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Evaluation of Urban circular economy development: An empirical research of 40 cities in China

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ABSTRACT

The city is an important component in the construction of circular economy (CE), and after years of development, assessment of urban CE and calculation of an urban circular development index (UCDI) is an important task that the Chinese government has faced. However, existing research into the indicator system and evaluation methods is not enough to support calculation and subsequent publishing of UCDI. Building off current research into CE, its index systems and its evaluation, this paper puts forward an evaluation index system for urban CE development (UCDI) that uses an improved entropy methodology combining expert and entropy weightings. The index was calculated for 40 cities that were part of China's pilot CE cities program for alternating years in the five year period between 2012 and 2016 (that is, the index was calculated for 2012, 2014 and 2016). The study found that the level of urban CE increased significantly over the five year period, with that in the CE pilot cities growing at a faster rate than the national average. Results show that a certain relationship exists between UCDI, urban types and economic development, but has little relationship with industrial structure. Finally, recommendations for the promotion of urban CE are proposed.

1. Introduction

Rapid economic development is often accompanied by materials/energy consumption and environmental pollution. This has especially been the case in China, where GDP has grown by nine times over the period 2000–2015 (The World Bank, 2017a,b), but which has also produced nine of the ten most polluted cities in the world (Jacob et al., 2010). Recent efforts have been made to decouple economics from both consumption and pollution, particularly in the field of circular economy (CE). The circular economy, also called the "cradle-to-cradle" model, goes beyond recycling of waste into resources. It is a new way of thinking how to achieve growth without expending resources (Pearce and Turner, 1990; Esposito et al., 2017).

Germany is often considered the pioneer of CE due to its early adoption of the "Closed Substance Cycle and Waste Management Act" in 1996 (Heck, 2006), and has continually developed CE policies and mechanisms since. Similarly, in order to create a recycling-oriented society, the Japanese government established a series of laws and regulations that related to waste management and recycling (Guo et al., 2017). Success of CE in these two countries had inspired the Chinese government to create its own mode of CE development. Initially, experts and politicians in China came up with their own definitions of circular economy (Wang, 2005). This lasted until 2008, when finally the "Circular Economy Promotion Law" (2009) was passed, cementing the concept of CE in China as a broad term for reduce, reuse and recycling during all stages of the value chain (including production, distribution and consumption). However, the understanding of CE has continued to improve through recent research. For instance, Murray et al. (2017) proposed a revised definition from economic activity, environmental wellbeing and ethical dimensions, and Geissdoerfer et al. (2017) defined CE as a regenerative system in which resource inputs,

Abbreviations: CE, Circular economy; UCDI, Urban circular development index; MFA, Material flow analysis; WRI, World Resources Institute; EU, European Union; NDRC, National Development and Reform Commission; NBS, National Bureau of Statistics of the People's Republic of China; EIS2017, Evaluation Index System of Circular Economy Development (China, 2017 Edition).

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waste emissions, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. The connotation of these new concepts will also be included in our research.

1.1. CE helps to break through resource and environmental bottlenecks

CE consists of a multitude of different concepts to extend the lifetime of materials, reduce pollution from production, and thus decouple economic growth from environmental harms (Ghisellini et al., 2016). Some of those concepts include ‘efficiency’ to optimize energy and materials and thus maximize production output while minimizing inputs and pollutant discharge to the environment; ‘recovery’ of any waste throughout the value chain before it goes to landfill or other waste disposal method; and ‘valorization’ of waste – re-economized for further social benefit. Recent EU documents focus on encouraging recycling and recovery strategies along the lifecycle of a product (EEA, 2016), in which CE follows the 3R principle of reduction (material inputs reduction), reuse (process repair and refurbishment) and recycling (output resource utilization). Similarly, the Ellen MacArthur Foundation considers that preserving and enhancing natural capital, optimizing resource yields, and fostering system effectiveness are the three principles of CE.

That said, the circular economy can achieve organic unity among economic development, resource conservation, and environmental protection; it is a fundamental measure to solve bottlenecks in solving resources and environmental constraints, provides multiple alternative pathways for value creation that are premised on the idea of finite resources, as opposed to unfettered growth (Ellen MacArthur Foundation, 2017). As Mathews and Tan (2016) put it, the only solution to the world's resource-security problem is to move away from the linear economy and embrace the circular economy.

1.2. Development of CE in China

Unlike in places such as the European Union, Japan, and the United States, where CE developed from the bottom-up, CE in China is promoted as a top-down national policy objective, used to design environmental and waste management policies (Ghisellini et al., 2016). As shown in Fig. 1, CE development in China can be divided into three stages:

(1) Prior to 2002, in the context of increasing resource productivity and enforcing more environmental constraints, the state began to advocate CE concepts, for example with the regulation “Approaches to Waste Car Recycling Management”. While disjointed, these were the beginning stages that laid the groundwork for more comprehensive CE legislation.
(2) In 2002, China promulgated the “*Cleaner Production Promotion Law*”, which marked the entrance of China's CE into an action stage (2002–2009). The state released a series of laws, regulations and fiscal support policies; the most important of which was the “Opinions to Speed Up Development of the Circular Economy” promulgated by the State Council in 2005.
(3) The “*Circular Economy Promotion Law*” was approved at the 4th meeting of the Standing Committee of the 11th National People's Congress of China, and took effect on January 1st, 2009 (Geng et al., 2012), marking a stage of active, comprehensive CE promotion in China. Following the promotion law, the State Council issued the “Development Strategy and the Immediate Action Plan of Circular Economy” in 2013.

Driven by strong top-down actions, resource intensity and waste intensity in 2013 had improved by 34.7% and 46.5%, respectively, compared to 2005, a clear sign of decoupling of resource consumption from economic growth (NBS, 2015). OECD statistics reveal the long-term trend of falling resource intensity, from 4.3 kg of materials per unit GDP in 1990 to 2.5 kg in 2011. Over the same period, however, China's overall resource consumption rose fivefold, from 5.4 to 25.2 billion tons as a result of its economic boom (Mathews and Tan, 2016).

1.3. The importance of reevaluating urban CE

Cities are major contributors of environmental problems and resource consumption. With only 1% of the world's total land mass, they are home to over 50% of the human population. In 2016, the urban population was an estimated 4.027 billion (The World Bank, 2017a,b), and is expected to approach 5 billion by 2030 (UNFPA, 2011). Further, cities disproportionately consume more than 70% of total energy and are responsible for more than 70% of greenhouse gas emissions worldwide (Boyd and Pablo, 2016). They are and will continue to be a crucial part in solving resource constraints and environmental problems through CE development.

China's development of urban CE began as early as 12 years ago. In 2005, 2007, the National Development and Reform Commission (NDRC) appointed a total of 178 CE pilot units, which included 20 cities. In 2013, 2015, the NDRC joined with three other ministries to select 44 cities and 57 counties, creating the national CE model cities (including counties) program. This study focuses on the first batch of these model cities.

Successful development of CE requires a system of indicators to assess and track progress, and provide guidelines for decision-makers to further develop policy instruments (Su et al., 2013). In April 2017, the NDRC released the “Leading Actions on Circular Development”, promoting CE model city construction, and establishing an accounting, publishing and evaluation system for an urban circular development index (UCDI) (NDRC, 2017). More recently, the “Evaluation Index System of Circular Economy Development (China, 2017 Edition)” (EIS2017) was published to assess national level development and guide local governments to develop their own CE evaluation indices with the goal of incorporating more CE practices in their city or province.

While some work (see Table 2) has been done in the area, there is no one-size-fits-all solution for assessing urban CE development. Bottlenecks in data availability (EIS2017), representativeness of selected indicators (Su et al., 2013; Zaman and Lehmann, 2013; Geng et al., 2009), and accurate evaluation methods (Jiang, 2013; Hao et al., 2009) have restricted the calculation and subsequent publishing of an Urban Circular Development Index (UCDI). This is discussed in further detail in Section 2.1 and 2.2.

To bridge these gaps, this study makes several academic contributions to the field. For one, a new assessment method was developed by using an improved weighting methodology that combined expert weightings and entropy weightings. We abandoned the traditional methods applied in CE evaluation such as analytic hierarchy process (e.g. Peng et al., 2005), fuzzy synthesis appraisal (e.g. Hao et al., 2009), principal component analysis (e.g. Xiong et al., 2008), or grey correlation degree method (e.g. Zhang and Huang, 2005). Instead, entropy weighting addressed the relativity of UCDI scores between cities, while expert weightings incorporated direct feedback from academic and industry experts in the field on circular economy development in China. Its methodology is thoroughly discussed in Section 3. Secondly, on the basis of previous research, a comprehensive evaluation indicator system of UCDI is re-designed (Table 3) that included resource output, industrial and residential circularity, and CE mechanisms and