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ABSTRACT

This paper discusses the prospective of renewable energy in the process of sustainable development in China. Along with the high-speed economic development and increasing energy consumption, the Chinese Government faces a growing pressure to maintain the balance between energy supply and demand as well as reduce environmental pollution. To ensure energy security and mitigate climate changes the inappropriate energy consumption structure should be changed. As an alternative, a suitable infrastructure for the implementation of renewable energy may serve as a long-term sustainable possibility. Such sustainable energy strategy typical involves three technologies issue: energy conservation, efficiency improvement and replacement fossil fuel by renewable energy sources. Denmark is an example of such strategy can be implemented and it shows the possibility of converting into a 100% renewable energy system. This paper analyses the current status and programming of renewable energy utilization in China and compares the potential of renewable energy sources and energy demand between China and Denmark. It proposes and discusses a forward-looking issue that is the perspective of a 100% renewable energy system in China. The conclusion is such development is not impossible in the future in terms of technology and domestic resources. Due to the uncertainty of estimation and exploitation level of renewable energy sources, energy conservation and efficiency improvement are essential for China to achieving the sustainable energy development.

Key words: Perspective, Renewable Energy System, China, Denmark

1 Introduction

Energy demand in China has risen rapidly and reached an unprecedented level due to the massive economic growth and the large-scale industrialization. Since 1978, China's GDP has been increasing at a rate of 10% annually and the average energy consumption jumped by 5.2% [1]. After 2001 the primary energy consumption kept soaring, an average annual increasing of 9.8% during 2001-2007 and the average rise of 10.2% in GDP in the same period [2]. Today the China's energy consumption has significantly influenced the energy demand on a global scale since it's the second largest energy consumer and owns the second

largest electricity industry in the world. It seldom doubts that energy demand in China will continue to grow driven by its highly energy intensive economy and strong GDP growth.

Long-lasting coal-dominated energy structure brought severe challenges and tasks to maintain energy consumption and environmental protection. In 2007 total primary energy supply in China was 2354 million tonne of coal equivalent (tce). The total amount of coal and crude oil productions in 2007 were 1804 million tce and 266 million tce respectively [2], the former ranked the first in the world. Moreover the rapid developing economic needs the import of fossil fuels especially the oil. The amount of imported oil in 2007 was 2.523 billion ton and ranked the first in the world as well [3]. Emissions of pollutions from coal consumption were major contributions to the level of pollution, as 70% of particulate, 90% of SO_2, 67% of NO_x and 70% of total CO_2 all came from coal burning [4]. The total amount of SO_2 emissions in 2005 was more than 25 million ton which increased 27% than 2000 in China [5].

In order to change the inappropriate energy consumption structure and promote a harmonious coexistence of human beings and environment in China, it is essential and meaningful to integrate renewable energy into future sustainable energy development strategies and a suitable infrastructure for the implementation of renewable energy may serve as a future sustainable possibility. China is endowed with an abundant reserve of renewable energy sources which are currently under-exploited, offering significant opportunities for renewable energy system development and environmental sustainable alleviation of its reliance on fossil fuel [6]. The PRC Law of Renewable Energy went into effect in February 2005 and acts as the milestone to lay a special emphasis on the issue of renewable energy development. Based on such challenges and opportunities the perspective of renewable energy system development has become a significant and forward-looking issue in China. Based on energy supply and consumption in the past three decades this paper analyses the potential of renewable energy sources and discusses possibility of the renewable energy sources meeting the needs of energy demand in China.

Sustainable energy development typically involves three major technological changes [7]: energy saving on the demand side [8, 9], efficiency improvement in the energy production [10, 11] and replacement of fossil fuel by various sources of renewable energy [12, 13]. Today many countries in the world achieved remarkable success in such transformation and Denmark emergences as one of leaders especially in a renewable energy sector. By means of energy conservation and expansion of combined heat and power production (CHP) and district heating, Denmark has been able to maintain the same primary fuel consumption for a period of more than 30 years in spite of about 70% increase in GDP. Moreover, today, more than 20% of the electricity demand in Denmark is supplied from wind power; and in 2007, renewable energy including biomass and waste incineration accounted for about 15% of the primary energy supply in Denmark [14, 15]. Thus, Denmark is an example of how sustainable development strategies constituted by a combination of conservation, efficiency improvements and renewable can be implemented. Moreover Denmark shows the possibility of converting into a 100% renewable energy system in terms of technology and domestic resources [7, 14]. Based on comparing the potential of renewable energy sources and energy demand in terms of per capita and per area in China and Denmark this paper proposes and discusses a forward-looking issue of the perspective of a 100% renewable energy system in China.

2 Chinese energy structure and energy intensity

Figure 1 shows a graphical representation of Chinese primary energy supply (PES) structure in 2007 [2]. Coal accounted for about 76.6% of PES and is the most important fossil fuel in

China. Oil energy and natural gas have the share of 11.3% and 3.9% respectively and the remaining 8.2% of primary energy is supplied by renewable and nuclear power. Hydro power represented a significant share of renewable energy supply and it accounted about 7.1% of PES. The feature of energy supply structure in China is fossil fuel dominated especially the coal.

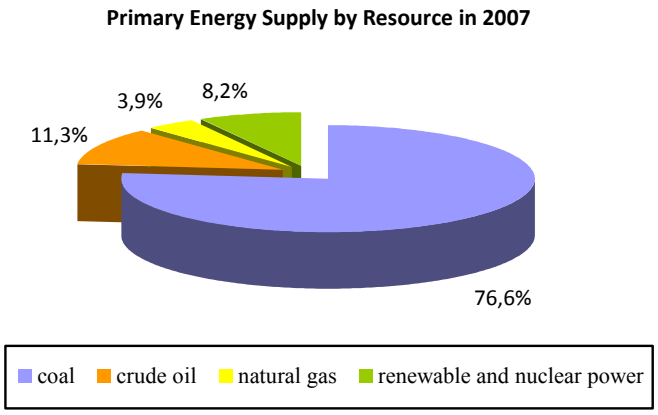

Figure 1. Chinese primary energy supply by resource in2007

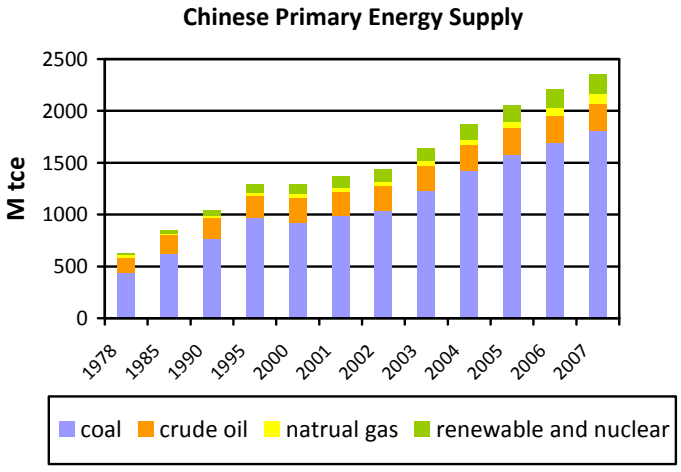

Figure 2. Chinese primary energy supply

Figure 2 and Figure 3 show the graphical representations of Chinese Primary Energy Supply (PES) and Gross Energy Consumption (GEC) in the past 30 years [2]. Figure 2 presents two important things. First, the rapid development of economy and society has tremendously stimulated the expansion of energy demand and the amount of PES in 2007 was nearly 4 times as much as in 1978. There appear to be three periods of energy production during the last three decades. During the 1978-1995 the growth rate of energy production was approximately 4% per annum. Energy production growth reached a stagnation stage during the period 1995-2000. After 2000 the primary energy supply kept soaring, an average annual increase of 9% during 2001-2007. Second, the energy supply structure changed little in the past three decades and coal continues to dominate the primary energy production. The amount of crude oil production has not increased obviously meanwhile the share has obviously declined over times and it has accelerated after 2000. Natural gas production has increased but with fluctuation and renewable energy supply has grown steadily.

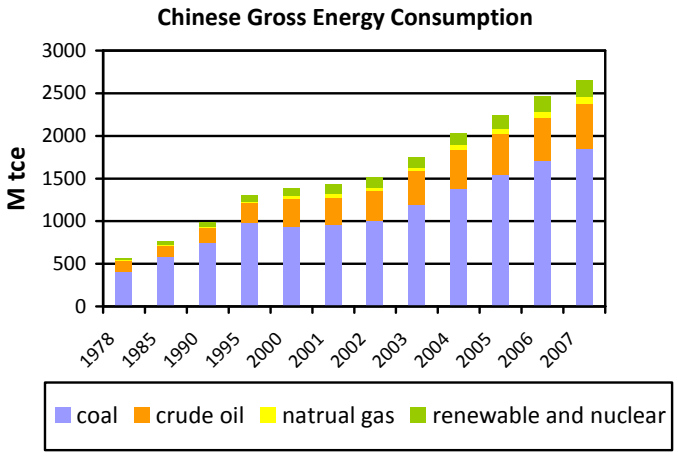

Figure 3. Chinese gross energy consumption

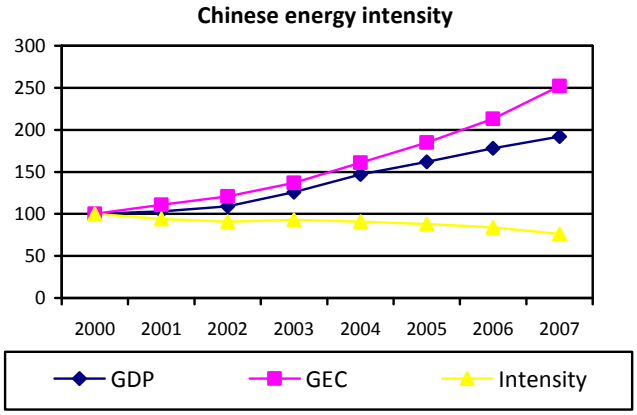

Figure 4. Chinese energy intensity (indexed, year 2000=100)

Same structure and increasing tendency can be seen in Figure 3. It shows how China has substantially increased its energy consumption in the same periods. Before 2000 the amounts of PES and GEC in China were basically equal; however after 2000, the GEC began to surpass PES and the import of fossil fuel, especially the oil, has increased gradually.

Figure 4 shows a index figure how Gross Domestic Product (GDP) has increased by 150% between 2000 and 2007[2]. Thus the energy intensity (defined as GDP divided by the GEC) has fallen by 25%. In other words, one GDP unit in 2007 cost only three quarters of the energy consumption it used in 2000.

By means of reviewing Chinese energy supply and consumption in the past three decades, it can conclude that the share of renewable energy has increased steadily and began to play a role in the energy structure but the energy supply and consumption structure which dominated by fossil fuel especially coal has remained basically. Although China has gained some achievements in decreasing energy intensity it seldom doubts that energy demands in China will continue to grow driven by its highly energy intensive economy and strong GDP growth. Meanwhile energy conservation is the absolutely necessary strategy for China to maintaining the energy demand.

3. Potential renewable energy sources in China

China is blessed with an abundant reserve of renewable energy sources and due to the enormous territory the estimation of potential renewable energy sources shows an enormous diversity between east and west [16].According to the reports given by Chinese Development and Reform Commission the total amount of solar energy reserve in theory is equal to 50000 EJ/yr in China. The annual radiant quantity of solar energy is between 3300MJ/m^2yr and 8400MJ/m^2yr and two-thirds of the country area can receive more than 2000hours/yr of sunlight and over 6000MJ/m^2yr. If the technology is feasible and the cost is acceptable, the exploitation and utilization of solar energy sources can be almost infinite [17]. As estimated by China Meteorology Research Institute, the overall reserves of wind power resource in 10 meters high above the land in China is about 3226 GW, and in which about 1000GW can be exploited and utilized [18]. The potential of the electric energy production can be calculated according to average annual equivalent full load hours of wind turbine in China (about 2500hours) [19]. According to the results of China's latest hydropower resource survey the reserves of hydropower is 6000 TWh and the average rate of exploitation is about 30%. The potential capacities of tide and wave power in China are 110GW and 500GW respectively [20]. The proven resources of geothermal in China are about 93EJ and in which 1000PJ can be exploited now [21]. The available biomass recourses of China in 2020 and 2050 have been estimated and the total amount of potential biomass located are 15981PJ in 2020 and 28070 PJ in 2050 [22].

It should be noted that such estimation of potential renewable energy sources should has some uncertainties since the reserves of many kinds of renewable energy sources like solar energy and geothermal energy in China are extremely huge and the potentials are very dependent on the technological development. Besides that the amount of biomass will also increase along with technology and economic development. Table 1 shows the potential of renewable energy sources in China.

Table 1. Potential renewable energy sources in China [17-22]

Renewable energy sources	unit	potential
Wind	TWh/yr	2500-8000
Photo Voltaic	TWh/yr	1300-6500
Tidal energy	TWh/yr	>200
Wave	TWh/yr	>1500
Hydro power	TWh/yr	1760-3000
Total electricity	TWh/yr	7260-19200
Solar thermal	PJ/yr	6000-30000
Geothermal	PJ/yr	>1000
Total heat	PJ/yr	7000-31000
Straw	PJ/yr	5561-6439
Wood	PJ/yr	4332-5210
Waste (combustible)	PJ/yr	1171-3454
Biogas	PJ/yr	1259-2488
Energy crops	PJ/yr	3659-10479
Total biomass fuel	PJ/yr	15981-28070

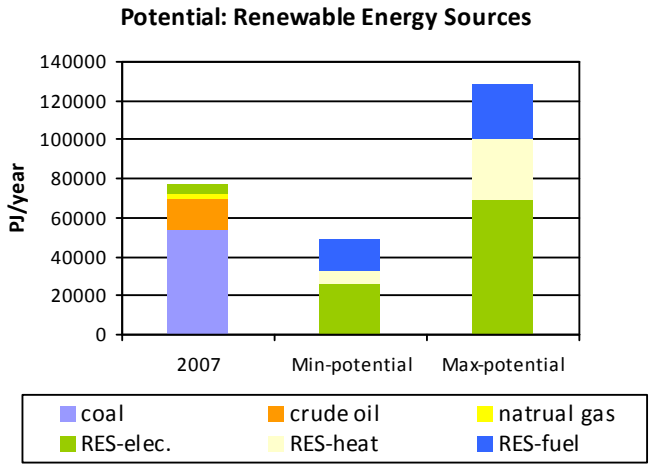

Figure 5. Potential of RES in China compared to the gross energy consumption in 2007

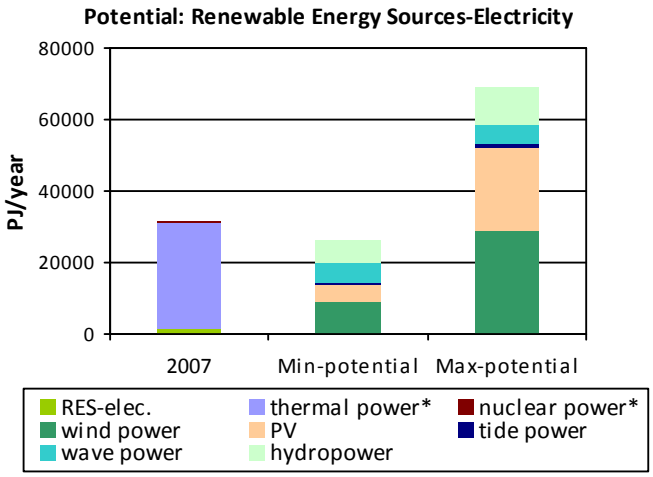

Figure 6. Potential of RES-electricity in China compared to the electricity consumption in 2007 (* fuel equivalent: electricity multiplied by 3)

In Figure 5 and Figure 6, the potentials of renewable energy sources are compared to the present gross energy consumption and electricity consumption in China [2]. The minimum potential renewable energy sources is less than the current energy consumption but the maximum is about 50% more than current energy consumption in China. The same results appear in the comparison between the potential renewable energy sources of electricity and current electricity consumption. It shows the possibility for renewable energy sources to afford future energy consumption in China.

4 Current status and objectives of renewable energy in China

Table 2 shows the current renewable energy utilization and development objectives in China according to the Middle and Long-term Development Programming for Renewable Energy [23] and Eleventh Five Years Development Programming for Renewable Energy [24] made by the Chinese government. At the end of 2006 the total amount of renewable energy utilization (not including the traditional biomass utilization) had added up to 5854 PJ which accounted for 8% of primary energy consumption in China. The programming set general

objectives for renewable energy development: renewable energy utilization accounts for up to 10% of the total energy consumption in 2010 and 16% in 2020.

Table 2. Current renewable energy utilization and development target in China [23, 24]

Renewable energy sources	2006	2010	2020	Potential
Wind	3.87 TWh	21 TWh	30GW	2500-8000 TWh
Photo Voltaic	0.11 TWh	0.54 TWh	1.8GW	1300-6500 TWh
Hydro power	436 TWh	665 TWh	225GW	1760-3000 TWh
Solar thermal	142 PJ	792 PJ	1756 PJ	6000-30000 PJ
Biomass	21.75 PJ *	59 8 PJ *	1595 PJ*	15981-28070 PJ
Geothermal	-	117 PJ	350 PJ	>1000 PJ

(*Not including conventional biomass utilization)

By the end of 2006 the installed capacity of wind power had reached to 2.6 GW with the productivity of 3.87 TWh and the annual growth rate was about 34%. According to the programming, the targets of large-scale development of wind turbines are 10GW and 30GW in year 2010 and year 2020 respectively. In 2030, total capacity of wind power will reach 150-200 GW and can become the third power resource (behind coal and hydropower) in China. In terms of photo voltaic, China's installed capacity of PV systems had reached 100MW in 2006 with productivity of 0.11 TWh in which about 50% is used to supply electricity to the residents of remote rural area that and it is growing at a rate of about 30% annually. The excepted targets of installed capacity are 0.3GW and 1.8 GW in year 2010 and year 2020 respectively. The total installed capacity of hydropower was more than 120GW in 2006 which including 38GW capacity of small-scale hydropower. The productivity of total hydropower had reached 436 TWh and accounted for 16% of electricity supply in China. It is expected that during the period between 2010 and 2020 China's hydropower resource will be developed faster with capacity of 190GW in 2010 and 300GW in 2020.

By the end of 2006, the accumulated installed capacity of solar water heaters was more than 80 million squares meters of collector area with a increasing rate of 27% in the past ten years. In 2010 and 2020, it is expected that the installation area of solar collectors will reach 140 million and 300 million square meters, respectively with the conservation of 792 PJ in 2010 and 1756 PJ in 2020.

Today biomass energy resources in China are utilized mainly through the conventional combustion technologies. Meanwhile, Biomass gasification, biomass liquefaction and biomass power generation technologies are gradually being developed. In 2006 the total energy contribution from biomass was about 22 PJ. The installed capacity of biomass power generation was 2000 MW and the yield of biogas and ethanol fuel were add up to 7 billion cubic meters and 1.02 million tons respectively. According to the programming the total supply from biomass in China will reach about 600 PJ and 1595 PJ in 2010 and 2020. In terms of other renewable energy, the utilization of geothermal will reach to 117 PJ in 2010 and 350PJ in 2020.

As can be seen obviously, renewable energy in China is in a rapid development stage and it began to play a role in energy structure. Hydropower, wind power, solar energy and biomass all show the highly annual growing rate. However, as shown in table 2, compared with the potential of renewable energy sources, today the renewable energy is still under-exploited and accounts few parts of total amount of renewable energy sources in China. Even achieving the development objectives in 2010 and 2020 China still has huge development space and

opportunities for implementing larger-scale renewable energy development and promoting renewable energy to playing more important role in future energy system.

5 Comparisons of potential renewable energy sources and energy demand in China and Denmark

5.1 Comparison of renewable energy sources per capita and per area in China and Denmark

The potential of renewable energy sources in Denmark was estimated by the Danish Energy Agency in 1996 as part of the data which provides the basis for the Danish Government's energy plan "Energy 21"[7]. In a recent Danish energy plan "IDAs Climate Plan 2050", for the international engineering project future climate, the potentials for renewable energy was subject to concrete efforts to locate practically achievable renewable energy potentials in 2050 [25]. In Denmark the potential for onshore wind in 2050 is 12.6 TWh and 18.9 TWh for offshore wind power. These figures are based on a concrete plan for locating and expanding wind power to a total of 70% of the electricity demand including electricity for electric vehicles. In terms of photo voltaic the potential located is 4.5 TWh in 2050 and for wave power is 2.5 TWh. The level of wind power, photo voltaic, wave power, geothermal and solar thermal in "IDAs Climate Plan 2050" confirms the level in the publication from 1996 and biomass was also considered in the Plan. Table 3 shows the potential of renewable energy sources in Denmark. The potential renewable energy sources per capita and per area were calculated in China and Denmark respectively and Table 4 and Figure 7 present the results of comparison.

Table 3. Potential of renewable energy sources in Denmark [25-27]

Renewable energy sources	unit	potential
Wind (onshore)	TWh/yr	5-24
Wind (offshore)	TWh/yr	15-100
Photo Voltaic	TWh/yr	3-16
Wave energy	TWh/yr	17
Tidal energy	TWh/yr	-
Hydro power	TWh/yr	0
Total electricity	TWh/yr	40-160
Solar thermal	PJ/yr	16-90
Geothermal	PJ/yr	>100
total heat	PJ/yr	100-200
Straw	PJ/yr	39-55
Wood	PJ/yr	23-50
Waste (combustible)	PJ/yr	24-30
Biogas	PJ/yr	31-40
Energy crops	PJ/yr	65-144
Total biomass fuel	PJ/yr	182-319

As shown, in spite of the territories, population and renewable energy sources reserves differ significantly, the same results and tendency can conclude in the comparison of potential renewable energy sources per capita and per area in China and Denmark. The totally amounts of potential renewable energy sources per capital and per area in Denmark are basically two times as many as in China. Although the climate situation in China is more suitable for agriculture, Denmark owns more potential biomass fuel per capita and per area since Danish cultivated land area per capita is about 4900 square meter which is four times more than the cultivated land area per capita in China.

Table 4. Renewable energy sources per capita and per area in China and Denmark

Renewable energy sources per capita				Renewable energy sources per area			
Index	Unit	China	Denmark	Index	Unit	China	Denmark
Population(2006)	Million	1321.29	5.48	Area	Million km^2	9.6	0.0431
Wind (onshore)	Mwh/capita	1.9-6.1	0.9-4.4	Wind (onshore)	Mwh/capita	260-833	116-557
Wind (offshore)	Mwh/ capita		2.7-18.2	Wind (offshore)	Mwh/ capita		348-2320
Photo Voltaic	Mwh/ capita	1-5	0.5-2.9	Photo Voltaic	Mwh/ capita	135-677	70-371
Wave energy	Mwh/ capita	>1.1	>3.1	Wave energy	Mwh/ capita	>156	>394
Tidal energy	Mwh/ capita	>0.2	-	Tidal energy	Mwh/ capita	>21	-
Hydro power	Mwh/ capita	1.3-2.3	0	Hydro power	Mwh/ capita	183-313	0
Total electricity	Mwh/ capita	5.5-14.5	7.3-28.6	Total electricity	Mwh/ capita	756-2000	928-3643
Solar thermal	GJ/ capita	4.5-22.7	2.9-16.4	Solar thermal	GJ/ capita	625-3125	371-2088
Geothermal	GJ/ capita	>0.8	>18.2	Geothermal	GJ/ capita	>104	>2320
total heat		5.3-23.5	18.2-34.7	total heat		729-3229	2320-4408
Straw	GJ/ capita	4.2-4.9	7.1-10.0	Straw	GJ/ capita	579-671	905-1276
Wood	GJ/ capita	3.3-3.9	4.2-9.1	Wood	GJ/ capita	451-543	534-1160
Waste (combustible)	GJ/ capita	0.9-2.6	4.4-5.5	Waste (combustible)	GJ/ capita	122-360	557-696
Biogas	GJ/ capita	1.0-1.9	5.7-7.3	Biogas	GJ/ capita	131-259	719-928
Energy crops	GJ/ capita	2.8-7.9	11.9-26.3	Energy crops	GJ/ capita	381-1092	1508-3341
Total biomass fuel	GJ/ capita	12.1-21.2	33.2-58.2	Total biomass fuel	GJ/ capita	37-79	116-557

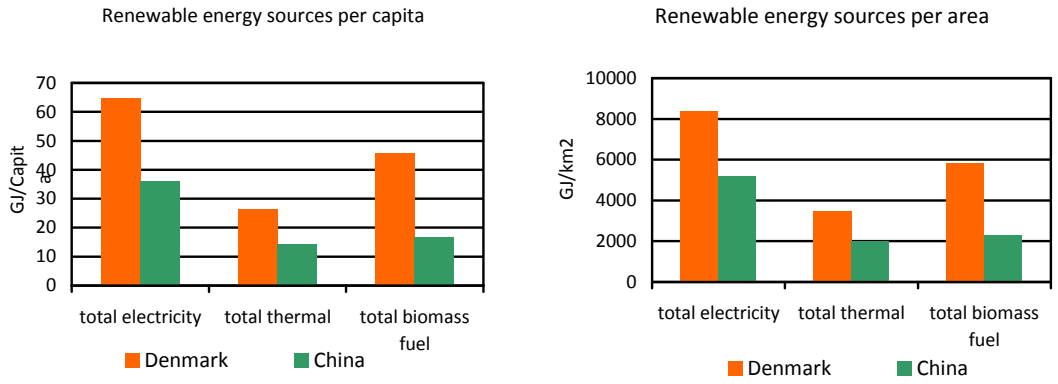

Figure 7. Comparisons of renewable energy sources per capita and per area in Denmark and China

5.2 comparison of energy demand and energy intensity in China and Denmark

Three kinds of indexes were compared between China and Denmark in table 5 [12, 28].

As can be seen, both energy supply and energy consumption per capita in China were distinctly less than in Denmark. The electricity demand per capita in China was about one third in Denmark and the heat demand per capita in China was only about one tenth in Denmark. Moreover, the primary energy supply per capita in China is one quarter of which in Denmark. However, as far as energy intensity, one GDP units in China cost more energy consumption than in Denmark. The gross energy consumption per GDP in China was about seven times as much as in Denmark and the same situation appeared in primary energy supply per GDP. In terms of replacement of fossil fuel by renewable energy sources, the shares of renewable energy in energy consumption and domestic energy supply of China were both lower than the shares in Denmark. It shows that China needs less energy than Denmark in terms of per capita but it has distances in energy intensity and renewable energy development.

Table 5. Comparison of energy demand energy intensity in China and Denmark

Type	Index (2007)	unit	China	Denmark
Energy supply and demand	Primary energy supply per capita	GJ/ capita	52.21	207.48
	Gross Energy Consumption per Capita	GJ/ capita	59	160
	Electricity demand per capita	GJ/ capita	8.35	25.73
	Heat demand per capita	GJ/ capita	1.93	22.08
Energy intensity	Primary energy supply per GDP*	TJ/ Million US$	20.79	3.65
	Gross Energy Consumption per GDP*	TJ/ Million US$	23.43	3.28
Renewable energy	Share of Total Gross Energy Consumption	%	7.1	17.0
	Share of Total Domestic Electricity Supply	%	14.8	27.9

(*2007 currency)

As present previously, compared with Denmark, which has not only gained remarkable achievements in energy conservation, energy efficiency improvement and renewable energy development but also shown the possibility and on the way to converting into a 100% renewable energy system, China's potential renewable energy sources per capita is about half of in Denmark meanwhile its energy demands per capita are about a quarter of in Denmark. Moreover considered the total amount of potential renewable energy sources can possible meet the needs of energy consumption in China it can receive that China has the potential to developing large-scale renewable energy systems and a 100% renewable energy system is mot impossible in the future in terms of technology and domestic resources.

6 Conclusion

China is facing two severe challenges of maintaining energy balance and improving environmental protection. Both challenges are rooted in the inappropriate energy structure which had changed little in the past three decades. It seldom doubts that energy demands in China will continue to grow driven by its highly energy intensive economy and strong GDP growth.

In order to change the inappropriate energy structure and implement the sustainable energy strategy it is essential and meaningful to integrate renewable energy into future energy systems in China. The PRC Law of Renewable Energy went into effect in February 2005 and strongly stimulated the renewable energy development. Today renewable energy is in a rapid development stage in China and began to play a role in the energy structure.

Although the estimation value of potential renewable energy sources in China have some uncertainties and have more exploitation spaces along with the development of technology and economic, the totally amount of potential renewable energy sources is substantial and can possibly meet the needs of energy consumption in China. It shows the possibility for renewable energy to afford future energy consumption in China. Compared with the potentials, today renewable energy is under-exploited in China. There are huge development space and opportunities for developing large-scale renewable energy systems and promoting renewable energy to play more important role in future energy system.

Denmark is an example of how sustainable development strategies constituted by a combination of conservation, efficiency improvements and renewable development can be implemented and it shows the possibility of converting into a 100% renewable energy system. The overall amount of renewable energy sources per capita and per area in China is about half in Denmark, meanwhile China needs significant fewer energy consumption than Denmark in terms of per capita. In terms of domestic resources and technology it is potential for China to

developing large-scale renewable energy systems and a 100% renewable energy system in the future is not impossible.

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