A Review of the Circular Economy in China: Moving from Rhetoric to Implementation

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Abstract

In China's thousands of years of civilization, the conflict between nature and humankind has never been as serious as it is today. The environmental deterioration and resources scarcity stand as two of the most urgent problems needed to be tackled with. With full realization of its responsibility, the Chinese government has accepted and been kept promoting a sustainable development model, the so-called "circular economy", since 2002. With the aim to improve the efficiency of using materials and energy, the successful enforcement of a CE can be seen as a way for China to leapfrog to a green economy. In this paper, we provide a holistic literature review on Chinese CE which covers from the concept, current practices and assessment system. A case study of Dalian city in China is used as the numeric illustration of the actual development of CE. We also discuss about the underlying challenge and barriers for a full implementation of this national strategy. Finally, we give the conclusion as well as policy recommendations for CE's future improvement.

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1. Introduction

1.1 Concept of a Circular Economy

The concept of circular economy (CE) has been first raised by two Britain environmental economists D. W. Pearce and R.K. Turner (1990). In their book Economics of Natural Resources and the Environment, they pointed that traditional economy was developed with no in-build tendency to recycle and it treated environment as a reservoir of wastes. However, there was a need to contemplate earth as a closed economic as a closed economic system: one in which the economy and environment are not characterized by linear interlinkages, but by a circular relationship (Boulding, 1966). To achieve a win-win situation for economy and environment, they proposed a closed-loop of materials in the economy.

The starting point of CE's implementation is in Germany 1996, accompanied with an enactment of a law: "Closed Substance Cycle and Waste Management Act". This law provided for managing waste in a closed cycle and ensuring environmentally compatible waste disposal. Then, in 2000, Japan became the second country that issued a law to promote CE nationally. The Japanese government tried to transform the society featured with high production, high-consumption and high waste into a "recycle-oriented society" (Wang et al., 2004; Zang, 2006). One common feature of both countries' CE policy is to prevent further environmental deterioration and to conserve scarce resources through effective waste management, especially the solid-waste management.

In the case of China, rather than viewing CE as an incrementally improved environment management policy, CE has been introduced as a new development model to help China leapfrog into a more sustainable economy structure (Zhu, 2008; Geng and Doberstein, 2010). The main focus of CE, embedded in the original concept, has gradually been shifted from the narrow waste recycle to the broad efficiency-oriented control during the closed-loop flows of materials in the all stages of production, distribution and consumption process. Moreover, involved objects have been expanded: aside from resources and waste problems, energy efficiency and conservation, land management and soil protection, and integrated water resources management problems are also been taken as key issues.

It has been reached a consensus that Chinese CE's concept in many ways resonates with the concept of industrial ecology which emphasizes the benefits of utilizing residual waste materials, including energy, water, different by-products as well as information (Jacobsen, 2006; Yuan et al., 2006). The most common example of this concept would be the industrial symbiosis where collective benefits come from both economic and environmental aspects. Economically, firms' agglomeration brings pools of common production factors such as labor, capital, energy etc. which may decrease factor prices or raise productivity (Anderson, 1994). Besides the transportation and transaction costs saved by spatial proximity, firms that locate together can obtain technology spillover more easily (Coe et al., 2004). On the other hand, environmental benefits will be obtained not only by minimizing the amount of discharged waste, but -more importantly- by minimizing the use of virgin materials for economic activity (Andersen, 2007). Zhu (2005), one of the pioneers who firstly brought the concept of circular economy in China, suggested that it is, in essence, an ecological economy that would bring fundamental changes to the traditional way of development. Three aspects, that are economic, social, and environmental dimensions, need to be considered in this model. On economic aspect, it contributes to a higher regional and domestic competitiveness through an increase in the effectiveness of resource allocation, resource utilization and productivity. Environmentally, it reduces negative externalities mainly by redesign of the industrial structure in an ecological way. Socially, it resolves the unemployment problems, equals distribution of economic growth and improves people's overall well-being.

In order to implement CE, the 3R principles (consisting of Reduce, Reuse, and Recycle) present as the core for guidance and have been embedded in production and consumption since flow of materials and energy penetrates in both areas (Zhu and Qiu, 2007). Reducing refers to minimize the input of raw energy and materials during production through the improvement of production efficiency. As for consumers, a more frugal way of consumption has been encouraged. Reusing suggests using the by-products and wastes from one firm as resources for other firms or industrials. It also refers to use products to its maximum capability with frequent maintenance and reclamation to prolong its endurance. Recycling encourages processing the recyclable materials into new products to prevent waste of potentially useful materials. These principles, as parts of the whole process, occupy different places in terms of importance, with reduction of resource use as the leading principles within a circular economy system.

1.2 Importance of a Development Strategy

The recent enacted 12th five-year plan (2011-2015) for China's economic and social development suggests a continuous implementation and further development of CE. It is not surprising to see the Chinese government spares no effort to push this economic model into practice for a number of reasons. First, China faces daunting environmental challenges due to the rapid industrialization as well as lax environmental oversight. Striking problems facing the country include land degradation, desertification, deforestation, water depletion, loss of biodiversity, etc. Globally, increasing concerns about climate change brings controversy and extended pressures over China's position on carbon dioxide emissions. Given the statistics from (Energy Information Association) EIA (see Figure 1), China has an increasing trend of total carbon dioxide emission, and the numbers soar up dramatically from 2000 to 2009. According to EIA the China's share of carbon dioxide emission over the world increased from 10.6% in 1990 to 21.1% in 2007. This increase is resulted from China's heavy dependence on the energy-intensive industries and an immense consumption of coal-based energy. In response of serious environment problems, mitigation of carbon emission and reversal of environmental degradation have become urgent necessities.

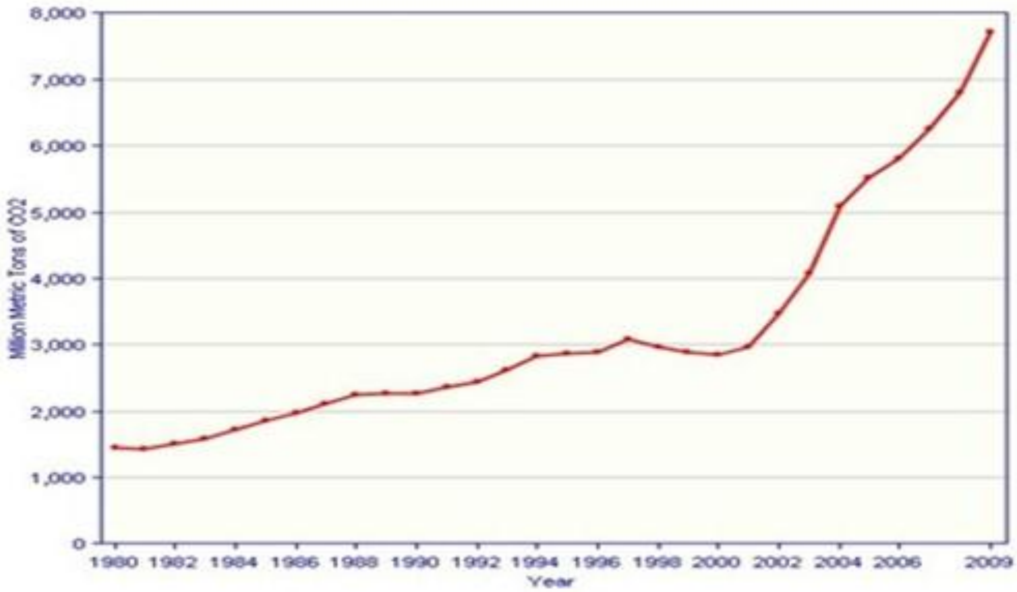

Figure 1. China’s Carbon Dioxide Emission from Consumption of Fossil Fuels

Second, the severe shortage of resources and energy poses strong contrast to their growing demand for China and raise questions of its future economic growth (Li et al., 2010). One Chinese individual owns half the world average per capita in mineral resources, one-third in arable land and grassland, one-fourth in water resources, one-fifth in forest, one-seventh in energy, and only one-tenth in oil (Information Office of the State Council, 2006). While on the demand side, a boom in economic growth and a surge in the output of heavy industries starting from 2002 has been dragging up the consumption of various resources and energy ever since. Up to 2009, China’s energy use has been more than doubled over the last decades and it has overtaken the US as the world’s biggest energy user according to the preliminary data from International Energy Agency (2009). Since high-energy and resources-consuming industries remain dominating the Chinese industrial structure in the new future (Li et al., 2010), shortage of those two factors make a way of sustainable economic development as the only choice available for China.

Third, in recent years, strict production or environmental standards and regulations in international trade, so-called “green barriers”, are put into effect. These compulsory barriers hurt developing countries’ trade revenue largely, since they not only require acquisition of advanced technologies but also implementation of a green reform in the production mode. Wang and Liu (2007) regarded CE as the fundamental resolution to surmount green barriers and expected that through its implementation China would gain enhanced national competitiveness in the international trade.

Last, CE helps to strengthen the national security due to the importance of sustainable supply of energy for a country. Additionally, the positive environmental effects help to improve the overall well-being in the society and advance a nation’s modernization (Heck, 2006).

All in all, the urgent environmental and resources situation in China and the potential implementation benefits in the long-run are the primary reasons to explain Chinese government's resolution to carry out CE. The abovementioned discussion suggests that circular economy is a sustainable development strategy aiming to improve the efficiency of materials and energy use. This strategy has been implemented and further developed in a number of pilot areas in China. The literature has developed in regard with the fundamental concept and the practical implementation of the circular economy. A successful enforcement of the circular economy can be seen as a way to tackle urgent twin problems of environmental degradation and resource scarcity. In this research we provide a holistic review of carefully selected literatures on the circular economy with the goal to provide a panorama of how this strategy has been developed and evolved in recent years in China. It also serve as an assessment of past policies design, implementations and effectiveness.

This research is conducted in a number of steps. First, the concept of circular economy and why it is imperative for China is studied. Then it introduces the current practices in China and discusses the assessment of its development, including a discussion and comparison of indicators designed and utilized by governmental agencies and scholars. In the empirical part, in order to provide a picture of how the circular economy has developed in China, we provide data analysis of the key CE indicators for Dalian and compare the changes with those of other three pilot cities, Beijing, Shanghai, and Tianjin. Then based on our analysis and other literatures, we reflect the underlying problems and challenges for this national strategy. Finally, we provide the conclusion of the circular economy development as well as policy suggestions for future improvement. In sum, this study contributes to the rapidly growing literature on circular economy in general and its development and impact on the improvement in the efficiency of materials and energy uses in the Chinese economy in particular.

In the following part we introduce CE's current practices in China. More details are given in part three to discuss the assessment of its development, including an introduction to and comparison of various indicators designed by governmental agencies and scholars, how these indicators are estimated through the parametric evaluation methods, and the underlying problems of current way for assessment. In the empirical part, we provide data analysis of the key CE indicators for Dalian and compare the changes estimated with other three pilot cities, Beijing, Shanghai, and Tianjin. Then based on our analysis and those of other literatures, we reflect the underlying problems and challenges for this national strategy. Finally, in part six we provide the conclusion of the circular economy development as well as suitable policy suggestions for enhanced effectiveness and potential future improvement.

2. Current Practices of CE

General agreement exists that a successful implementation of circular economy requires efforts at three different scale levels: micro-level, meso-level, and macro-level (Yuan et al., 2006; Geng and Doberstein, 2010; Zhu and Huang, 2005). Inspired by Zhu and Huang's (2005) work we categorize the current but under developing CE practices into four areas (see Table 1). The table shows that, the four main areas, production, consumption, waste management and other support, are changing in parallel, but practices at micro and meso levels are more vibrate than those at the macro level due to the fact that complexity of the practices increases as the scale level increases.

Table 1. Structure of Practices of CE in China

	Micro (single object)	Meso (symbiosis association)	Macro (city, province, state)
Production area (primary, secondary, and tertiary industry)	Cleaner production Eco-design	Eco-industrial park Eco-agricultural system	Network of Eco-industrial parks
Consumption area	Green purchase and consumption	Eco-living park	Renting service
Waste management area	Product recycle system	Waste trade market Renewable resources industrial park	Regional circular industry
Other support	Policies and laws; NGOs		

At the micro level, in production area, factories and agricultural products producers are encouraged or required to adopt cleaner production (CP) and eco-design. In the industry sector, cleaner production has been the most effective measure and it has been widely developed than other practices especially after the enactment of China's "Cleaner Production Promotion Law" in January 2003 (Geng et al., 2010). CP is a strategy for addressing the generation of pollution as well as efficient use of resources at all states of the production process. For heavily polluting enterprises in printing and dying, foundry, tannery, food processing, pulp and paper, electroplating and chemical industries, CP is compulsory and plays a prominent role to reduce their environmental externalities and their energy intensity (Hicks and Dietmar, 2007). Peng et al. (2005) Studies on barriers for promotion of clean technology in SMEs of China reveal that the exterior barriers of policy and financial barriers should be stressed rather than the inner barriers of technical and managerial barriers. For the second area, consumption, practices intend to improve consumers' green awareness that their preferences, behavior, and patterns should be oriented toward environmental protection, ecological balance, and sustainable social development, such as to reduce the use of disposable goods, avoid unnecessary purchase, and adopt waste classification etc. (Zhu and Huang, 2005). As for waste management area, it encourages companies to design their products so that they can be returned at the end of their useful lives and build product recycle system in order to maximize the use of recycled parts and equipment that have been produced (Zang, 2006). For instance, Xerox Corporation in U.S. offers recycling for toner and cartridge suppliers which can be easily disassembled and remanufactured, and parts of the used product can be reused or recycled.

At the meso-level, the practices include developing eco-industrial parks and eco-agriculture; environmental friendly design of the eco-living parks, and building up waste trading system and renewable resource industrial parks. For the first area, the eco-industrial park applies a concept of industrial symbiosis that through cooperative management of resource flow of geographically clustered firms, improvements in environmental performance can be coupled simultaneously with decrease of overall production cost. (Chertow, 2000) In an eco-industrial park, firms share common infrastructure and services and trade industrial byproducts such as heat, energy, wastewater and manufacturing wastes. It helps domestic companies to abate the dependency on external resources and reduce their environmental externality. In the agricultural sector, eco-agricultural system resembles industrial symbiosis aiming to utilize by-products and wastes from crops and livestock (Yin et al., 2006). A second program is mainly a commitment to "green" design of residential communities to reduce energy, water, and land consumption. Besides, a system should be designed that the household wastewater and solid waste can be easily recycled. Ultimately this eco-friendly human habitation environment helps to restore the ecosystem in cities and boost the quality of life (Zhu and Huang, 2005). Last, in the waste management area, regulating and expending of waste trade market and building renewable resources industrial park aim to increase the productivity and economic benefit of waste utilization.

At the macro level (city or regional scale), more complex and extensive co-operative networks between industries and industrial parks from primary, secondary and tertiary sectors emerge in production area. The 3R principles are achieved by redesign and rearrangement of city's infrastructure and industrial layout in according to regional characteristics. Reform or cut the number of the heavy polluting enterprises, while supporting high-tech industries like biopharming and the touring industry etc.. On the consumption side, Zhu (2005) proposed to form the renting system in the city based on the concept of Stahel's service or functional economy. Stahel (1986) suggested that in contrast of the current products economy, service economy shifts from selling and buying products themselves to just the utilization of the products. It would create new job positions such as labor-intensive service centers, for workers who are no longer needed in centralized, automated production units. Moreover, resource usage would be lowered as products no longer are moved rapidly from factory to customer and to landfill. In the waste management area, a newly circular industry sector is under development. It is similar to the environment industry that supplies pollution control, reduction, clean-up and waste handling equipment and related services with five sub-aspects. These include environmental-friendly products and equipment, environment test and analysis, utilization of recycled waste, materials, clean-up technologies and clean-up products, and restore and protection of natural ecosystem (Dong and Fan, 2005; Wang and Huang, 2006).

Other supports that are mentioned in Table 2 include governmental and non-governmental initiatives. Chinese government regulates the implementation of CE through two agencies, the

State Environmental Protection Administration (SEPA) and the National Development and Reform Commission (NDRC). The former one is in charge of the National Pilot Eco-industrial Park Program while the latter one is in charge of the National Pilot Circular Economy Zone Program in cooperation with SEPA and other 4 related ministries. Great efforts from both programs have made possible to build eco-industrial parks (EIP). All together 60 industrial parks have received approval to be developed into national pilot EIPs (Zhang et al., 2010). Apart from focusing at the meso-level, the second program also covers missions at other levels and by issuing policies it pushes the practices mentioned above with the aims to be carried out.

A number of laws and policies in the context of CE are noteworthy. First is the enactment of the "Cleaner Production Promotion Law" in January 2003. It was built upon with the amended Law on Pollution Prevention and Control of Solid Waste which took effect on April 1st 2005. In the same year, NDRC has announced eight initiatives in the formulation of circular economy policies. There are initiation of the legislation process, launching pilot projects, the development of economic instruments, research and development of technology, industrial restructuring, studies on measuring indicators, financing key pilot projects by using funds raised through state bonds, and training and education. On January 1st 2009, the Circular Economy Promotion Law went into enactment. It is the third law related to a circular economy in the world, after those of Germany and Japan, and serves as a fundamental law guiding all circular economy policies in China. (See Ren, 2007)

Another concern of current practices of CE is the development of environmental Non-Governments Organizations (eNGOs). Though governmental regulations and industrial efforts are crucial elements of development of circular economy, the underlying requirement for its success is a change in attitudes and expectations throughout the society. This requires education, information, and the encouragement of active participation on this transformation to increase people's awareness. NGOs, which have easy access to grassroots, possess large, if not current, potential influence on promoting of CE in the society. No particular studies have investigated the relationship between CE and eNGOs in China, but a rapid development of China's eNGOs can be seen. The total number of eNGOs increased from 2,768 in 2005 to 3,539 in 2008[1] and they are highly interacting with the transnational environmental movement (Xie, 2011).

3. Assessment of CE

Successful development of CE requires a system of indicators for its assessment. Good indicators are valuable metrics for evaluating the soundness of its development and providing guidelines for decision-makers to further develop effective policy instruments. Given the fact, governmental agencies and scholars have studied intensely and made efforts on promoting unified programmatic indicators. However, different implementation levels of CE and different characteristics of enterprises, industries or regions present some variation in the types of assessment indicators used.

For the basic micro-level, each enterprise needs to tailor the firm-specific indicators according to its characteristics, condition, existed problems, etc. Thus a unified and only one standard set of indicators may fail to capture the full development of circular economy in the different enterprises. Chen et al, (2009) formed the indicators for one iron and steel enterprise with 4 indicators in the first-level reflecting CE's 3R principleindustrial value addeds, 12 in the secondary level which are closely combined with the condition of the enterprise with 3R principles and 66 indicators with the concrete definition in the tertiary level. Some scholars, rather than focusing on one enterprise, they estimated the performance of one industry (Du and Cheng, 2009; Xu, 2010, among others). The indicator system appears to be more general and focus on the overall performance. For instance, Du and Cheng (2009) used Date Envelopment Analysis model with 9 input-output indicators and the Malmquist productivity index as an alternative approach estimated economic efficiency of 47 iron and steel enterprises' observed for the period 2003-2006. Others gave their attentions to the enactment of CP in China (Shi et al., 2008; Heidi et al., 2005, among others). Shi et al. (2008) formed twenty indicators to estimate the barriers inhibiting CP uptake. They consider four barrier categories: policy and market, financial and economic, technical and information, and managerial and organizational.

At the intermediate meso-level, Chinese governmental agencies NDRC and SEPA have published two sets of tentative EIP evaluation indicator systems respectively to ensure objective and credible information on the status of EIP in China.

Table 2. Evaluation indicator system for CE by NDRC (at the meso level)

Dimensions	No.	Indicators
1.Resource output rate	1.1	Output rate of main mineral resources
	1.2	Output rate of land
	1.3	Output rate of energy
	1.4	Output rate of water
2.Resource consumption rate	2.1	Energy consumption per unit of production value
	2.2	Energy consumption per unit of production in key industrial sector
	2.3	Water consumption per unit of production value
	2.4	Water consumption per unit of production in key industrial sector
3.Integrated resource utilization	3.1	Utilization rate of industrial solid waste
	3.2	Reuse ratio of industrial water
	3.3	Recycling rate of industrial wastewater
4.Reduction in waste generation	4.1	Decreasing rate of industrial solid-waste generation
	4.2	Decreasing rate of industrial wastewater generation

*In total 13 indicators were categorized into 4 groups

* Key industrial sector: iron, copper, aluminum, cement, fertilize, paper, etc.

NDRC's indicator system has four dimensions: resource output rate, resource consumption rate, integrated resource utilization, and reduction rate in waste discharge (see Table 2.). Resource output rate refers to the amount of production value in EIP generated from one unit of material, land, energy, and water consumption. The higher the ratio indicates the higher efficiency of resources. In the second dimension, resource consumption rate, indicators capture the energy and water intensity in EIP, an alternative way to see how resource efficiency has been achieved. Resource comprehensive utilization rate is designed to examine the reuse rate of industrial water and recycling rate of industrial waste. The last dimension examines the reduction in industrial waste discharge. Seen from those dimensions, it is clear that this set of system has been built upon the 3R principles targeting at tracing the improvement of resource and energy efficiency and reduce, reuse and recycle of industrial waste.

A different story can be told in regards with the SEPA's structure of indicators. Though the number of dimensions is the same in the two sets of indicator systems, the concerns are different. SEPA has compressed the four dimensions in NDRC's indicator system into one (material reducing and recycling) and added three more dimensions concerning about economic development, pollution control and administration and management (see Table 3). The design of SEPA's dimensions seems more appropriate if we take account of special characteristics of China's EIP. Unlike most North American models, where industrial parks are predominantly manufacturing-based, China's industrial parks have dual functions as both production and residential based areas are included (Geng and Cote, 2003). Thus residents' behaviors, awareness, and economic well-being are closely related with the development of EIP. Additionally, this set of system focuses on, but not limit to, estimating the realization of 3R principle in EIP. It has covered economic, social, and environmental aspects all at once that are consistent with the ultimate goal of CE.

Another distinguishing difference from the indicators developed by NDRC is that SEPA grouped the industrial parks into three groups, namely sector-integrated group, the venous group and the sector-specific industrial parks[2], according to their characteristics and subsequently designed three sets of indicators respectively (Geng et al., 2008). Generally, indicators for those three types of EIP remain the same, while a few minor changes lie in the second category of indicators: material reducing and recycling. In the cases of sector-integrated parks and sector-specific parks the set contain indicators related to material reduction and recycling. For venous parks, however this group contains more indicators related to resource recycling and reuse. We see those designs as a betterment of non-specific indicators since the customized ones can give more accurate assessment of the temporal development of EIP.

On the other hand, very few scholars studied the building of a particular indicator system like the one showed above. But there is evidence that certain efforts have been made to evaluate and assure the development of EIP. Geng and Cote (2003) suggested that Environmental Management Systems such as International Organization for Standardization 14001 can be used as a tool in China by industrial park managers to improve their environmental performance. Dai (2010) applied biological theory to the development of two indexes by which the author evaluated an EIP. The first index is the eco-connectivity of an EIP that defines the degree of connectivity among the enterprises or factories in an EIP; while the second index defines the degree of byproduct and waste recycling in an EIP.

Table 3. Evaluation indicator system for CE by SEPA (at the meso level)

Dimensions	No.	Indicators
Economic development	1.1	Industrial value added per capita
	1.2	Growth rate of added industrial value
Material reducing and recycling	2.1	Energy consumption per industrial value added
	2.2	Fresh water consumption per industrial value added
	2.3	Industrial wastewater generation per industrial value added
	2.4	Solid waste generation per industrial value added
	2.4	Reuse ratio of industrial water
	2.5	Utilization rate of industrial solid waste
	2.6	Reuse ratio of middle water
Pollution control	3.1	Chemical oxygen demand loading per added industrial value
	3.2	SO_2 emission per industrial value added
	3.3	Disposal rate of dangerous solid waste
	3.4	Centrally provided treatment rate of domestic wastewater
	3.5	Safe treatment rate of domestic rubbish
	3.6	Waste collection system
	3.7	Centrally provided facilities for waste treatment and disposal
	3.8	Environmental management system
Administration and management	4.1	Extent of establishment of information platform
	4.2	Environmental report release
	4.3	Extent of public satisfaction which local environmental quality
	4.4	Extent of public awareness degree with eco-industrial development

* In total 20 indicators were categorized in 4 groups
*Middle water is a Chinese term for the recyclable treated wastewater from wastewater treatment plants.

And last, we look at the aggregate macro-level, probably the level which has been studied most intensively in terms of forming indicator system and evaluating CE's performance by the scholars. For the indicator system developed by NDRC, no major changes have been made from the one for the intermediate meso-level except for which one more dimension has been added. Under this added dimension, the importance of recycling at regional level has been stressed and materials such as iron scrap, non-ferrous metal, waste paper, glass, plastic, and rubber are given prior consideration. It is obvious that China's political commitment of promoting circular economy emphasizes heavily on resource efficiency and conservation.

In contrast, scholars have suggested that aside from indicators evaluating of 3R principles or the environmental aspect, a more systematic evaluation system should be established by adding indicators of economic development and social aspects (Geng et al., 2008; Jiang 2010, etc.). For the economic development, there were indicators for the state of economy like GDP per capita, growth of economy (Wang et al., 2006; Qin et al., 2009; etc.); indicators for the potential of the economy like export share, technology development, capital investment (Chen, 2006; Yang et al., 2011; etc.); and indicators for the structure of the economy (Yang et al., 2011; Li and Zhang, 2005; etc.). As for the social aspects, unemployment rate, living area, Engel's coefficient, resident's disposable income, were the most chose indicators (Qian et al., 2008; Wang, 2009).

While majority of the scholars designed the indicators based on 3R principles and goals of CE, some other scholars (Zhu, 2007; Zhou et al., 2007) argued that, the development of CE was, in itself, an improvement of eco-efficiency that was the ratio of GDP and consumption of natural resources. Zhu built the eco-efficiency indicators for Shanghai which included the productivity of land, water, energy, and raw materials, as well as the productivity of sulfur dioxide, waste water, and solid waste. And then he combined them with IPAT[3] function (Ehrlich and Holdren, 1970) for evaluating and further planning of future scenarios of energy consumption and pollutes generation.

Another issue about assessment CE related with indicator system is how to decide the weight of each sub-indicator prior to an aggregation. The often used methods are including average weighting (Li and Zhang, 2005) which takes the same weight for every indicator; principal component analysis (Meng and Shen, 2006; Xiong et al., 2008; among others) that identifies patterns in data of high dimensions, and expresses the data in reduced dimension in such a way as to highlight their similarities and differences; analytic hierarchy process (Chen, 2006; Qian et al., 2008; among others) which decomposes complex problems into several elements and then incorporate them into different levels to forming a multi-level structure; fuzzy synthesis appraisal (Hao et al., 2009; Jiang, 2010) and grey correlation degree method (Zhang and Huang, 2005) which both feature with avoiding personnel subjective judgment; and full permutation polygon synthetic indicator method (Li et al., 2009). More detailed information about these studies, the measurement methods and findings has been listed in the Appendix A.

4. Development of CE in Pilot Cities

How is CE developed in China in recent years? We answer this question by firstly looking at the performance of one pilot city Dalian for the time period from 2006 to 2010. Thanks to its geographic advantages, Dalian is one of China's biggest industrial centers and one of China's most prosperous business areas. With the aspiration to be a leading environmentally friendly city in China, Dalian's government has taken a series of initiative to implement CE strategies.

Geng et al. (2009) had comprehensively reviewed Dalian's focus and goals of CE implementation for the period of 2006-2010. Dalian had the objective that by 2010 to: (i) further improve land, water and energy use efficiency, and thus remove the bottlenecks that restrict Dalian's sustainable development; and (ii) improve levels of reuse, recycling and recovery for solid wastes and wastewater, and thus significantly reduce disposal amounts (Dalian Municipality, 2007)

The data for 2005 and the Goals by 2010 are derived from Dalian Municipality (2006). Thanks to the access to consistent statistical data for 2010, we are able to observe whether the stated goals have been achieved and the appropriateness of CE practices in Dalian. Ten indicators have been chosen to assess the close linkage to Dalian's industrial advantages and prevalence of development bottlenecks (Dalian Municipality, 2006). The indicators are classified into four aspects: energy and water efficiency, waste discharge, Waste treatment and Waste reclamation.

In 2007 Dalian municipality decided to shut down small scale facilities with high energy use rates; encourage advanced technologies and equipment for large manufactures; and regulate the structure of industries by attracting services with low energy intensity (Dalian Municipality, 2007). From Table 4 we can see that energy consumption has been evaluated in terms of energy efficiency with respect to the economic size and the produced industrial value added. The results are impressive as the goals have been well achieved. The increases of energy efficiency are 21% and 27% with respect to GDP and industrial value added respectively. As Figure 2 showed, the economic growth rate of Dalian has been significantly high and fluctuated between 10%-25% per year during recent years. That is to say the reason behind the attained energy use efficiency with respect to GDP would be ambiguous: it could either be a reduction in the total consumption, or due to a greater expansion of economic scale than that of the energy consumption. While the story for other indicator is much clearer since the growth rate of the industrial share are small varying from -4% to 3%, thus a rise in efficiency are more likely to be caused by a reduction in energy consumption. The results show a success of implementation of CE policies in terms of energy use efficiency and could be set as an example for other pilot areas with similar regional features.

A number of plans have been set up to improve the water use efficiency (See Geng et al., 2009). As parts of these plans, Dalian municipality attempts to pursue both supply and demand-driven approaches to water management including finding new water sources, minimize water loss, and encourage water saving behavior among residents through price incentives and quota management. Apparently, those collaborations from government, enterprises and citizens have been effective leading to a substantial rise in water use efficiency in forms of 52% reduction of water consumption per produced industrial value added and 67% reduction of water consumption per capita.

Table 4. Key CE indicators in Dalian in 2005 and 2010 and goals set in 2006

	Indicators	Actual 2005	Goals by 2010	Actual 2010	Goals by 2010	Percent Change
Resource efficiency	Energy consumption per GDP (standard coal, tons/10^4RMB)	1.0	0.8	0.8	-21%	-21%
	Energy consumption per industrial value added (standard coal, tons/10^4RMB)	1.6	1.2	1.2	-27%	-27%
	Water consumption per industrial value added (tons/10^4RMB)	37.5	26.2	18.0	-15%	-52%
	Water consumption per capita (m^3/year)	186.9	--	62.1	--	-67%
Waste discharge	Municipal waste generation per capita (kg/year)	163.7	--	136.4	--	-17%
Waste treatment	Rate of municipal wastewater treatment	73%	90%	90%	17%	17%
	Rate of safe disposal of municipal solid wastes	80%	98%	100%	18%	20%
Waste reclamation	Rate of treated wastewater recycling	10%	35%	42%	25%	32%
	Rate of industrial solid waste reclamation	62%	75%	96%	13%	34%

Source: Dalian Municipality, 2006, 2011 and Liaoning Statistic Yearbook, 2006, 2011.
Note: Municipal waste includes waste from both industrial and residential sectors.

Waste management in Dalian focuses on the reducing the quantity of waste disposed and safe disposal or reclamation of waste in both industrial and residential sectors (Geng et al., 2009). Enterprises are supported and encouraged by government to obtain CP, ISO14001 certification, and embed 3R principles set within the production procedures. The municipality has established a waste reporting system to trace and track all waste flows. For residential side, demonstration project has been carried in selected community to improve the recycle rate of waste (Qu and Zhu, 2007). From Table 4, we see a 17% decrease of municipal waste generation per capita. The ability for wastewater and solid-waste treatments has increased by 17% and 20% respectively. Moreover, performances of waste reclamation are considerable and both exceed the set goals implying a contribution to reduce the consumption of virgin materials and waste disposal.

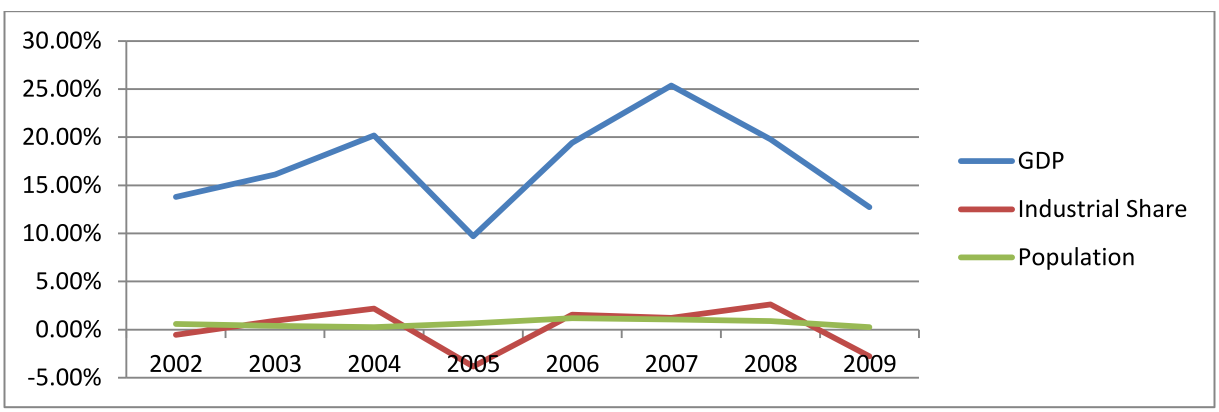

Figure 2. Growth rate of GDP, industrial share and population of Dalian for period 2002-2009
Source: China City Statistical Yearbook, 2002-2010

In sum, with the collaborative efforts from the key stakeholders including government, enterprises and citizens, the implemented CE polies have helped Dalian to accomplish the goals for resource use efficiency and waste management. In the next part, we compare Dalian's performance with other three CE pilot project cities taking account of the same indicators mentioned above.

Beijing, Shanghai and Tianjin are three economic developed areas in China with different economic and demographic characteristics. To have a more intuitive view of CE's development, we compare the percentage change in the individual indicators of the four cities (including Dalian) from 2005 to 2010 (See Table 5) and also compute the relative performance of the four cities in the years of 2005 and 2010 by dividing the raw number with the best performed one for each indicator (See Table 6). This allows comparison with the best practiced city technology in a given year as reference.

From Table 5 we can see that all four cities have achieved fruitful improvements in terms of energy and water efficiency. Compared with other three cities, Dalian's energy use efficiency improvement seemingly lags behind, but preforms much better in improving the water use efficiency. Beijing has a large increase in energy and water use efficiencies with respect to one unit of produced GDP; Tianjin, with the largest share of industrial sector among the four cities (China city statistical yearbook, 2002-2010) has improved its energy use efficiency mainly in industrial sector which is much higher than its energy use efficiency at the GDP level; Shanghai acts moderately to improve the energy use efficiency while it exceeds other cities levels in terms of water consumption per capita.

As for waste management, Dalian reduces the municipal waste by 17% which is the highest reduction among all cities. In contrast, Shanghai and Tianjin, fail to reduce their waste generation in 2010 compared with those of 2005 levels. The reason may be that the economic development in those cities blows up the total amount of production and consumption resulting in an increase in waste generation. For the rate of wastewater treatment, Tianjin has a substantial improvement which is nearly twice of what has been achieved by the follower. Shanghai is the only city that has a decreasing rate of wastewater treatment. It happens when speed of wastewater generation increases faster than the speed of technological development for wastewater treatment. As for the rate of safe disposal of municipal solid wastes, all cities have introduced a similar process and the variations between them are relatively small. Last, for the waste reclamation aspect, Shanghai again shows evidence of inability in its goal achievement when the city deals with the wastewater posing a strong contrast with Beijing: the percentage change in rate of treated wastewater recycling is -5% vs. 45%. For the rate of industrial solid waste reclamation, Dalian's progress (34%) overtakes that of Tianjin (27%), Shanghai (21%) and Beijing (16%).

Table 5. Development (percentage change) reflected by key CE indicator in four cities during 2005-2010 period

	Indicators	Beijing	Shanghai	Tianjin	Dalian
Resource efficiency	Energy consumption per GDP (standard coal, tons)	-62%	-31%	-21%	-21%
	Energy consumption per industrial value added (standard coal)	-66%	-36%	-76%	-27%
	Water consumption per industrial value added	-69%	-58%	-43%	-52%
	Water consumption per capita	-45%	-71%	-30%	-67%
Waste discharge	Municipal waste generation per capita	-11%	4%	1%	-17%
Waste treatment	Rate of municipal wastewater treatment	3%	-8%	31%	17%
	Rate of safe disposal of municipal solid wastes	15%	10%	14%	20%
Waste reclamation	Rate of treated wastewater recycling	45%	-5%	5%	32%
	Rate of industrial solid waste reclamation	16%	21%	27%	34%

Source: Data are collected from Statistical Yearbook of Liaoning, Beijing, Shanghai, Tianjin, and Dalian in 2006 and 2011.

Table 6 shows the relative performance of the four cities in 2005 and 2010. Since the best performance has been chosen as the benchmark during calculation, thus the ratio “1” represents a fine example and a reference point, and for other numbers, the smaller the gap from “1”, the better the performance is suggested to be and vice versa.

It is obvious that the CE has been developed over time, for all the “1” ration cases have been found in the year of 2010. In general, Tianjin performs the best since it has four “1”s out of nine, two in the energy efficiency aspect and two in the waste management aspect. Only for the indicator of water consumption per produced industrial value added, the result is slightly inferior to the corresponding for other cities. Beijing performs well in improving energy use efficiency and treated water recycling but need to improve the rate of municipal wastewater treatment. Dalian reduces waste generation and improves the rate of safe disposal of municipal solid waste significantly while improved energy use efficiency would be needed to be put forward as a priority. Shanghai, with the highest rate of growth of economy among those four cities performed the worst. Though it has cut the water consumption per produced industrial value added largely, the water consumption per capita is the highest among others. That is to say, the consumption of water for industrial sector may be reduced but not for the total water consumption. Additionally, Shanghai scores the lowest in three indictors out of four indicators which evaluate the extent of waste reusing and recycling, suggesting a poor performance in its waste management.

Table 6. The relative performance of four cities in 2005 and 2010 for each indicator

Indicators		Beijing		Shanghai		Tianjin		Dalian	
		2005	2010	2005	2010	2005	2010	2005	2010
Resource efficiency	Energy consumption per GDP (standard coal)	2.58	1.00	2.06	1.42	1.88	1.48	2.02	1.60
	Energy consumption per industrial value added (standard coal)	3.03	1.03	1.67	1.06	4.09	1.00	1.82	1.33
	Water consumption per industrial value added	3.59	1.11	2.35	1.00	2.06	1.18	2.21	1.06
	Water consumption per capita	2.39	1.32	4.50	1.33	1.42	1.00	3.88	1.29
Waste discharge	Municipal waste generation per capita	2.66	2.37	2.71	2.83	1.03	1.04	1.20	1.00
Waste treatment	Rate of municipal wastewater treatment	0.78	0.81	0.90	0.82	0.69	1.00	0.73	0.90
	Rate of safe disposal of municipal solid wastes	0.82	0.97	0.81	0.90	0.85	0.99	0.80	1.00
Waste reclamation	Rate of treated wastewater recycling	0.25	1.00	0.33	0.24	0.55	0.63	0.17	0.71
	Rate of industrial solid waste reclamation	0.83	0.99	0.76	0.97	0.73	1.00	0.63	0.98

In sum, the implementation of CE in China has been carried on effectively in Dalian and other three pilot cities. Since the goals set for Dalian have been fully realized in 2010 and performances of the other 3 pilot cities are impressive especially in terms of resource use efficiency. The primary reason behind the potential success of the improvement would be the government's decision to focus its efforts on those sectors which will yield the greatest short-term impact, such as heavy industry and applying instrument regulations which are likely to be most effective sectors. Second, those four pilot cities are more modernized, richer and with lower level of heavy industry than other regions in China, thus they could raise their energy use efficiency more easily. Another reason, though suspicious, lies in the credibility of the data. A lack of trust in China's economic statistics persists, and data on economic growth and energy consumption could be messaged to produce the required energy intensity estimates (Andrews-Speed, 2009).

What is more pronounced is the performances of four cities vary from one to another in regards to different indicators. In general Tianjin performs the best while Shanghai needs more catch up especially in the area of waste management. The reasons are manifold such as natural and environmental conditions, social and economic basis, and promoting policies by local government, etc. Nevertheless, through the data analysis, we are able to identify the relative performance among the sample of four pilot cities and distinguish the strong and weak points for each city which are essential for establishment of their policies.

5. Challenges and Barriers to Implementation of CE

Current performance in pilot areas demonstrates a promising future for developing CE in China, while it has not been coming along without problems. As a matter of fact, several challenges that can slow down or prevent the implementation of CE have been recognized and repeatedly stressed by a number of scholars. The most easily identified challenges are: lack of reliable information, shortage of advanced technology, weak economic incentives, poor enforceability of legislation, poor leadership and management, lack of public awareness, and lack of a standard system for performance assessment.

Geng and Doberstein (2008) pointed to the importance of information for enterprises to be able to plan and design the firm-specific scenarios for their optimal reduction, reuse and recycle activities. For each enterprise, not only the internal information would be needed, but also, being as a part of a larger economic system or web. Thus, the inter-linked relationship with other firms or areas should be also considered. Therefore, an efficient information system is crucial if decision-makers are to find more environmentally and financially beneficial ways to plan and manage their resources and structures etc. However, such systematic information systems are rare in China. In most cases, accurate information is not available to decision-makers, or is not conveyed in a timely manner. Moreover, due to fragmented management frameworks, different kinds of information often belong to different agencies which further decrease the efficiency in information exchange.

Secondly, technology is a key factor in the development of a circular economy. Each of the three CE principles already mentioned requires advanced technology and development and updating of facilities and equipment. However, the overall technology level in China is characterized as backward and due to insufficient financial and technology support the development in environmental technology area is not satisfactory. SMEs, generally accounted for 99.88% of the total number of manufacturing establishments in China, are the key players in this respect (Shi et al., 2007). Most of them have no or just few incentives to carry on “greener actives” in terms of waste reduction and reclamation, since changing or updating the equipment are usually time- and money- consuming while the potential economic benefit is limited. Let along the more requiring activities such as innovation and research to promote green technology. An alternative way is to transfer the technologies from developed countries, but it also appears to be risky due to the “lacked-in effect” which implies a strong dependence on exporter’s supports when technique failures occur (Xing et al., 2011).

The third constraint is the apparent continued unwillingness on the part of the government to use suitable economic and financial instruments to complement the preferred administrative approach (Wang et al., 2008). On the one hand, insufficient financial support from banks and inadequate public tax incentives pull off enterprises from innovating more environmental friendly technologies. On the other hand, producers see little economic incentives to save energy, material and water because the increase in price of these resources have been tightly constrained, and even if the price has gone up, producers can easily transfer the cost to consumers in form of higher price markups. Andrews-speed (2009) further traced underlying reasons for this unwillingness of price regulation by combining the current policies in other sectors. He pointed that China's economic and industrial policies had been devoted to promoting heavy industry, infrastructure and manufacturing which were closely associated with the price of energy and materials. Additionally, the government's insistence on keeping tight control on end-user energy prices derives from the desire to protect poor consumers as well as constraining inflation.

Another problem that is prevailing in China is the poor enforcement of legislation. This deficiency remains because: enforcement is superficial; excessive time exists between noncompliance and enforcement; available punishment for noncompliance is inadequate; injured parties are not properly compensated and some environmental crimes receive administrative instead of criminal punishment (Wang, 2007).

Fifth, government's management system has been questioned in China due to the complex structure of government agencies, poor accountability of local governments and straight-forward corruption. The implementation of CE over a sustained period required rounded management from the top leadership, pro-active participation from major actors at all levels of government, and transparency and predictability in both the administrative and the economic policy instruments implementation (Ma and Ortolano, 2000). As a result, failures in the management of energy, materials and environment in China can be attributed to a great extent to deficiencies in these respects.

Sixth, practices in Germany and Japan indicate that public participation is indispensable to development of a CE program. It could be more important for China due to both the complex nature of the concept, and the array of potential contributions that more than one billion Chinese consumers can make (Geng and Doberstain, 2008). In fact, however, China lacks the human and institutional capabilities to encourage public participation in a CE. And environmental management programmes and facilities at many Chinese academic institutions are limited. Even in a well-performed pilot city like Tianjin, residents have limited awareness and a poor understanding about the CE program (Liu et al., 2009). A more surprising survey results have been given by Xue et al. (2010) that 16.70% of the interviewed officials (252 in total) had just heard of CE suggesting there is still a need for government officials to acquire more sophisticated understanding of CE.

Last but not least, Chinese government needs to build a more completed system for performance assessment with concerns covering from standardizing the process of data collection, and calculation and submission to setting specific and quantitative goals in each local government

(Geng et al, 2012). Given the autonomy, local governments are fully in charge with developing their own way to collect, evaluate and submit their data to the central government. Without a transparent monitoring and auditing mechanism, the validity and accuracy of the provincial data collected are brought into question. Further, no specific goals and values are provided by the central government to the local governments considering development guidelines. Such a reality may discourage the eagerness of local governments as they do not know to what level they need to improve or what goals they should adhere to and attain.

6. Conclusion and Policy Suggestions

In the recent decade, there is an increasingly large body of literature discussing the CE, a Chinese economic model for sustainable development. Four reasons, i.e. environmental problem, resource scarcity, international comparativeness and national security illustrate the imperative for China to adopt a more sustainable way of development. Given the importance, our research provides a review of studies in this field intending to give a panorama of CE development and impacts in China.

The past practice and recent evidences have suggested that improvement in CE will move in waves and that these waves will advance across the country through key projects in a number of ways: from sectors of the economy which have great environmental externalities to those which are less environmental damaging and from regions with effective government to those with less effective government, from cities with agglomerated industrial areas or EIPs to cities which have scattered industrial firms. Current practices are carried at the micro, meso and macro levels simultaneously and cover the areas of production, consumption, and waste management. Other supports, from government and non-governmental organizations, help to promote, propagandize, regulate and monitor the implementation of CE.

In our review, we find that indicator evaluating systems are the most widely used instruments for assessment of the development of CE disregarding the economic scale level. At the enterprise level, indicators are tailored to individual firm or industry's characteristics. At the EIP level, two governmental agencies NDRC and SEPA have issued two different indicator evaluation systems. The former one focuses exclusively on the realization of 3R principles and the latter additionally considers EIP's impact on economic, environmental and social aspects. At the regional level, where the scholars' studies are the most abundant, the indicator systems are generally based on CE's ultimate goals and 3R principles (Wang et al, 2006; Yang et al., 2011; among others), but few scholars built the indicator system based on ecological efficiency theory (Zhu, 2007; Zhou et al., 2007). As for the weight of each sub-indicator prior to an aggregation, different methods have been used, such as principal component analysis, average weighting, analytic hierarchy process, fuzzy synthesis appraisal, etc.

In the empirical part, we provide data analysis of the key CE indicators for Dalian and compare the changes with those of other three pilot cities, Beijing, Shanghai, and Tianjin. The results show that Dalian municipality has well achieved its goal of development of CE in 2010. Compared with other three pilot cities, Dalian does fairly good in the waste management but lags behind in terms of energy efficiency. In general, Tianjin performs the best while Shanghai needs more catch up especially in the area of waste management. Accompany with other scholars' effort of estimating CE's implementation at the macro level (See in the Appendix A), it is obvious that local governments have had some success in turning their local economies into circular ones, yet where China as a whole stands in the CE adoption process is hard to gauge due to the lack of clear, standardized and quantitative measurements and goals.

Other challenges that impede a successful implementation of CE in China are: lack of reliable information, shortage of advanced technology, poor enforceability of legislation, weak economic incentives, poor leadership and management, and lack of public awareness.

Bearing with those problems in mind, the recent issued 12th five-year plan (2011-2015) has put forward the implementation of CE to a deeper and wider extent in China. It is evident that a transformation into a more sustainable way of development is now very high on the policy agenda of China's government, and the measures that it has taken show that a considerable amount of effort is being devoted to achieving the ambitious and praiseworthy goals of CE. The question is whether this trend of improvements can be sustained, or whether the country reverts to old practice and standards considering the complexity, diversity and great regional discrepancy of this economy.

But one thing is for sure, if China wants to achieve sustained progress and realize CE at a national level, as it says to adopt CE as future economic model, immense efforts are required to perfect existed measures as well as to deploy of a wider range of policies to break down the challenges that faced right now.

As international practices reveal that economic measures remain one of the most effective means of conserving the environment and resources, China's government should promote economic incentive through policies to stimulate enterprises and residents behave under the principles of CE. The current measures, for example pricing reforms, and preferential tax policies should be developed continuously and accordingly. New measures, say environmental taxes, insurance for liability resulting from environmental damage, and environmental labeling, should be explored and be included in legislation to ensure their enactment.

The government needs to continue its support for the major technologies necessary for CE. This requires government accurately identifies key technological areas and projects in line with current and long-term requirements for the economy and lends support to research into energy saving, alternatives, and recycling. And eventually boost the nation's capacity in proprietary technological innovation through R&D investment at both enterprise and academic levels.

In order to improve the public awareness and participation, activities related to the CE concept such as TV promotions, newsletters, achievement exhibitions and workshops should be carried out periodically. Such initiatives can provide platforms at which experiences from different parts of the world and from different institutions could be objectively reviewed. Moreover, enterprises could strengthen their mutual understanding and friendship through information exchanges, which will be the solid foundation for further collaboration on promoting CE.

Improvements of the enforceability of legislation as well as management system within the government are also impressive. It calls for a reform in judicial management mechanisms, a more transparent monitoring and auditing mechanism. On the other hand, government should form standardized ways of data collection, calculation and submission procedures so as to ensure more accurate assessment of CE's development and should provide local government with quantitative goals for short- and long- term development to enable the progress of CE development to be observed.

Notes

1. The data is according to two national surveys conducted by the All China Environmental Federation
2. Sector-integrated group refers to parks with multiple industrial sectors, especially the development zones, which are the main form of Chinese industrial park. The venous industrial park refers to those resource recovery parks where environmental technology companies and firms making "green products" coexist. The sector-specific group refers to parks with primarily one main sector or anchor tenant. Since most of the indicators are the same, here we only present the list of indicators for sector-integrated park in Table 3.
3. (I) stands for environmental impact, (P) stands for the product of population, (A) stands for GDP per capita and (T) stands for environment impact per unit of GDP.

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Appendix A

Summary table of the empirical literature on Circular Economy in China

Author(s)	Topic of research	Study period	Dimensions (number of indicators)	Estimation/computation method	Summary of findings and conclusion
Wang et al. (2006)	Evaluating regional CE: a case study of Jiangsu Province	1986-2003	Economic development; Resource reduction; Recycling, Pollution (16)	Analytic hierarchy process	The analysis showed that the CE is developing at a steady speed. According to the trend of development from 1986-2003, the official goal will not be achieved until 2022.
Wang et al. (2006)	Evaluation and diagnosis of obstacle for CE in Jiangsu's industry sector	1985-2003	Social and economic development; Resource reduction; Recycle and reuse; Waste reduction; Safety of resources and environment (35)	Analytic hierarchy process and Obstacle analysis	The results showed 10 obstacles that are impeding the CE's development in Jiangsu's industrial sector. Among which energy efficiency was the biggest obstacle. The average growth of CE indicators: in general (10.21%), waste reduction (17.63%), resource reduction (9.56%), recycle and reuse (3%).
Chen (2006)	Evaluation of CE for 3 different economic-scale cities Shanghai, Yinchuan, Rizhao,	Experience and consulting	Economic development; Living environment; Structure feature; Resource utilization Social Development (38)	Analytic hierarchy process	Shanghai (metropolitan) scored 93, Yinchuan (big city in the west) scored 76, Rizhao (medium sized city in the east) scored 65
Qian et al. (2008)	Assessment of development level of CE and the countermeasure in Qingdao City	Recent year data	Resource efficiency; Environmental impacts; Social development (28)	Analytic hierarchy process	The comprehensive index of CE development of Qiandao is 0.733, i.e. the mid-circular state; identify the bottlenecks in the development of CE. Development countermeasures are put forward to the existing problem in the development of CE in Qingdao.
Meng and Shen (2006)	Research on the CE evaluation of Central Plain cities	2003	Economic development; Green development; social development (25)	Principal component analysis	Economic development has proposed the most influence on CE, followed by reduction of resource usage and social development.
Xiong et al. (2008)	Comprehensive evaluation of circular economy development in Shaanxi	1998-2004	Resource reduction; Resource efficiency; Waste generation; Resource reuse and recycle; Economic aspects (19)	Principal component analysis	From 1998-2004, the performance of CE has been gradually improved. Waste per produced unit of GDP decreased and utilization of solid-waste improved.
Wang (2009)	Evaluation of	2006	Economic	Principal	16 cities' comprehensive

	CE on 29 Chinese cities		development; Reuse and recycle; Resource reduction; Emission reduction; Social development (10)	component analysis	score had been over zero, and it indicates that these cities' CE development is more balanced than others in all aspects; 12 cities' comprehensive score had been below zero and there is a huge gap in the goal of CE for them. Also pilot cities scored lower than the non-pilot cities.
Yang et al. (2011)	Integrative evaluation on the development of CE of Shaanxi	2004-2008	Economic development; Resource efficiency; Resource recycling and reuse; Environment protection; Pollution reduction (59)	Principal component analysis and Analytic hierarchy process	The results showed that CE's development in this province is in steady upward developing. Different indicators have different trends.
Zhang and Huang, (2005)	Research on CE indicator system and demonstrable assessment for Nantong city	Data of 2002 and goals in 2020	Economic development; Resource reduction; Waste reduction; Resource recycle; Eco-environment (12)	Grey correlation degree method	In 2002-2007 the goal is to focus on reducing pollution and resource consumption; In 2008- 2010 the goal is to focus on eco-environment protection, reducing pollution and management; in 2011-2020 the goal is to control for a balanced development among all aspects.
Hao et al. (2009)	Design of CE index at the city level	--	Economic development; Social stability; Resource consumption; Environmental Protection (16)	Fuzzy synthesis appraisal	The indicator system should be built according to the features of the city. The index system can be classified into main index system and assistant index system.
Jiang (2010)	Empirical Analysis of Regional CE development of Jiangsu, Heilongjiang, Qinghai Provinces	---	Resources consumption; Environmental disturbance; Recycling; Social development (16)	Fuzzy synthesis appraisal; Comparison evaluation method	Jiangsu had higher development in CE than other two provinces. Helongjiang needed to adopt energy conservation. The CE development and efficiency in recycling need powerful economic strength security.
Qin et al. (2009)	Integrative evaluation and case study on the development level of CE in Guangdong	2005	Resource usage reduction; Resource recycling and reuse; Resource and environment protection; Economy and social	Obstacle analysis	Different status of development in 21 cities in Guangdong owing to the dissimilarities of natural and environment condition as well as social and economic basis.

			development (23)		
Zhu and Qiu (2007)	Analytical tool for urban CE planning and its preliminary application for Shanghai	1990-2004	Productivity of resource and waste (7)	Eco-efficiency and IPAT	It lists three most serious problems in the case of Shanghai: energy supply, management of waste gas and solid waste.
Zhu and Qiu (2008)	Eco-efficiency indicators and their demonstration as the CE measurement in China	1990-2005	Productivity of resource and waste (7)	Eco-efficiency	The eco-efficiency of natural resource input in China has increased from 1990~2005. But it is not enough for China to decouple the economic growth from natural resources.
Li et al. (2009)	Measurement indicators and an evaluation approach for assessing urban sustainable development: case for Jining	Plan of 2004-2020	Economic growth and efficiency; Ecological and infrastructural construction; Environmental protection; Social and welfare progress. (52)	Full permutation polygon synthetic indicator method	Value of a synthetic indicator for sustainable development of Jining was 0.24 in 2004, which indicates a low level of sustainable development. According to the ecological plan of 2004-2020, the indicator will improve to 0.45 in 2007, 0.62 in 2010, and 0.90 in 2020.
Li and Zhang (2005)	CE evaluation index system in resource based cities	Recent data in two cities	Resource factors; Economic factors; Eco-environmental factors; Social factors. (21)	Same weight	Strategies for developing CE should be made according to the features of the different cities and external restricting factors to promote sustainable and all-round development of CE.
Du and Cheng (2009)	Evaluating CE efficiency of 47 iron and steel industry establishments in China	2003-2006	Input: water, energy, labor productivity, financial support. Output: waste water, waste gas and solid waste. (9 for inputs, and 4 for outputs)	Data envelopment analysis and Malmquist productivity index	The circular economy efficiency of iron and steel industry on the whole is not high, but has a fluctuated upward trend. The main factor that affects the enhancing of CE efficiency of iron and steel industry is pure technical efficiency.
Peng et al. (2005)	Studies on barriers for promotion of clean technology in SMEs of China	2002	20 barriers are grouped into four major categories: Policy and market barriers, Financial and economic barriers, Technical and information barriers and Managerial and organizational	The Analytic Hierarchy Process (AHP)	The exterior barriers of policy and financial barriers should be stressed rather than the inner barriers of technical and managerial barriers. Absence of incentives, lax enforcement of regulations and high initial capital cost were the most important barriers to adoption of clean technologies in China.

			barriers.		
Li and Su (2012)	Evaluation of the circular economy development level of Chinese chemical enterprises	Enterprises' confidential data	Economic development, resources exploiting, pollution reducing, ecological efficiency, development potential. (18)	Weighted sum model	The analysis on the CE development of Beijing Petrochemical New Material Base indicates that the CE development in this base is in a transitional stage from the transitional development to the circular mode. In the future more importance should be attached to the efficiency of resources-exploiting and its potential development to raise the level of CE development