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Comprehensive assessment of hydrocarbon resources carrying capacity—take China for example

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Abstract

Hydrocarbon resources carrying capacity (HRCC) is utilized to assess the degree of oil and gas (O&G) resources for meeting the demand of regional economy and sustainable development of society. The higher the degree, the bigger the capacity is. A novel assessment system focuses on regional production capacity is developed in this paper. Specifically, to perform comprehensive assessment for an area, the main influence factors of HRCC are fully investigated first. Then, the energy consumption structure and the supply-demand situation of O&G in this area are analyzed. Based on the aforementioned analysis, O&G production and consumption of this area in the future time can be predicted. Afterwards, the most influential factors are selected on the basis of the investigation of all influence factors and the recognition of the area. Moreover, to carry out effectively assessment, the whole study area is divided into several assessment units based on their geological condition. Finally, we can construct an assessment system for assessing the HRCC comprehensively. In this paper, the developed assessment system was applied to evaluate the HRCC of China, which contains 23 assessment units (all of them are petroliferous basin). It is reported that 12 most influential factors, including geological resources, unproved geological resources, recoverable reserves, unproved reserves, remaining recoverable reserves, annual production, recovery efficiency, grade of O&G, buried depth of O&G, acreage of the assessment unit, landform of the assessment unit, and traffic condition are selected for all the 23 units, through the factors in different assessment units are varied. Furthermore, as predicted, the O&G production of China in the future 15 years will be 2.59×10^8t and $2642.33\times10^8m^3$ while the O&G consumption will be about 7.09×10^8t and $5127\times10^8m^3$. Accordingly, the comprehensive assessment HRCC indicates that Bohai Bay basin has the maximum oil carrying capacity while the Erdos basin is endowed with the maximum gas carrying capacity.

Keywords: Oil and gas; Carrying capacity; Predict; Assessment system

1. Introduction

China is the largest developing country in the world. It has maintained an extensive growth in both economic aggregate and energy consumption since the economic reform and the opening up initiated in 1978 [1]. Especially, sustained economic growth of China makes rapid increase of oil and gas (O&G) demand. The foreign dependence ratio of oil in China has been over 50% since 2009 as shown in Fig. 1. In 2015, the apparent O&G consumption of China is estimated to be 543 million tons, in which more than 60% depends on import [2]. Therefore, whether or not the O&G can support the sustainable development of economic and society has become a more concerned problem, which affects the energy planning deeply.

To assess the degree of O&G resources for meeting the demand of regional economy and sustainable development of society, this paper put forward the concept of hydrocarbon resources carrying capacity (HRCC). The higher the degree, the bigger the capacity is. Generally speaking, HRCC is comprised of regional production capacity of O&G, supply capacity of imported O&G, emergency capacity of O&G storage, and the promoted carrying capacity from energy-saving, cost-reducing as well as the development and utilization of new energy. Due to the regional production capacity is a crucial component for the assessment of HRCC, especially for the HRCC assessment of China, a novel assessment system focuses on regional production capacity is developed in this paper.

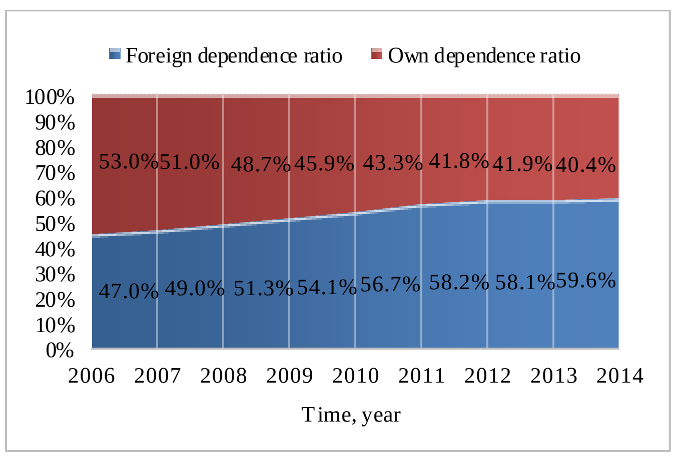

Fig. 1 Data of Oil consumption in China.

Due to reasonable knowledge of past energy consumption, present energy consumption, and likely future demands are essential for perceived optimum of the energy demand management activities [3], multi-cyclic hubbert (MCH) model and energy consumption elasticity coefficient (ECEC) model are respectively utilized for O&G production and consumption predicting in the presented assessment system. Then, analytic hierarchy process (AHP) is used to determine evaluation index weights. Afterwards, production and demand of O&G are forecasted up to year 2030 on the basis of the obtained results of MCH, ECEC, and AHP.

2. Methodology review

In this section, the MCH model for O&G production predicting, the ECEC model for O&G consumption predicting, and the AHP for determining evaluation index weights are briefly reviewed in Section 2.1, 2.2, and 2.3, respectively.

2.1 MCH (*Multi-cyclic hubbert model*)

Hubbert model, as one of the famous growth curve models, is derived from logistic model [4]. The growth curve model is usually made up of life growing period, growth period, and stationary growth stage [6-8]. In this paper, hubbert model is used to predict the change trend of O&G production due to all the basins will go through the evolution from appearance to die out [4].

In the previous literatures, Laherrere et al [7-8] preformed the hubbert model with one cycle (Monocyclic hubbert model). The utilized mathematically equation in the hubbert model is shown in Eq. (1) as follows:

$$Q = \frac{2Q_m}{1+\cosh[b(t-t_m)]} \quad (1)$$

where Q and Q_m are the annual production and the peak value, respectively, b is the parameter controls the size of the curve opening, t is the year, t_m is the year the peak value occurs. The Solution of the Parameters can be calculated as shown in Fig.2.

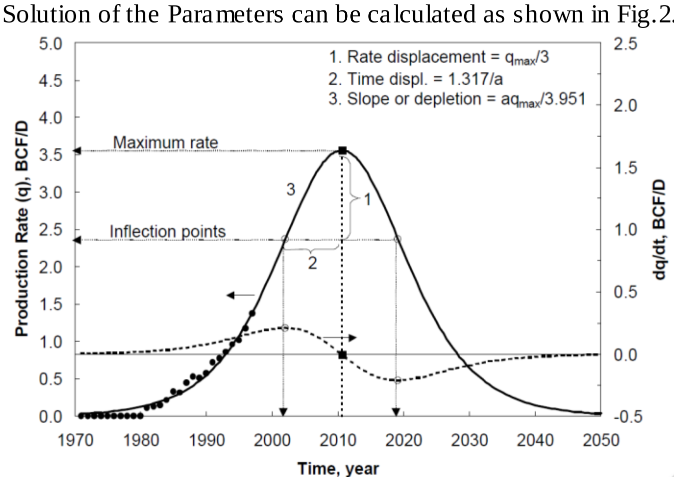

Fig. 2 The solution of Monocyclic hubbert modeling[8].

Recently, some multiple hubbert models with one cycle accumulated, namely multi-cyclic hubbert (MCH) model is presented in [9-10], which can be demonstrated as shown in Fig.3. The Eq. (1) is modified to Eq. (2) as follows:

$$Q = \sum_{i=1}^{k} \frac{2(Q_m)_i}{\{1+\cosh[b(t-t_m)]\}_i} \quad (2)$$

where k and i are the number of cycles.

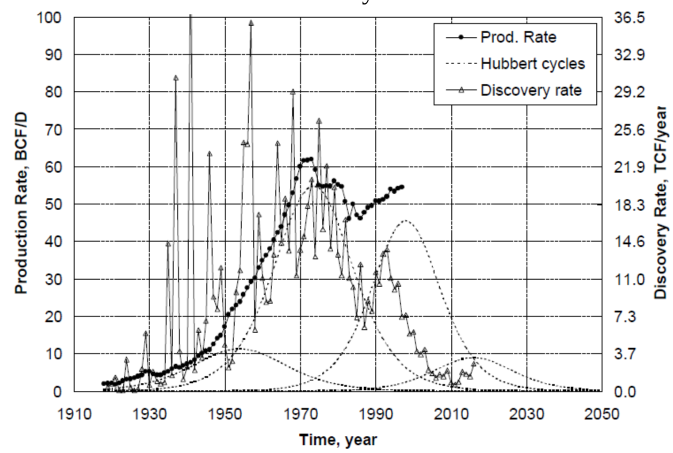

Fig. 3 The building of multi-cyclic Hubbert model [8].

2.2 ECEC (energy consumption elasticity coefficient model)

In this section, the energy consumption elasticity coefficient (ECEC) is used to analyse the relationship between economic development and energy consumption[11]. The related equations of ECEC are shown in Eqs. (3)-(4) as follows :

$$e_t = \frac{ECGR}{GDP_{\text{growth}}} \times 100\% \quad (3)$$

$$E_n = \left(\frac{E_0 \prod_{t=t_0}^{t_{0+n-1}} (1+e_t M)}{GDP_n} - \mu_n\right) GDP_n \quad (4)$$

where ECGR is the energy consumption growth rate; GDP_{growth} is the GDP growth rate; E_0 and E_n are the energy consumption in the reference period and the energy consumption in one year, respectively; M is the average annual growth rate of GDP; μ is the number of cycles, n is the serial number of one year.

2.3 AHP (*Analytic Hierarchy Process*)

The Analytic Hierarchy Process (AHP) is a decision-aiding method developed by T.L.Saaty [12-13]. Both quantitative and qualitative factors are considered when Decision-makers Make the final decision. On one hand, the AHP aims at quantifying relative priorities for a given set of alternatives on aratio scale based on the judgment of the decision-maker. On the other hand, it stresses the importance of the intuitive judgments of a decision-maker and the consistency of the comparison of alternatives in the decision-making process [13]. Matching AHP，HRCC demands both quantitative index and qualitative index.

The mainly process of AHP contains the following 3 steps:

Step 1: Select reasonable evaluation indicators and build the hierarchical structure of the synthetical evaluation model.

Step 2: Figure out the index weight. The indexes are assigned by expert experience method and average assignment method, and it is got the weight table of evaluation index.

Step 3: Using weighted sum method to calculate the final value of the index.

3. The proposed evaluation system

The whole flowchart of the proposed evaluation system mainly consists of five components as shown in Fig. 4. The first step is to analyse the energy consumption structure and the supply and demand status of O&G for understanding the background of the assessment. Accordingly, the production and consumption of O&G in the future years can be forecasted as show in the following step. Afterwards, the most influential factors can be selected on the basis of the investigation of all influence factors and the recognition of the area. In the fourth component, to carry out effectively assessment, the whole study area is divided into several assessment units based on their geological condition. Finally, the proposed assessment system for assessing the HRCC comprehensively is constructed.[16]

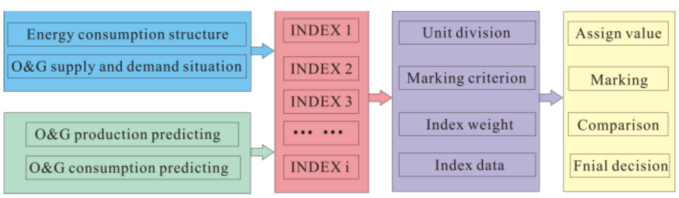

Fig. 4 Evaluation system of HRCC

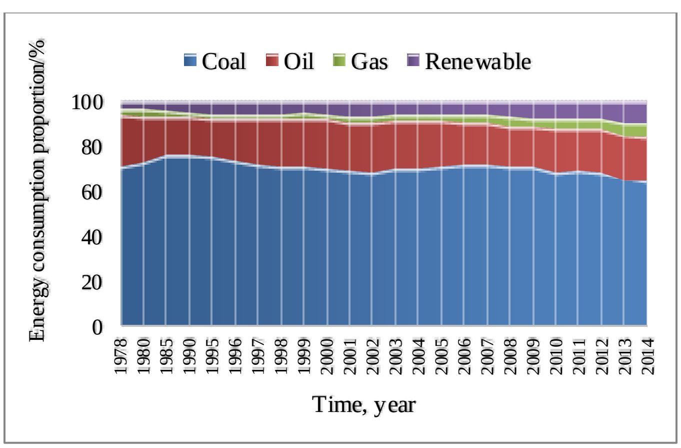

Fig. 5 The energy consumption structure of China.

Fig. 5 shows the energy consumption structure of China and Figs. 6-7 display the supply and demand situation of Oil Gas in China. As shown in Fig. 5, the analysis of energy consumption structure of China reported that the proportion of O&G consumption is increased by years in recent years. By comparison, data in Fig. 6 and Fig. 7 revealed that the energy demand for O&G has exceeded the supply for many years.

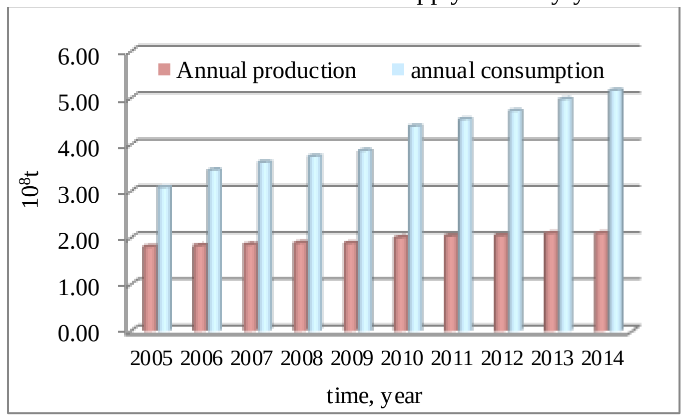

Fig. 6 The supply and demand situation of Oil in China.

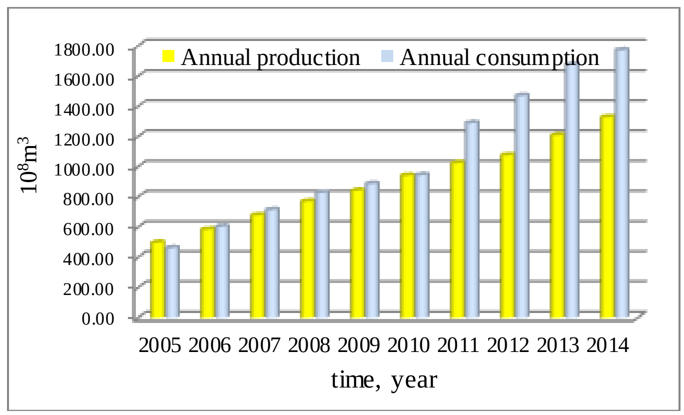

Fig. 7 The supply and demand situation of Gas in China.

Table 1 Evaluation index.

Objective	Factors	Index
HRCC	resource endowment	A: geological resources
		B: unproved geological resources
	Reserves	C: recoverable reserves
		D: unproved reserves
		E: remaining recoverable reserves
	Production	F: annual production
		G: recovery efficiency
	Quality	H: grade
		I: buried depth
	Geographical conditions	J: acreage
		K: landform
		L: traffic condition

As the hydrocarbon in China distributed as basins or belts, quantity, types, grade, and mining conditions of O&G are very different in different basins. Therefore, basin is selected to be the evaluation unit. 12 most influential factors are selected to be used in the evaluation system as reported in Table 1[15].

4. Results and discussions

4.1 Production predicting

As described in Sections 2-3, the MCH is applied to forecast the annual production of the petroliferous basin in China. As the forecasted results shown in Tables 2-3, the sum of all of the basin's predicting values are the ultimate forecasted results of China.

Table 2 The predicting results of oil production.

BASIN	2020/10^4t	2025/10^4t	2030/10^4t
Songliao	4195.17	4062.61	4100.66
Bohai Bay(land)	5039.95	5085.84	4670.56
Nanxiang	166.86	169.88	163.65
Erdos	3435.12	3859.83	4071.52
Sichuan	21.23	23.42	25.60
Northern Jiangsu	174.93	167.95	156.72
Jianghan	106.00	103.65	97.00
Qaidam	330.79	376.33	402.83
Jiuquan	77.26	86.47	90.23
Junggar	1997.56	2208.96	2350.24
Tarim	2383.11	2901.14	3305.90
Tuha	313.34	336.57	342.17
Bohai Bay(sea)	2395.28	2915.82	3339.05
Pearl river mout	1287.47	1392.86	1150.88
Beibu Wan	573.91	798.23	900.00
Donghai	67.40	41.83	40.98

Table 3 The predicting results of gas production.

BASIN	2020/10^8m^3	2025/10^8m^3	2030/10^8m^3
Songliao	116.30	148.19	161.37
Bohai Bay(land)	45.73	53.79	57.11
Nanxiang	0.74	0.79	0.83
Erdos	510.95	519.26	545.22
Sichuan	446.87	559.63	640.52
Northern Jiangsu	0.50	0.60	0.64
Jianghan	1.55	1.53	1.55
Qaidam	107.38	137.85	160.62
Jiuquan	0.30	0.28	0.24
Junggar	54.03	63.29	69.00
Tarim	370.31	470.61	537.81
Tuha	14.08	26.32	35.22
Bohai Bay(sea)	18.20	23.07	25.08
Pearl river mout	29.57	61.97	89.01
Donghai	17.29	48.33	96.64
Yinggehai	98.44	90.96	86.18
Qiongdongnan	49.81	59.89	67.27

As predicted, the annual O&G production of China in the future 15 years will be 2.59×10^8t and $2642.33\times10^8m^3$.

4.2 Consumption predicting

In this section, O&G consumption of China in the future 15 year is predicted. As demanded in Eqs. (3)-(4) of ECEC model, the hypothesis of GDP growth rate is made before predicting the O&G consumption. As shown in Fig. 8, the hypothesis of GDP growth rate is divided into 3 cases first.

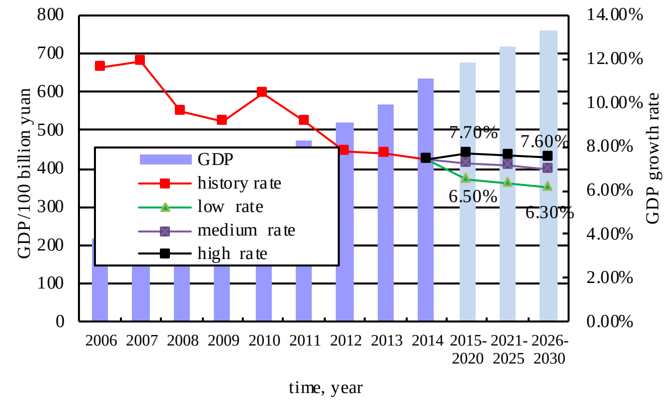

Fig. 8 GDP growth rate of China in the future years.

In this paper, energy consumption elasticity coefficient was set to be 0.45, 0.4, 0.35, respectively in 2015~2020, 2020~2025, 2025~2030[17-19].

On the basis of the predicted GDP growth rate above, the energy consumption structure in China is predicted as shown in Table 4.

Table 4 The predicting results of energy structure.

YEAR	Coal	Oil	Gas	renewable
2020	＜57%	18.5%	10%	15%
2025	＜51%	18%	13%	18%
2030	＜45%	18%	16%	21%

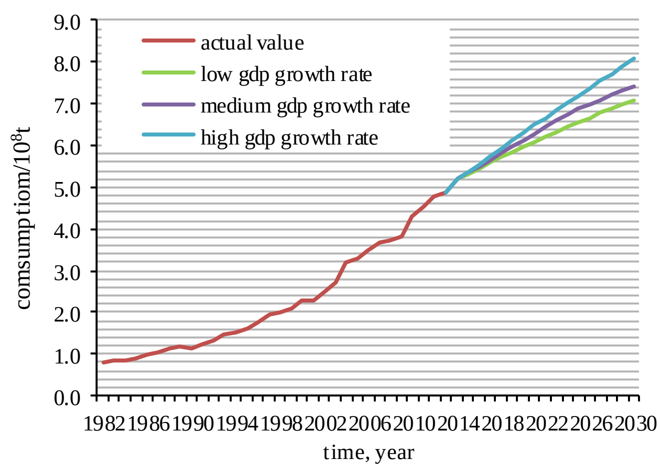

Fig. 9 The predicting results of oil consumption.

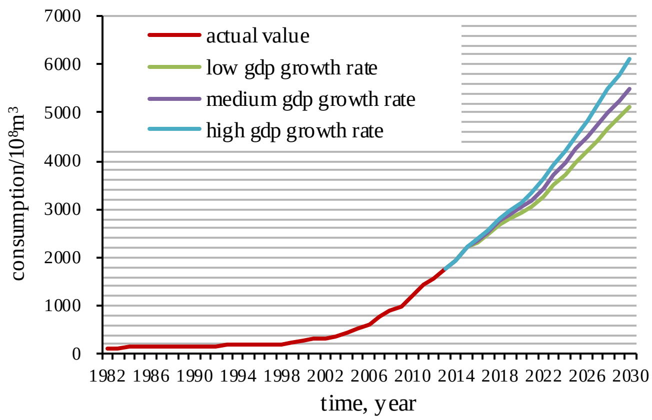

Fig. 10 The predicting results of gas consumption.

As predicted, the annual Oil Consumption of China in the future 15 years will be $7.08\sim8.0\times10^8 t$ and the annual Gas Consumption will be $5127\sim6133\times10^8 m^3$ as illustrated in Figs. 9-10.

4.3 Regional HRCC calculating

Following the selected 12 indexes displayed in Table 1, the pair-wise comparison matrix(X) for experience was established based on AHP. The produced results calculated as Eq.(5) are shown in Table 5.

$$x_{ij}=1,\quad x_{ij} = 1/x_{ij}\quad (i,j= 1,2,\ldots,n) \tag{5}$$

$$XW=\lambda_{max}*W \tag{6}$$

where λ_{max} is the maximum eigenvalue of X， W is the normalized eigenvector of λ_{max}.

Table 5 The pair-wise comparison matrix(X) for experience.

	A	B	C	D	E	F	G	H	I	J	K	L
A	1	4	1/5	3	1/4	1/5	1/2	4	6	4	5	8
B	1/4	1	1/7	1/4	1/5	1/6	1/3	5	7	3	4	5
C	5	7	1	3	1/3	1/4	1/2	6	8	5	7	9
D	1/3	4	1/3	1	1/4	1/6	1/3	4	5	4	5	6
E	4	5	3	4	1	1/2	1/2	5	6	6	7	7
F	5	6	4	6	2	1	1/3	8	9	7	8	8
G	2	3	2	3	2	3	1	4	5	5	5	5
H	1/4	1/5	1/6	1/4	1/5	1/8	1/4	1	4	3	3	5
I	1/6	1/7	1/8	1/5	1/6	1/9	1/5	1/4	1	2	2	3
J	1/4	1/3	1/5	1/4	1/6	1/7	1/5	1/3	1/2	1	2	2
K	1/5	1/4	1/7	1/5	1/7	1/8	1/5	1/3	1/2	1/2	1	3
L	1/8	1/5	1/9	1/6	1/7	1/8	1/5	1/5	1/3	1/2	1/3	1

Then,calculate the vector W based on Table 5 and Eq.(6). Vector W is perceived as the weight vector for the 12 indexes as follows:

W=(0.09, 0.05, 0.15, 0.08, 0.16, 0.21, 0.14, 0.04, 0.02, 0.03, 0.02, 0.01), CR=0.015 ＜ 0.1

In the base of the former work, comprehensive assessment of all the 23 petroliferous basins is made. The actual data of the 12 indexes has been got before the index are scored. Final score of each basin is the sum of the 12 indexes' scores multiplied by weighting coefficients (W). The results are reported in Table 6.

Table 6 HRCC result of O&G.

BASIN	Oil score	Gas score
Bohai Bay(land)	**66.89**	34.15
Songliao	**63.85**	49.23
Erdos	**60.09**	**84.32**
Tarim	48.83	**76.16**
Bohai Bay(sea)	47	27.36
Junggar	37.86	37.26
Pearl river mout	29	35.12
Hailar	23.54	8.25
Qaidam	20.39	11.43
Erlian	19.54	6.84
Tuha	17.25	19.35
Beibu Wan	17.86	11.24
Donghai	16.51	50.07
Jiuquan	10.07	12.54
Jianghan	12.78	13.43
Sichuan	15.02	**72.3**
Northern Jiangsu	16.98	20.12
Nanxiang	14.97	6.34
Qiongdongnan	10.94	41.9
Santanghu	16.65	8.23
Yanqi	9.36	6.21
Baise	9.75	5.63
Yinggehai	4.22	48.68

From Table 6, we can concluded that Bohai Bay (land) basin, Songliao basin, and Erdos basin have the larger oil carrying capacity while the Erdos basin, Tarim basin, and Sichuan basin are endowed with the larger gas carrying capacity.

5. Conclusions

In this paper, a novel comprehensive assessment system of hydrocarbon resources carrying capacity (HRCC) is developed in this paper. To be specific, the energy consumption structure and the supply and demand situation of O&G is analysed first. Then, based on the predicting of production and demand of O&G in the future years using MCH model and ECEC model is conducted in a macroscopic view. Moreover, the study proven that geological resources, unproved geological resources, recoverable reserves, unproved reserves, remaining recoverable reserves, annual production, recovery efficiency, grade of O&G, buried depth of O&G, acreage of the assessment unit, landform of the assessment unit, and traffic condition are 12 specific practicable quantized indexes, which can reflect the HRCC fully. Accordingly, the HRCC can be assessed.

The final prediction results shown that the O&G demand of China will keep a continued growth in the future 15 years. As predicted, the O&G production of China will be $2.59\times10^8 t$ and $2642.33\times10^8 m^3$ in 2030 while the consumption will be $7.08\sim8.0\times10^8 t$ and $5127\sim6133\times10^8 m^3$. The results also reveals that Bohai Bay (land) basin, Songliao basin, and Erdos basin have the larger oil carrying capacity while the Erdos basin, Tarim basin, and Sichuan basin are endowed with the larger gas carrying capacity.

Abbreviations

AHP:	Analytic hierarchy process
ECEC:	Energy consumption elasticity coefficient model
GDP:	Gross Domestic Product
HRCC:	hydrocarbon resources carrying capacity
MCH:	Multi-cyclic hubbert model
O&G:	Oil and gas

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Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
Dr. Kumar is visiting faculty at Prince of Songkla University, Thailand. He have 16 years of research and teaching experience in the field of solar energy, drying and energy efficiency.

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