Journal of Cleaner Production 23 (2012) 216–224

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Government initiatives

Towards a national circular economy indicator system in China: an evaluation and critical analysis

Yong Geng [a,b,*], Jia Fu [a,b], Joseph Sarkis [c], Bing Xue [a]

[a] Circular Economy and Industrial Ecology Research Group, Key Lab on Pollution Ecology and Environmental Engineering, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, Liaoning Province 110016, PR China

[b] Key Lab on Environmental Engineering, Shenyang University, Shenyang, Liaoning Province 110044, PR China

[c] Graduate School of Management, Clark University, Worcester, MA, USA

ARTICLE INFO

Article history:
Received 1 March 2011
Received in revised form
27 June 2011
Accepted 5 July 2011
Available online 18 July 2011

Keywords:
Circular economy
Eco-industrial development
Indicator system
Eco-efficiency
China

ABSTRACT

It is widely acknowledged that China's economic miracle has been achieved at the expense of its natural capital and environment. In order to deal with this problem, the circular economy (CE) has been chosen as a national policy for sustainable development. National laws and regulations have been enacted to facilitate the implementation of CE and national CE demonstration projects have been initiated such that national benchmarking activities could be completed. China is the first country to release nationally focused CE indicators so that objective and credible information on the status of CE implementation can be recognized. These CE indicators are valuable metrics for policy and decision-makers and can help achieve CE goals and outcomes. This unique indicator system has not been communicated to international communities. This paper aims to more broadly introduce this unique national CE indicator system. China's CE efforts are first detailed with various provisions of the national indicator system. A critical analysis of such an indicator system is presented. We show that certain benefits can be gained, but substantive revision is also needed due to the lack of a comprehensive set of sustainability indicators which should include social, business indicators, urban/industrial symbiosis, absolute material/energy reduction, and prevention-oriented indicators. Concerns related to barriers on implementation are also presented in this paper. The knowledge gained from Chinese efforts on CE indicators are valuable to both developed and developing nations seeking to implement sustainable development measures within their regulatory policies.

1. Introduction

Significant environmental burdens related to acceleration of global warming and resource scarcity have caused many countries to seek innovative approaches to ease these concerns. The circular economy (CE) policy instrument is an increasingly popular regulatory policy to address this issue especially within China. The CE concept originates from eco-industrial development (EID) theory and thought. CE is based on the 'win–win' philosophy that a healthy economy and environmental health can co-exist (Geng and Doberstein, 2008; Park et al., 2010). It incorporates myriad strategies to achieve greater efficiency through economies of systems integration. Partnerships amongst businesses to meet common service, transportation and infrastructure needs are encouraged. The policy potentially adds value to businesses and communities by optimizing the use of energy, materials and community resources (Geng et al., 2009b). The EID foundation of CE encourages economic activities to mimic the natural ecosystem metaphor, such as a closed loop of material flow within the broader economic system (Geng and Doberstein, 2008).

Given these characterizations, the Chinese central government has adopted CE as a national regulatory policy priority introducing numerous regulations to support and build its implementation. The first of these regulatory actions is the "Cleaner Production Promotion Law" which took effect in January 2003.This regulation was built upon with the amended Law on Pollution Prevention and Control of Solid Waste which took effect on April 1st 2005. On August 29th 2008, 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 taking effect on January 1st 2009. This law promotes the development of the circular economy, improving resource utilization efficiency, protecting the natural environment and realizing sustainable development.

* Corresponding author. Circular Economy and Industrial Ecology Research Group, Institute of Applied Ecology, Chinese Academy of Science, Shenyang, Liaoning Province 110016, PR China. Tel.: +86 24 83970372; fax: +86 24 83970371.
E-mail address: gengyong@iae.ac.cn (Y. Geng).

0959-6526/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jclepro.2011.07.005

The latest version of the CE regulation can be effectively categorized to influence three levels, including the micro or individual firm level, the meso- or eco-industrial park level, and the macro- or eco-city/eco-province level respectively (Yuan et al., 2006; Park et al., 2010). At the firm level, CE mainly focuses on eco-design and cleaner production (CP) strategies and actions. All the enterprises are required or encouraged to conduct eco-design and carry out cleaner production audits, publicly releasing information on their environmental performance so that the public can monitor their operation (Pintér, 2006; Yuan et al., 2006). The main objective of the meso-level (inter-firm level) is to encourage the development of eco-industrial parks and networks that will benefit both the regional economy and the natural environment (Yuan et al., 2006; Geng et al., 2008). Finally, the macro/national level promotes both sustainable production and consumption activities and aims to create a recycling oriented society (Geng et al., 2008; Li et al., 2009).

In support of the overarching CE natural regulatory policies various ministries have initiated programs to further promote the application of CE. One example is the Ministry of Environmental Protection (MEP) which initiated national eco-industrial park (EIP) projects in 2002 and consequently released a national EIP standard (Geng et al., 2008, 2009a). Currently, 50 industrial parks exist which serve as national EIP pilot projects.

In the latest CE-focused national regulation the governmental agency assigned the most significant CE responsibility is the National Development and Reform Commission (NDRC, a ministry level agency). Within NDRC the Department of Resource and Environment is responsible for preparing national CE policies, including drafting related legal documents, selecting national CE projects, establishing national CE indicators, and coordinating and communicating CE-related issues with other relevant agencies. To date, NDRC has initiated two batches of national CE pilot projects, including participation by 109 enterprises, 33 industrial parks, seven provinces and nineteen cities (Xue et al., 2010). One of the NDRC's critical initiatives in support of CE is the release of the national CE indicators in 2007, which is the first in the world. It is these indicators that we shall target our discussion and critical analysis.

These CE indicators from China have yet to be translated into English, explained in detail, or critically evaluated. Therefore, the main purpose of this paper is to introduce these indicators and evaluate their applicability, limitations, and potential. Benefits and challenges of applying these indicators are discussed, as well as the recommendations on improving such indicators. Finally, we draw our conclusions on future prospects and further investigation of CE-oriented indicators.

2. National and regional CE indicators

Sustainability and programmatic indicators are necessary for evaluating, monitoring, and improving upon various policies and programs. Various tools and methodologies may exist for indicator management. For example, material flow accounting or analysis (MFA) has been commonly used for developing and managing indicators in many developed countries (Bringezu et al., 2003). MFA is a quantitative procedure for determining the flow of materials and energy through the economy on multiple scales, including national, inter-industrial/eco-industrial park (Sendra et al., 2007), enterprise, and product levels (Binder, 2007; Bringezu et al., 2003). It is an accounting system that captures the mass balances in an economy, where inputs (extractions + imports) equal outputs (consumptions + exports + accumulation + wastes), and based on fundamental principles, specifically the laws of thermodynamics.

There are two widely used MFA-derived indicator systems, namely, the European Union and the Japanese material flow indicator systems. The former was published in "Economy-wide Material Flow Accounts and Derived Indicators—A methodological guide", prepared by Statistical Office of the European Commission (EUROSTAT). This system contains three categories – input indicators, consumption indicators, output and balance indicators (Pintér, 2006). The main indicators listed in the input category include: (1) Direct Material Input (DMI) representing the total direct input of materials; (2) Total Material Input (TMI) containing both DMI and unused domestic extraction, and (3) Total Material Requirement (TMR) including indirect material flows in addition to TMI (EUROSTAT 2001). In the consumption category, the core indicators are Domestic Material Consumption (DMC) measuring the total amount of material directly used in the economic system and Total Material Consumption (TMC) including the total material requirement of domestic consumption (EUROSTAT 2001). Net Additions to Stock (NAS) and Physical Trade Balance (PTB) are the main balance indicators. NAS can be used to measure the 'physical growth of the economy', while PTB represents physical trade surplus or deficit of the economy (EUROSTAT, 2001; Pintér, 2006). Domestic Processed Output (DPO) is the main output indicator measuring all outflows of used materials. Here materials that are recycled are not included (Pintér, 2006).

Additional broader MFA-policy frameworks have also been developed. For example, following the logic of the driving force-pressure-state-impact-response (DPSIR) framework, commonly used for analyzing environment-development interactions, the input and output indicators derived from MFA would typically fall in the pressure category. These indicators can be shown to influence the environmental state, or lead to impact on ecosystem or human well-being (EEA 1999; OECD 1998). Main input and output indicators such as TMR or TMC are direct sources of pressure, driven by economy-wide processes such as population growth. These pressures directly influence the state of the environment, such as water quality or land degradation. While the DPSIR framework has some limitations, in the context of material flow related measures, it helps establish causal linkages at least at the conceptual level between total or disaggregated material production and consumption and related impacts on the state of the environment and human well-being. Recognizing and quantifying these linkages, while not always simple, is necessary for designing effective policy responses. Thus, support of indicators is also shown in through the framework.

Japan is another typical regional/national example for applying material flow indicators within its various levels. Historically, Japan is a country relying heavily on imported raw material in addition to having very limited land space for waste disposal. Improving overall eco-efficiency has been a primary element of their economic system. Resource productivity (RP), material reuse and recycling rate, and the rate of waste for final disposal are the three core sustainability indicators in the Japanese material flow indicator system (Bringezu et al., 2003; Moriguchi, 2007). RP is the ratio of Gross Domestic Product (GDP) to Direct Material Input (DMI); Material reuse and recycle rate is the ratio of "total amount of recycled and reused material" to "total amount of DMI"; and the last indicator is the ratio of total amount of waste for final disposal to total amount of DMI. These indicators have been used to analyze Japan's production and consumption cycle and tackle the problems associated with mass resource consumption and mass production of waste. However, there are also several challenges related with these indicators, such as how to define a commonly accepted and transparent indicator for recycling rate and continuing data problems associated with imported hidden flows (Moriguchi, 2007).

In addition to these two cases of applying MFA to various CE related indicators, other countries have made their MFA-derived indicator efforts based on regional nuances and policies. For instance, the United States established a consistent MFA framework that integrates existing and future data in 2003 (National Research Council, 2003). The World Resources Institute (WRI) released a series of reports for detailing calculations on material flow indicators in the US, including not only some economy-wide aggregate measures but also sub-accounts for specific materials both on the input and output side (Matthews et al., 2000). These reports emphasize the importance of providing information on material flows throughout their lifecycle, from extraction through manufacturing, use and disposal or dispersion. Improving the overall eco-efficiency is the main goal of these systems. Several indicators have been introduced and calculated, including decoupling of material flow intensity measured as DPO per unit of GDP or per capita.

The Republic of Korea launched their national strategy for green growth in 2009, with a total funding of US$ 83.6 billion (2 per cent of GDP) (UNEP 2010). The aim of their initiative is to encourage policy goals and targets to tackle climate change and enhance energy security, increase material efficiency, create new engines of growth through investment in environmental sectors, and develop ecological infrastructure. Several indicators, such as energy and material efficiency indicators, have been set up for their first five-year plan (2009–2013), with the application of input–output tables for calculating the expected economic and environmental gains (UNEP 2010).

As we can see there is a preponderance of various MFA-derived indicators. These indicators quantify the linkage of environmental problems and human activities, and thus can serve as a systems-wide diagnostic procedure related to environmental problems and support the planning of adequate management measures and provide for monitoring the efficacy of those measures. Nevertheless, MFA-derived indicators have several limitations. First of all, the effective application of MFA requires that adequate and reliable data should be available. But such data may not be easily obtained in developing countries where appropriate data and information gathering systems have yet to be established. Second, in terms of quantifying environment or human health impact and liability, MFA considers the weight of materials, rather than material quality. But the impact and relevance of material flows depends on the status and type of the impacted ecosystem. Calibrating material flows according to material quality and ecosystem or human system sensitivity is not always a straightforward exercise and needs careful consideration of context (Pintér, 2006). Finally, MFA-derived indicators are most applicable and applied at the macro national level and thus most valuable in the context of developing macro level policy measures (Bringezu et al., 2003). However, in order to detail material production and consumption dynamics at the meso or micro levels, other diagnostic tools and indicators are required, such as substance flow analysis, life cycle analysis or supply chain analysis. Consequently, there is a need to combine MFA with other related methods so that a multi-scale and comprehensive analytic system can be set up.

Given the above characteristics of MFA and MFA-based CE indicators for developed countries, China, through NDRC released its national CE indicators in 2007. Such indicators were designed to promote the application of CE, assessing the general performance of CE practice and supporting policy-making process on CE through a scientific analysis on relevant data and information. MFA has been selected as the main method to develop such indicators, while other tools, such as eco-efficiency indicators, have also been adopted so as to measure environmental performance related to economic performance, especially for water use, energy use and waste generation. We now focus the discussion on China's specific CE indicators.

3. China's national circular economy indicators

China's CE indicator development process required inputs from various selected experts and government agencies. When the NDRC developed these indicators the major stakeholders invited to participate were policy and academic experts. These experts were major contributors to the national government in Beijing to when preparing these indicators. These experts did utilize information they had gathered from other national and supranational examples as mentioned in the previous section. In an effort to minimize overlap and redundancy in indicators, the NDRC asked both Ministry of Environmental Protection and the National Statistics bureau to make comments on these indicators and before releasing them officially. Clearly, the involvement of a broader set of stakeholders (e.g. consumers, communities, non-governmental organizations, and even a broader industrial sector representation) may have resulted in differing measures and addressed some of the barriers identified later in this paper.

Overall, the stated purpose of developing indicators is to provide objective, credible information on the status of a system to decision-makers and thus help clarify and reach desired outcomes. The old adage 'you can't manage what you can't measure' is especially pertinent in this situation. If certain conditions are met, indicators can facilitate meeting goals and outcomes. China's national circular economy indicators are based upon the 3R principles (Reduction, Reuse and Recycle). Different planning and implementation levels of CE present some variations in the types of indicators used. Specifically, the published Chinese Circular Economy Evaluation Indicator System provides two separate sets of indicators. One set of indicators is used at macro-level for the general evaluation of the CE on development for both individual region and national-level analysis. This macro indicator system provides guidance for future CE development planning. The other set of indicators is used for assessing the state of CE development at the industrial park (meso) level.

Both indicator sets contain four categories: resource output, resource consumption, integrated resource utilization, and waste disposal/pollutant emission indicators. Resource output indicators refer to the amount of GDP produced from resource consumption. Higher values of these indicators mean higher material efficiency. Resource consumption indicators refer to the amount of resource consumed on a per unit product or per unit GDP level. Lower values of these indicators mean that less water, material and energy are consumed by our economic system. The implication is that there are fewer impacts on the natural ecosystem and with higher economic performance. Integrated resource utilization indicators reflect the level of material recycling. Higher values of these indicators represent increased materials recycling with return of these materials back into the economic system. The result would be reduction in total consumption of virgin materials and total wastes sent to disposal in landfill sites. It also reflects dematerialization perspectives of one economic system. Finally, waste disposal/pollutant emission indicators refer to the total amount of waste disposal and the emission amounts of key pollutants. Lower values of industrial wastes for final disposal and lower values of emissions of key pollutants (such as COD, SO_2) reflect more efficient CE performance.

Table 1 lists the macro CE evaluation indicators with 22 indicators categorized into 4 groups. Two indicators are listed for resource output, seven are listed for resource consumption, nine are listed for resource integrated utilization and four are listed for waste disposal and pollutant emission. Table 2 lists the CE

Table 1
Circular economy evaluation indicator system (at macro level).

Groups	NO.	Indicators
1. Resource output rate	1.1	Output of main mineral resource
	1.2	Output of energy
2. Resource consumption rate	2.1	Energy consumption per unit GDP
	2.2	Energy consumption per added industrial value
	2.3	Energy consumption of per unit product in key industrial sectors
	2.4	Water withdrawal per unit of GDP
	2.5	Water withdrawal per added industrial value
	2.6	Water consumption of per unit product in key industrial sectors
	2.7	Coefficient of irrigation water utilization
3. Integrated resource utilization rate	3.1	Recycling rate of industrial solid waste
	3.2	Industrial water reuse ratio
	3.3	Recycling rate of reclaimed municipal wastewater
	3.4	Safe treatment rate of domestic solid wastes
	3.5	Recycling rate of iron scrap
	3.6	Recycling rate of non-ferrous metal
	3.7	Recycling rate of waste paper
	3.8	Recycling rate of plastic
	3.9	Recycling rate of rubber
4. Waste disposal and pollutant emission	4.1	Total amount of industrial solid waste for final disposal
	4.2	Total amount of industrial wastewater discharge
	4.3	Total amount of SO_2 emission
	4.4	Total amount of COD discharge

COD means chemical oxygen demand
"Table 1 lists the CE evaluation indicators at macro level, at which 22 indicators were categorized into 4 groups. Two indicators are listed for resource output, seven are listed for resource consumption, nine are listed for resource integrated utilization and four are listed for waste disposal and pollutant emission."

evaluation indicators at the industrial park level. At this level 12 indicators are categorized into 4 groups. Four indicators are listed for resource output and four are listed for the resource consumption category, two indicators are listed for both resource integrated utilization and two indicators exist for waste disposal and pollutant emission.

Interestingly, carbon reduction and some other ecological indicators are not incorporated into these listings. The reason for this omission is that the Department for Climate Change Response at the National Development and Reform Commission (NDRC) initiated a "low carbon economy development" project in 2010, where CO_2-related indicators have been used to evaluate their carbon reduction performance. Thus, carbon emission indicators can be found outside the CE indicator set, and may be integrated for a more complete analysis. Other ecological indicators have been also adopted by the Ministry of Environmental Protection (MEP) when it initiated its "eco-city" indicators (totally 28 indicators) in 2003. These eco-city indicators include the land greening rate, local ecosystem service value, biodiversity etc. Both NDRC and MEP are national agencies and are not allowed to release the same indicators through different programs.

In order to facilitate the practical application of such indicators, NDRC also released a detailed guideline on how to calculate such indicators with consideration of local conditions. Table 3 lists the methods on how to calculate indicators at a macro level, while Table 4 lists the methods on how to calculate indicators at a meso level.

4. Benefits and challenges

4.1. Benefits

China's increased attention, from various stakeholder groups, on both increasing resource efficiency and reducing negative impacts to the ecosystem has caused provincial governors and local officials to increase their environmental awareness. Most have integrated environmental protection efforts as one of the key priorities in their decisions. This political commitment ensures that CE, eco-industrial parks and cleaner production efforts will tend to become institutionalized through long term development strategies and adequate budgeting of financial, human and technical resources. A "green image" has become a key mission for regional and local governments, not just national governmental bodies. Given this political evolution, both local governments and industrial park managers are eager to join national CE initiatives as they believe that their participation will bring comprehensive economic,

Table 2
Circular economy evaluation indicator system at the industrial park level.

Groups	N.	Indicators
1. Resource output rate	1.1	Output of main mineral resource
	1.2	Output of energy
	1.3	Output of land
	1.4	Output of water resource
2. Resource consumption rate	2.1	Energy consumption per unit industrial production value
	2.2	Water consumption per unit industrial production value
	2.3	Energy consumption of per unit key product
	2.4	Water consumption of per unit key product
3. Resource comprehensive utilization rate	3.1	Recycling rate of industrial solid waste
	3.2	Industrial water reuse ratio
4. Waste disposal and pollutant emission	4.1	Total amount of industrial solid waste for final disposal
	4.2	Total amount of industrial wastewater discharge

"Table 2 lists the CE evaluation indicators at the industrial park level, at which 12 indicators are categorized into 4 groups. Four indicators are listed for resource output and four are listed for consumption category, two indicators are listed for resource integrated utilization and two are for waste disposal and pollutant emission."

Table 3
Indicator calculation and explanation at macro level.

No.	Calculation formula	Explanation
1	Output of main mineral resource = GDP/total consumption of main mineral resource(*Unit: 10,000 ¥/ton*)	A higher value means more efficient use of mineral resource. The main types of mineral resources include iron–, copper–, lead–, zinc–, tin–, antinomy–, tungsten–, molybdenum–, pyrite-, and phosphate ore, etc.
2	Output of energy = GDP/Energy consumption(*Unit: 10,000 ¥/ton sce*)	A higher value means more efficient use of energy. The energy source includes coal, oil, natural gas, nuclear power, wind power and hydro power.
3	Energy consumption per unit of GDP = Energy consumption/GDP (*Unit: ton sce/10,000 ¥*)	The total energy consumed per 10,000 ¥ produced. The lower value means more efficient energy consumption.
4	Energy consumption per added industrial value = Industrial energy consumption AVI(*Unit: ton sce/10,000 ¥*)	The lower value of this indicator means more efficient energy consumption.
5	Energy consumption of key industrial product = Energy consumption of steel(copper, aluminum, cement, fertilizer, paper)/steel production (copper, aluminum, cement, fertilizer, paper) (*Unit: ton sce/ton*)	Key industrial sectors include mining industry, manufacturing industry, water, electricity and gas production and supply industry. Main products include steel/iron, copper, aluminum, cement, fertilizer, paper etc. The lower value means more efficient energy consumption.
6	Water withdrawal per unit of GDP = total amount of water withdrawal/GDP(*Unit:10,000* m^3/¥)	Water withdrawal includes all kinds of fresh water sources, such as surface water, groundwater, recycled wastewater, rainwater, desalinated seawater etc, but excludes the directly used seawater. The lower value means more efficient water consumption.
7	Water withdrawal per added industrial value = amount of industrial water withdrawal/AVI(*Unit:10,000* m^3/¥)	Water withdrawal means water consumption. Water withdrawal here is the water consumed during the industrial processes, such as manufacturing process, cooling process, air conditioning and purification processes. Fresh water consumption value here does not include any recycled water. The lower value means more efficient water consumption.
8	Water consumption of key industrial sector product = total amount of fresh water consumption/total amount of steel production (copper, aluminum, cement, fertilizer, paper)(*Unit:*10^8 m^3*/ton*)	Water consumption efficiency in key industrial sectors.
9	Coefficient of irrigation water utilization = actual amount of irrigation water consumption/total amount of irrigation water consumption	Ratio of actual amount of irrigation water consumption to total amount of irrigation water consumption. The higher value means more efficient water use in agricultural sector.
10	Recycling rate of industrial solid waste = (industrial solid waste integrated utilization Q/Industrial solid waste generation) × 100%	Ratio of amount of integrated utilized industrial solid waste to total amount of industrial solid waste.
11	Industrial water reuse ratio = (industrial repetitive water use Q/Industrial water consumption) × 100%	Industrial water reuse includes both recycled water reuse and cascaded water reuse. Industrial water consumption includes water consumption for both industrial and living purposes.
12	Recycling rate of wastewater = (Treated wastewater reuse Q/Total treated wastewater Q) × 100%	The reuse of treated wastewater includes both treated domestic wastewater and industrial wastewater that is qualified with the national recycling water standard. The total treated wastewater is the actual amount of wastewater treated in the wastewater treatment plant, including physical, biological and chemical treatment.
13	Safe treatment rate of municipal rubbish = (total amount of safely treated domestic waste/total amount of domestic waste cleaned up) × 100%	Ratio of total amount of safely treated domestic rubbish to total amount of domestic rubbish.
14	Recycling rate of iron scrap = (Amount of recycled iron scrap/total amount of iron production) × 100%	Ratio of amount of recycled wasted iron scraps to total amount of iron production.
15	Recycling rate of non-ferrous metal = (Amount of recycled non-ferrous metal/total amount of non-ferrous metal production) × 100%	Ratio of amount of recycled mom-ferrous metal to total non-ferrous metal production.
16	Recycling rate of paper = (Amount of recycled paper/total amount of paper production) × 100%	Ratio of amount of recycled paper to total amount of paper produced.
17	Recycling rate of plastic = (Amount of recycled plastic metal/total amount of plastic production) × 100%	Ratio of recycled plastic to total amount of plastic produced.
18	Recycling rate of rubber = (Amount of recycled rubber/total amount of rubber production) × 100%	Ratio of recycled rubber and total amount of rubber produced.
19	Industrial solid waste for final disposal(*Unit: ton*)	Total amount of industrial solid waste for final disposal.
20	Industrial wastewater discharge(*Unit: ton*)	Total amount of discharged industrial wastewater.
21	SO_2 emissions(*Unit: kg*)	Total amount of SO_2 emission
22	COD discharge(*Unit: kg*)	Total amount of chemical oxygen demand (COD).

¥ is the symbol of Chinese currency RMB, currently, 1 USD = 6.58 RMB.
"sce" represents standard coal equivalent energy; AVI represents annual added industrial production value; Q represents quantity.

environmental and social benefits. The proposed indicator systems can help decision-makers design effective policy responses for promoting CE.

For example, absolute waste disposal indicators, such as total amounts of industrial waste for final disposal, SO_2 emission, COD emission, and industrial waste water emission, have been established so that increases or decreases in environmental impacts can be effectively reflected. This monitoring through indicators is particularly important in a rapidly developing country like China, especially given that the rate of growth may outstrip the rate of improvement in eco-efficiency, leading to a greater negative environmental pressures and burdens. These indicators can also be effective tools for practical and research purposes such as monitoring the progress towards decoupling of environmental burden and economic growth. That is, decoupling can be observed only if the rate of improvement in resource use intensity is higher than the rate of growth of the physical economy.

The potential economic benefits from this monitoring and improvement system include more efficient materials and energy use, increased revenues from the sale of "wastes", cost savings from

Table 4
Indicator calculation and explanation at industrial park level.

N.	Calculation formula	Explanation
1	Output of main mineral resource = Industrial production value/main mineral resource consumption *(unit: 10,000 ¥/ton)*	Mineral resource consumption = main mineral resource production + imported mineral resource − exported mineral resource
2	Output of energy = Industrial production/value Energy consumption *(unit: 10,000 ¥/ton sce)*	Ratio of energy consumption to GDP. The energy source here includes coal, oil, natural gas, nuclear power, wind power and hydro power.
3	Output of land = Industrial production value/total land area of industrial park *(unit: 10,000 ¥/ha)*	The higher value of this indicator means more efficient land use.
4	Output of water resource = Industrial production value/total amount of water withdrawal *(unit: 10,000 ¥/m^3)*	The higher value of this indicator means more efficient water use.
5	Energy consumption per unit industrial production value = Energy consumption/Industrial production value *(unit: ton sce/10,000 ¥)*	The lower value of this indicator means more efficient energy consumption.
6	Water withdrawal per unit industrial production value = Water withdrawal amount/industrial production value *(unit: 10,000 m^3/¥)*	The lower value of this indicator means more efficient water use. Water sources include surface water, groundwater, recycled wastewater, rainwater, desalinated seawater, but not includes directly used seawater.
7	Energy consumption of key product = energy consumption/weight of product production *(unit: Ton sce/ton)*	The lower value of this indicator means more efficient energy use. The key products include copper, aluminum, cement, fertilizer, paper etc.
8	Water consumption of key product = fresh water consumption/weight of product production *(unit: 10^8 m^3/ton)*	The lower value of this indicator means more efficient water use. The key product includes copper, aluminum, cement, fertilizer, paper etc.
9	Recycling rate of industrial solid waste = (recycled amount of industrial solid waste/total amount of industrial solid waste) × 100%	Ratio of amount of recycled industrial solid waste to total amount of industrial solid waste generated.
10	Industrial water reuse ratio = (amount of total reused wastewater for industrial purpose/total amount of industrial water consumption) × 100%	The reused industrial wastewater includes both treated domestic wastewater and industrial wastewater that is qualified with the national recycling water standard.
11	Industrial solid waste for final disposal (unit:ton)	Total amount of industrial solid waste for final disposal.
12	Industrial waste water discharge (unit: ton)	Total amount of discharged industrial wastewater.

¥ represents symbol of Chinese currency RMB;
"sce" means standard coal equivalent energy, AVI means Annual added industrial production value, and Q represents quantity.

lowered insurance costs and reduced environmental penalties, and increased competitive capacity. The potential environmental benefits include the conservation of natural resources (especially non-renewable resources such as water, fossil fuels and minerals), reduced environmental impact through efficient energy and material use and less waste discharge, avoidance of toxic materials, extended life cycle of landfill sites, and recovery of local ecosystem. The potential social benefits include improved social relations between industrial sectors and local societies, more employment opportunities from new recycling businesses, improved public environmental awareness and public health level.

However, although the application of this indicator system may bring certain benefits, problems and challenges still exist, including lack of direct social indicators, lack of indicators on industrial symbiosis, lack of indicators for businesses, lack of absolute energy/material reduction indicators, lack of prevention-oriented indicators, lack of measurable criteria and barriers on implementation. Each of these challenges will now be evaluated.

4.2. Lack of social indicators for the circular economy

The practical implementation of CE will involve and have implications on environmental, economic and social dimensions (Feng and Y, 2007). Thus, a systematic evaluation on various aspects should be addressed. This evaluation requires that in addition to environmental and economic indicators, social indicators should also be established. However, the published Chinese national CE standards are absent any social indicators. More indicators are thus needed to portray the social aspects in CE.

Exemplary indicators would include the degree of public awareness and participation, employment rate through CE efforts, environmental justice issues, etc. Taking public participation as an example, this indicator will help to measure the level of a fair and equitable allocation of resources when implementing CE concepts (Geng and Doberstein, 2008). In addition, investment on CE research and development (R&D) is a key factor for the success of CE implementation. Without advanced CE technologies and equipment, many innovative ideas will not be realized. In the Chinese political system, it's the governmental responsibility to invest in such an area, which may bring comprehensive social benefits to local communities. An indicator that can evaluate the level of R&D investment is a logical social indicator for CE. This type of indicator can be evaluated using a ratios based on CE R&D investment to overall R&D investment. A CE R&D investment indicator will ensure that enough funds for CE R&D activities can be allocated and expected outcomes can be achieved in various localities.

4.3. Lack of indicators on urban/industrial symbiosis

Industrial symbiosis is defined as encouraging traditionally separate industries to adopt a collective approach building competitive advantage by incorporating physical exchange of materials, energy, water and byproducts into their business processes. Industrial symbiosis can aid firms in diverse urban areas to benefit from concentrated intermediate inputs that are not specific to any particular industry, such as reuse and recycling of municipal solid waste (MSW) and shared public infrastructure, accounting services and labor market (Chertow, 2000). Urban symbiosis is an extension for industrial symbiosis. It can be defined as "the use of byproducts (waste) from cities (or urban areas) as alternative raw materials or energy sources for industrial operations (Van Berkel et al., 2009; Geng et al., 2010). Both urban symbiosis and industrial symbiosis are key activities for CE success.

Both approaches are based on the synergistic opportunity arising from geographic proximity through the transfer of physical resources (waste materials) for environmental and economic benefit. Consequently, indicators on urban/industrial symbiosis should be established to evaluate the level of materials exchange at both industrial park and regional levels. Current national Chinese (and other nation) CE standards do not include such indicators. Potential indicators in this regard may include the total number of scavenger and decomposer businesses, diversity of industrial sectors involved in the urban/industrial symbiosis activities, connectivity among different industries, etc.

4.4. Lack of indicators for businesses

Chinese CE implementation has three levels. But the published indicators were designed only for macro- and meso-levels. The micro level, namely at the facility or corporate level, is notably absent from the adopted listing of indicators. However, businesses play a key role for promoting CE and cannot be ignored. For instance, promoting cleaner production and eco-design can significantly improve the overall eco-efficiency of the whole company by identifying the key opportunities for internal pollution prevention, dematerialization, process integration and safe treatment of their wastes. China is now playing the role of the world's factory, consuming substantial virginal materials, energy and water. There is an urgent need to set up appropriate indicators for evaluating the performances of various businesses so that managers and entrepreneurs have drivers, indicators, and tools to make internal changes. Due to the different operating nature of their businesses, it may be rational to set up specific indicators for different industrial sectors so that their concerns can be addressed in an appropriate way. For instance, highlighting energy efficiency indicators would be appropriate for the cement industry, while special attention may be given to water efficiency indicators for the pulp and paper industry. The usefulness of these indicators would include development of widely accepted internal business environmental performance measures and systems, which feed into activities ranging from continuous improvement efforts to making the 'business case' for specific environmental technology and processes.

4.5. Lack of absolute material/energy reduction indicators

Relative indicators may tell only part of the story, while absolute indicators are useful to show a true full measure of activities and outcomes from CE. However, unlike those indicators used in developed countries, most of the published CE indicators are relative ones, only few are absolute ones. With rapid economic development and growth in China, a relative reduction (ratio-based indicators) may not necessarily mean a net reduction of environmental emissions and material/energy consumption. A relative improvement may result in a net emission increase if one region/ industrial park's annual economic growth rate exceeds a certain level. The evaluation of relative indicators also depends on which types of GDP (or other units) are used for the calculation. For example, constant price GDP or power purchase parity (PPP) may provide variations in results. Constant price GDP is likely to appear lower than PPP for developing countries, which are countries with relatively lower prices. Hence, the difference in improvement level becomes larger in both absolute and relative terms when such indicators are calculated on the basis of GDP. Interestingly, this argument also means that the currency exchange rate substantially affects the interpretation of these indicators, especially when seeking to benchmark across countries.

4.6. Lack of prevention-oriented indicators

All the Chinese CE indicators focus on reuse and recycle dimensions. However, 3R principles have typically promoted reduction, namely, prevention, as the most important objective. Given these limited indicators, there is a risk of preferring recycling and reuse based solutions over the more preferable prevention and source reduction solutions integrated into the design of products and in production technology (proper integration often does not enable discrimination between the most desirable source reduction solutions as CE related investments).

Proper source reduction solutions could in fact worsen some indicators such as recycling and reuse, thus becoming unwanted at the end. This situation can be observed within OECD countries when preferences are given to environmental goods and services that are dependent on recycled materials which may have been reduced in various processes. The same trap can be hidden within promotion of urban symbiosis and industrial symbiosis on the costs of source reduction. Waste stream producers and consumers are at a disadvantage if there is otherwise feasible source reduction measures identified, creating supply and demand problems to both members of this symbiotic partnership. If there are contractual relationships motivating them to continue producing waste streams for product usage, then reduction may be counterproductive to their goals. Thus, a preferred approach of preventing and avoiding the inclusion of toxics in the products by designing them in a better way via eco-product design, green chemistry, green engineering are missed.

4.7. Barriers to implementation

There are a number of factors that serve as barriers to the effective and efficient implementation of such indicators. First, there is no detailed description or standardized process on data collection, calculation and submission. Local governments are required to develop their own approaches with full responsibility to collect data, conduct the related calculations and finally submit the outcomes to NDRC. Without a transparent monitoring and auditing mechanism, NDRC's capabilities to determine the validity and accuracy of data submitted by the local authorities are brought severely into question. It has been a well-publicized policy that the central government is only responsible for setting up broad national standards (Lo and Leung, 2000), similar to 'unfunded mandates'. Given this autonomy and lack of standardization, local governmental officials could cherry pick their achievements to collect political credits. Local governmental officials may only select indicators and valuation approaches that made them look good, rather than appropriate data. Another potential issue that arises within this barrier is that some data are not easily collected since they may involve many and disparate different agencies. Unless responsible officials can secure cooperation from other relevant governmental agencies, they will find it hard to guarantee the validity and accuracy of such data.

Second, this indicator system is a voluntary one and may be pursued with differing intentions. While relatively richer east China regions have genuine interests in improving resource efficiency and environmental performance, the poorer west China regions simply have a desire to gain access to national financial subsidies (Xue et al., 2010). Thus, various communicative approaches, including broad educational programs and compulsory reporting, should be adopted so as to improve CE awareness and knowledge and to ensure that such a reporting mechanism should be incorporated into regional and industrial long term development strategies.

Third, the NDRC only provides general lists of indicators that should be reported, but they do not provide specific goals and values that may be used as benchmarks. 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 attain. For example, the national eco-industrial park standards released by Ministry of Environmental Protection (MEP) in 2003 did provide detailed values to all of their indicators, facilitating industrial park managers to check the gap between their current levels and national standard (Geng et al., 2009a). Consequently, a further revision on CE indicators is necessary so that quantitative values for all indicators can be constructed using Chinese practicalities and realities.

5. Conclusion

With the rapid urbanization and industrialization, China is facing various environmental challenges including global warming, resource scarcity and environmental pollution. In grappling with these environmental burdens and as befitting a strong developmental state, the Chinese authorities have initiated numerous efforts. Among them, the circular economy policy has been chosen as a core dimension for the national sustainable development policy direction. National CE demonstration projects at different levels have been initiated and quantitative indicators have also been released to help evaluate the holistic performance of these various demonstration projects. Such indicators include two sets and were designed for both macro level and industrial park level analyses and monitoring, with 22 indicators and 12 indicators respectively. A detailed set of calculations and explanations were also provided. These calculations and explanations can be used to facilitate more detailed methodological processes for managing CE situations.

A methodological development initiative can ensure the enforcement of both the Cleaner Production Promotion Law and the Circular Economy Promotion Law and alleviate national environmental pressures. The indicator development policy also creates incentives and motivations for local governments to pay more attention to specified environmental issues.

A variety of benefits, including economic, environmental and social ones, can be gained through the implementation of such indicators. However, some problems exist, such as lack of social indicators, urban/industrial symbiosis, prevention-oriented indicators and absolute energy/material reduction indicators, as well as barriers to implementation. Thus, recommendations for further revision are made, especially considering the Chinese realities. Nevertheless, this new initiative can provide objective and credible information on the status of CE implementation at various levels and help decision-makers clarify and reach their desired outcomes. It can also encourage practitioners to improve their economic performance, environmental quality, and social development.

What we have provided is a critical analysis of a national level sustainability indicator system for a developing country. What we still need to do is to determine whether this indicator system has actually had any significant results to government, industry, communities and other stakeholders. A clear identification of how these indicators have actually been applied requires significant investigation. We do acknowledge that the indicators can be used for benchmarking, improvement of environmental performance at multiple levels, identification of problem areas, cost-benefit analyses, policy direction, business investment decisions, and many other applications. What needs to be determined is how these indicators can be integrated into methodologies for decision making and policy setting that allow for their effective implementation. The diffusion, usefulness, and evolution of indicators are also avenues of further investigation at multiple levels. Relationships amongst these levels and decision making are also fertile areas for further investigation. Whether the research methodology is through formal analytical modeling for decision making and policy setting, or empirical studies for further theoretical development and understanding, or through case and field studies for generation and dissemination of best practice knowledge and theory building, there is ample room for further understanding. We believe that this first step in a critical analysis of sustainability predictors for an innovative emergent nation environmental policy is an important first step.

Acknowledgments

This work is supported by the Natural Science Foundation of China (71033004), Chinese Academy of Science's "one hundred talent program" (2008-318), Ministry of Science and Technology (2011BAJ06B01), the Shenyang Scientific Research Foundation (1091147-9-00, F10-238-6-00), the Liaoning Science Foundation (20092078), and Institute for Global Environmental Strategy (IGES) of Japan. Especially, we want to thank those seven anonymous reviewers for their valuable comments and contributions to the revised version of this paper.

References

Binder, C., 2007. From material flow analysis to material flow management part I: social sciences modeling approaches coupled to MFA. Journal of Cleaner Production 15, 1596–1604.

Bringezu, S., Schutz, H., Mooll, S., 2003. Rational for and interpretation of economy - wide materials flow analysis and derived indicators. Journal of Industrial Ecology 7 (2), 43–64.

Chertow, M.R., 2000. Industrial symbiosis: literature and taxonomy. Annual Review of Energy and the Environment 25, 313–337.

Circular Economy Promotion Law of the People's Republic of China. available through, http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/09/circular-economy-law-cn-en-final.pdf.

European Environment Agency (EEA), 1999. Environmental Indicators: Typology and Overview. EEA, Copenhagen. Technical Report No. 25.

EUROSTAT, 2001. Economy-Wide Material Flow Accounts and Derived Indicators –A Methodological Guide. Office for Official Publications of the European Communities, Luxembourg.

Feng, Z.J., Yan, N.L., 2007. Putting a circular economy into practice in China. Sustainability Science 2, 95–101.

Geng, Y., Doberstein, B., 2008. Developing circular economy in China: challenges and opportunities for achieving "leapfrog development". International Journal of Sustainable Development and World Ecology 15 (3), 231–239.

Geng, Y., Zhang, P., C˜ot'e, R.P., Qi, Y., 2008. Evaluating the applicability of the Chinese eco-industrial park standard in two industrial zones. International Journal of Sustainable Development and World Ecology 15, 1–10.

Geng, Y., Zhang, P., C˜ot'e, R.P., Fujita, T., 2009a. Assessment of the national eco-industrial park standard for promoting industrial symbiosis in China. Journal of Industrial Ecology 13 (1), 15–25.

Geng, Y., Zhu, Q.H., Doberstein, B., Fujita, T., 2009b. Implementing China's circular economy concept at the regional level: a review of progress in Dalian, China. Waste Management 29, 996–1002.

Geng, Y., Fujita, T., Chen, X.D., 2010. Evaluation of innovative municipal solid waste management through urban symbiosis: a case study of Kawasaki. Journal of Cleaner Production 18 (2010), 993–1000.

Li, H.Q., Bao, W.J., Xiu, C.H., Zhang, Y., Xu, H.B., 2009. Energy conservation and circular economy in China's process industries. Energy 35 (1111), 4273–4281.

Lo, C.W.H., Leung, S.W., 2000. Environmental agency and public opinion in Guangzhou: the limits of a popular approach to environmental governance. The China Quarterly 2000, 677–704.

Matthews, E., Amann, C., Bringezu, S., Kowalski, M.F., Hüttler, W., Kleijn, R., Moriguchi, Y., Ottke, C., Rodenburg, E., Rogich, D., Schandl, H., Schütz, H., Vander Voet, E., Weisz, H., 2000. The weight of nations: material outflows from industrial economies, p125. World Resources Institute, Washington, DC.

Moriguchi, Y., 2007. Material flow indicators to measure progress toward a sound material-cycle society. Journal of Material Cycles and Waste Management 9, 112–120.

National Research Council, 2003. Materials Count: The Case for Material Flows Analysis. National Academy Press, Washington D.C.

Organization for economic co-operation and development (OECD), 1998. Towards Sustainable Development: Environmental Indicators. OECD, Paris.

Park, J., Sarkis, J., Wu, Z.H., 2010. Creating integrated business and environmental value within the context of China's circular economy and ecological modernization. Journal of Cleaner Production 18, 1494–1501.

Pintér, L., 2006. International Experience in Establishing Indicators for the Circular Economy and Considerations for China. Report for the Environment and Social Development Sector Unit, East Asia and Pacific Region. The World Bank, Washington.

Sendra, C., Gabarrell, X., Vicent, T., 2007. Material flow analysis adapted to an industrial area. Journal of Cleaner Production 15 (17), 1706–1715.

United Nations Environmental Programme (UNEP), 2010. Overview of the Republic of Korea's National Strategy for Green Growth. UNEP DTIE Economics and Trade Branch, Geneva, Switzerland.

Van Berkel, R., Fujita, T., Hashimoto., S., Geng, Y., 2009. Industrial and urban symbiosis in Japan: analysis of the eco-town program 1997–2006. Journal of Environmental Management 90 (2009), 1544–1556.

Xue, B., Chen, X.P., Zhang, W., Geng, Y., 2010. Study on the adjusting mechanism of regional circular economy. Soft Science 24 (8), 74–78 (in Chinese).

Yuan, Z.W., Bi, J., Moriguichi, Y., 2006. The circular economy: a new development strategy in China. Journal of Industrial Ecology 10 (1–2), 4–8.