Journal of Cleaner Production xxx (2017) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Impacts of urban transformation on water footprint and sustainable energy in Shanghai, China

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ARTICLE INFO

Article history:
Received 30 November 2016
Received in revised form
17 August 2017
Accepted 18 August 2017
Available online xxx

Handling Editor: Yutao Wang

Keywords:
Urban transformation
Sustainable energy
Water footprint
Regional input-output approach
Shanghai

ABSTRACT

For the past three decades, the notion of sustainable cities has become central in planning and managing urban areas in the world and the large-scale city formation has been formed in big cities. As a result of economic growth and urban transformation, Shanghai, a major Chinese international metropolis, faces ongoing issues with resource waste and low energy utilization. Therefore, this paper aims to consider the availability of water for energy production from a consumption-based perspective and estimate the water footprint of the energy supply using a regional input-output analysis approach for Shanghai. As a result, we conclude that the water footprint of the energy supply of Shanghai is about 1.28 billion m^3 in 2007, with 46.1% of water used for electricity and heat supply. The total water withdrawal by the energy sector is about 2.35 billion m^3 and additional water withdrawal needed is about 35% of the total water withdrawals by the energy sector in Shanghai. Furthermore, an energy self-sufficiency scenario was developed, and the scenario analysis reveals that 55% more water would be required to ensure a self-sufficient energy sector. To guarantee future regional energy security, it is important to manage water resources effectively by allocating water resources among sectors.

1. Introduction

Since 2007, more than half of the world's population has been living in cities for the first time in human history. Catalyzing sustainable urban transformation has become a key component of economic development that requires a significant concentration of water resources and energy consumption in cities (Zhang et al., 2016). Furthermore, because water is used extensively in energy development, water resources and energy are inextricably linked (Deng et al., 2015a). More specifically, the process of pumping, treatment, and distribution of water and wastewater constitutes one of the largest energy use sectors in many major cities of developed countries (Hightower, 2013). For example, around 39% of all freshwater withdrawals in US cities are used for thermoelectric energy production, which is roughly the same amount used for irrigation. With 1–18% of electrical energy in urban areas being used to treat and transport water and wastewater (Olsson, 2016), it is essential that authorities take water resources into account while formulating energy policy.

Energy is one of the key elements needed for sustaining human life as well as a host of activities such as building operation, transportation, household activities, manufacturing, and construction (X. Zhang et al., 2012). Global and regional demand for water and energy is projected to continue to increase at least until 2030, while climate change is expected to affect water availability over the long term. Water and energy are indispensable to human beings, and are the most critical elements of sustainable economic development (Olsson, 2016). According to National Intelligence Council, the demand for water and energy will grow by approximately 40% and 50%, respectively by 2030 because of increasing global population and the consumption patterns of an expanding middle class. Consequently, water stress will also increase in the coming years. Furthermore, climate change will increase the difficulty of securing water resources (Wang et al., 2015; Li et al., 2015). China is currently the largest energy consumer in the world (Wu, 2014), and is already under tremendous energy pressure. It is

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http://dx.doi.org/10.1016/j.jclepro.2017.08.157
0959-6526/

urgent that the problem of energy shortage be taken into consideration in the near term. The question then arises, how can we guarantee a constant energy supply with the successive rising demand and falling availability of water?

Distribution of water requires large amounts of energy, and the production of energy also requires large amounts of water for various processes such as thermal plant cooling systems or raw materials extraction. Many scientists have researched water used for producing energy from a production perspective. They found that the amount of water required to produce energy differed by the type of energy production (Gerbens-Leenes et al., 2009) and by region (Pfister et al., 2011). The development of energy production technology and transportation systems also affect the amount of water required. As long as energy for local consumption consists of local and imported energy, the water used for energy production can be also divided into two parts: domestic and exotic. Hence, dividing the energy applications of water into energy supply and energy production is scientifically reasonable (Okadera et al., 2015).

In this article, we adopt a water footprint (WF) analysis approach to evaluate water for energy supply and production. This method combines the consumption-based bottom-up approach and the input-output analysis approach, and has been applied widely to the field of agriculture at a national level (Chapagain et al., 2006; Gerbens-Leenes et al., 2013). In recent years, some scholars have already utilized this combined approach to evaluate the water consumed for energy production (Gerbens-Leenes et al., 2009; Okadera et al., 2014). However, few researchers have investigated the issue from a consumption-based perspective using a top-down approach. Therefore, to make up for this deficiency, we studied the approach for evaluating WF for energy in this article. We focus our analysis mainly on Shanghai, which functions as the center of Chinese finance, trade and shipping. Shanghai consumes a vast amount of water and energy every day, most of which is imported from other regions (Chen et al., 2016). The paper is organized as follows. First, section 2 introduces the study area and section 3 explains the method and data collection, and a literature review of the previous studies on water for energy production is also included. Then, section 4 covers the results of the study, including the virtual water content, water multipliers for energy sectors, and the WF of the energy supply (WFES) in Shanghai. Section 5 discusses the results obtained in section 4, and then a conclusion is made concerning the task of WF analysis of energy production for future study.

2. Study area

In this study, we select the easternmost region of Shanghai, which is located on the Yangtze River Delta (30°40′–31°53′N, 120°51′–122°12′E) as the case study area (Fig. 1). It lies on the eastern Pacific coast, centrally located between the north and south coasts of China. Shanghai is the most densely populated place in China. In 2014, the area of the target region was roughly 6300 km^2, and the population was at least 24.25 million, and the global Gross Domestic Product (GDP) of Shanghai was 23,567.7 billion yuan (about US$ 3414 billion) as of 2014, which accounted for 3.66% of China's whole GDP (Shanghai Statistical Yearbooks). The annual average temperature is 17.8 °C and the annual rainfall is 1457.9 mm, 60% which occurs in the rainy seasons from May to September. The city is well served with regard to transportation, but is at a notable disadvantage in terms of natural resources, such as metals, minerals and lumber (Guo, 2017).

Shanghai is one of four municipalities directly controlled by the central government of China, and the first Pilot Free Trade Zone (PFTZ) was founded to introduce a combination of floating exchange rate and capital account liberalization into Chinese macro policy mix (Yao and Whalley, 2015). In 2015, it ranked first as the most competitive city in China, and was the most expensive city to live in throughout Asia according to an authoritative survey (Lin and Liya, 2014). In terms of retail sales, it is the second-ranked city in China with a trillion-dollar consumer market scale. Total retail sales of consumer goods in 2015 added up to 10,056 billion yuan (about US$ 1456.7 billion). In 2016, Shanghai was selected as the pilot area to conduct innovation of the service trades by the State Council.

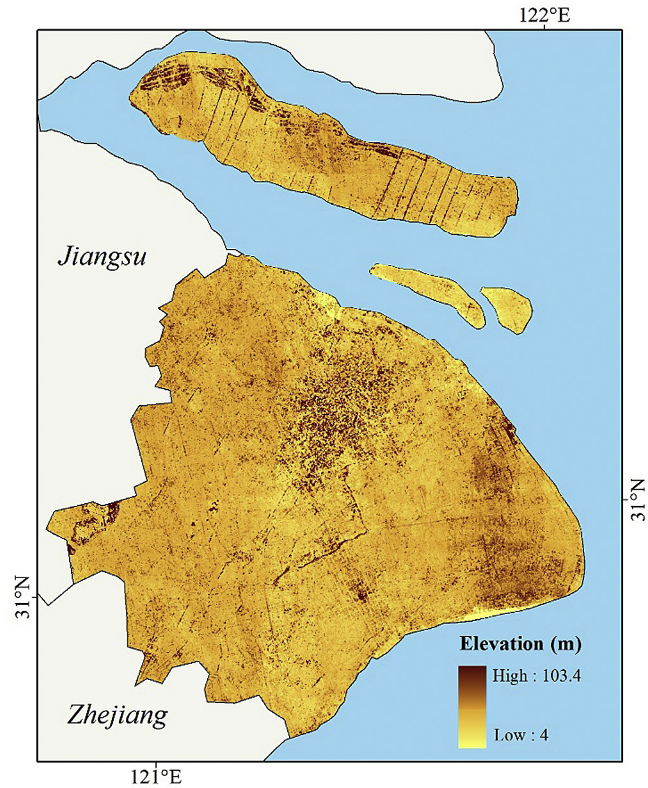

Fig. 1. Location and elevation of Shanghai.

By comparing Fig. 2 with Fig. 3, we find that there is a great difference between the trends of energy production and those of energy consumption in Shanghai. A Large amount of energy is consumed every year while only a small portion of it is produced

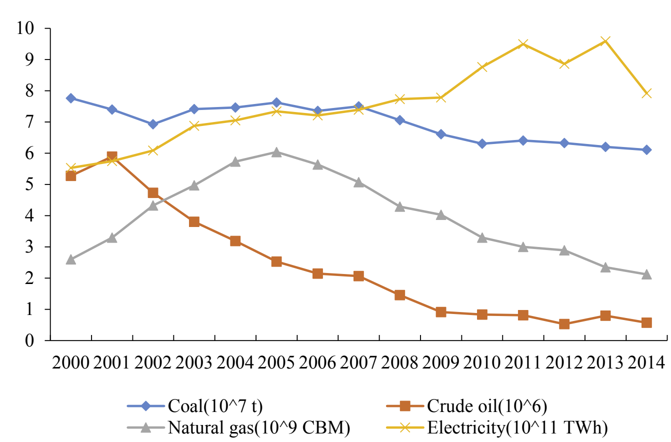

Fig. 2. Energy production in Shanghai, China.