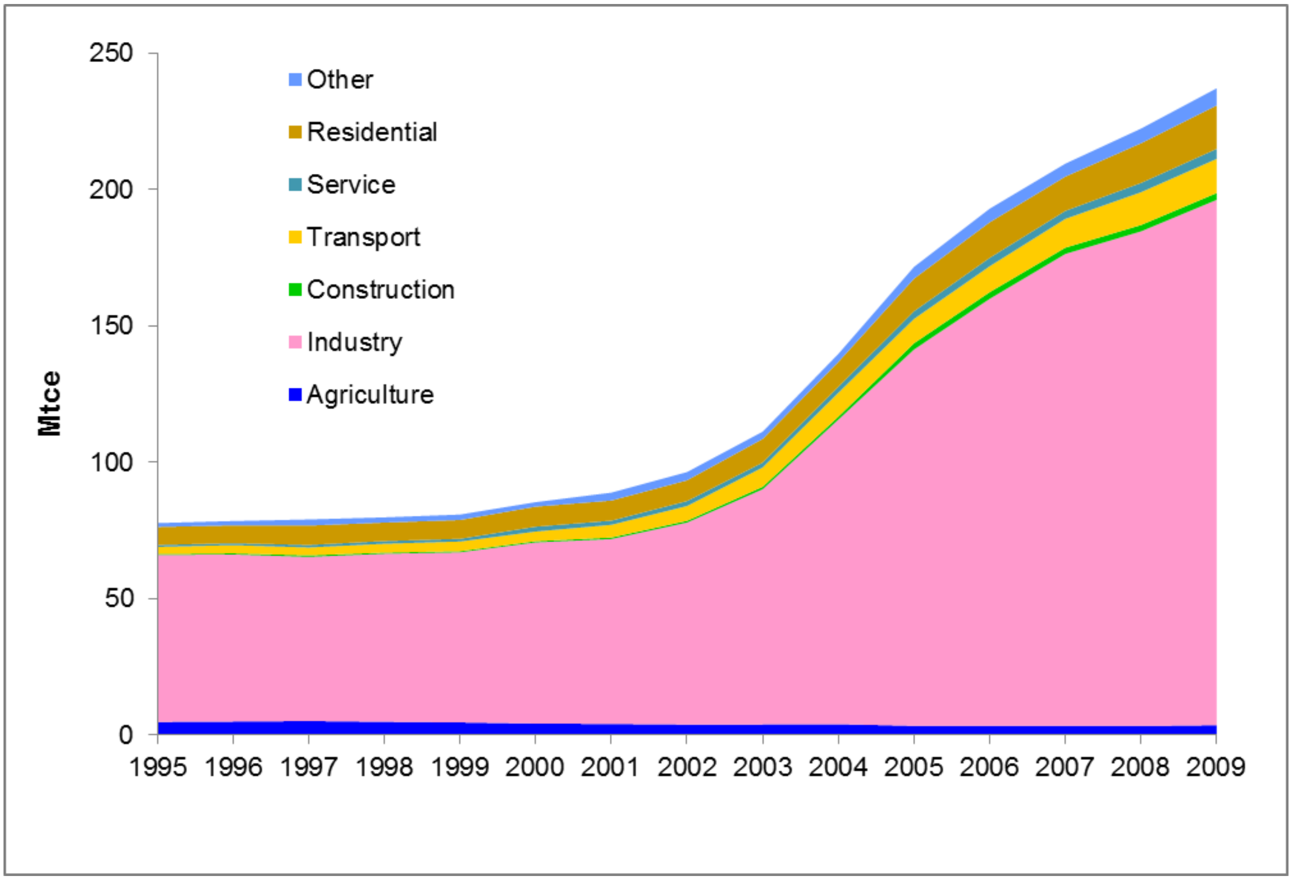

Fig.3 Trend of final energy consumption by sectors

Source: Statistics Bureau of China (1996-2010).

On the other hand, Jiangsu's energy structure is approximately 100% fossil fuel based (Fig.4). What makes the condition even worse is that the share of coal makes up as high as 79%. Power generation and supply sectors consumed 60% of the total coal consumption in 2009. Jiangsu's power system relies heavily on coal-fired thermal power plants, and the average efficiency of power generation is 39%, much lower than the efficiencies observed for the Nordic countries (42% for coal, 52% for gas and 45% for oil-fired power generation) (Graus et al., 2007). Even though energy intensity of Jiangsu has decreased by 58% from 1995-2009, yet it is still 3-4 times higher compared to that of the developed countries as shown in Fig.5. Regarding the energy intensity by sectors, Jiangsu is compared with Germany in Table 1. The largest gap of energy efficiency between Jiangsu and Germany lies in industry, where the industrial energy intensity of the former in average is approximately 8 times higher than that of the latter. In 2009, the sectors of textiles, paper, coke and petroleum, non-metallic mineral products and metals together consumed 53% of the total industrial energy consumption in Jiangsu. Given the fact that the energy intensities of these sectors are 6-10 times higher than those of Germany, there is huge potential of energy conservation in Jiangsu in future.

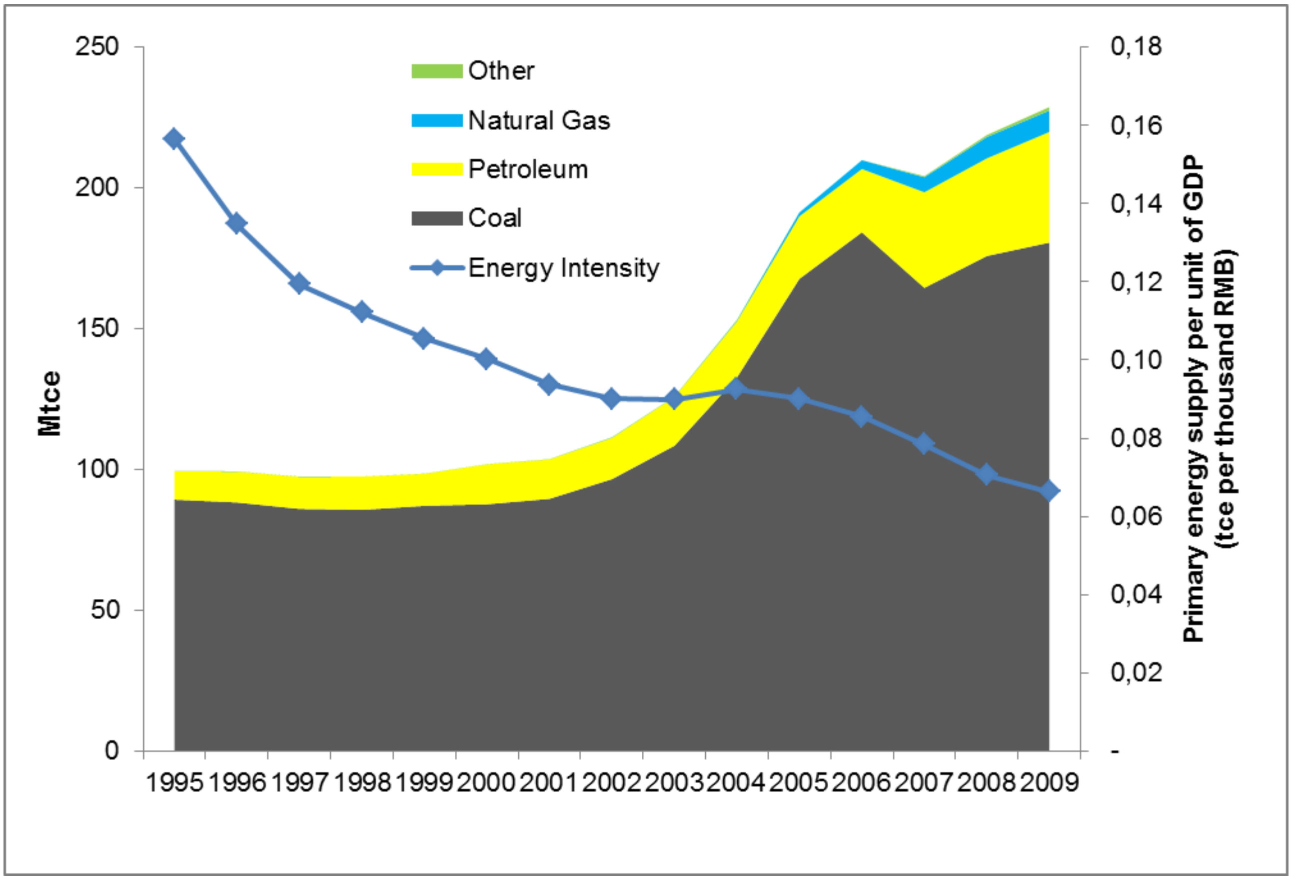

Fig.4 Tends of primary energy consumption and energy intensity

Source: Statistics Bureau of China (1996-2010).

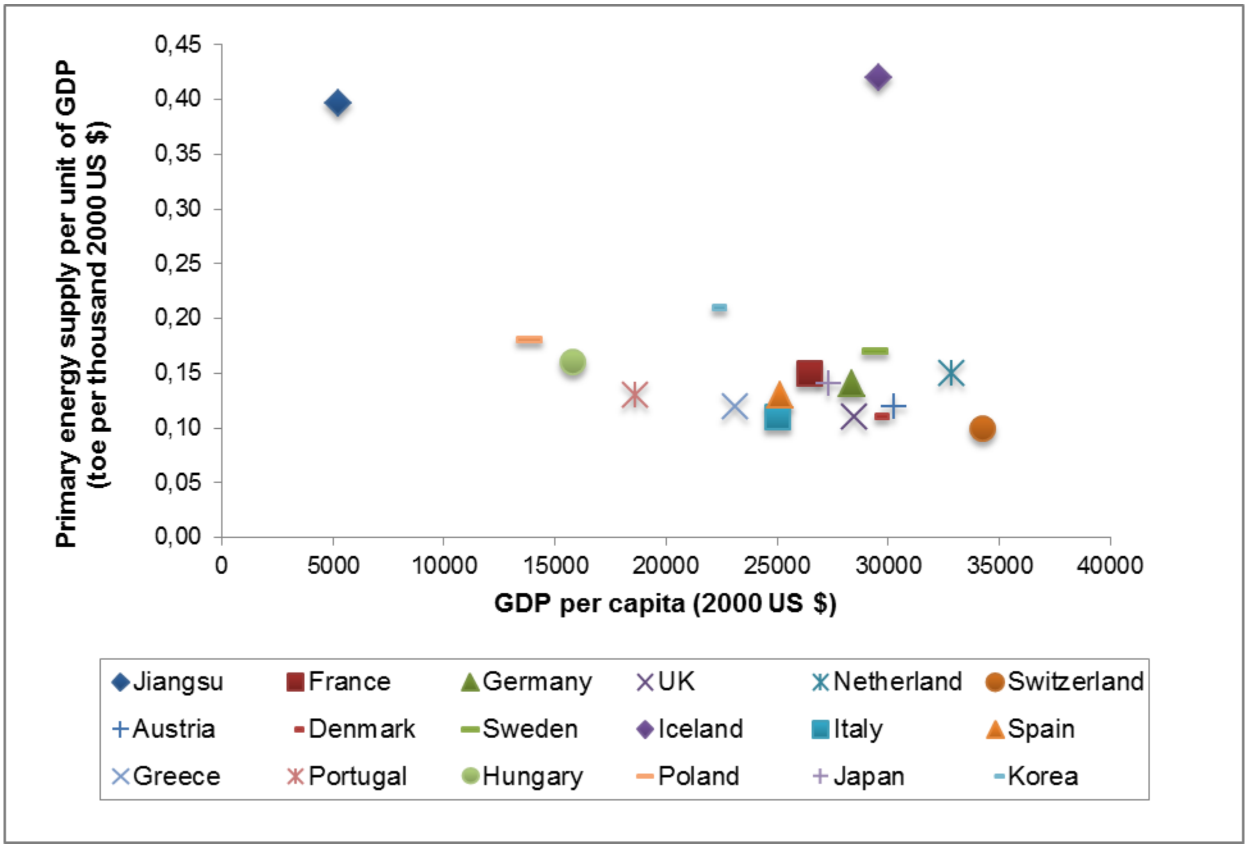

Fig.5 Comparison of energy supply and GDP per capita between Jiangsu and other countries

Source: OECD (2010).

Table 5 Comparison of energy intensity between Jiangsu and Germany, unit tce/10^4 Yuan

	Jiangsu	Germany
Agriculture	0.1596	0.0855
Industry	1.0508	0.1310
Mfr. of textiles	0.7073	0.0664
Mfr. of paper and paper products	1.8299	0.2690
Mfr. of coke and refined petroleum products	1.7095	0.2690
Mfr. of chemicals and chemical products	1.8967	0.3122
Mfr. of other non-metallic mineral products	2.2482	0.2757
Mfr. of basic metals	3.2322	0.3222
Service	0.0730	0.0256

Source: Statistics Bureau of Jiangsu (2010).

Statistisches Bundesamt Deutschland (2010).

3. Methodology

The methodology for analyzing the energy pathway of Jiangsu province during its transition period towards 2050 can be divided into four parts. Firstly, the social and economic transition pathway of Jiangsu is delineated based on several key socioeconomic indicators such as economic growth and population structure. It serves as the context for energy analysis in the following part. Then the CPS and APS are proposed respectively according to a series of assumptions on energy efficiency, energy structure and installed capacities of different energy technologies. Thirdly, the costs of fossil fuels and different energy technologies are summarized in order to analyze the overall system cost. Finally, all the inputs and assumptions used in the CPS and APS are put into the energy system analysis tool EnergyPLAN, which enables the socioeconomic feasibility study of the two energy scenarios in Jiangsu.

3.1 Key assumptions on social and economic transition

There are signs that the economic activities of developing Asian countries are now beginning to slow, and GDP growth in all regions is expected to fall, though non-OECD countries will continue to outpace the rest of the world (IEA, 2010a). The social and economic transition pathway of Jiangsu by 2050 is based on the official 12th Five Year Plan as well as predictions from groups of economists in Chinese Academy of Engineering. Key assumptions on economic and population growth, economic structure and urbanization rate are summarized in Table 1. Similar to the international trend, the GDP of Jiangsu keeps increasing but with a slowing rate from 2009-2050. At the same time, the growth rate of population decrease slightly until it becomes negative by 2050. Jiangsu's GDP per capita in 2009 is similar to the level of Korea in 1990, and it will reach the 2000 level of Australia and United Kingdom by 2030 and exceed the 2008 level of Germany by 2040 according to the assumed economic and population growth. Accompanied with this rising GDP per capita, Jiangsu's economy will shift towards more service-oriented with high share of value added in services by 2050. Simultaneously, the population continues to migrate from the rural areas to cities and metropolitans and the urbanization rate will reach as high as 85% like most developed countries.

Table 1 Key assumption of macroeconomic parameters

	2009	2015	2020	2030	2040	2050
GDP Growth	14%	10%	8%	6%	4%	2%
Population Growth	0.6%	0.5%	0.4%	0.3%	0.2%	-0.2%
GDP per capita ($)[a]	6526	11021	15654	26521	38740	56949
Urbanization rate	55.6%	63%	70%	75%	80%	85%
Share of value added in agriculture	2.1%	1.8%	1.5%	1.2%	1.0%	0.9%
Share of value added in industry	58.1%	50.2%	43.5%	39.8%	36.0%	32.1%
Share of value added in services	39.8%	48.0%	55.0%	59%	63%	67%

[a] 2009 average exchange rate: 1 USD = 6.835 RMB

Source: Chinese Academy of Engineering (2011).

3.2 Current Policy Scenario (CPS)

In COP 15, the Chinese government promised to reduce the carbon intensity (CO_2 emissions per unit of GDP) in 2020 to 40-45% that of 2005. An energy plan for China has been given high importance since then in order to realize the nation's promise to the world. In this study, the CPS reflects Jiangsu's shift towards a relative sustainable energy pathway aimed at structure adjustment and energy efficiency improvement that have already been reflected by published energy policies. However, these policies are fragmented, conservative and often in short-term. The starting point of this scenario is the 12th Five Year Plan (Development and Reform Commission of Jiansu, 2011a) and 12th Five Year Energy Plan (Development and Reform Commission of Jiansu, 2011b) of Jiangsu, and the future policies are not considered in the CPS. The 12th Five Year Plan envisions that Jiangsu's economic growth rate will be 10% in 2010-2015, and the GDP per capita in 2015 will reach around $11,021. The share of value added in service will increase from 39.6% in 2009 to 48% in 2015, and the contribution of high-tech industry to the value added in industry will reach 40%. Besides, the urbanization rate will increase from 55.6% in 2009 to 63% in 2015. The 12th Five Year Energy Plan of Jiangsu emphasizes the importance of renewable energy and energy efficiency. It indicates that the share of non-coal fuels will increase from 21% to 30% by 2015, including 10% of natural gas, 1.4% of nuclear energy and 1.3% of wind power. The energy intensity will decrease by 18% from 0.708 to 0.6 tce/10^4 Yuan, with an annual decrease rate of 3.37%. The coal heat rate will drop from 329 g/kWh in 2009 to 317 g/kWh by 2015. Under this trend, the energy intensity of Jiangsu in future is shown in Table 2. The total installed capacity of wind power, PV, biomass, pumped hydro and nuclear will be 5.8 GW (including 2.4 GW onshore and 3.4 GW offshore), 0.8 GW, 1 GW, 1.1 GW and 3 GW respectively by 2015. The projection of future installed capacity of renewable and nuclear energy is displayed in Table 3. Passenger-car ownership in Jiangsu is projected to climb from 44 cars per 1000 inhabitants in 2009 to 316 in 2030 and 673 in 2050 (Argonne National Laboratory, 2006; Zhou et al., 2011). The average annual growth rate of electricity demand has been estimated as 5.7% in 2009-2015, 5.0% in 2015-2020, 3.0% in 2020-2030, 1% in 2030-2040 and 0.48% in 2040-2050 (Chinese Academy of Engineering, 2011).

Table 2 Energy intensity by sectors in the CPS, unit tce/10^4 Yuan

	2009	2015	2020	2030	2040	2050
Agriculture	0.1596	0.1356	0.1153	0.1038	0.0934	0.0841
Industry	1.0508	0.7881	0.5911	0.4433	0.3325	0.2494
Service	0.0730	0.0621	0.0527	0.0475	0.0427	0.0385

Table 3 Projection of installed capacity by plant types (GW)

Plant types	2009	2015	2020	2030	2040	2050
Nuclear	2	4	8	12	16	20
Onshore wind	0.945	2.4	3	4	5	10
Offshore wind	0	3.4	7	10	15	20
Solar PV	0.08	0.8	1.2	2	3	4
Biomass	0.17	1	2	3	4	5
Pumped-hydro	1.1	1.1	2.6	5	8	10

3.3 Ambitious Policy Scenario (APS)

The APS represents a more ambitious transition towards sustainable energy pathway compared to the CPS. It promotes the large-scale integration of renewable energy and ambitious measures of energy efficiency improvement in Jiangsu's future energy system. The same socioeconomic parameters are applied for the APS as the CPS. However, a range of state-to-art technologies for the combined system will be utilized for the purpose of greater efficiency and flexibility. First of all, we assumed that Jiangsu's energy intensity by sectors with reach the current level of Germany by 2030, and further decrease by 20% until 2050 in the APS (Table 5). Besides, the existing low efficiency coal thermal power plants will be gradually replaced by ultral-supercritical coal power plants with the efficiency of 47% and natural gas-fired combined cycle plants with the efficiency as high as 60%. Given that the current Jiangsu's power system is almost purely coal thermal dominated, we assumed that 50% of coal-thermal power plants will gradually reach the fuel efficiency of 47% from current average efficiency of 39% by 2030, and all of them will be replaced by the state-of-art technology by 2050. Individual boilers have the average efficiency of 65% in Jiangsu's energy system in 2009, and they will be gradually replaced by industrial CHP with the electricity efficiency of 40% and thermal efficiency of 50%. Biomass and waste based CHP are introduced in order to reduce the share of coal consumption. On the other hand, installed capacities of renewable energy technologies are projected on the basis of Jiangsu's exploitable renewable energy resources as shown in Table 6 and Table 7. Jiangsu is rich in wind resources including both onshore and offshore, but limited potential of solar resources. Thermal heat storage, large-scale heat pumps, eletroylser, pumped hydro and hydrogen storage will be introduced in order to adjust electricity production from intermittent wind power production. Flexible demands of electricity are introduced for 5% of demand in industry and households by 2030 and 15% by 2050 due to the construction of smart grids.

Table 5 Energy intensity by sectors in the APS, unit tce/10^4 Yuan

	2009	2015	2020	2030	2040	2050
Agriculture	0.1596	0.1277	0.1021	0.0868	0.0781	0.0703
Industry	1.0508	0.6830	0.3415	0.1708	0.1281	0.1025
Service	0.0730	0.0548	0.0411	0.0287	0.0259	0.0233

Table 6 Renewable resources of Jiangsu

Items	Exploitable potential (TWh)
Wind onshore	146 [1]
Wind offshore	169 [2]
Solar PV	36.6 [3]
Biomass	188.18 [4-6]
Municipal Waste and sludge	7.3 [4]

Source: [1] Zhou et al., 2011; [2] Hong and Bernd, 2012; [3] Zhou et al., 2010; [4] Xu et al., 2011; [5] Liu and Shen, 2007; [6] Zhang et al., 2008;

Table 7 Projection of installed capacity by plant types (GW)

Plant types	2009	2015	2020	2030	2040	2050
Nuclear	2	4	8	12	16	20
Onshore wind	0.945	2.4	5	15	25	40
Offshore wind	0	3.4	7	18	30	50

PV	0.08	0.8	1.5	4	6	10
Biomass	0.17	5	10	20	40	60
Waste	0	0.2	0.5	1	1.5	2
Pumped-hydro	1.1	1.1	2.6	5	8	10

3.4 System cost inputs

In order to evaluate and compare the economic feasibility of different energy scenarios, it is important to collect system cost parameters beforehand. In this study, the overall system costs include investment, operation and maintenance, fuel and CO_2 cost. Investment and O&M costs as well as lifetime for different energy technologies in China can be found in Table 8. International fuel prices and fuel handling costs are displayed in Table 9 and Table 10 respectively. The annual operating costs do not include costs outside of the individual technologies such as transmission lines, and all the scenarios are based on current transmission condition. Based on the renewable energy CDM projects, the value of certified emissions reduction in China typically ranges from 10-20$/t, depending on project type and perceived level of risk (Lewis, 2010). Here, long-term CO_2 prices of 10$/t and 30$/t are used for calculation respectively.

Table 8 Investment, fixed O&M and variable O&M costs for different technologies

Technology Type	Investment costs ($/kW)	Unit cost of fuel ($/MWh)	Fixed O&M costs ($/kW)	lifetime
Coal	602-672	23.06	1.51-1.68	30
Gas CCGT	538	28.14	2.81-3.04	30
CHP in DH	720	49.22	0.92	30
Individual boiler	160	49.22	4.8	20
Nuclear power	1748-2302	9.33	7.04-9.28	30

Wind onshore	1223-1627	0	15.51-27.11	20
Wind offshore	2446-3057	0	23.27-38.78	20
Hydro	757-1583	0	1.37-9.85	50
Photo Voltaic	2878-3742	0	15.65-23.73	20

Source: IEA(2010b).

Table 9 Fuel prices of 2009, 2020 and 2030

$/GJ	Coal	Crude oil ($/bbl)	Crude oil	Fuel oil	Gas/Diesel	Petrol	Natural gas	Biomass
2009	3.32	60	9.87	6.91	12.34	13.13	7.4	5.73
2020	3.47	99	16.18	11.33	20.23	21.52	12.9	6.26
2030	3.60	110	17.97	12.58	22.46	23.90	13.3	7.11

Source: IEA(2010a).

Table 10 Fuel handling costs

$/GJ	Coal	Fuel oil	Gas/Diesel	Petrol	Natural gas	Biomass
Power stations (central)	0.093	0.374	0.374	-	0.580	2.243
Distributed CHP, district heating & industry	-	-	2.655	-	2.860	1.870
Individual households	-	-	2.898	5.272	4.375	-
Road transport	-	-	4.388	5.913	-	15.974
Airplanes	-	-	-	0.673	-	-

Source: DEA(2011).

3.5 The EnergyPLAN energy system analysis tool

After gathering all the technological and economic parameters, energy systems under the CPS and APS can be modeled by the energy system analysis tool EnergyPLAN. The structure of EnergyPLAN is shown in Fig.6. It is a deterministic input/output model that performs hour-by-hour simulations of regional or national energy systems including electricity, heating, industry and transport sectors. General inputs are demands such as electricity and district heating, renewable energy sources such as hydro and wind power, power station capacities, costs, and a number of optional different regulation strategies emphasizing import/export and excess electricity production. Outputs are energy balances and resulting annual productions, fuel consumption, import/export of electricity, CO_2 emissions and total system costs. In order to ensure the model is simulating the Jiangsu's energy system correctly, a reference model is created representing the year 2009. Details of the inputs used and the assumptions made to create the reference model are discussed in (Hong et al., 2012) where it concludes that EnergyPLAN can provide an accurate simulation of the Jiangsu's energy system. Once the reference model is proved accurate, scenarios based on the year 2015, 2020, 2030 and 2050 are built correspondingly.

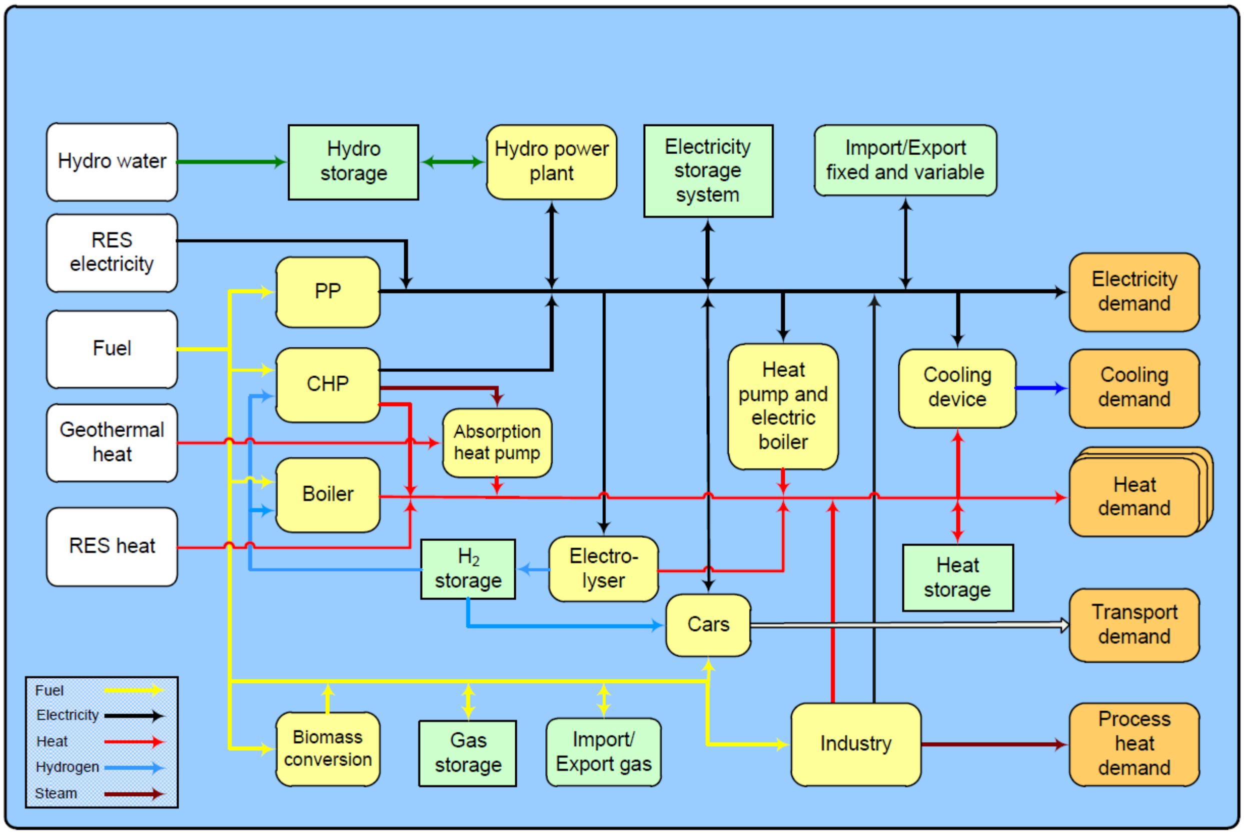

Fig.6 The structure of EnergyPLAN 9.0

Source: Aalborg University (2011).

4 Results

Once the models for CPS and APS are created using EnergyPLAN, the analysis and comparisons on primary energy supply, non-fossil fuel and renewable energy percentage, CO_2 emissions and overall system costs can be conducted. Fig.7 shows the primary energy supply in the CPS and APS. Compared to the reference year 2009, primary energy supply will increase by 1.7 times by 2050 in the CPS, while the increase rate is around 89% by 2050 in the APS. Meanwhile, the coal consumption is decreasing in the APS through industrial structure adjustment, efficiency improvement in thermal power plants and replacement by wind, PV, biomass and nuclear energy. The percentages of non-fossil fuels and renewable energy in the CPS and APS are shown respectively in Fig.8. Given that the increasing trend of energy demands in Jiangsu and limited local renewable energy resources, the percentages of non-fossil fuels are 16% and 37% in the CPS and APS respectively. However, as Jiangsu finishes its transitional period of social and economic development, both population and energy demands begin to be stable and even slightly decrease after 2050. Then we would expect higher integration percentage of non-fossil fuels and renewables with the technological improvements of renewable energy technologies. Regarding CO_2 emission trajectory of Jiangsu, the difference between CPS and APS are shown in Fig.9. In the CPS, the CO_2 emissions increase tremendously from 605 Mt in 2009 to 1271 Mt in 2050, which reflects the insufficiency of current energy policies to control the GHGs emissions in future. Instead, the CO_2 emissions are successfully controlled in APS and it foresees a possibility of mitigation if the technology of carbon capture and storage (CCS) is widely adopted. Meanwhile, the outcome in three intermediate years including 2015, 2020 and 2030 suggest that the next 5-10 years is a very important period for Jiangsu's energy and GHGs control (Fig.7 and Fig.9). Large amounts of investments are needed in the arena of renewable energy technologies and energy efficiency measures.

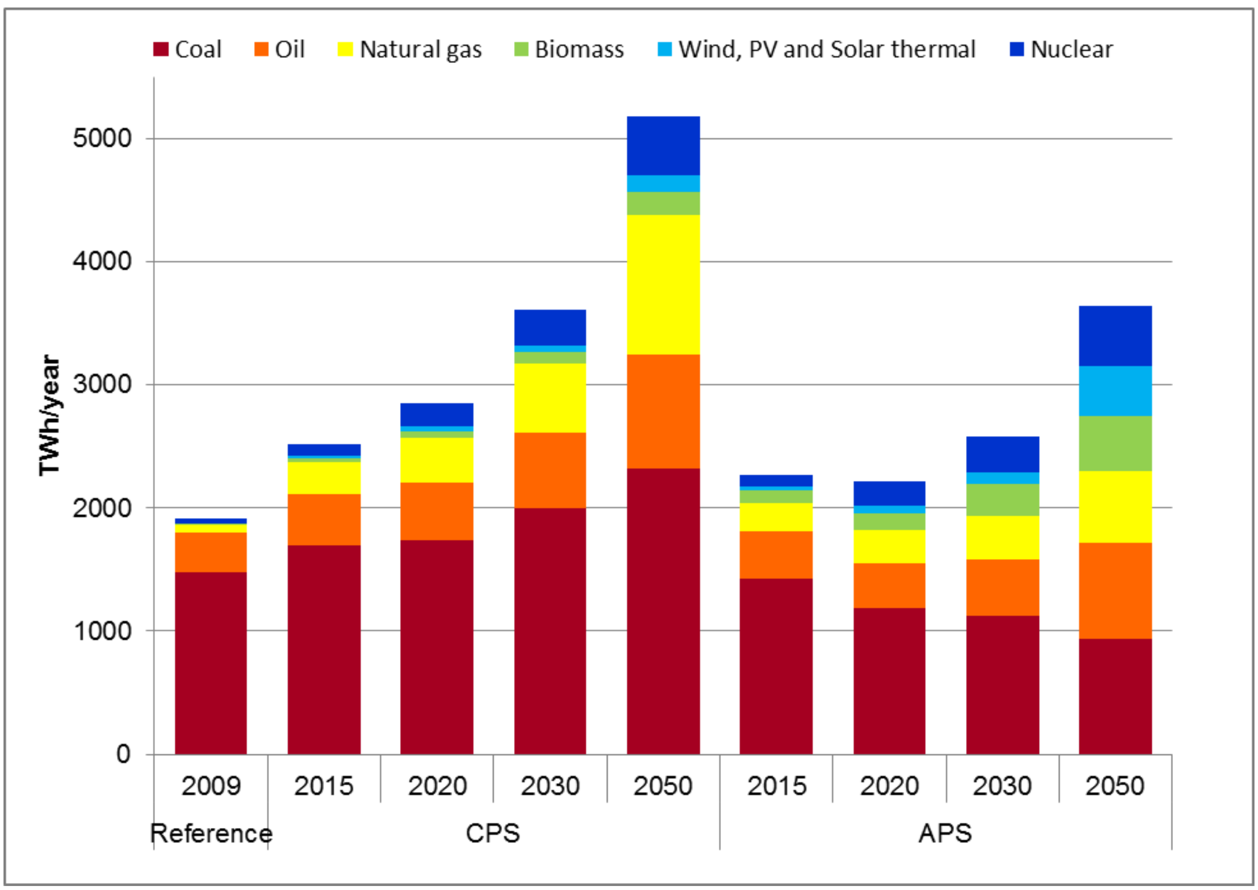

Fig.7 Primary energy supply in the CPS and APS (TWh).

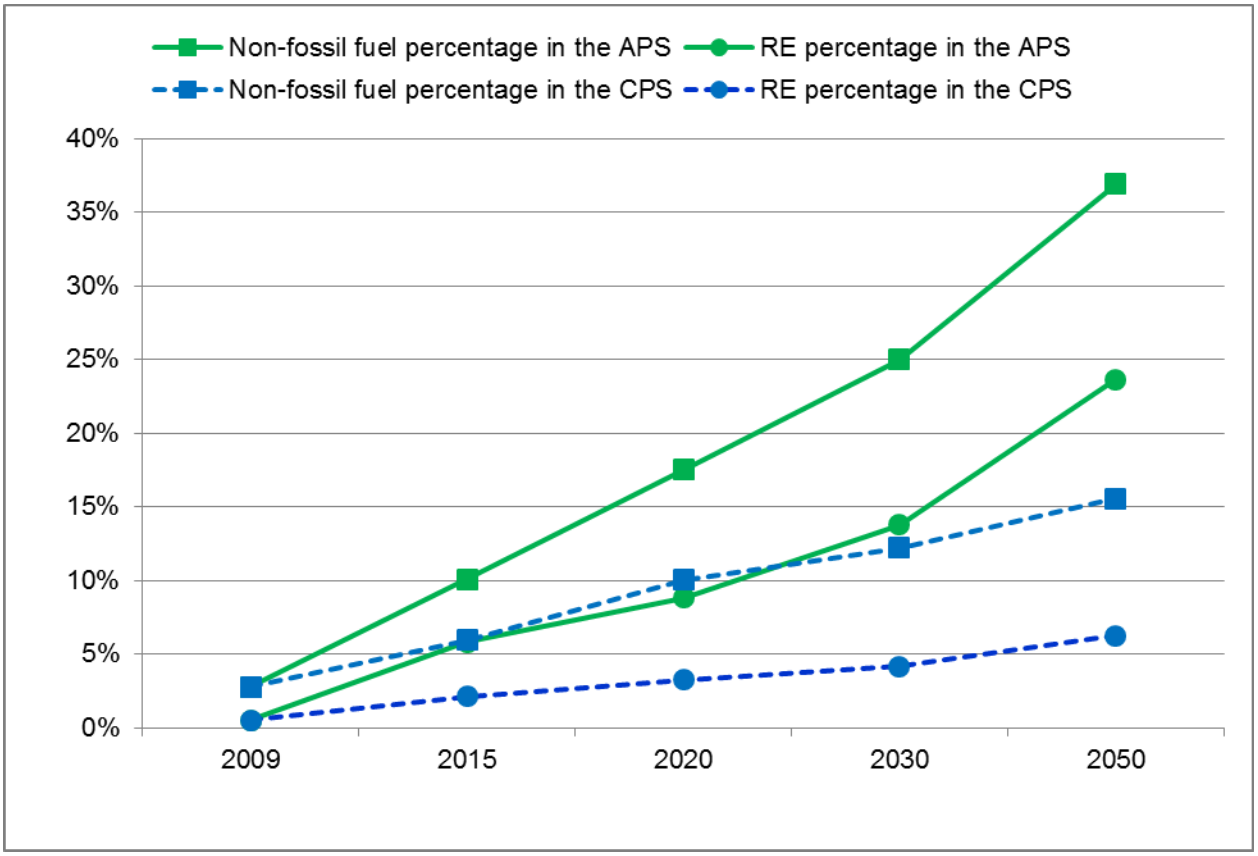

Fig.8 Non-fossil fuel and renewable energy percentage in the CPS and APS.

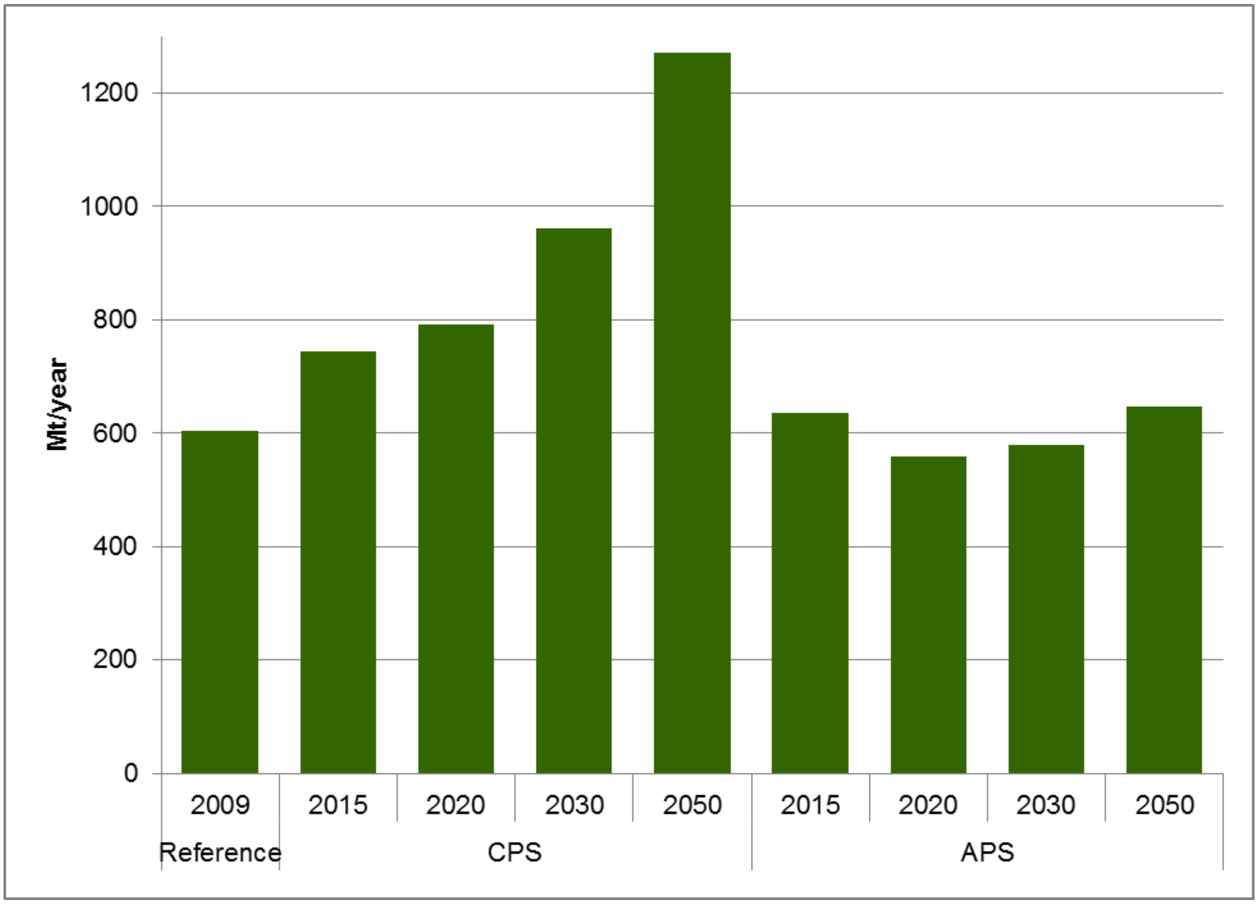

Fig.9 CO_2 emissions in the CPS and APS.

The annual economic costs of Jiangsu's energy system in the CPS and APS are displayed in Fig.10. We use the oil price of \$60/bbl in 2009 and CO_2 price of 10\$/t as a reference for the comparison in the CPS and APS. A benchmark interest rate of 8% for existing renewable energy investment is used in the calculation (UNFCCC, 2007, 2009). Considering the high uncertainty of fuel and CO_2 prices and interest rates in the future costs of Jiangsu's energy system, the sensitivity analysis is conducted in the later section. In the reference year of 2009, fuel costs almost dominate the overall system costs, with rather small portion of annual investment and O&M costs. As Jiangsu's energy system relies heavily on coal-fired thermal power plants in 2009, this simple but rigid system causes a low investment and O&M costs but high fuel costs and inefficiency. As the large-scale integration of renewable energy technologies such as wind, PV and biomass, the investment and O&M costs increase sharply in future years. It is evident that the APS will achieve a better economy compared with the CPS during Jiangsu's transitional period. Even though the investment costs are 1.7 times than that in the CPS, it helped saved \$33,908 million/year of fuel costs. In general, the economic benefit of investing the APS instead of the CPS is approximately \$20,205 million/year by 2050.

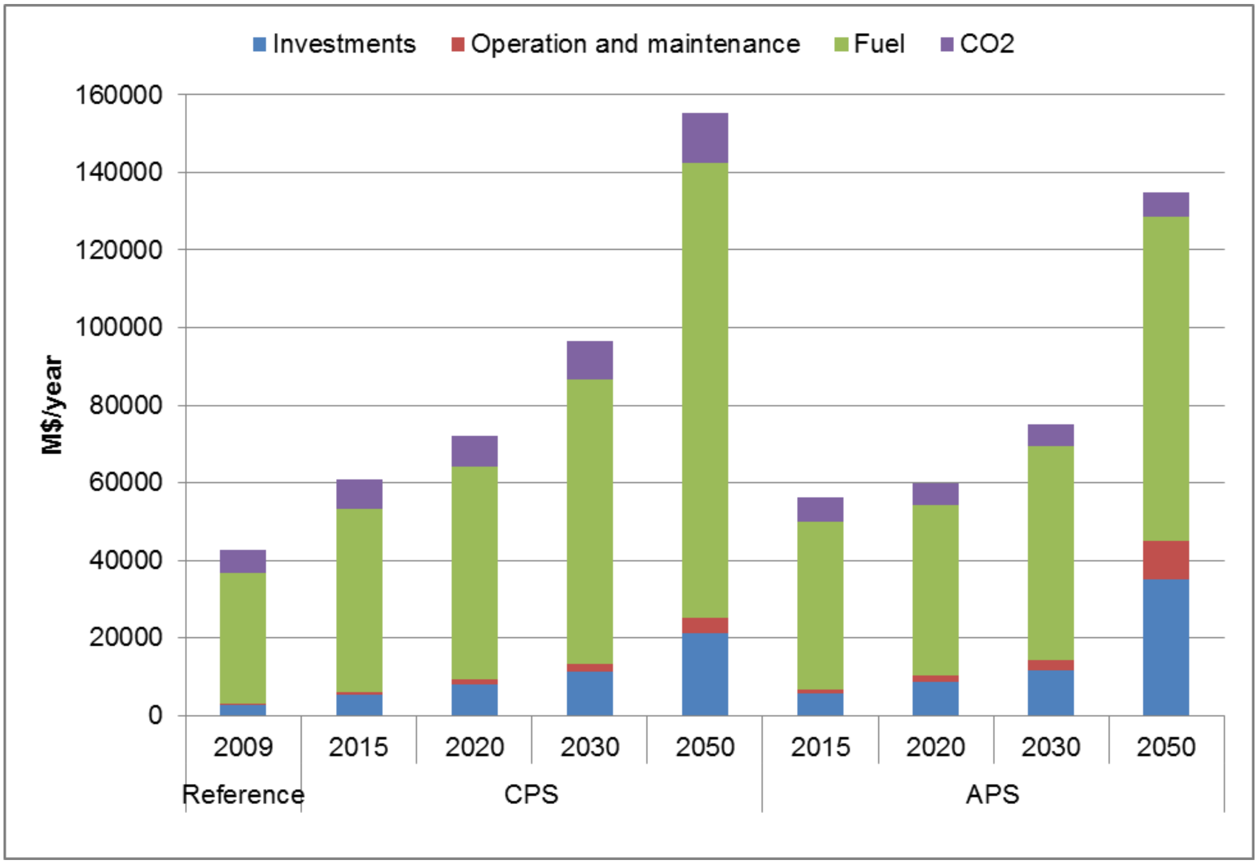

Fig.10 Socioeconomic costs in the CPS and APS.

5 Sensitivity Analyses

In this section we further use fuel prices, CO_2 prices and interest rates to discuss the sensitivity of socioeconomic costs in the CPS and APS by 2050. Coal prices are largely unregulated in China, and the price for crude oil is dependent on international markets. However, the Chinese government regulates oil product and electricity prices, which cannot reflect the cost of the raw inputs for producing these final energy products. Since 2006 the Chinese government had to provide large subsidies to energy suppliers in order to address these mismatches. There is a general expectation that subsides will decline over time as domestic energy prices gradually reach the international level (Zhou et al., 2010). Three levels of fuel prices are used; the low and medium levels are based on the international fuel price projections of $60/bbl in 2009 and $110/bbl in 2030 respectively. For the high price level, the highest crude oil price of $145/bbl in 2008 is used. There is no domestic carbon market nowadays, but it is a hot topic under discussion. We assume CO_2 costs of $10/t and $30/t respectively for the Jiangsu's energy system by 2050. In addition, the calculations are completed using two real interest rates: 4% (Fig.11) and 8% (Fig.12). In China, the renewable energy projects usually use a real interest rate of approximately 8% when assessing the economic potential. On 30 May 2006, China's Ministry of Finance promulgated the Interim Measure on Administration of Renewable Energy Development Specialized Funds (Ministry of Finance of China, 2006). It is used to subsidies the interest payments on loans used for a renewable energy project. The amount of such subsides is determined on a case-by-case basis, according to the amount of the loan that has been provided, the related interest rate and the amount of interest that has been paid. Thus, an interest rate of 4% is used along with 8% for analyzing the sensitivity of the results.

By analyzing the results shown in Fig.11 and Fig.12, the sensitivity of Jiangsu's energy system in 2050 to various economic parameters can be identified. It is evident that fuel cost contributes to the major part of the annual costs for Jiangsu's energy system. In addition, the CO_2 price also has a significant effect on the overall system costs, especially for the CPS. The annual investment cost increase by 1.4 times using an interest rate of 8% instead of 4%. And the annual O&M costs merely take account of a small amount of the overall system costs. It is because coal-thermal power plants still make up a high percentage in the power generation mix, approximately 65% in the CPS and 45% in the APS. This cost analysis indicates that uncertainty of future oil prices will have great impacts on the future costs of energy system in Jiangsu. Compared to the CPS, the APS will be more economically beneficial as there are higher fuel and CO_2 prices in the future. Furthermore, current high interest rate for renewable energy investment contributes much to the overall system costs.

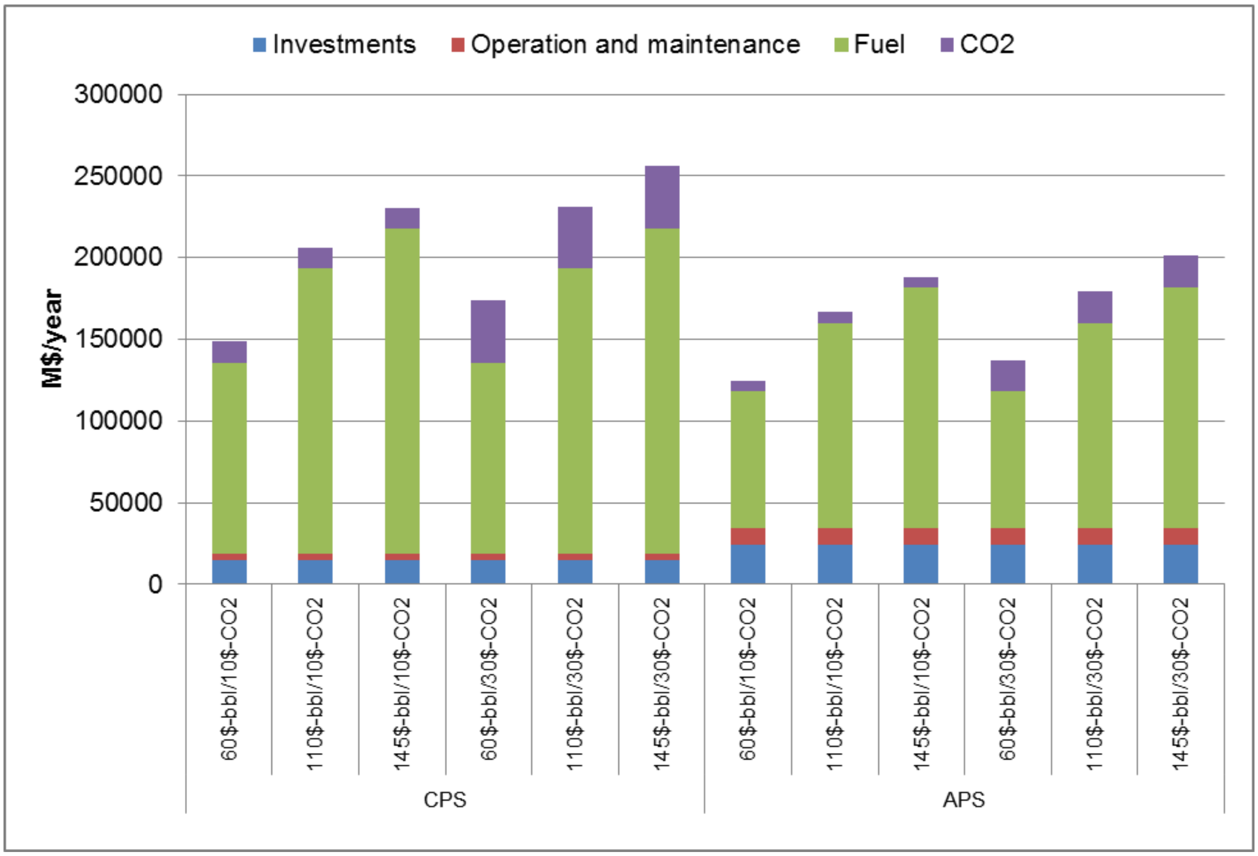

Fig.12 Socioeconomic cost in 2050 at different fuel and CO_2 prices, using a real interest rate of 4%.

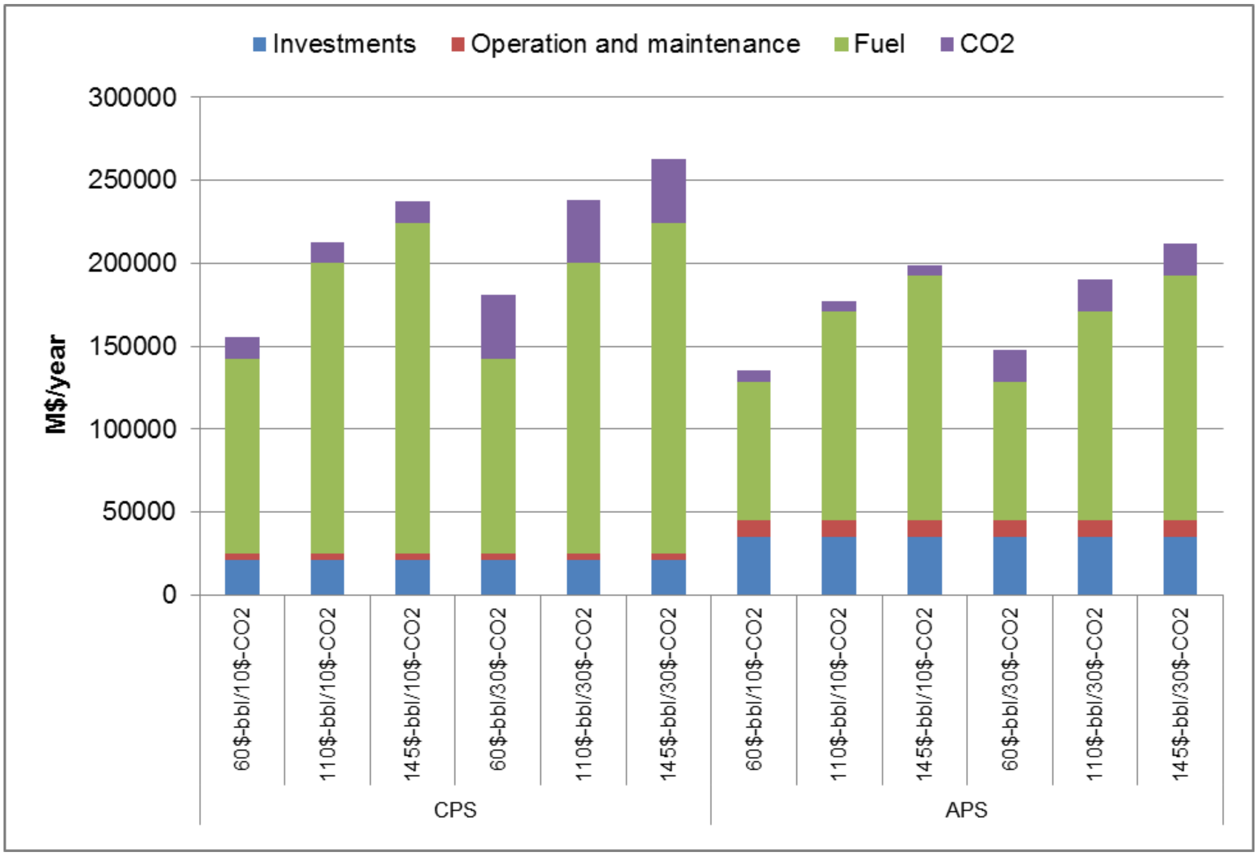

Fig.13 Socioeconomic cost in 2050 at different fuel and CO_2 prices, using a real interest rate of 8%.

6 Conclusions

During the past decades, the social and economic development of Jiangsu province was accompanied by the consumption of large amounts of fossil fuels. However, this mode of development can't be sustainable in future taking account of soaring energy prices, increasing pressure of GHGs emission mitigation as well as pollution control requirements. Therefore, how to ensure sustainable economic growth with energy security is of prime importance. This study designed two energy pathways towards 2050 for Jiangsu province and compared their technology combination, renewable energy percentage, socio-economic cost from the coherent energy system perspective. The CPS is based on current short-term energy policies and conservative projections of renewable energy installation in future, while the APS reflects more ambitious energy policies on energy efficiency improvement and renewable energy utilization. It is concluded that the APS compared to the CPS not only help Jiangsu's energy system shift towards a much higher percentage of non-fossil fuels and renewables by 2050, but also stabilize its GHGs emissions and achieve better economy as a whole. It is also identified that the next 5-10 years would be a key period for the implement of stringent energy efficiency standards and the investment for renewable energy projects in order to control energy demands and achieve energy conservation. It is suggested that policy-makers need to establish long-term energy efficiency policies and set clear standards and targets for specific sectors especially energy intensive sectors in different time periods. Comparing the condition of Jiangsu with the international best technologies would be a useful way for identifying energy conservation potential and setting targets in future. Besides, long-term plans and stable promotion policies for renewable energy technologies are very important for renewable energy industry to achieve technological learning and thus the economies of scale. The current average interest rate for renewable energy projects is found to be very high, which is not good for the overall economy of Jiangsu's energy system. Furthermore, deregulation of energy prices and establishment of carbon tax mechanism are useful for stimulating the transition of current 100% fossil fuel based energy system in the long run. This work is an initial attempt to propose and evaluate long-term integrated energy strategies for Jiangsu, which can be further improved by detailed studies of energy efficiency technologies, future transportation system, health costs as well as employment effects. What's more, this paper puts an emphasis on the introduction of radical technology change from renewable energy technologies, while issues on the role of transitional technologies such as clean coal technology and nuclear energy need further discussion. It is hoped that this work can motivate larger interest in designing long-term energy pathway for provincial level energy plan in China in future.

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