Comparative Study of the Potential of Renewable Energy Sources and Solutions between Denmark and China

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Abstract: This paper compares the potential of renewable energy sources in Denmark and China and analyses renewable energy solutions in the two countries. Denmark is one of the leaders in the renewable energy sector and represents a remarkable transformation. Even through lacking almost entirely in hydroelectric resources, Denmark has built up one of the biggest renewable energy sectors in the world. Today, more than 20% of the electricity demand in Denmark is supplied from wind power and, in 2007, renewable energy accounted for approximately 27% of the total gross electricity production. Meanwhile, China is the biggest developing country in the world and endowed with abundant renewable energy sources. Along with the high-speed economic development and increasing energy consumption of the country, the government faces a growing pressure to maintain the balance between energy supply and demand as well as to reduce environmental pollution. To ensure energy security and mitigate climate changes, the inappropriate energy consumption structure should be changed. In the past few years, more attention has been paid to the development of renewable energy laws and policies and planning initiatives have been implemented to support the development of renewable energy in China. A comparative analysis shows that, in terms of renewable energy sources per capita and per area, the overall potential is almost equal in Denmark and China, but differences can be found in the types of renewable energy sources of the two countries. The advantages and experiences of Danish renewable energy solutions have been identified and some proposals have been put forward also for renewable energy development in China.

Key words: comparative analysis, renewable energy sources, solutions, Denmark, China

1 Introduction

Energy is a critical foundation for economic growth and social progress [1].Along with the economic advances and the increasing energy demand of human society, the shortage of fossil fuel and its environmental pollution have brought about serious problems related to energy security, environmental protection and economic development. Renewable energy, which is characterized as renewable and environmentally friendly, is the inevitable choice when wishing to satisfy the increasing energy demand, improve the energy structure, decrease environmental pollution and promote sustainable development.

Denmark's emergence as a leader in the renewable energy sector represents an important transformation. Despite the lack of indigenous fossil fuels and hydroelectric resources of the country, the Danish government has used

policies to build up one of the biggest renewable energy sectors in the world [2]. Denmark has been a strong supporter of renewable energy, since the first oil crisis in the 1970s. It is one of the few countries in the world that actively, and in a persistent way, supported renewable energy development from the late 1970s, through the 1980s and 1990s, to the present [3]. Today, more than 20% of the electricity demand in Denmark is supplied from wind power; and in 2007, renewable energy accounted for approximately 27% of the total gross electricity production, while renewable energy including biomass and waste incineration accounted for about 15% of the primary energy supply in Denmark [4,5].

The energy use in China has significantly influenced the energy demand on a global scale, since it is the largest developing country in the world and the second largest country in terms of producing and consuming energy. China is blessed with an enormous territory and an abundant reserve of renewable energy resources. Today, China has gained a remarkable achievement in high-speed economic development, but, at the same time, the country faces an increasing pressure to maintain the balance between energy supply and demand as well as reduce the environmental pollution caused by a long-lasting coal-dominated energy consumption structure. In order to change the inappropriate energy consumption structure and promote a harmonious coexistence of human beings and environment in China, it is essential to integrate renewable energy into future energy development strategies.

A brief overview of the two countries is shown in the Table 1. It is worth noting that, even if huge distinctions exist in terms of territory and population, the population density of the two countries is almost equal.

Table 1

Overview of Denmark and China (in 2006) [6-9]

	unit	Denmark	China
Area	km^2	43098	9598077
Population	million	5.48	1321.29
Population density	person/ km^2	127	137
Total primary energy supply	PJ	876	78659
Electricity demand	GWh	36356	2857322
Heat demand	PJ	128	2468
Renewable energy production			
Biomass	TJ	84302	9442809
Geothermal	TJ	491	11
Solar energy	TJ	435	142324
Hydro power	GWh	23	435786
Wind power	GWh	6108	3868
Installed wind capacity	MW	3135	2593

After comparing the potential of renewable energy resources in Denmark and China, measured in resources per capita and per area, this paper presents the differences and features of the potential renewable energy sources in the two countries. Furthermore, by analyzing the strategies and solutions in the process of promoting renewable energy in Denmark and China, this paper identifies the advantages and experiences of Danish renewable energy policy and puts forwards some proposals for renewable energy development in China.

2. Comparison of potential renewable energy sources in Denmark and China

2.1 Comparison of gross renewable energy sources in Denmark and China

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"[10]. In the case of China, due to the enormous territory, the estimation of potential renewable energy sources shows an enormous diversity between east and west, including differences between the reserves of renewable energy resources [11]. Table 2 shows the potential of renewable energy sources in Denmark and China.

Table 2

Potential of renewable energy sources in Denmark [12] and China [9] [13-15]

Renewable energy sources	unit	potential	
		Denmark	China
Wind (onshore)	TWh/yr	5-24	300-700
Wind (offshore)	TWh/yr	15-100	1050-2200
Photo Voltaic	TWh/yr	3-16	>140
Wave energy	TWh/yr	17	-
Tidal energy	TWh/yr	-	60
Hydro power	TWh/yr	0	1760
Total electricity	TWh/yr	40-160	3950-5950
Solar thermal	PJ/yr	16-90	>4920
Geothermal	PJ/yr	>100	92600
total heat	PJ/yr	100-200	>97520
Straw	PJ/yr	39	6439
Wood	PJ/yr	23	5210
Waste (combustible)	PJ/yr	24	3454
Biogas	PJ/yr	31	2488
Energy crops	PJ/yr	65	10479
Total biomass fuel	PJ/yr	182	28070

The potential of renewable energy sources in Denmark was estimated more than ten years ago. It should be noticed that, today, some of the potential of renewable energy sources in Denmark seems to have been underestimated, as shown in Table 2. Especially the offshore wind potential, which is very dependent on technology development, and the theoretical biomass potential in Denmark, which is as high as 530PJ/yr. Biomass has a total potential of 180PJ/yr, including only a minor share of energy crops, and is to be considered a "business as usual" scenario in terms of food production[10].

As was also the case earlier, 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 over 6000MJ/m^2yr, more than 2000hours/yr of sunlight. If the technology is feasible and the cost is acceptable, the exploitation and utilization of solar energy sources can be almost infinite. The exploitable onshore wind energy potential is 253GW, while the offshore sum is 750 GW with a total exploitable potential about 1000GW [13]. The potential of the electric energy production can be calculated separately in China, according to annual equivalent full load hours of onshore (from 1200 to 2800 hours) and offshore (from 1400 to 3000 hours) wind power [16].

2.2 Comparison of renewable energy sources per capita and per area

The potential renewable energy sources per capita and per area were calculated in Denmark and China, respectively. Table 3 and Fig. 1 present the comparison result of renewable energy sources per capita in Denmark and China.

Table 3

Renewable energy sources per capita in Denmark and China

Key index	Unit	Denmark	China
Population(2006)	Million	5.48	1321.29
Wind (onshore)	Mwh/capita	0.9-4.4	0.2-0.5
Wind (offshore)	Mwh/ capita	2.7-18.2	0.8-1.7
Photo Voltaic	Mwh/ capita	0.5-2.9	>0.1
Wave energy	Mwh/ capita	3.1	-
Tidal energy	Mwh/ capita	-	0.1
Hydro power	Mwh/ capita	0	1.3
Total electricity	Mwh/ capita	7.3-28.6	3.0-6.1
Solar thermal	GJ/ capita	2.9-16.4	>3.7
Geothermal	GJ/ capita	>18.2	70.1
total heat		18.2-34.7	>73.8
Straw	GJ/ capita	7.1	4.9
Wood	GJ/ capita	4.2	3.9
Waste (combustible)	GJ/ capita	4.4	2.6
Biogas	GJ/ capita	5.7	1.9
Energy crops	GJ/ capita	11.9	7.9
Total biomass fuel	GJ/ capita	33.2	21.2

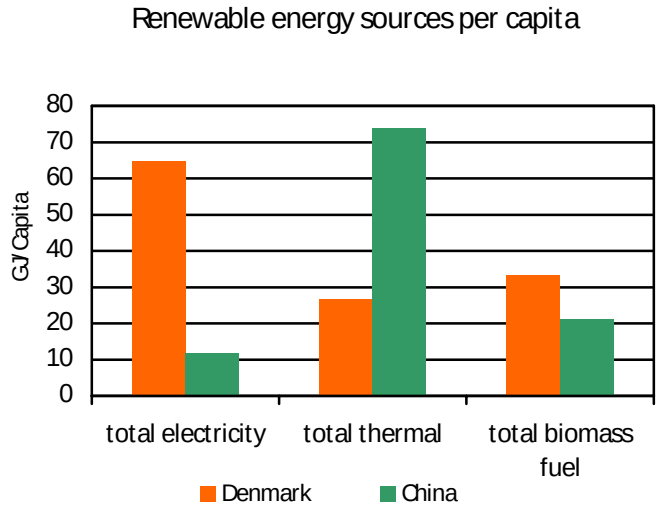

Fig.1. Comparison of renewable energy sources per capita between Denmark and China

As can be seen, the overall amount of energy sources per capita in Denmark and China does not differ much. But in terms of the types of renewable energy sources, differences appear between the two countries. Due to its remarkable advantage in the wind power source per capita, Denmark has a larger electricity production potential per capita than China, even though Denmark has almost no hydroelectric power resource. On the other hand, China

is superior in terms of thermal energy per capita, since it has plenty of solar energy and geothermal energy especially at the low and mid temperature levels. Geothermal energy in China accounts for approximately 7.9% of the world's geothermal energy potential [17,18].

Table 4

Renewable energy sources per area in Denmark and China

Key index	Unit	Denmark	China
Area	Million km^2	0.0431	9.6
Wind (onshore)	Mwh/km^2	116-557	31-73
Wind (offshore)	Mwh/km^2	348-2320	109-229
Photo Voltaic	Mwh/km^2	70-371	>15
Wave energy	Mwh/km^2	394	-
Tidal energy	Mwh/km^2	-	6
Hydro power	Mwh/km^2	0	183
Total electricity	Mwh/km^2	928-3643	345-506
Solar thermal	GJ/km^2	371-2088	>513
Geothermal	GJ/km^2	>2320	9646
total heat	GJ/km^2	2320-4408	>10158
Straw	GJ/km^2	905	671
Wood	GJ/km^2	534	543
Waste (combustible)	GJ/km^2	557	360
Biogas	GJ/km^2	719	259
Energy crops	GJ/km^2	1508	1092
Total biomass fuel	GJ/km^2	4223	2924

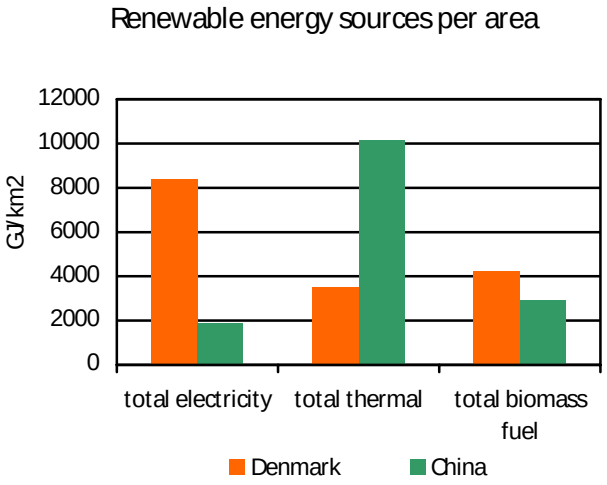

Fig.2. Comparison of renewable energy sources per area between Denmark and China

Table 4 and Fig. 2 present the comparison results of renewable energy sources per area in Denmark and China. In terms of potential renewable energy source per area, similarities between Denmark and China can be identified, as before. The total amount of renewable energy sources per area in Denmark and China is almost equal in spite of the fact that the territories differ significantly.

3 Comparison of renewable energy solutions in Denmark and China

3.1 Renewable energy solutions in Denmark

The overall objectives of Danish energy policy have changed over time, because of the different impact of national and international problems in different periods of time. Energy security, self-sufficiency and energy efficiency have been the principles of the Danish energy policy, and Denmark has persistently promoted renewable energy, even when it discovered oil and gas sources in the North Sea.

Like many countries, Denmark's initial interest in and support for renewable energy can be dated back to the first oil crisis of 1973. Meanwhile, from the mid-70s to the mid-80s, the Danish energy policy was characterized by the debate on nuclear power. The official energy policy was aiming at introducing nuclear power into the Danish electricity system as soon as possible. However, the opposition to nuclear power was represented by a group of experts from Danish universities and some NGOs. After the oil crisis, a number of initiatives were taken in promoting renewable energy and especially wind power in the Danish energy system. The history of nuclear power in Denmark was terminated in 1985, when the Danish parliament decided that nuclear power should not form part of the Danish energy supply [19].

In spite of lacking almost entirely hydroelectric resources, Denmark decided to build wind farms. It engaged in a fully ambitious scheme for promoting renewable energy. This scheme was also well known for its Feed-in Tariffs (FiTs) which guarantee an above-market price for the sale of electricity generated by certain technologies, primarily wind [2]. The Danish support for wind power and other renewable energy sources combines a number of different elements which are summarized in Table 5. Today, the Danish parliament has just improved the FiTs for wind, biomass and biogas to make the investment in these technologies even more attractive [20].

Table 5

Danish solutions for promoting renewable energy [2] [20,21]

Policy/solution	Effect /brief introduction
Principle support -FiTs	FiTs introduced in 1993 which obliged the utilities to purchase wind-generated electricity at a rate that equaled 85% of the price paid by consumers Fixed feed-in tariff exists for solid biomass and biogas under certain conditions, and subsidies are available for CHP plants based on natural gas and waste (biomass, being CO_2 neutral, is exempt from CO_2 duty)
New premium system	It combining with market price and promoting incorporate market elements into the support framework A spot price and an environmental premium (€13/MWh) and an additional compensation for balancing costs (€3/MWh) for 20 years are available for new onshore wind farms
Investment subsidies	Eligibility and levels of subsidy depend on: fuel type, plant technology type, size and age of the plants Since 1979, private citizens who installed wind turbines were reimbursed 30% of the turbine's purchase price by the Danish government
energy tax strategy	A tax on the use of fossil fuel Solar heating plants are exempt from both energy and CO_2 taxes. The executive order related to solar heating obligations in new building outside the district heating areas which was adopted in 2001 -but has not yet come into force- will require the introduction of solar heating to new buildings (excluding the domestic sector). Solar thermal installations are eligible for subsidies
Tender process	Is used for two new large offshore wind installations. Operators will receive a spot price and initially a setting price addition
Long-term government support for research and development	In 1982, a government committee was established with the aim of promoting energy systems based on renewable energy sources, including wind, solar and biomass
Government energy planning and targets	From 1981, the official Danish energy plan proposed a wind power production target for the year 1995, which is more or less realized "Energy 2000"was published in 1990 with a target of 1500MW of installed wind capacity by 2005 and it has been surpassed by a factor two already by the end of 2003 Following previous planning, a series of strategies have been published including "Energy 21"(1996), the "Agreements of 29 March 2004" and "Energy Strategy 2050", etc. All of these expanded and upgraded the penetration of renewable energy utilization

3.2 Renewable energy solutions in China

As mentioned before, China is facing two severe challenges of maintaining energy balance and improving environmental protection. Both challenges are rooted in the present inappropriate energy consumption structure of the country. In order to maintain the rapid and stable economic development, China has to promote a sustainable and effective policy for its future energy development.

Through many years of development, China's renewable energy policy has played a significant guiding role. Especially after the PRC Law of Renewable Energy went into effect (2005), many relevant supporting laws and regulations stipulated to promote the development of renewable energy. In 2006, China's total renewable energy use reached 180 million tons of coal equivalents, which accounted for 7.5% of the total primary energy consumption [22].

Though still unable to compete with fossil fuels, renewable energy is at a rapid development stage and its development needs more governmental support. Some of China's important policies can be summed up at Table 6.

Table 6

Solutions for the development of renewable energy in China [23-25]

Type	Time	Policy/solution	Effect/brief introduction
Renewable energy laws	2005	PRC Law of Renewable Energy was passed	Bringing the exploitation and use of renewable energy to the strategic height of increasing energy supply, improving energy structure, guaranteeing energy safety, protecting the environment and realizing the sustainable development of economy and society
Renewable energy regulation and programming	Since 2006	Guidance and Content for the Development of the Renewable Energy Industry, Temporary Method for Managing the Special Capital of RE Development, Temporary Management for Price and Cost Sharing in RE Power Generation, Mid and long-term Development Programming for Renewable Energy	After the passage of the PRC Law of Renewable Energy, five sets of supporting regulation have been enacted. In these, mid and long-term Development Programming for Renewable Energy sets the general goal for the development of renewable energy: renewable energy shall account for up to 10% of the total energy supply in 2010 and 16% in 2020.
Renewable energy research institutions	1980s	Center for Renewable Energy Development (CRED), Energy Research Institute of State Development and Reform Commission (NDRC), Biogas Institute of the Ministry of Agricultures	Focus on economic and development policy of renewable energy
Renewable energy research programs and projects		State Technical Problem Tackling Program, 863 program (since 1986), 973 program (since 1997)	Raising capital to support the research on development and techniques of renewable energy including many national model projects, namely , all the Five Year Plans, the Bright Project, Fair Wind Project, Rural Household Marsh Gas State Debt Project, etc.
Economic encouragement policy	Since Late 1970s	Financial subsidy, favorable taxation policy, favorable price policy	The main part of the support was dedicated to the household power use in remote and rural areas, including Rural energy special cashing interest loan, Temporary Management for the Price and Cost Sharing in Renewable Energy Power Generation, Rural Marsh Gas Construction State Debt Program Management Method, etc.
Renewable energy Industrialized support policy		Industrialized development special item, key equipment special item and Wind power Concession Bidding Project	The support of the use of solar energy, photovoltaic and wind power generation equipments accelerated the localization and state manufacturing process of renewable energy equipment

3.3 Comparisons of renewable energy solutions in Denmark and China and proposals for renewable energy development in China

(1) Strategies focus on different types of renewable energy sources in Denmark and China

Denmark has a powerful determination to integrate renewable energy into its national energy system, especially wind power. This is not only due to the principle of self-sufficiency in energy supply, but also because of Denmark's remarkable advantages in wind power sources. Although the Danish government recently formulated more objectives and proposals which make other renewable energy sources, like biomass, more attractive, wind turbines are still considered the main technology in terms of improving the renewable energy penetration, especially in the electricity supply system.

Meanwhile, renewable energy sources in China are rich in variety and amount and are also localized all over the country. For this reason, wind power development has not attracted dominant attention in China, while hydrogen and biomass attract more attention from policy-makers, technology and industry. By means of analysis of China's own feature and advantages in renewable energy sources reserve and development opportunities, it is crucial for China to identify its own suitable process and directions which meet China's actual conditions to promote renewable energy development.

(2) Earlier political decision-making and more consistent renewable energy development in Denmark

After the first oil crisis in the late 1970s, Denmark began to pay close attention to renewable energy. With an early decision not to develop nuclear power and no indigenous fossil fuels, Denmark's choice of self-sufficiency was limited. The early acceptance of renewable energy as a complementary source of energy rather than an alternative was also important in Denmark [21]. The FiTs which were introduced in 1993 represented the stimulus needed for widespread wind development. These policies combined with an early investment in research and development (R&D) and considered land-use planning encouraged the widespread participation in turbine investment [26]. Even if there is some disagreement about whether the previous FiTs in certain cases may have created over-subsidization, the government has decided for a capped premium, which, combined with market prices, is a positive step towards the incorporation of market elements into the support framework [2]. Another more market-oriented approach is the tendering system which supported and applied for offshore wind. All of these policies and solutions from 1970s to present showed that Denmark is keen on renewable energy and is consistent in its development policy.

The academic research on renewable energy techniques and the modeling of renewable energy projects were implemented at an early stage in China (1970s). However, most of the large-scale programs were launched in the 1990s; national policy and planning were initiated late and the renewable energy law was only recently issued. In other respects, China' renewable energy business is managed by many different sectors at the same time, such as the National Development and Reform Commission, the State Commission of Economy and Trade, the Department of Agriculture and the Department of Water Conservation. This situation led to the development of great numbers of strategies and projects from various sectors. Due to their different fields and objectives, it is rather difficult to find consistence in the renewable energy policy and solutions presented. Moreover, due to the actual situation of China, large differences can be found between east and west China, including renewable energy resources reserve and economic and social development. Some solutions have not yet to be adjusted to local conditions, which also hinders the consistence of policy implementation in the regional areas. In order to ensure the consistence of policies and the successful implementation of solutions, it is necessary to construct an effective system and implement the PRC Law of Renewable Energy as a new beginning.

(3) Differences in economic support targets and greater quantity and variety of economic incentive in Denmark

Denmark and China have some common characteristics in terms of economic incentives to support renewable energy, such as investment subsidy and tax exemption. But still large differences can be found in terms of the quantity and variety of these solutions, between the two countries. The economic support of renewable energy is given by both customers and government in Denmark. The above-market price payments for electricity generated by renewable sources are recovered from electricity customers as a component of the Public Service Obligation (PSO). In 2005, the renewable energy component of PSO was approximately 5.4 Øre[2] per kWh on every kWh of electricity sold in Denmark. This surcharge was equal to approximately 3% of the final bill paid by each household, when all taxes and grid charges are included. Danish customers paid directly a total of DKK 2088 billion in 2004 to support renewable energy [2]. Apart from the direct subsidy payments from customers, additional costs result from the governmental support for renewable energy.

In China, financial funding is especially dedicated to the supply of domestic power in remote and rural areas. Compared to the support needed, the encouragement and measures seem not strong enough. The support is given to small-scale projects and only small amounts are paid [25]. It is important to explore the capital market for renewable energy including enlarging the governmental support and strengthening the public funds and other market finance methods.

4 Conclusions

Renewable energy is the inevitable choice when aiming at mitigating the pressure on the energy supply, improving the harmonious coexistence of human beings and environment, as well as promoting sustainable development. The overall potential renewable energy sources per capita and per area in Denmark and China are almost equal and both countries demonstrate the same tendencies. However, the types of renewable energy sources differ in the two countries. Denmark has more potential electricity sources than China, while China is superior in terms of total potential thermal sources. Renewable energy has begun to play a role in the energy supply in China and it has the potential for large-scale development. China has a large development potential in terms of resources, technology and industry. Denmark has its own advantages and experiences in promoting renewable energy. China can draw some significant conclusions from these experiences. The development of renewable energy in China includes the identification of suitable ways and directions which meet China’s actual situation to promote renewable energy; the making of comprehensive policies or strategies which are consistent and proceed orderly; as well as the strength to enhance and construct appropriate financing methods.

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