LIU JICHENG
WANG GANG
ZHAO ZHENLI
and
WEI QIUSHUANG

Impact of large-scale new energy grid connection on China energy and power structure analysis model

Developing new energy is an important way to optimize energy structure, which makes significant sense on improving energy efficiency, reducing carbon emission, and lowering external dependence degree. New energy power generation costs are generally higher than conventional ones at this time. They would quickly decrease because of their scale effects, as technology improving and the scale expanding. Referring to the developing trend of new energy power generation costs, this paper sets the minimize generation costs and pollutant emission as optimization objectives, selects primary energy consumption and new installed generation capacity of each year as decision variables, and establishes an optimization model for new energy and energy structure. By setting and calculating the optimal energy structure, new energy developing scale, generation capacity and building sequences, we can get comparative results of power generation costs under three different scenarios, namely reference scenario, energy security scenario and low-carbon scenario. And use a sensitive analysis to clear the effect of total energy consumption and non-fossil energy consumption proportion. A simulation result shows resource and environmental benefits would be greater than new energy exploration and utilization costs. The larger scale, greater benefits and the less operation cost of the energy system as well as the lower external dependence degree will occur. Therefore, China should adhere to low-carbon energy structure developing direction, to improve energy conversion and utilization efficiency, to strengthen investment in new energy and finally achieve energy development strategies and goals.

Keywords: New energy, energy structure, electric structure, multi-objective, multi-scenario

1. Introduction

Energy sustainable development is a significant strategic problem related to the overall economic and social development. In China, since reform and opening, industry has experienced a rapid development which supported economic and social development. During this period, contradictions between economic growth, energy development, resources supplement, environment protection etc. gradually appeared. China has overall plentiful energy resources, but its per capita energy level is lower than the world average level. Coal is occupying a dominant position in energy structure. And high quality clean energies, such as petroleum and gas, have small proportions of consumption and low electrification degrees. The continuous and rapid increasing of energy demand causes a large consumption amount of fossil energy, which produces pollutant and greenhouse gas emission and makes adverse influence on ecological environment[1].

Restricted by resource endowment, the increasing external dependence of petroleum brings potential risks to national energy security. Unscientific energy developing mode leads to recurring shortages of coal, electricity, petroleum, gas and so on. On the one hand, as economical social sustained development and energy demand continuously increasing, the constraints and contradictions related to China energy development would be more and more prominent, and the pressure on energy security would also be increasing[2]. On the other hand, facing the status of conventional fossil energy shortage and the pressure on environment carrying capacity, the exploitation of solar energy, wind power and other new energies has become urgent problems. Chinese government has put forward “increase non-fossil energy proportion up to 15% by 2020” and “reduce 40-45% carbon emission per GDP by 2020” and other development goals, therefor new energy would play an important role in the adjustment process of energy and power structure in China[3].

2. Research status

At this time, new energy has not yet been defined normally. Generalized new energy includes advanced nuclear power, wind power, solar power, biomass power, geothermal power, unconventional gas, non-aqueous renewable energy and so on. And in this paper new energy mainly refers to wind power, solar energy and non-aqueous renewable energy. The randomness, intermittently and volatility of new energy power generation caused a series of complex technology and

Messrs. Liu Jicheng, Wang Gang*, Zhao Zhenli, Wei Qiushuang, North China Electric Power University, Chang Ping District, Beijing, 102206, China.
* Corresponding author

economic problems to their large-scale development, grid connection, scheduling and consumption[4]. To solve these problems properly, we need to plan rational new energy development timings. Studies on large-scale new energy grid connection mainly focus on three points: policy planning, development mode and building technology model.

On aspect of policy planning, key constraints has changed from energy consumption intensity to carbon emission intensity, which reflects a strategic conversion that China energy policies would face with[5]. Liu Cuilan et al. (2009) think that Chinese government should complete greenhouse gases statistical mechanisms, promote energy saving by improved technology and formulate fiscal policies, reduce its reliance on fossil fuels, and build science and low-carbon technology foundation that response to climate change[6]. Yu Hua et al. (2011) analyzed problems existing in China's new energy industries developing process from three aspects, namely technology obstacles, operation costs and safety and environment issues, and put forward some incentive policies in financial, credit, land-use and other areas to create better investment mechanisms for new energy development[7]. Zhou Fengao et al. (2013) hold the opinion that though the existing policies and legal protection system related to new energy development has already played its role, there are still many problems, such as lack of policies for low-carbon long term developing strategy, implementation issues in pollutant emission control price subsidies, imperfect statues of policies for environment protecting industries, differential pricing execution issues in some regions etc.[8].

With respect to developing mode, the 13th five-year plan would be a turning point for China's new energy industries to enter into a large-scale developing period from the initial period[9]. However, as industries are expanding, obstacles, namely insufficient understanding of new energy strategic development, rigid grid system, irrational pricing mechanism, would become the bottleneck of new energy scale expanding[10-12]. Chinese government should create opportunities and conditions for new energy development by reforming legislation system, reforming decision-making mechanisms, introducing incentive mechanisms, improving the policy framework and introducing innovation, to promote mutual support, synchronous connections and other collaborations between grid corporations. Compared to developed countries, China's new energy industries maintain a rapid developing speed, but are still in backward state. So these industries should strengthen investment in technology researches to enhance their innovation capacity, complete industry system to improve supporting capacity, improve industry management level to strengthen the standards system and personal training[14,15].

Regarding technology model, to achieve conversion in power generation, China should focus on technology optimization and innovation to accumulate quantitative change of power generation methods, and finally achieve a fundamental shift of power generation[16-18]. Wang Qiulin et al. (2009) got a calculation that China power development should select circular economic measure to promote new energy development and optimize energy structure[19]. Sun Rongfu et al. (2011) put forward a grid acceptance capacity evaluation system based on power structure, load feature and peaking capacity, which can calculate the various backup capacity demand responding to a specific power reliability index and then evaluate grid acceptance capacity according to conventional peaking capacity of units during low load time. To rationally allocate new energy installation and grid connection capacity Song Xudong et al. (2013) posed a new energy power generation and grid connection allocation mechanism based on regional comparison, as well as its corresponding allocation mode. In that allocation mechanism, one-echelon regional allocation takes uneven development and unbalanced resource distribution into consideration to ensure the fairness of allocation, while two-echelon regional allocation focus on power generation efficiency and benefits to guarantee high-efficiency of allocation[21].

On this basis, to analyze the influence of large-scale new energy grid connection on China energy structure and power structure comprehensively, this paper adopts a method which combined multi-objective decision making and multi-scenario theories. Multi-objective decision making theory considers developing costs, environment pollution degree, energy resources sustainable utilization and other objectives to meet various requirements of energy exploitation. Multi-scenario analysis method can convert uncertain study of future energy utilization into certain study. And it lists maximum and minimum utilization amount to get upper and lower boundaries of energy utilization and guide multiple developing ways.

The rest of the paper is organized as follows: Section 3, sets minimum energy consumption cost, including investment cost and pollutant emission cost as optimization objective, takes various constraints during energy consumption process, and establishes an analysis model about the influence of large-scale power generation and grid connection on China energy structure and power structure. Section 4 discusses three scenarios, namely the reference scenario, the energy safety scenario and low-carbon scenario. Section 5 does a simulation which uses actual data of China, and a sensitive analysis of total energy consumption and non-fossil energy consumption proportion. Section 6 highlights the main conclusions and gives the response policy recommendations.

3. Model building

3.1. Objective function in energy-saving model

This paper studies the influence of new energy grid connection on China energy and power structure from 2011 to 2020 while new energy mainly refers to wind power, solar energy, biomass energy and garbage power[23]. According to the characteristics of China energy, this paper studied 12 kinds of energy modes, namely coal for power generation and other use, petroleum for transportation and other use, gas for power generation and other use, hydro power, nuclear power, wind power, solar photovoltaic and thermal power, and biomass power generation.

The energy development strategy of China contains multiple objectives, such as the minimum total energy consumption, the maximum non-fossil proportionate consumption, and the minimum carbon emission intensity etc.. When calculating value of each variable in energy system, we can choose one of the objectives as the optimization objective or use the combination of multi-objective objectives, and set the unselected objectives as new constraints. As for energy investment and emission cost showing a linear relationship with energy consumption scale, to simplify optimization model and circumvent the problem that non-linear programming may not get the global optimal solution, this paper uses a linear function to represent the cost of investment and emission costs, and sets the minimum pollution control cost as optimization objective. The specific objective function is:

$$(P1)\ \text{Min } F(X) = f_{rest}(X_{rest}) + f_{ems}(X_{rest}) + f_{elec}(X_{inv}, X_{acc})$$

Where $f_{rest}(\cdot)$ stands for non-power energy consumption costs function; $f_{ems}(\cdot)$ stands for non-power energy pollutant emission costs function; X_{rest} is the non-power energy consumption amount. As for power generation resource consumption has a close relationship with new installed capacity and total installed capacity, $f_{elec}()$ stands for the consumption costs function of power generation resource, including investment costs and pollutant emission costs.

$$f_{rest}(X_{rest})=\sum_{i=1}^{N}\sum_{r=1}^{R}(1+r)^{-i}P^{i}_{rest,r}x^{i}_{rest,r} \quad (1)$$

Where n is the total planning period; stands for the set of non-power generation resources, mainly including coal for other use, petroleum for transportation and other use, and gas for other use; $_r$ is the basic discount rate; $P^{i}_{rest,r}$ is the consumption price of non-power generation resource r in the i year; $x^{i}_{rest,r}$ is the consumption amount of non-power generation resource r in the i year.

$$f_{ems}(X_{rest})=\sum_{i=1}^{N}\sum_{r=1}^{R}\sum_{j=1}^{J}(1+r)^{-i}P^{j}x^{i}_{rest,r}\alpha^{j}_{rest,r} \quad (2)$$

Where j is the set of pollutants, namely SO_2, NO_x, smoke and dust, CO_2, P^j is the emission price of pollutant j; $\alpha^{j}_{rest,r}$ is the emission coefficient of pollutant j by non-power generation resource r.

3.2. Power structure model in objective function

When optimizing energy structure, it cannot be ignored that power structure has a significant influence on energy consumption structure, and new energies are mainly utilized in power generation. Conventional power structure optimization model can be classified into two categories, namely "microscopic methods" and "macro methods", as is shown in Table 1.

Table 1. Comparison between microscopic and macro methods

Modelling methods	Types of the objective function	Major theories	Applicability
Microscopic methods	Mixed-integer non-linear model	The decision making variables are directly corresponding to each unit to be installed. Considering typical daily generation simulation of the power system and time, network, unit statue and other constrictions, its optimization model can be built.	When the planning is with bright prospects and the basic data is credible, the method can get an accurate power expansion scheme.
Macro methods	Linear equilibrium model	Set power plant or generation unit as basic unit and build a model from "bottom-up" mode, which can describe the input-output relationship in the planning period.	Generally, it is used in the macroeconomic field and can incorporate various simplifying conditions to get linear equilibrium model.

This paper combines the advantages of "microscopic methods" and "macro methods", and puts forward a new modelling idea:

(1) Upgrading the decision-making foundation from the unit/plant level to the certain unit level. Analyzing from national macro-control aspect, capacity growth of each categories unit is continuously rather than decentralized, so this dealing mode has little influence on the accuracy of the model.

(2) Bringing output of various types of units as decision-making variables into the model to replace production simulation links under "microscopic methods" mode. To ensure the balance between supply and demand, and to guarantee the safe and steady operation of the power system, the model should be able to allocate power generation assignments between various types of units according to

real-time power structure and the load demand. And in this way non-linear degree of the original model can be cut down.

(3) As for the decision-making foundation has been upgraded to the certain unit level, and production simulation links are substituted by the generation decomposition scheme, the national macro power planning model can ignore physical connection and network conditions between units, as well as the transmission cross section capacity between power generation and consumption areas. And that can reduce the complexity of modelling.

Compared to “microscopic methods”, the new modelling mode can eliminate the non-linear factors in the original model and convert mixed-integer non-linear programming problems into standard lp, which can slash the non-linearity degree. Compared to “macro methods”, the new modelling mode forms a linear model that can improve the confidence level. So the new modelling mode combines the advantages of those two conventional modelling mode and can achieve a balance between complexity and accuracy.

To coordinate with the total objective optimization, we set minimum power generation cost as the optimizing objective in power structure optimization. Assume investment cycle is one year, and ending installed capacity of current period = ending installed capacity of last period + new installed capacity in current period – scrapped installed capacity in current period. Investment cost of current period is a linear function of new installed capacity in this period. Operation cost, fuel cost and emission cost are linear functions of ending installed capacity of current period. Set the minimum npv of power generation cost during the life-cycle as optimization objective, and set ending installed capacity and new installed capacity of current period as decision-making variables, we can get the expression of the objective as:

$$\text{(P2)}\quad f_{elec}(X_{inv},X_{acc})=\sum_{i=1}^{N}(1+r)^{-i}[C^i_{inv}(X^i_{inv})+ C^i_{acc}(X^i_{acc})+C^i_{fuel}(R^i_{opr}X^i_{acc})+C^i_{em}(R^i_{opr}X^i_{acc})]$$

Where $f_{elec(\cdot)}$ is built when investment cycle is one year; i is a number of year; n is the number in the whole life-cycle; r stands for the discount rate; X^i_{inv} and X^i_{acc} stand for new unit capacity and cumulative unit capacity in year i; is the operation efficiency of power generation units in year i; C^i_{inv}, C^i_{acc}, C^i_{fuel} and C^i_{em} are investment cost, operation cost, fuel consumption cost and emission cost in year i.

$$C^i_{inv}(X^i_{inv})=\sum_{k=1}^{K}P^i_{inv,k}x^i_{inv,k} \tag{3}$$

Where k is the set of types of power generation units; $P^i_{inv,k}$ is the investment cost of type k in year i; $x^i_{inv,k}$ is the new installed capacity of type k in year i.

$$C^i_{acc}(X^i_{acc})=\sum_{k=1}^{k}P^i_{acc,k}x^i_{acc,k} \tag{4}$$

Where $P^i_{acc,k}$ is the operation cost of type k in year i; $x^i_{acc,k}$ is the accumulated installed capacity of type k in year i.

$$C^i_{fuel}(R^i_{opr}X^i_{acc})=\sum_{g=1}^{G}\sum_{k=1}^{K}P^i_{fuel,g}\beta^i_{k,g}FLH^i_kR^i_{opr,k}x^i_{acc,k} \tag{5}$$

Where G is the set of types of power generation resources; $P^i_{fuel,g}$ is the consumption price of type g in year i; $\beta^i_{k,g}$ is the consumption coefficient of type g in year i.

$$C^i_{em}(R^i_{opr}X^i_{acc})=\sum_{g=1}^{G}\sum_{k=1}^{K}\sum_{j=1}^{J}P^j\varphi^j_g\beta^i_{k,g}FLH^i_kR^i_{opr,k}x^i_{acc,k} \tag{6}$$

Where is the pollutant j emission coefficient of type g.

Assume that the accumulated installed capacity has a significance corresponding relationship, namely:

$$E^i_{elec,g}=\sum_{k=1}^{K}\phi_{k,g}FLH^i_k\,\square R^i_{opr,k}x^i_{acc,k} \tag{7}$$

Where E^i_{elec} is the total energy consumption in year i; $\phi_{k,g}$ is the coefficient of unit type k consumes energy type g; FLH^i_k is the utilization hours of unit type k in year i; $R^i_{opr,k}$ is the operation efficiency of unit type k in year i; $X^i_{acc,k}$ is the accumulated installed capacity of unit type k in year i.

Energy structure and power structure model contains 20 decision-making variables, wherein 12 related to energy consumption and 8 related to the new installed capacity, that is:

$$X_{toal}=\{X,X_{inv}\} \tag{8}$$

$$X=\{X_{acc},X_{inv}\} \tag{9}$$

3.3. Constrictions

The variables of energy structure optimization model have a closely relationship with the change trend of energy structure and power structure. To ensure the results meet minimum cost and rational development requests of energy and power development, this paper builds constructions from four aspects, namely the balance of energy demand and supply, non-power generation energy consumption proportion, power generation energy consumption proportion and power demand and supply. Details are as follows:

(1) Energy demand and supply balance construction

$$\sum_{r=1}^{R}x^i_{rest,r}+X^i_{elec}=E^i_{rest}+\sum_{g=1}^{G}E^i_{elec,g} \tag{10}$$

$$X^i_{elec}=\sum_{k=1}^{K}FLH^i_k\,g\,R^i_{opr,k}x^i_{acc,k} \tag{11}$$

Where X^i_{elec} is the annual power generation of year i, which has a direct relationship with power generation units' capacity; E^i_{rest} is the demand of non-power generation energy; E^i_{elec} is the power generation energy demand.

(2) Energy consumption constructions

$$\beta_c^N = \frac{x_c^N}{\sum_{r=1}^{R} x_{rest,r}^N + \sum_{g=1}^{G} E_{elec,g}^N}, \ c \in \{C\} \tag{12}$$

$$\beta_k^N \in [\underline{\beta}_k, \overline{\beta}_k] \tag{13}$$

Where {C} is the set of types of fossil energies; is the consumption amount of fossil type c, c =1,2,3 respectively means coal, petroleum and natural gas; β_c^N is the ending consumption proportion of energy c; $\underline{\beta}_k$ and $\overline{\beta}_k$ are the upper and lower limits of energy c.

(3) Power supply and demand balance constraints

$$X_{elec}^i = D_{elec}^i \tag{14}$$

Where D_{elec}^i is the annual power demand in year i.

(4) Capacity construction in current period

$$X_{acc}^i = X_{acc}^{i-1}(1-Rold^i) + X_{inv}^i \tag{15}$$

Where $Rold^i$ is the scrap rate in year i.

(5) Installed capacity growth rate constraints

$$(X_{acc}^i - X_{acc}^{i-1}) / X_{acc}^{i-1} < Rold^i \tag{16}$$

(6) Ending total installed capacity constraints

$$X_{acc,k}^N \in [\underline{X}_{acc,k}, \overline{X}_{acc,k}] \tag{17}$$

Where $\underline{X}_{acc,k}$ and $\overline{X}_{acc,k}$ are the upper and lower limits of ending total installed capacity of type k.

(7) Power demand forecast constructions

When optimizing energy structure, the ending power demand can be calculated. To get power demand data of each year, this paper dose a linear sharing of the power consumption amount at the beginning and ending.

$$\mu = \frac{D_{elec}^N - D_{elec}^0}{D_{elec}^0} \tag{18}$$

$$D_{elec}^i = D_{elec}^0 (1 + i\mu) \tag{19}$$

Where the original power demand is D_{elec}^0; μ is the growth rate of power demand.

4. Basic scenarios

To analyze the influence of large-scale new energy grid connection on China energy and power structure, this paper sets three basic scenarios, namely the reference scenario, the energy safety scenario and low-carbon scenario.

4.1. The reference scenario

According to the 13th five-year plan and the commitment on energy development, to 2015 the proportion of non-fossil fuels should not lower than 11.4%, and to 2020 not lower than 15%. On 2018, GDP is forecasted to be 85.6 Hundred million Yuan. Energy consumption and carbon emission per unit of GDP should be respectively reduced at least 16% and 17% from 2010, and by 2020, that should be reduced by 40%-50% from 2017. Details are as shown in Table 2.

Table 2. Computing velocities in different mass ratios

Key indicators	2012	2015	2020
GDP/hundred million Yuan	51.9	56.1	75.6
CO_2 emission/ hundred million tonne	82.5	92.6	106.7
Total consumption of primary energy/ million tonnes of coal	36.5	42	49
Total electricity demand/one trillion kWh	4.96	6.45	8.58

4.2. The energy safety scenario

In this scenario the key issue is the influence of petroleum import dependency degree on energy structure. According to the petroleum consumption growth speed at this time, at 2015 annual petroleum consumption was more than 6 million tonne, and petroleum import dependency proportion was more than 67%. Different from the reference scenario, the import dependency in 2012-2020 is limited to increase in the 0.5% range and the upper limit of 2020 is 60%. When petroleum consumption is limited, petroleum alternative energy consumption would rise. That would increase annual coal consumption proportion by 5% in each level, and power consumption would increase correspondingly. To meet the requirements of the increasing power demand, assuming that the upper limit of each type of energy generation units increased by 10%, total power demand in 2020 would be 8.78 hundred million kWh.

4.3. The low-carbon scenario

As global climate change is becoming the focus point in countries around the world, China would face more and more pressure from on the energy-saving aspects. So it is important to make a pre-judgment on low-carbon development path that may arise in the future. Considering that hydro, wind, nuclear power and other clean energies would be exploited in large-scale, based on the reference scenario, this scenario changes the proportion of non-fossil energy in 2020 to 17%, and changes the upper installed capacity of non-fossil energy units correspondingly.

5. Simulation analyze

5.1. Basic data

To do simulation for the model above, at first we need to get consumption prices of various types of energies in the future, unit investment cost and unit operation cost of power generation of each type of energy. Wherein, the prices of coal for power generation and petroleum for other use are equal to the 2011 average of coal for power generation and the average price of petroleum for non-traffic in China.

Assume that coal for other use and petroleum for traffic are 90% of them correspondingly, and nominal growth rate is 2%. Table 3 shows the result of energy consumption from 2015 to 2020. As for hydro and nuclear power technologies are quite mature, their cost reduction space is limited, this paper assumes that their investment cost and operation cost are decreasing by 2% nominal growth rate. Power generation and operation costs are shown in Table 4.

Table 3. Forecast of the energy consumption prices

Type	2011	2015	2020	Nominal growth rate
Coal for power generation[1]	852	922	1018	2%
Coal for other use	767	830	916	2%
Coal for traffic[2]	5250	5918	6861	3%
Coal for non-traffic	5834	6577	7625	3%
Natural gas[3]	1923	2075	2291	3%

Source: international energy and electricity price analysis report[22] Yuan/Tec

Table 4. Power generation cost of hydro, nuclear power and new energies

Type	cost classification	2010	2015	2020
Hydro power	Investment cost	8500	7840	7086
	Operation cost	128	115	104
Nuclear power	Investment cost	10400	9400	8498
	Operation cost	520	479	434
Wind power	Investment cost	9000	7800	7500
	Operation cost	0.135	0.129	0.122
Solar photovoltaic	Investment cost	24000	7500	6500
	Operation cost	0.48	0.434	0.392
Solar thermal power	Investment cost	28000	12424	5512
	Operation cost	0.168	0.168	0.168
Biomass and waste power generation	Investment cost	10000	3277	1074
	Operation cost	0.06	0.06	0.06

Source: China power supply development and energy supply and demand analysis[23] BP world energy statistics yearbook[24] Yuan/kW

To study the influence of large-scale new energy grid connection on China's energy structure and power structure, we need to determine the proportion of each type of energy rationally, namely energy consumption structure and power generation capacity. Tables 5 and 6 list these data in 2015 and 2020.

Table 5. Primary energy consumption structure of China in 2015 and 2020

Type	2012	2015	2020
Coal	68.2%	60%~65%	55%~60%
Thermal coal	56.8%	50%~65%	55%~70%
Petroleum	17.8%	15%~20%	15%~20%
Natural gas	4.9%	5%~10%	5%~20%

Source: China electric power and energy 2012[25]

Table 6. Power generation units capacity of China in 2015 and 2020

Installed capacity	2015	2020
Natural gas/hundred million kW	0.4~0.7	1~1.5
Hydro power/hundred million kW	2.8~3.0	3.0~3.5
Nuclear power/hundred million kW	0.3~0.45	0.8~1
Wind power/hundred million kW	0.8~1.1	1.4~2
Solar photovoltaic/ten thousand kW	200~500	1000~3000
Solar thermal power/ten thousand kW	100~500	500~1000
Biomass power generation/ten thousand kW	500~1000	2000~3000

Source: China electric power and energy 2012[25]

This paper takes SO_2, smoke, nitrogen oxides, carbon monoxide and other atmospheric pollutants' emission cost into consideration. According to related studies by the state grid energy academy[26], we set SO_2, nitrogen oxides and smoke emission cost as 8000, 6000, and 5000 Yuan/t. And the emission coefficient of each energy type is as shown in Table 7. This paper collected CO_2 emission data from U.S. Department of Energy, IEA and other energy institutes, and calculated their average value (Table 8).

Table 7. Unit energy consumption pollutant emission (kg/tec)

Coal			Petroleum			Natural Gas		
SO_2	NO_x	Smoke	SO_2	NO_x	Smoke	SO_2	NO_x	Smoke
20	13.9	13.1	7	5.1	1.05	0.47	3.07	0.21

Table 8. CO_2 emission amount of each type of energy (ton CO_2/ton standard coal)

Data sources	Coal	Petroleum	Natural Gas
DOE/IEA	2.57	1.75	1.43
Japan's Institute of Energy Economics	2.77	2.15	1.65
National Science and Technology Commission of Climate Change Project	2.66	2.14	1.5
Energy Research Institute National Development and Reform Commission	2.74	2.14	1.63
Average value	2.69	2.04	1.55

[1] Raw coal power coal price is converted into standard coal according to coal to heat 5000kcal/kg

[2] Calculated according to the average cost of production of gasoline, diesel, kerosene and other petroleum transport 8,000 yuan / ton price

[3] 2.5 yuan per cubic meter

5.2. Simulation results

Using GAMS to solve the proposed model, we can get different optimization results under three scenarios. List related data from 2010 to 2020 to compare results in "eleventh five-year plan", "twelfth five-year plan" and "thirteen five-year plan" periods is indicated in Table 9.

5.2.1.Reference scenario

In the reference scenario, coal consumption increased while its proportion in primary energy decreased. At the end of the "thirteen five-year plan" period, the proportion of coal consumption in primary energy consumption reduced to 60%. Petroleum consumption keeps increasing to 9.33 hundred million tec in 2020, which accounts for 19% of the total energy consumption. China has a crude petroleum production capacity for only two hundred million tonnes, while its petroleum import dependency proportion would be more than 70% in 2020. Natural gas consumption increases steadily and in 2020 it would be 2.92 hundred million tec, approaching 6% of total primary energy consumption amount.

At the end of the "thirteen five-year plan" period, the proportion of primary energy would increase to 15%. Hydro power consumption increases in a slow speed, which causes its proportion decreasing. By contrast nuclear power develops rapidly, increasing about 24% per year, and occupies about 5% of the total primary energy consumption in 2020. New energy has an increasing speed of 25% per year, and its proportion would come to 3.25% in 2020.

From energy generation installed capacity point of view, hydro power installed generation capacity would be 3 and 3.5 Ten thousand kW in 2015 and 2020, both achieve the maximum scale that can be exploited. New installed generation capacity of nuclear power would achieve 8000 and 12000 thousand kW in "twelfth five-year plan" and "thirteen five-year plan" periods. Table 9 and 10 respectively show the predicted energy structure and power generation capacity in reference scenario.

Table 10. Power generation capacity per year of each type of energy in reference scenario (ten thousand kW)

Year	2010	2015	2020
Coal-fired power	69000	100000	115706
Gas-fired power	2642	7000	11070
Hydro power	21605	30000	35000
Nuclear power	1082	5000	11000
Wind power	2958	9000	20000
Solar photovoltaic	89	500	1264
Solar thermal power	0	300	800
Biomass power generation	400	800	3000
Total installed power generation capacity	96857	152600	197841
Total installed power generation capacity of new energy	3528	10600	25064

To achieve the scales listed in Table 10, we use power structure optimization model to calculate the rational development sequence of wind power, solar power, biomass power and other new energies. The result is drawn in Fig. 1. In 2015 and 2020 the total installed generation capacity of new energies in China would exceeds 1 hundred million and 2.5 hundred million respectively; while wind power, solar photovoltaic power and biomass power all achieve the upper limit of the scale in the simulation, and it would gain its room for growth if the demand of non-fossil energy is bigger. During the "twelfth five-year plan" period, wind power in China experienced a slow development rate, which is because the lack of technical maturity and the weak marketing demand. In the "thirteen five-year plan" period, wind power installed generation capacity grew rapidly at a rate of 2200 ten thousand kW new per year, and come to its peak value of about 3000 ten thousand kW in 2016. Considering environment cost, the growth speed of wind power in China

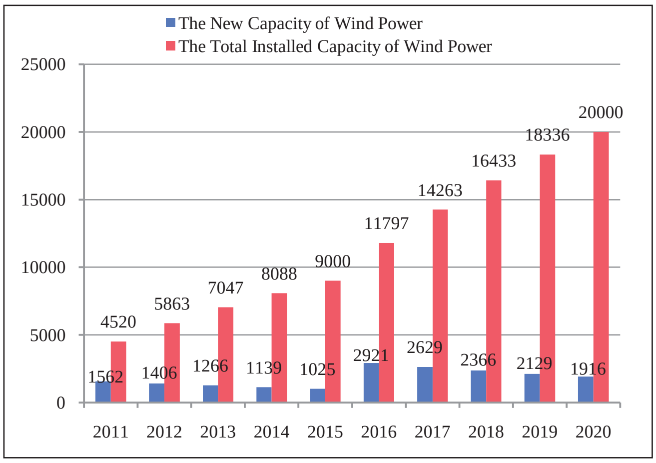
Table 9. The predicted energy structure and power generation capacity in reference scenario (hundred million tec)

		2010		2015		2020	
		Consumption/tec	Proportion/%	Consumption/tec	Proportion/%	Consumption/tec	Proportion/%
Total primary energy consumption		32.5	100	42	27.3	49	100
Coal		22.1	68	27.3	65	29.4	60
Petroleum		6.18	19	7.67	18.26	9.33	19.04
Natural gas		1.43	4.4	2.24	5.34	2.92	5.96
Power	Hydro power	2.37	7.28	3.02	7.2	3.42	6.97
	Nuclear power	0.26	0.8	1.1	2.61	2.34	4.77
	New energy	0.17	0.52	0.67	1.59	1.59	3.25
Non-fossil energy		2.8	8.6	4.79	11.4	7.35	15

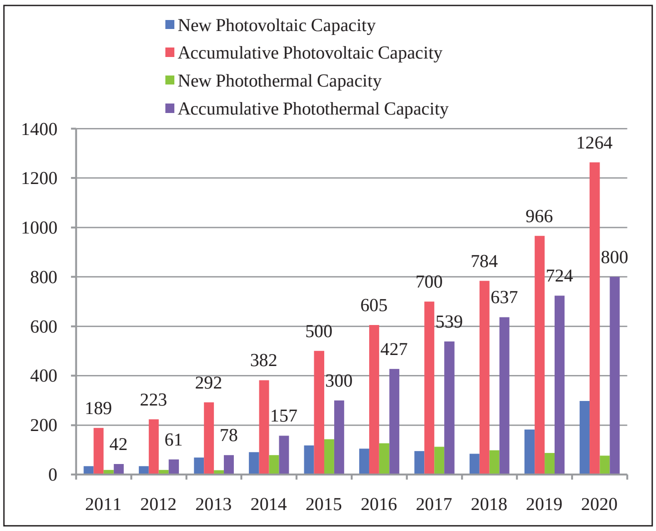
would be high at first and gradually slowdown, which obeys the lowest cost principle.

The photovoltaic power shows an exponentially growing trend, with a 25% average growing rate. Every year there is about new 600 thousand kW installed generation capacity during the "twelfth five-year plan" period, and 1700 thousand per year in the "thirteen five-year plan" period due to the decrease in cost. As for solar thermal power, it keeps a linear growth at 800 thousand kW per year.

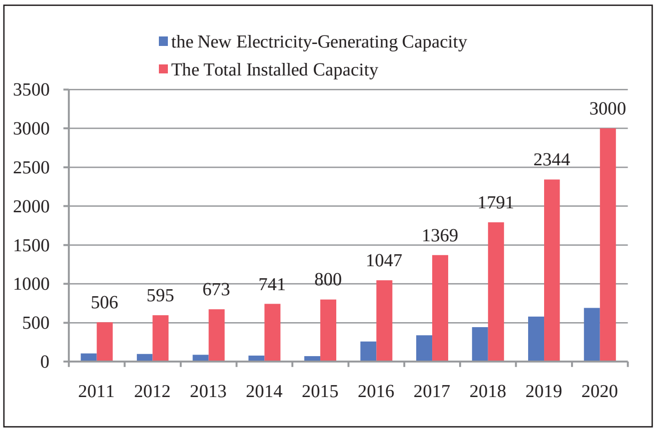
And the cumulative installed capacity of power generation of biomass power in China exponentially increases year by year. During the "thirteen five-year plan" period it has an average annual increasing amount of 400 ten thousand kW, 80 ten thousand kW more than that in the "thirteen five-year plan" period. This is because the initial parameters of the simulation set the capacity upper limit in 2015 to be 800 ten thousand kW which limits the growth of installed capacity in the "thirteen five-year plan" period biomass power generation would experience a rapid development after a slow progress at first, which meets the cost reduction process.



(a)



(b)



(c)

Fig.1: Installed generation capacities of wind power, solar power and biomass power in 2011-2020 in reference scenario

5.2.2. Energy safety scenario

In energy safety scenario the external dependence degree of petroleum is limited under 60%. In 2020 petroleum consumption is estimated to decrease to 7.14 tec, and its consumption proportion would decrease to 14.6% which is 4.5% than that in the reference scenario. That is because to meet the requirement of 60% external dependence degree the average consumption growth rate should be not more than 3%. And the decrease of petroleum consumption would cause a general consumption growth of other energies. During the "twelfth five-year plan" period coal would replace petroleum to be the main energy and its growth rate would be higher than the reference scenario. While in the "thirteen five-year plan" period new energies would play their role, and coal consumption growth rate would slowdown and its proportion would decrease to 63%. Natural gas consumption amount would have a steady growth rate and increase to 3.52 tec at 2020, which is 0.6 tec more than that in projected scenario, and its consumption would exceed 7%.

In 2020 non-fossil energies consumption proportion would increase to 15.25% higher than that of the external commitments goal of China. Wherein hydro power keeps in a low increasing rate of 7.2% and would reach 3.53 hundred million tec in 2020. Nuclear energy develops rapidly and its consumption proportion would achieve at 4.5% in 2020, which means a 9 times increase in consumption amount. The average growth speed of new energies per year would be 27% and the consumption proportion comes to 3.6% in 2020, which is faster than reference scenario.

Let us see the installed generation capacity, as for hydro power, it would be 3 and 2.5 hundred million kW new per year respectively in 2015 and 2020. And for nuclear power it would be 6 and 12 million kW new per year respectively during the "twelfth five-year plan" period and the "thirteen five-year plan" period, which is slightly lower than that of projected scenario.

TABLE 11. ENERGY STRUCTURE FORECAST RESULTS OF CHINA IN ENERGY SAFETY SCENARIO (HUNDRED MILLION TEC)

		2010		2015		2020	
		Consumption	Proportion/%	Consumption	Proportion/%	Consumption	Proportion/%
Total primary energy consumption		32.5	100	42	27.3	49	100
Coal		22.1	68	28.46	67.75	30.87	63
Petroleum		6.18	19	6.52	15.52	7.14	14.58
Natural gas		1.43	4.4	2.16	5.13	3.52	7.18
Electric power	Hydro power	2.37	7.28	3.21	7.65	3.53	7.2
	Nuclear power	0.26	0.8	0.98	2.33	2.2	4.48
	New energy	0.17	0.52	0.68	1.61	1.75	3.57
Non-fossil energy		2.8	8.6	4.87	11.59	7.47	15.25

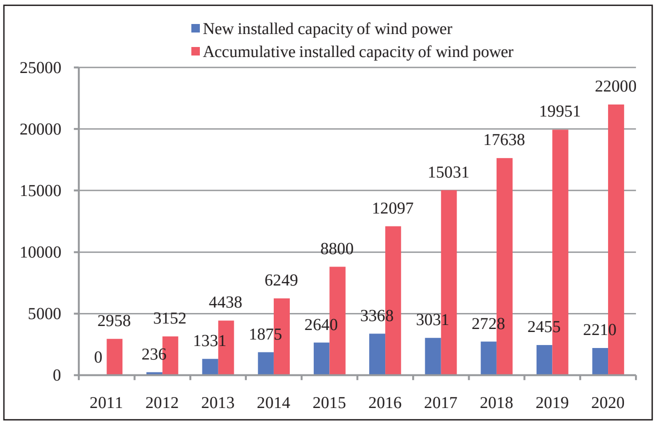
TABLE 12. POWER GENERATION CAPACITY PER YEAR OF EACH TYPE OF ENERGY IN ENERGY SAFETY SCENARIO (TEN THOUSAND KW)

Year	2010	2015	2020
Coal-fired power	68000	101451	121758
Gas-fired power	2642	5674	15000
Hydro power	21605	30000	35000
Nuclear power	1082	4196	10000
Wind power	2958	8800	22000
Solar photovoltaic	89	607	2394
Solar thermal power	0	100	1000
Biomass power generation	400	1100	3000
Total installed power generation capacity	96857	151927	210151
Total installed power generation capacity of new energy	3528	10607	28394

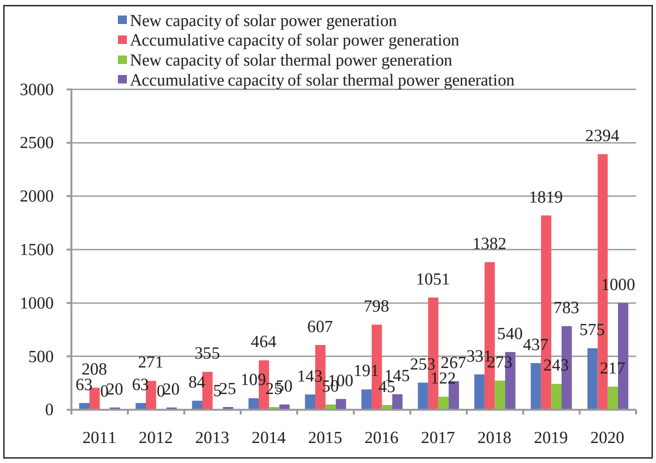
Installed generation capacity of new energy would come to 1 and 2.8 hundred million kW respectively in 2015 and 2020. Fig. 2 shows installed generation capacity of new energy in the following decade. Wind power would develop slowly in the "twelfth five-year plan" period and would be 8800 ten thousand kW at 2015. But during the "thirteen five-year plan", it would experience a rapid development with an average increasing speed of 260 ten thousand kW per for new installed generation capacity, and in 2015 it comes to its peak value at about 240 ten thousand kW. Finally wind power would have 2.2 hundred million installed generation capacity in 2020, higher than projected scenario.

Solar photovoltaic and solar thermal power would develop exponentially and faster than projected scenario. Solar photovoltaic power average new installed capacity per year increases year by year. And in the "twelfth five-year plan" period it would be 90 ten thousand kW, while in the "thirteen five-year plan" period it would be 360 ten thousand kW due to the rapid decreasing of cost. New solar photovoltaic power average installed capacity per year would be 125 ten thousand kW.

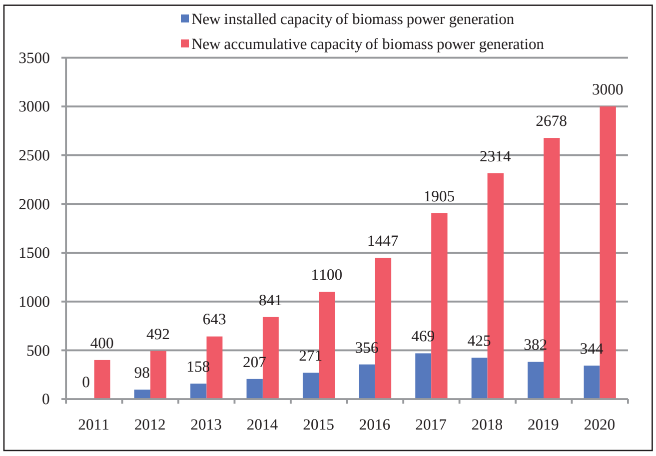
Biomass power would also develop exponentially due to the decrease in total cost of coal replacement, the average new installed capacity per year would be 400 ten thousand kW in the "thirteen five-year plan" period which is faster than that of the "twelfth five-year plan" period of 140 ten thousand kW. The average new installed capacity per year of biomass power shows a trend that increases at first and then gradually decreases.



(a)



(b)



(c)

Fig. 2: Installed generation capacities of wind power, solar power and biomass power in 2011-2020 in energy safety scenario

5.2.3.Low-carbon scenario

As non-fossil energy consumption is increasing, consumption growth speed of fossil energies is slowing down. Coal consumption proportion in primary energy comes down to 58.7%. In the "twelfth five-year plan" period coal consumption amount grows rapidly at 1 hundred million per year, while in the "thirteen five-year plan" period it slows down to 0.2 hundred million per year. Natural gas consumption would have a steady growth and in 2020 it would be 3.07 Tec, the same with projrcted scenario. In 2020 petroleum consumption proportion would decrease to 17%, 1.3% less than that of projected scenario, and its external dependence volume is less than 60%. The development of clean energy would mainly influence petroleum consumption, and has little influence on coal and natural gas consumption. So improving non-fossil energy consumption proportion can effectively improve energy safety aspect in China.

In 2020 non-fossil energy consumption proportion would increase to 17%, 1.1% higher than that of planning. Hydro power consumption would be 3.24 Tec in 2020, which is the same with projected, and achieve to the exploitation of upper limit. Nuclear power develops rapidly with a consumption growing speed of 25% per year, which is higher than projected scenario. In 2020 nuclear consumption would be 2.76 hundred million tec and its proportion would be about 5.6%. The growing speed of new energies all achieve at 29%. Total new energy consumption would come to 2.15 tec in 2020, which takes 4.38% of total energy consumption, 1.1% higher than that of projected scenario, and is the fastest growing one among all non-fossil energies.

Table 13. Energy structure forecast results of China in low-carbon scenario (hundred million tec)

		2010		2015		2020	
		Consumption	Proportion/%	Consumption	Proportion/%	Consumption	Proportion/%
Total consumption amount of primary energy		Total consumption amount of primary energy	100	42	27.3	49	100
Coal		Coal	68	27.3	65	29.27	59.73
Petroleum		Petroleum	19	7.19	17.11	8.33	17
Natural gas	Natural gas	4.4	2.25	5.36	3.07	6.27	
Electric power	Hydro power	2.37	7.28	3.02	7.2	3.42	6.97
	Nuclear power	0.26	0.8	1.34	3.18	2.76	5.64
	New energy	0.17	0.52	0.9	2.15	2.15	4.38
Non-fossil energy		Non-fossil energy	8.6	5.26	12.53	8.33	17

Table 14. Power generation capacity per year of each type of energy in low-carbon scenario (ten thousand kW)

Year	2010	2015	2020
Coal-fired power	68000	103409	121693
Gas-fired power	2642	7093	13000
Hydro power	21605	30000	35000
Nuclear power	1082	6086	13000
Wind power	2958	11500	24631
Solar photovoltaic	89	634	2000
Solar thermal power	0	727	2000
Biomass power generation	400	1500	5000
Total installed power generation capacity	96857	160949	216324
Total installed power generation capacity of new energy	3528	14361	33631

Seeing the installed generation capacity, for hydro power it would be 3 and 2.5 hundred million kW respectively in 2015 and 2020, achieving the upper limit of its exploration. And for nuclear power it would be new 10 and 14 million kW per year respectively during the "twelfth five-year plan" period and the "thirteen five-year plan" period, which is higher than that of projected scenario.

Installed generation capacity of new energy would come to 1.44 hundred kW and 3.36 hundred kW, which is much higher than that of what is projected. Hydro power has already achieved its upper scale limit, and nuclear power has been limited by its long term of exploration life-cycle. To achieve the goal of 17% non-fossil energy consumption proportion we can only rely on new energies. But new energies usually have low energy density and small power generation equipment utilization hours. To meet power generation demand requirement we need to add its installed generation capacity. The development statue of new energy installed capacity in the following decade is drawn in Fig. 3.

Wind power would come to 1.15 and 2.46 hundred million kW respectively in 2015 and 2020, both are higher than that of projected scenario and relative planning in China. In the "twelfth five-year plan" period there would be 1700 ten thousand kW new installed generation capacity per year, and in the "thirteen five-year plan" period wind power develops rapidly with 2600 ten thousand kW per year. In 2016 it comes to its peak value that new installed 3500 ten thousand kW, is higher than projected scenario.

Solar power would develop exponentially. And in 2020 installed generation capacity of solar power would achieve 2100 ten thousand kW is higher than projected scenario. Solar photovoltaic power shows a trend that is increasing year by year. In the "twelfth five-year plan" period it adds 100 ten thousand kW per year, and in the "thirteen five-year plan" period it adds 2700 ten thousand kW per year, which is because of the decreasing of cost. New solar thermal power installed generation capacity increases year by year, and in 2015-2019 its cumulative generation capacity would exceed solar photovoltaic power. That means solar thermal power has economies of scale.

Because of its developed technology and low investment cost, biomass power would also develop exponentially. In 2020 its cumulative generation capacity can achieve 2000 ten thousand kW. In the "twelfth five-year plan" period its new installed generation capacity per year would be 200 ten thousand kW, which is less than that in the "thirteen five-year plan" period with 700 ten thousand kW. New installed generation capacity would increase slowly, from 160 ten thousand kW in 2012, to 919 ten thousand kW in 2019.

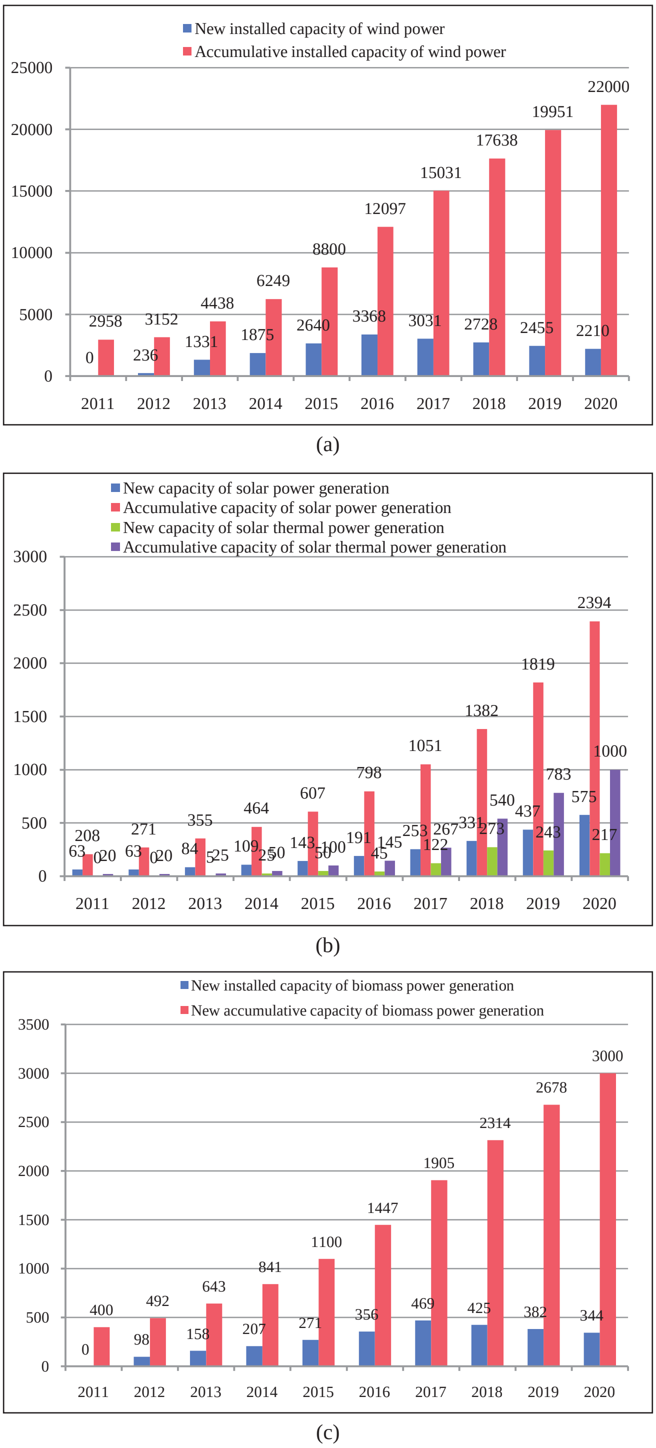


Fig. 3: Installed generation capacities of wind power, solar power and biomass power in 2011-2020 in low-carbon scenario

5.3. Cost-effectiveness

This section set five years as a cycle to analyze cumulative cost and environmental benefits of new energy development in each scenario. Cost mainly means the total social cost, power generation equipment investment cost, yearly operation cost and fuel consumption cost. Environmental benefits mainly means energy conservation benefits, including reducing carbon tax, pollutant emission and opportunity cost of consuming fossil fuel.

5.3.1.Power generation economic cost

Firstly, analyze from the aspect of new energy power generation cost. Total investment costs are 8500, 8232 and 11200 hundred million Yuan respectively in three scenarios. That means investment cost in energy safety scenario is lower than that of projected scenario, while investment cost in low-carbon scenario is higher than that of projected scenario. That is because in energy safety scenario, the decreasing of petroleum consumption is mainly relying on coal consumption and has little impact on new energy in the “twelfth five-year plan” period. Although in the “thirteen five-year plan” period new energy consumption would increase and exceed projected scenario, its total cost would be small than projected because of its late building and low NPV. In low-carbon scenario the required non-fossil consumption proportion is improved to 17%, which causes a larger building scale and more investment cost of new energy.

Then analyze from the power generation cost per kW. Both of that in projected scenario and low-carbon scenario are decreasing, respectively, from 0.471 and 0.478 Yuan/kW in the “twelfth five-year plan” period to 0.436 And 0.444 Yuan/kW in the “thirteen five-year plan” period. Because solar photovoltaic and thermal power need high investment cost, and their installed generation capacity in energy safety scenario is much more than other scenarios. Electricity costs in energy safety scenario would increase from 0.409 Yuan/kW in the “twelfth five-year plan” period to 0.413 Yuan/kW in the “thirteen five-year plan” period. Taking pollutant and emission costs into consideration, new energy would have a competition advantage against thermal power.

Third, analyze from the aspect of the operation cost of energy system. All three scenarios keep increasing, and respectively achieve 128, 118 and 123 million in 2020. That is almost equal with the summation of GDPs of energy companies, mining and power generation equipment manufacturing and construction in the second industrial, which means the results are essentially correct. New energy investment cost only takes a small part of the system operation total cost, on average less than 1%. Table 15 shows power generation cost, electricity costs per kW in the end of the year and system operation total cost of each type of new energy in three scenarios.

5.3.2.Power generation environmental benefits

During the “thirteen five-year plan” period, as cumulative installed power generation capacity is increasing, the replacement amount that new energy replacing coal and “revenue ratio” of new energy are much higher than those in the “twelfth five-year plan” period. Reduced coal consumption cost takes 80% of the total revenue. When only considering environmental cost, new energy could have competition advantage against conventional energy. New energy revenues in three scenarios are listed in Table 16.

Table 15. New energy generation cost in China in three scenarios

	Basic situation		Energy safety scenario		Low-carbon scenario	
	Twelfth Five-Year Plan	Thirteen Five-Year Plan	Twelfth Five-Year Plan	Thirteen Five-Year Plan	Twelfth Five-Year Plan	Thirteen Five-Year Plan
Wind power/hundred million Yuan	1489	3031	1160	2933	1679	3675
Solar photovoltaic/hundred million Yuan	854	1517	670	1742	1015	1929
Solar thermal power/hundred million Yuan	157	358	123	449	209	693
Biomass power/hundred million Yuan	329	768	292	864	480	1479
Total power generation cost of new energy/ hundred million Yuan	2830	5674	2245	5987	3383	7775
Electricity cost per kW in the end of year/ Yuan/kWh	0.471	0.436	0.416	0.422	0.477	0.444
System operation total cost in the end of year/hundred million Yuan	100050	127759	95270	117633	99247	122985

Table 16. New energy revenues in three scenarios (hundred million yuan)

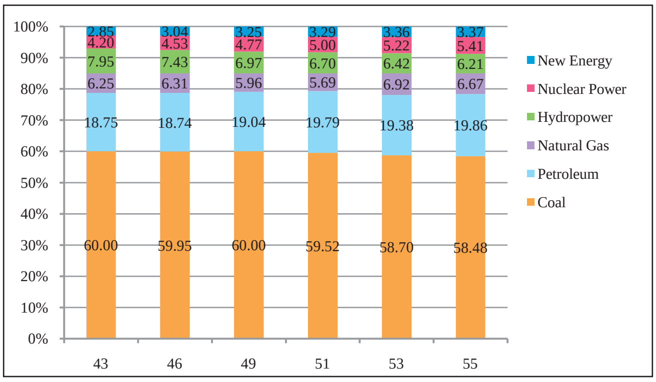
	Basic Situation		Energy Safety Scenario		Low-Carbon Scenario	
	Twelfth Five-Year Plan	Thirteen Five-Year Plan	Twelfth Five-Year Plan	Thirteen Five-Year Plan	Twelfth Five-Year Plan	Thirteen Five-Year Plan
Replacement amount/hundred million tec	2.58	6.19	2.02	6.74	3.04	8.36
Environmental benefits of pollutant emission reduction	480	998	373	1086	564	1347
Reduced carbon tax	58	151	46	164	69	203
Reduced coal consumption cost	2345	4872	1822	5302	2753	6576
Total revenue	2883	6021	2241	6552	3385	8126
Revenue-cost	54	346	-4	565	2	351
Revenue ratio	1.89	6.11	-0.17	9.45	0.05	4.52

5.4. Sensitive analysis

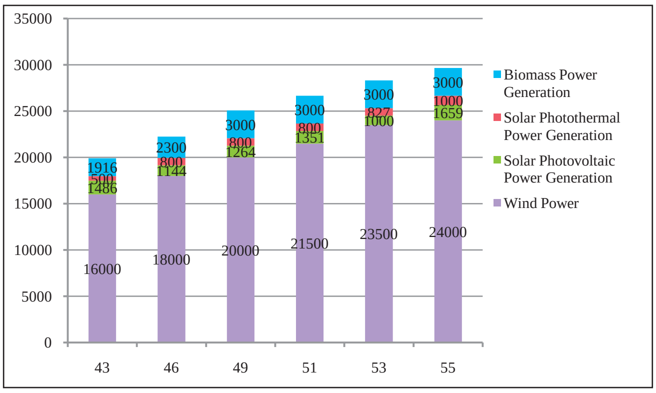
5.4.1. Sensitive analysis of the total cost of primary energy

The projected scenario sets total energy consumption amount in 2015 and 2020 are respectively 42 and 49 hundred million. But there would be some deviations in the actual development progress. In this section we change total cost of primary energy to see its influence on energy structure, new energy installed generation capacity, and cost-effectiveness. We set six development scenarios, wherein GDP and CO_2 emission upper limits are relative to load demand and energy consumption, all are listed in Table 17.

As primary energy consumption increases, coal consumption proportion would generally decrease, and can achieve a minimum of 58.5%. Petroleum consumption proportion would keep around 19% and natural gas can be a maximum proportion at 6.9%. Hydro power would keep decreasing because of its exploration limit, and its consumption proportion can be as low as 6.2%. Nuclear energy would experience a rapid development and become the main energy to meet no-fossil energy goal. New energy installed generation capacity and power generation proportion would improve gradually. And when energy consumption amount achieve 55 million tec, new energy installed generation capacity would be 3 hundred million and power generation proportion would be 5.5%, which respectively exceeds those in the projected scenario of 20% and 37.5%.



(a)



(b)

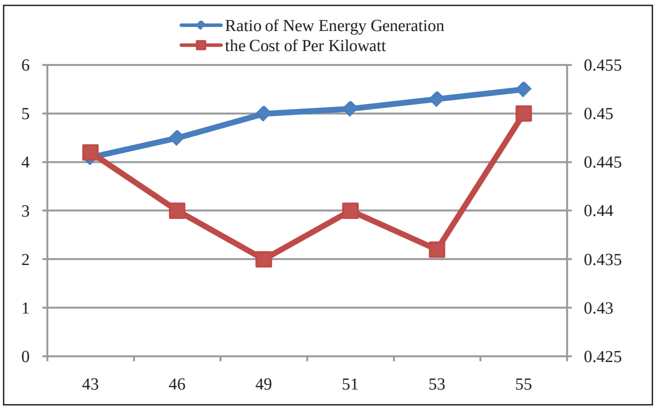
Fig. 4: The influence of primary energy consumption amount change on energy structure and new energy installed generation capacity

Average power generation cost has a positive relationship with solar power installed generation capacity. When solar power installed generation capacity increases, average power generation cost also increases. That means new energy electricity cost per kW changes in a non-linear trend. When it is waving from 0.435 To 0.455 Yuan/kWh, to reduce new energy power generation cost, we should give priority to the development of wind power, and develop large-scale solar energy when solar power generation technology is mature enough. Details are as shown in Fig. 5(a).

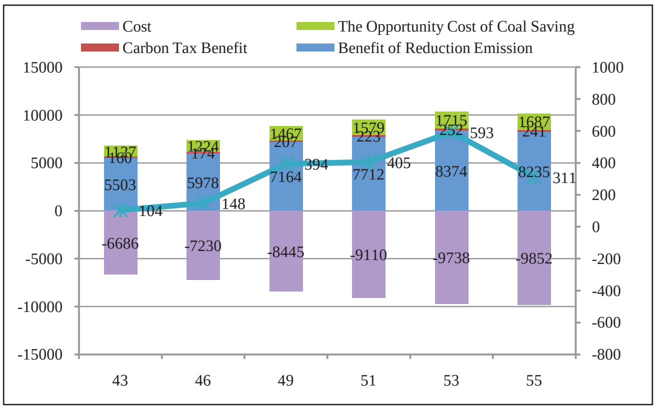
As new energy power generation increases, its environmental benefits gradually increases and can achieve a maximum value of 10000 hundred million Yuan. Reduced coal consumption cost takes 80% or more of the total revenue, followed by reduced pollutant emission cost. Investment and operation cost of new energy power generation devices are equal with environmental benefits. But if we do not take environment cost into consideration, costs would exceed revenue. Under the premise of non-fossil energy consumption occupying 15% of total energy consumption and developing solar energy as late as possible, the increase of total energy consumption would increase net revenue gradually. But when energy consumption amount is big enough to increase solar power exploration scale, net revenue would decrease. Details are as shown in Fig. 5(b).

Table 17. Parameters in the sensitive analysis of the total cost of primary energy

Key indicators	2015	2020	2015	2020	2015	2020
Scenario index	1	2	3			
Total primary consumption/million tec	38	43	40	46	42	49
Gdp/hundred million yuan	56.1	75.6	59.1	80.9	62	86.2
Co2emission amount/hundred million t	83.8	93.7	88.2	100.2	92.6	106.7
Total load demand/trillion kWh	6.15	8.25	6.3	8.45	6.45	8.58
Scenario index	4	5	6			
Total primary consumption/million tec	43.5	51	45	53	46	55
Gdp/hundred million yuan	64.2	89.7	66.5	93.2	67.9	96.7
Co2emission amount/hundred million t	95.9	111.1	99.2	115.4	101.4	119.8
Total load demand/trillion kWh	6.6	8.78	6.75	8.95	6.9	9.1



(a)



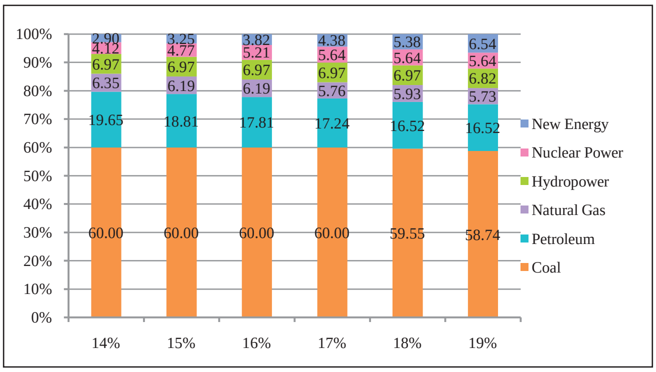
(b)

Fig. 5: The influence of primary energy consumption amount change on new energy power generation proportion, electricity cost per kW and power generation cost-effectiveness

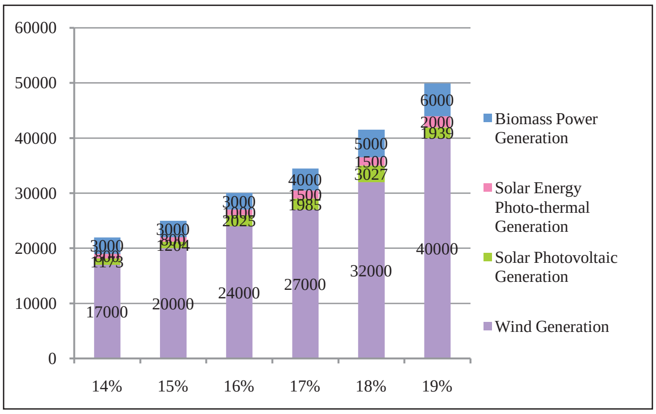
5.4.2. Sensitive analysis of non-fossil energy consumption proportion analysis

This sector would gradually improve non-fossil consumption proportion in 2020 to 19% to do a sensitive analysis. By adjusting relative fossil energy installed generation capacity upper limit to meet the requirement that non-fossil consumption proportion should be promoted. The total energy consumption change's impact on each variable is drawn in Fig. 6. Coal consumption proportion is limited in 60% and would influence by substitution effect of non-fossil energy. When non-fossil energy consumption proportion achieves 19%, consumption proportion statues of energies are following: coal consumption proportion would decrease to 58.7%; petroleum consumption proportion would be limited to production and import limits, and finally comes down to 16.5%; natural gas consumption proportion would decrease by 5.7%; hydro power consumption proportion would almost keep at 7%; nuclear consumption proportion would increase and finally remain steady at 5.6%; new energy would develop rapidly and its consumption proportion would come up to 6.5%, which is 3.3% more than projected (coal consumption proportion is 15%). As non-fossil consumption proportion increases, petroleum consumption proportion would be slashed at first, and followed by natural gas and coal consumption.

A substantial increase of new energy consumption proportion would improve its installed generation capacity at the same time. When non-fossil energy consumption proportion is 15%; new energy total installed generation capacity is 3 hundred million kW. But when it comes to 19%, the total installed generation capacity would achieve 5 hundred million kW. Wind power occupies the most proportion of new energy installed generation capacity, which exceeds 80%. And the second one is biomass power at 12%. Solar power takes less than 10%, owing to its high investment cost.



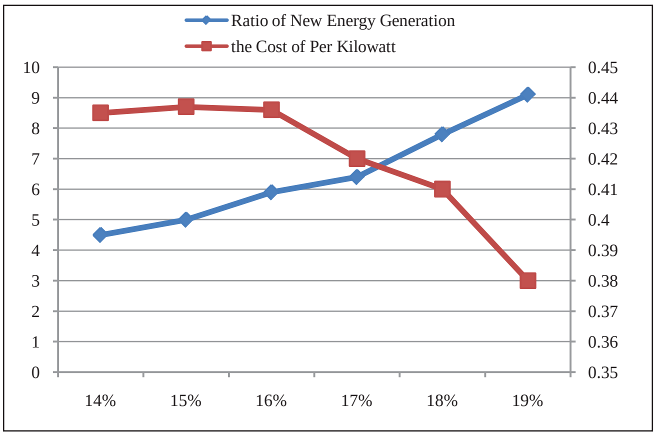
(a)



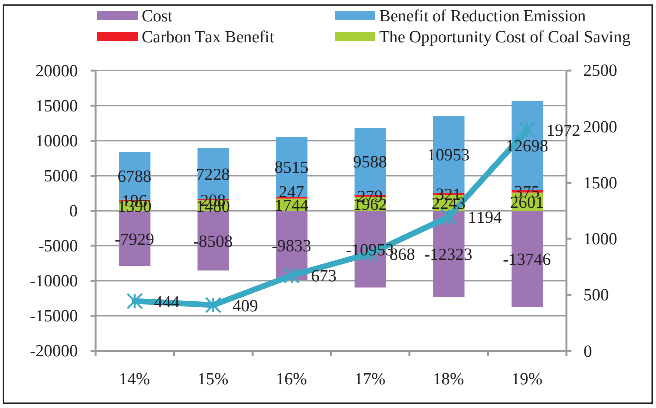
(b)

Fig. 6: The influence that non-fossil energy consumption proportion change on energy structure and new energy installed generation capacity

As non-fossil energy consumption proportion increases, new energy power generation proportion increases from 4% to 9%, and its electricity cost per kW gradually comes down from 0.44 Yuan/kWh to 0.38 Yuan/kWh. Environmental benefits would increase synchronously. When non-fossil energy consumption proportion is 19%, environmental benefit would be 15000 hundred million Yuan. Wherein reduced coal consumption cost takes more than 80%, followed by reduced pollutant emission cost. Equipment investment cost and operation cost are almost equal with environmental benefits. So if we do not take the internalization of environmental costs into consideration, its cost would be more than revenue. With non-fossil consumption proportion increasing, net revenue would gradually increase. Details are shown in Fig. 7.



(a)



(b)

Fig.7: The impact of non-fossil energy consumption proportion change on new energy power generation proportion, electricity cost per kW, and new energy power generation cost-effectiveness

5. Conclusions

Summing up the analysis above, we can draw following conclusions:

(1) During the "twelfth five-year plan" new energy power generation cost is quite high. But as its scale keeps expanding, power generation cost gradually comes down. During 2011-2015 new energy power generation average electricity cost per kW is 0.47 Yuan/kWh, higher than the grid tariff of desulphurization coal-fired units. But during 2016-2020 it becomes 0.43 Yuan/kWh, which has gained price advantages against conventional energy to some degree. If we take conventional energy pollutant emission cost and fossil consumption cost into consideration, new energy power generation would be an inevitable choice for energy development in China.

(2) During the "twelfth five-year plan" period new energy power generation cost is equal to environmental benefits. But in the future its environmental benefits would be far more than power generation cost. Integrating all kinds of scenarios, we can get some more objective results. In the "twelfth five-year plan" period, total cost of exploitation and utilization of new energy is about 2000-3000 hundred million Yuan, slightly less than environmental benefits. In the "thirteen five-year plan" period, it comes up to about 4000-6500 hundred million Yuan due to its scale expansion, and environmental benefits increase to about 5000-8000 hundred million Yuan. So if we see one decade as a whole, total revenue of new energy would be more than its total cost.

(3) Issuing environmental policies would conductive to improve the competitiveness of new energy against conventional energies. When considering pollutant emission tax and carbon tax, new energy in total power generation revenue would exceed its total power generation cost. But if we do not have supportive policies the total cost would be equal to, or exceed the total revenue, which leads to new energy's lack of competitiveness. So issuing environmental policies and relative financial policies can promote new energy development.

(4) Limiting petroleum consumption and improving clean energy consumption proportion would be conductive to cut down operation cost of energy system. In projected scenario, energy system operation cost in 2015 and 2020 are higher than that of other scenarios. As new energy exploittaion and utilization cost are decreasing, energy external dependence degree and total operation cost of the energy system would decrease synchronously, and this can be beneficial to macroeconomic development.

Acknowledgements

This work was supported by NSFC (grant no: 71771085)

References

1. Lin Boqiang, Yao Xin, Liu Xiying. (2010): "The Strategic Adjustment of Chinaps Energy use Structure in the Context of Energy-Saving and Carbon Emission Reducing Initiatives". *Social Science in China*, 01,58-71+222.
2. Zhang Weibo, Pan Yuchao, Cui Zhiqiang, Zhang Weidong. (2012): "New Energy Generation Development Approach in China". *Energy of China*, 04,26-28+41.
3. Zhang Xuanxuan. (2011): " Study on optimization of energy structure and countermeasures of new energy development during "The Twelfth Five-Year Plan Year Plan". *Shandong University of Science and Technology*.
4. Zhang Liying, Ye Yanlu, Xin Yaozhong, Han Feng, Fan Gaofeng. (2010): "Problems and measures of power grid accommodating large scale wind power". *Proceedings of the CSEE*, 25,1-9.
5. Lin Boqiang. (2009): "Power development method under lo-carbon economic". *China Power Enterprise Management*, 31,11- 14.
6. Liu Lancui, Gan Lin, Cao Dong, Jiang Hongqiang. (2009): "Analysis and enlightenment from climate policies of major economies". *Sino-Global Energy*, 09,1-8.

7. Yu Hua, Guo Zonglin, Chen Guangya, Chen Xin. (2011): " Energy industry statues and developing trends". *Electric Power*, 01, 83- 85.
8. Zhou Fengao, Cao Zhiguo. (2013): " Low-carbon development policies and the legal guarantee of China's electric power industry". *Journal of north China Electric Power University (Social Sciences)*, 01,1-7.
9. Wang Zhonghui, Wang Yanhua. (2013): " Talk aabout changing the way our generation from global climate changes". *Energy Conservation & Environmental Protection*, 01,52-54.
10. Ren Dongming. (2011): "New energy development and system innovation in China". *Sino-Global Energy*, 01,31-36.
11. Wang Hongyan, Li Jingming, Zhao Qun, Lin Yingji. (2009): " Resources and development of new energy in China". *Acta Petrolei Sinica*, 03,469-474.
12. Wang Yankang, Tang Jing.(2009): "Lessions from us energy policy and new energy development strategies in China". *Journal of Southwest Petroleum University (Social Sciences Edition)*,04,7-11+126.
13. Jiang Kai, Yang Meiying. (2010): "Development pattern of global new energy sources and enlightenment for China". *Water Resources and Power*, 01,151-154+53.
14. Meng Hao, Chen Yingjian. (2010): "Comprehensive assessment on developing capability of new energy industry". *Forum on Science and Technology in China*, 06,51-58.
15. Chen Wei. (2010): "Japanese new energy industry and sino-japan comparison". *China population, Resources and Environment*, 06,103-110.
16. Li Jingming, Wang Hongyan, Zhao Qun. (2008): "Potential and prospects on new energy sources in China". *Natural Gas Industry*, 01,149-153+179-180.
17. Kang Chongqing, Chen Qixin, Xia Qing. (2010): " Innovation incurred by carbon capture technologies utilized in power systems". *Automation of Electric Power Systems*, 01,1-7.
18. Wang Jun, Cai Xingguo, Ji Feng, Li Xianzhong. (2012): " Evaluation of Risk and Benefit of ATC Relating to University of Renewable Energy Power Generation". *Automation of Electric Power Systems*,14,108-112.
19. Wang Qiulin, Hou Yanshuang. (2009): "Electric power of strategy develop to deal with the challenge of the environment and climate changing in our country". *Ecological Economy*, 01,308-312.
20. Sun Rongfu, Zhang Tao, Liang Ji. (2011): "Evaluation and application of wind power integration capacity in power grid". *Automation of Electric Power Systems*, 04,70-76.
21. Song Xudong, Mo Juan, Xiang Tieyuan. (2013): "Initial alllocation mechanism of carbon smission permit in electric power industry". *Electric Power Automation Equipment*, 01,44-49.
22. State Grid Energy Institute. 2013 International Energy and Electricity Price Analysis Report 2013. Beijing: China Electric Power Press.
23. State Grid Energy Institute. 2013 China Energy Supply and Power Generation Development Analysis. 2013. Beijing: China Electric Power Press.
24. Bp.2012. Statiscal Review of World Energy 2012.
25. IEA.2011. Electric Information 2011.
26. State Grid Energy Institute. 2013 China Energy Generation Analysis Report. 2013. Beijing: China Electric Power Press.
27. IEA. 2011. CO_2 emission from fuel combustion 2011
28. IEA. 2011. World Electric Outlook 2011

APPLICATION OF FRACTURING AND REFORMING IN LOW PERMEABILITY AND TIGHT RESERVOIR OF MA-S DRAG REDUCER FRACTURING FLUID

Continued from page 540

References

1. Cheng Jun, Pei Jingui, Xu Fanghai, Wu Xiangyang. (2016): "The synthesis and application of a new type of drag-reducing agent for slippery water fracturing fluid", *Contemporary Chemical*, 45(3),456-459.
2. Du Kai, Zhao Fangyuan, Huang Fengxing, Yi Zhou, Zhang Wenlong.(2015): "Bio-shale pressure reducing agent preparation and characterization", *Journal of Beijing (Natural Science Edition)*, 42 (3),72-76.
3. Tang Hanqing. (2015): "The exploration and application of new type of pressure drop inhibitor for shale gas", *Chemical Engineering and Equipment*, 1(11),76-78.
4. Shao Limin. (2015): "The development and application of new type reducing resistance agent DR-12", *Energy Chemical*, 36(1), 44-47.
5. Li Jia, He Qiping, Cai Yuanhong, Pu Zufeng, Luo Zhiqin. (2014): "synthesis and application of anti-phase emulsion reducing agent", *Natural Gas Industry*, 3(1), 27-30.
6. Wei Hou, Ying Hua Shen, Hui Min Liu, Aiqin Zhang, Sheng Dai. (2014): "Mechanical properties of pH-responsive poly (2-hydroxyethyl methacrylate/methacrylic acid) microgels prepared by inverse microemulsion polymerization", *Reactive & Functional Polymers*, 74 (1),101–106.
7. Kui Zhang,Qian Wang, Hong Meng, Mian Wang, Wei Wu, Jianfeng Chen.(2014): "Preparation of polyacrylamide/ silica composite capsules by inverse Pickering emulsion polymerization" Contents lists available at Science Direct, Particuology, 14 (1),12–18.
8. Zhang, W.H., Fan, X.D, Tian, W, & Fan,W.W.(2012): "Polystyrene/nano-SiO_2 composite microspheres fabricated by Pickering emulsion polymerization: Preparation mechanisms and thermal properties". *Polymer Letters*, 6(1),532–542.
9. Plumeré, N., Ruff, A., Speiser, B., Feldmann, V. & Mayer, H.A. Stöber, (2012): "Silica particles as basis for redox modifications: Particle shape, size polydispersity and porosity". *Journal of Colloid and Interface Science*, 368(1),208–219.
10. Dong Ho Yoon, Jung Won Jang, In Woo Cheonga, (2012): "Synthesis of cationic polyacrylamide/silica nanocomposites from inverse emulsion polymerization and their flocculation property for papermaking", *Colloids and Surfaces A: Physicochem. Eng. Aspects*, 4(1),18-23