



Exploring temporal and spatial evolution of global energy production and consumption



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ABSTRACT

The purpose of this paper is to use a center of gravity theory to study the spatial distribution and centers of gravity for the global energy supply and consumption and to determine how they have changed over time. In 2011, Middle East was the biggest oil producer and Asia Pacific was the biggest oil consumer; Europe and Eurasia was the biggest natural gas producer and consumer; Asia Pacific was the biggest coal producer and consumer. The center of gravity for oil production is an overall movement towards the northeast. Compared with the shift of the center of gravity for crude oil production, that for oil consumption is an overall movement towards the southeast. The center of gravity for natural gas production and consumption moved towards the east. Our results also show that the center of gravity for coal production is an overall movement towards the southeast.

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1. Introduction

Energy source is the basic element of socio-economic development. Energy supply and security has become the major issues of the development of human society and global political and economic pattern. Countries in the world have natural resource endowment conditions and different economic development level. Thus, energy supply and consumption of different countries also have some geographical differences. It is very meaningful to study temporal and spatial evolution of global energy supply and consumption, which can better know about how the center of the global energy

supply and consumption has changed. To accomplish this purpose, the center of gravity theory is a useful tool.

The concept of a center of gravity was first used to study population problems in the United States by Hilgard [6]. That concept derives from physics, and represents the point at which the distribution would balance if it were represented by weighted points on a weight less line, plane, or sphere [10]. Nowadays, the concept of a center of gravity has been commonly used to study geographic distributions of many fields. Duan et al. [2] studied the characteristics and law of the population distribution evolution in the Changjiang River Delta since the beginning of the reform and open-up of China. Movement of the gravity of carbon emissions per capita was analyzed by Wang et al. [14]. Peng and Lin [13] analyzed the temporal and spatial evolution of SO₂ and industrial dust emissions of energy consumption. Fu et al. [4] utilized the model of regional gravity

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center to study the consumption gravity center and economic gravity center of Xinjiang during 1965–2009. A spatially explicit ecosystem services value index and gravity model were used to explore spatial change and gravity center movement for ecosystem services value [5]. The theory has been used to study the movement of centers of gravity related to economic parameters [7,9]. Liang and Zhang [12] studied the measure and analysis on the spatial inequality of urban energy consumption in China.

Some researchers also utilized the theory of centers of gravity to study the temporal and spatial differences of energy consumption. Fesharaki [3] argued that Asia has become the center of gravity of the world energy system. Based on the theory of centers of gravity, the spatial distribution and the application prospects of coal resource, economic potentials were analyzed by Wang et al. [15]. Li et al. [11] studied the change of the spatial pattern of rural energy consumption in China. Zhang et al. [16] also utilized this theory measured how China's energy production and consumption centers changed from 1997 to 2009. So far many researchers have paid more attention to different aspects of world energy supply and consumption. The Hierarchical Partial Least Squares model (Hi_PLS) was used to study spatial differences and influencing factors of global energy consumption [8]. However, no study has been devoted to explore the spatial distribution and centers of gravity for the global energy supply and consumption. This paper attempts to analyze the temporal and spatial evolution of global energy supply and consumption based on the theory of centers of gravity.

The remainder of paper is organized as follows: Section 2 presents the gravity model and the related data in this paper. The main results are presented in Section 3. The conclusions drawn are summarized in Section 4.

2. Gravity model and data

The position of the center of gravity in year t , (X^t, Y^t) , is expressed as follows,

$$X^t = \frac{\sum_{i=1}^n M_i^t \times x_i}{\sum_{i=1}^n M_i^t} \quad (1)$$

$$Y^t = \frac{\sum_{i=1}^n M_i^t \times y_i}{\sum_{i=1}^n M_i^t} \quad (2)$$

where M_i^t represents the property value of i region in year t ; (x_i, y_i) is the coordinate of i region.

The spatial distribution and centers of gravity for world energy production consumption is analyzed. Since the capital is a country's economic and political center, this paper uses the longitude and latitude coordinates of each countries capital city represent the coordinate of its region. Each countries energy production and consumption represents the property value of a region. The position of the center of gravity is then calculated using a combination of the geographical coordinates of each country and their corresponding property value. The longitude and latitude coordinates of each country capital city come from Google Earth. The related data over 1965–2011 in this paper has been collected from the BP Statistical Yearbook ([1]). The energy data is measured in standard oil consumption in Mtoe (million tones of oil equivalent). This paper only considers three energy types: oil, natural gas, and coal.

3. Main results

3.1. Oil production and consumption

World oil production increased from 1567.87 Mtoe in 1965 to 3995.62 Mtoe in 2011, representing an annual average growth rate

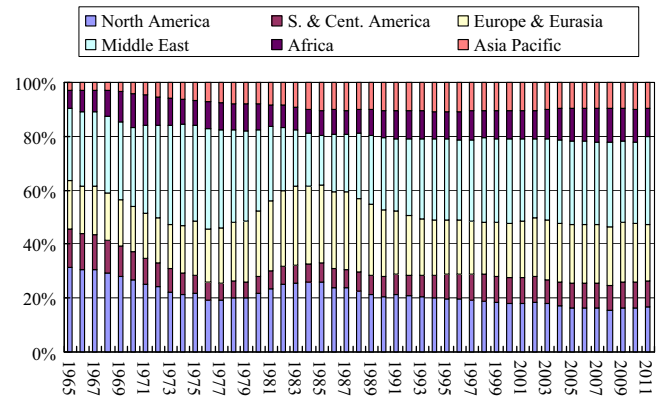


Fig. 1. Oil production share in the world.

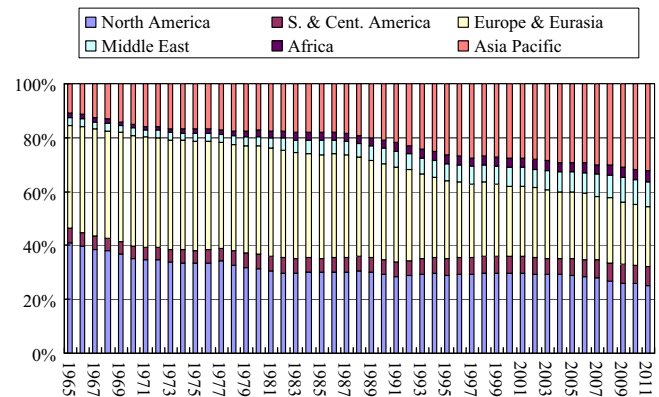


Fig. 2. Oil consumption share in the world.

of 2.05%. In 1965, North America was the largest oil producer, followed by Middle East, Europe and Eurasia, S. and Cent. America. But the share of Asia Pacific in world oil production only accounted for 2.86% in 1965. However, Middle East, as the largest oil producer, produced 1301.41 Mtoe in 2011, which accounted for 32.57% of world oil production. The oil production share in the world is presented in Fig. 1, which shows that there is a substitution between the increasing shares of Middle East (from 26.70% in 1965 to 36.57% in 2011) and a decreasing share of North America (from 31.22% in 1965 to 16.76% in 2011). Since 1979, the share of Middle East had presented a declining trend and reached the lowest point (18.46%) in 1985. During 1965–2011, the growth speed of crude oil production of Asia Pacific was the fastest, representing an annual average growth rate of 4.8%. Its share reached 9.71% in 2011.

In 2011, the world oil consumption reached to 4059.07 Mtoe from 1512.8 Mtoe in 1965, with an average annual growth rate of 1.1%. In 1965, North America was biggest oil consumer, followed by Europe and Eurasia, and Asia Pacific, as shown in Fig. 2. Since 2004, Asia Pacific has exceeded North America and become the biggest oil consumer. There is a clear substitution between the increasing shares of Asia Pacific (from 10.8% in 1965 to 32.4% in 2011) and Middle East (from 3.1% in 1965 to 9.1% in 2011) and a decreasing share of North America (from 40.9% in 1965 to 25.2% in 2011) and Europe and Eurasia (from 37.9% in 1965 to 22.1% in 2011). Over the period 1965–2011, annual average growth rate of Asia Pacific, Middle East, and Africa exceeded 4%.

Figs. 3 and 4 present the changes in the centers of gravity for world oil production consumption. During 1965–2011, the center of gravity for oil production was between 22.21W and 13.50E and between 28.55N and 30.09N. In contrast, the oil consumption

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