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A Review of the Circular Economy and its Implementation

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Abstract: Circular economy (CE) is a sustainable development strategy that is being proposed to tackle urgent problems of environmental degradation and resource scarcity. CE's 3R principles are to reduce, reuse and recycle materials. The principles account for a circular system where all materials are recycled, all energy is derived from renewables; activities support and rebuild the ecosystem and support human health and a healthy society and resources are used to generate value. This study is a review of the rapidly growing literature on CE covering its concept and current practices and assessing its implementation. The review also serves as an assessment of the design, implementation and effectiveness of CE related policies. It first presents the concept of CE and compares it with the current linear economy of taking materials, producing goods and disposing waste. It explains why it is imperative to move away from a linear economy towards regenerative sustainable industrial development with a closed loop. The paper then introduces current practices that have been introduced and discusses standards for the assessment of CE's development and performance. The main focus here is on providing a summary of the data analysis of key CE indicators to give a picture of CE practices. Third, based on an analysis of literature, the paper identifies the underlying problems and challenges to CE in an entrepreneurial perspective. Finally, the review provides a conclusion on CE's current development and gives policy suggestions for its future development as part of an entrepreneurial and innovative national level development strategy.

Keywords: Circular economy; environmental policy; national development strategy; sustainable development strategy; entrepreneurial strategy.

JEL Classification Codes: E01; F18; F64; H23; O44; Q50; Q53; Q55; Q58; R11;

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1. Introduction to Circular Economy

Environment and economics are closely inter-related. However, most economics textbooks pay little attention to the environment and in the best case scenario, a chapter illustrating how the economic theory can be applied to diverse environmental issues is added to them. This approach obscures the fundamental ways in which environment affects economic thinking. Circular economy (CE) with its 3R principles of reducing, reusing and recycling material clearly illustrates the strong linkages between the environment and economics. In an effort to breach this gap, the concept of circular economy was first introduced by Pearce and Turner. In their *Economics of Natural Resources and the Environment* (1990) they outline the theories within and between economics of natural resources and their interactions and implications for the concept of how economics works. The authors elaborate on environment both as an input and as a receiver of waste. They illustrate that ignoring the environment means ignoring the economy as this is a linear or open-ended system without an in-built system for recycling.

The amount of resources used in production and consumption by the first law of thermodynamics cannot be destroyed and are equal to waste that ends up in the environmental system. Kenneth Boulding's 1966 essay *The Economics of Coming Spaceship Earth* contemplates the earth as a closed economic system in which the economy and the environment are characterized by a circular relationship where everything is input into everything else. The model of economics and environmental relation in Pearce and Turner (1990) is further extended by Boulding to account for the natural environment's assimilative waste capacity, disposal of non-recyclable resources and non-renewable or exhaustible resources. The search is to find out what needs to occur for economics and the environment to coexist in equilibrium. Leontief (1928, 1991 translation) in *The Economy as a Circular Flow* refers to the economic theory's main focus on price theory and neglecting the material point of view. He suggests re-establishing the correct relationship between the material and value points of view and arranging the two views such that the material approach is of considerable importance (also see Samuelson, 1991).

Rapid environmental deterioration around the world has led to the development of policies for reducing the negative impacts of production and consumption on the environment. A number of countries have introduced acts and laws for establishing the recycling principle of a circular economy. Germany is the forerunner in this as it started implementing CE in 1996. This was accompanied by the enactment of the law 'Closed Substance Cycle and Waste Management Act'. The law provides a framework for implementing closed cycle waste management and ensures environmentally compatible waste disposal and assimilative waste capacity. Another example of an attempt to start implementing CE is in Japan. The Government of Japan has developed a comprehensive legal framework for the country's move towards a recycling-based society (METI, 2004; Morioka et al., 2005). 'The Basic Law for Establishing a Recycling-Based Society', which come into force in 2002 provides quantitative targets for recycling and long-term dematerialization of Japanese society (Van Berkel et al., 2009).

China is the third country that is engaged in serious efforts to implement CE on a large scale. However, in contrast to the German and Japanese cases, the Chinese government for various reasons like retaining competitiveness, intends to initially introduce the CE framework on a smaller scale through a number of pilot studies so that it has a better basis for assessing its large scale and full coverage in the longer run. This policy is similar to economic liberalization which started with costal free economic zones.

Several other countries like Sweden have for a long time successively introduced various incentive programs. They have also tried to facilitate optimal conditions for gradual and effective increase in the rate of recycling through public education. The policy has been successful and to the satisfaction of policymakers and environmentalists. Sweden, Germany and several other European countries have managed to incorporate green political parties in their political systems and processes of decision making which have both encouraged and eased a transfer towards a circular economy.

Another significant effort by the European Commission (2012) is the *European Resource Efficiency Platform (EREP) – Manifesto and Policy Recommendations*. The manifesto calls on business, labor and civil society leaders to support resource efficiency and move to a circular economy. It provides an action plan for transitioning to a resource efficient Europe and ultimately becoming regenerative towards CE. The common feature in these countries' CE policies is preventing further environmental deterioration and conserving scarce resources through effective use of renewable energy and managing production and consumption wastes, especially through integrated solid waste management.

The limited existing evidence on the implementation of the circular economy in practice in China and elsewhere suggests that consensus has been reached on the concept of CE which in many ways resonates with the concept of industrial ecology. This concept emphasizes the benefits of reusing and recycling residual waste materials. It includes energy, water, different byproducts as well as knowledge (Jacobsen, 2006; Park et al., 2010; Yuan et al., 2006). Industrial symbiosis is an extended concept which states that the overall benefits come from integrated economic and environmental aspects. According to Anderson (1994) economic benefits are attributed to firms' agglomeration attracting pools of common production factors such as capital, labor, energy, materials and infrastructure reducing unit costs and raising factor productivity. Other economic benefits resulting from firms' proximity include gains from transportation and transaction costs and technology spillovers between firms (Coe et al., 2004). The environmental benefits arise from reduced discharged waste and reduced use of virgin materials (Andersen, 2007). A third dimension – social -- is added to the economic and environmental aspects by Zhu (2005). According to him an ecological economy is required to bring about a fundamental change in the traditional way of open and linear development. The three aspects jointly promote competitiveness through efficient resource allocation and higher productivity by redesigning industrial structures reducing negative externalities and finally by improving the overall well-being in society.

This study is a review of the rapidly growing literature on CE covering its concept and current practices as also assessing its implementation. The review serves as an assessment of the design, implementation and effectiveness of CE's policy and practices. It is conducted in a number of steps. First, the CE concept is presented and compared with our current linear economy where one uses materials, producing goods and disposing waste and explains why it is imperative to move towards a regenerative sustainable industrial development with a closed loop. Second, current CE practices are introduced and the standards for the assessment of its development and performance are discussed. Third, based on an analysis of literature, the underlying problems and challenges in an entrepreneurial perspective are analysed. Finally, the review provides a conclusion to CE's development and makes some policy suggestions for future improvements, adaptations and further development as part of an entrepreneurial and innovative national level development strategy.

The rest of this review is organized as follows. In Section 2 the importance of CE as a development strategy is discussed. Current CE practices are presented in Section 3. An assessment of CE and national indicators are classified in Section 4 which leads to the development of a circular economy development index system. Section 5 looks at the development of a circular economy in pilot studies while Section 6 discusses the challenges and barriers in the successful development of a circular economy. The discussion is extended to the future of CE as an entrepreneurial and innovative sustainable national level development strategy in Section 7. The last section gives policy recommendations and conclusions.

2. CIRCULAR ECONOMY AS A DEVELOPMENT STRATEGY

Zhou (2006) finds developing CE an urgent and long-term strategic task for China to build a resource-saving and environment-friendly society. The timing is seen as optimal as China is in an accelerating stage of urbanization and industrialization. The country has invested significant resources and efforts in developing CE with the objective of promoting eco-industrial development (EID). By using the coexistence of a healthy economy and environmental health such a development attempts to integrate environmental management so as to meet environmental, economic and community development goals (Chertow, 2000). Discussing CE's development in China, Geng and Duberstein (2008a) describe the measures being implemented for its long-term promotion. These include formulating objectives, legislations, policies and incentive measures for China to leapfrog its way from the current environmentally damaging development to a more sustainable path. They identify a series of barriers and challenges to CE's implementation and draw conclusions from these. Geng et al. (2010a) evaluate the applicability and feasibility of the eco-industrial park standard indicators.

In a review of CE as a development strategy in China which aims at improving efficiency of material and energy use, reducing CO2 emissions, promoting enterprises' competitiveness and removing green barriers in international trade, Su et al. (2013) evaluate the implementation of the strategy in a number of pilot areas. The rich Chinese literature on CE's practical implementation is seen as a way of tackling the urgent problems of environmental degradation and resource scarcity in the country. They study and compare the performance of pilot cities Beijing, Shanghai, Tianjin and Dalian. There is evidence of positive changes but the authors are not sure if the improvement trends will hold. They identify the underlying problems and challenges and offer conclusions regarding CE's current and future developments. The current practices are carried out at the micro, meso and macro levels and cover production, consumption, waste and water recycling management. Evidence suggests that CE presents a unique policy strategy for avoiding resource depletion, energy conservation, waste reduction, land management and integrated water resources management. The challenges include lack of clear, standardized quantitative measurements and goals, data quality, shortage of advanced technology, poor enforcement of legislations, weak economic incentives, poor leadership and management and lack of public awareness. Deploying a wider range of policies and economic incentives is required to overcome these challenges so that a successful CE can be implemented as a development strategy.

Implementing CE based on the 3R principles (of material use reduction, reuse and recycling) is embedded in both production and consumption as the flow of materials and energy penetrates both these areas. Zhu and Qiu (2007) elaborate on the principles and flows. They see CE as a sustainable economic growth model which aims at effective use and circulation as the principle. It also considers low demand and consumption, low emissions and high materials, water and energy use efficiency in production and maximizes uses of renewable resources as core characteristics. Reduction refers to minimizing inputs of primary energy and raw materials which can be achieved through improvements in production efficiency. Reuse suggests using byproducts and waste from one stage of the production in another stage. This includes the use of products to their maximum use capacity. Finally, recycling of used materials substitutes consumption of virgin materials (see also Zhu and Qiu, 2008 and Zhu et al., 2010). In another related research Li et al. (2011) schematically illustrate the agricultural development of CE and compare it with traditional agriculture. The important theoretical models of China's agricultural circulation economy practice are: multi-industry, ecological protection type and agricultural waste recycling development models. The main differences in these are in the conservation of resources and recycling. The authors recommend implementing the agro-circular economy development models accounting for these modes in the context of the Erhai Lake Basin.

China's special environmental circumstances have led to the government sparing no efforts to push CE as an economic development strategy into a nation level and full scale practice to mitigate environmental challenges. The 12th five-year plan (2011-15) for the nation's economic and social development is evidence of the government's determination to continuously implement and further develop CE. Motivation for this comes from a number of reasons attributed to the problems of land degradation, expansion of desertification, deforestation, water depletion, air pollution, loss of biodiversity and waste generation. First, China is facing great environmental challenges due to large scale and rapid industrialization and urbanization which combine with lack of strong environmental regulations and oversight. Chinese national statistics suggest a 7.5 per cent annual growth rate in CO2 emissions (Guan et al., 2012). The emission rate which is lower than the rate of economic growth is a result of heavy reliance on energy-intensive industries and coal as the primary energy source.

The second reason for continuously implementing and further developing CE is severe shortage of resources and energy to meet growing demands and high rate of economic growth so that a pathway to sustainable development can be found (Li et al., 2010). CE is an alternative way of reducing the large gap in resource requirements and supply shortages in relation to the population and industry structure (Vermander, 2008). The boom in economic growth and surge in the output of heavy and energy intensive industries have implied a doubling of energy consumption over the last decade (Guan et al., 2012). Energy is mainly sourced from non-renewable polluting sources. Heshmati (2014a) suggests use of demand response to reduce the consumption of electricity.

The third strong argument for CE as a development strategy in general and for China in particular is the recent decade of strict production and environmental standards, regulations in international trade and tendencies towards implementation of higher labor standards. These are called 'green barriers' which are expected to hurt developing countries' competeviness and export earnings. Implementation of these standards requires acquisition of advanced technologies and implementation of green reforms in production and transportation. In this regard Wang and Liu (2007) view CE as providing a fundamental solution for removing green barriers and for China to gain enhanced national competeviness in its international trade relations.

The fourth reason for investing in a new development strategy is that CE strengthens national security because it promotes alternative primary energy resources and because of its saving and efficiency in the use of materials. The effects are reflected in sustainable energy and material supplies. In addition, positive environmental effects help improve the health and overall well-being in society and advance knowledge, technology and modernization (Heck, 2006). The positive effects spill over national borders and impact global well-being.

This discussion indicates that urgent environmental problems, resource shortages and scarcity and potential strong competitiveness in international trade and overall well-being benefits of CE in the short and long-run for a country like China support the new national level development strategy. The strategy which aims at changing and saving materials and energy use induces radical changes in education, technology and regulations. The strategy has been implemented in a number pilot study areas. Several studies provide explanations about the concept and its practical implementations. However, there is also evidence of CE's limited success. Designing effective policies, evaluating their effectiveness and creating measurements and evaluation standards are among the areas which require intensified interdisciplinary research. A chronologic summary of selected empirical studies on CE, sustainable development and entrepreneurship is provided in Appendix A.

3. Current Practices of Circular Economy

3.1 The case of China as a single and major CE implementer.

China is the only country that has developed the concept of CE and has practiced it as a development strategy on a large scale. This explains the reason for the emphasis that is placed on the case of China in investigating current CE practices. Ideally, successful implementation of the CE policy must take place simultaneously at all three levels of aggregation: micro, meso and macro. This is emphasized in a number of studies (Geng and Duberstein 2008a; Su et al., 2013; Yuan et al., 2006; Zhu and Huang, 2005). Su et al. (2013) categorize on-going CE practices into four areas of production, consumption, waste management and other support. The authors maintain that the complexity of practices increases with the aggregation level suggesting that the micro and meso levels are vibrant as compared to the macro level. Inspired by Su et al.'s (2013) categorization each combination of these levels and areas are now described.

At the low level of aggregation and activity area, namely production of firms and agricultural products, producers are encouraged and required to adapt cleaner production methods and eco-designs. Clean production refers to low levels of emissions, while eco-design refers to incorporating environmental aspects in production processes designs and products that are efficient and sustainable through innovative designs and production lines. China's Cleaner Production Promotion Law was enacted in 2003 (Geng et al., 2010b; Negny et al., 2012; Peng et al., 2005). The law addresses key issues related to generating pollution and the efficient use of resources at all stages of the production process. Implementation for heavily polluting enterprises to reduce their energy intensity, material use and negative externalities is compulsory (Hicks and Dietmar, 2007). A survey conducted by Yu et al. (2008) on electrical and electronic manufacturing firms showed little evidence of eco-design in their products. Considering consumption and waste management areas, green consumption and use of environmentally friendly services and products is promoted and the generated wastes have to be recycled into new production stages as part of an industrial eco-system (Geng and Cote, 2002; Geng and Duberstein, 2008b).

At the intermediate meso level, the CE practices include developing eco-industrial parks and eco-agricultural systems. These must be complemented with other measures such as environmental friendly designs of industrial parks and managing the waste accordingly. Building waste trading systems and venous industrial parks for resource recovery from green products are other measures (Geng et al., 2009a). By applying the concept of industrial symbiosis, eco-industrial parks utilize common infrastructure and services. This enables clusters of firms to cooperatively manage resource flows and trade industrial byproducts which decrease environmental externalities and reduce both firms' and the nation's dependency on resources. The reduced overall production cost raises industrial productivity and competitiveness. A similar effect is achieved from the eco-agricultural system (Chertow, 2000; Liu et al., 2012; Yin et al., 2006). In parallel with eco-industrial and eco-agricultural parks, the program includes green design for residential communities to create an eco-friendly habitation environment. Again the focus is on regulation and management of urban consumption of energy, water and land to reduce their use, as well as on managing and recycling of waste water and solid waste to improve the quality of life and general public well-being (Zhu and Huang, 2005).

Finally, the CE practice at the aggregate macro level requires forming complex and extensive cooperative networks and active cooperation between industries and industrial parks including primary, secondary and tertiary sectors in production areas and in the residential sector. In the context of China, the macro level is aimed at major cities or region/provinces. The objectives of the 3R principles can be achieved by proper design and management of urban infrastructure and sub-urban industrial production and agricultural layouts, as well as through inventive public programs to phase out energy intensive and polluting technologies and replacing them with environmental friendly technologies and activities. Regarding the consumption area, Stahel (1986) and Zhu (2005) suggest a system of renting and a service economy as a shift from a system of selling and buying to just utilization of products. The suggested system will reduce resources' needs and the wasted and lower production capacity will be compensated for by the creation of a new service economy. An urban symbiosis as an extension of an industrial symbiosis which needs to be developed to take care of waste management through transfer of waste materials for environmental and economic benefits from recycling and reusing (Geng et al., 2010a).

The last area of other support includes initiatives from governmental and non-governmental organizations covering all areas of production, consumption and waste management at all levels of aggregation. China regulates the environment and CE implementation through two agencies: the Ministry of Environmental Protection (MEP) and the National Development and Reform Commission (NDRC). The former is in charge of the National Pilot Eco-industrial Park Program with the main focus on the meso level, while the latter is in charge of the National Pilot Circular Economy Program focusing on both meso and macro levels (Zhang et al., 2010). As part of other support, a number of laws and policies related to CE have been introduced in the recent decade including the cleaner Production Promotion Law of 2003, the amended law on Pollution Prevention and Control of Solid Waste in 2005, various initiatives to facilitate implementation of CE and the circular Economy Promotion Law in 2009 (Ren, 2007). Regulations and initiatives are further strengthened by the development of environmental and non-governmental organizations to change attitudes towards the environment in society. This is facilitated by investments in education, providing information and active public participation to increase environmental awareness (Xie, 2011).

3.2 Other practiced cases

Besides China, many individual countries which are mainly industrialized, newly industrialized and emerging economies partially apply the 3R principles (reduce, reuse and recycling of material). The reduce component is mostly practiced in production as a result of competition and the necessity of achieving high input use efficiency. In developed nations' households recycling of certain materials such as glass, plastic, paper, metal and burnable solid waste is becoming more common. Municipalities take the responsibility of treating and reusing waste water from households as well as solid waste and recycling auto and household appliances. Treatment of waste water from industry is also regulated but reuse of material is less developed and provides far from full coverage. In practice greater attention is paid to the consumption rather than the production stages. Regulations remain one step behind environmentally hazardous technology development and monitoring producers' responsibilities.

Europe has developed concepts and mechanisms for a common environmental policy for its members and regions. These cover all aspects including production, consumption, waste management and environmental policies. It is not necessarily called a circular economy but the patterns are closely in line with the circular economy's principles. *The European resource efficiency platform (EREP): Manifesto and policy recommendations* (EC, 2012) is a call on labor, business and civil society leaders to support resource efficiency and to move to a circular economy. The document presents a manifesto for a resource-efficient Europe, lists actions for a resource efficient Europe and suggests ways towards a resource efficient and circular economy. This effort is a result of the growing pressure on resources and on the environment to embark on a transition to a resource-efficient and ultimately regenerative circular economy. A circular resource-efficient and resilient economy is expected to be achieved in a socially inclusive and responsible way by encouraging innovations and targeted investments, smart regulations and standards, abolishing environmentally harmful subsidies and tax breaks, creating market conditions for CE friendly products, integrating resource scarcities and vulnerabilities into wider policy areas and setting targets and standard indicators to measure progress. Estimates suggest that by using resource efficiency as an economic strategy EU could reduce its material requirements by 17-24 per cent and create 1.4-2.8 million jobs (EC, 2012: 5). The manifesto call on the European Parliament, Commission and the Council to make resource efficiency and the circular economy an essential building block in the Europe 2020 agenda in an effort to deliver smart, sustainable and inclusive economic growth. Product service systems (PSS) have been heralded as an effective instrument for moving society towards a resource-efficient economy. In a review of product services for a resource-efficient and circular economy, Tukker (2015) sheds light on business to consumer relations and the PSS inflexibility as the reason why the system has still not been widely implemented.

In the report *Towards the circular economy* published by Ellen MacArthur Foundation (EMF, 2012) emphasis is placed on the economic and business rationale for an accelerated transition to the current system. The foundation views CE as providing a framework for system level redesign offering opportunities to harness innovations and creativity to enable a positive and restorative economy. Steady-state economics claim a low circulation rate of natural and social-economic systems to achieve sustainable development. However, due to its anti-consumerism and anti-technical tendency, this ecological view of evolutionary economics has never been in the mainstream. Pin and Hutao (2007) suggest that a circular economy can be enriched by the steady state economy for China which is not rich in natural and environmental resources and which is highly dependent on substance recovery. In relation to a discussion of zero growth and the possibilities of maintaining past standards through political and social mobilization and transition to some regulated *steady-state* capitalism, Garcia-Olivares and Sole (2015) are of the view that zero growth and competition conditions will probably transform the system into a post-capitalist *Symbiotic Economy*.

In a recent study, Kalmykova et al. (2015) investigate resource consumption drivers and pathways to resource efficiency and reduction. They studied the economy, policy and lifestyle impacts on the dynamics of resource use at the national (Sweden) and urban scales (Stockholm and Gothenburg) during 1996-2011 (see Tables 1 and 2). Empirical resources' (domestic material consumption, fossil fuels, metals, non-metallic materials, biomass and chemicals and fertilizers) consumption trends show that the implemented policies have failed to reduce resources and energy to desired levels. The biased focus on energy use efficiency has reduced the consumption of fossil fuels, but waste generation outpaces improvements in material recycling impeding the development of a circular economy. Policies that have been implemented have addressed efficiency in use but not on reducing demand for resources including non-fuel resources (see also Li et al., 2013 and Kalmykova et al., 2015). The role of recycling within the hierarchy of material management strategies is investigated by Allwood (2014). His focus is on growth trends in global demand for materials during 1960-2010 and covers airplane passengers carried, transport CO2 emissions, steel, cement, paper and car production, built space, silicon wafer production and electric motor data. His data analysis suggests that the vision of a future sustainable material economy is not prescribed by the ambition to create a circular economy, but aims to minimize its total environmental impacts. Reducing demand and reusing products, components and materials have greater potential of reducing environmental impacts.

4. ASSESSMENT OF CIRCULAR ECONOMY PRACTICES

A system of indicators is required to assess the successful development and implementation of CE. The indicators are expected to be metric measures of CE's development and outcomes to provide guidelines for decision makers to further develop and assess the effectiveness of various used policy instruments. Environmental and other government agencies and scholars in different countries have made efforts to develop and promote a unified set of indicators. However, in practice implementation approaches and the heterogeneity of enterprises, industries and regions and their characteristics and operational environments have implied that different sets of assessment indicators need to be concurrently developed. As mentioned earlier developments have taken place at different levels of aggregation such as micro, meso and macro and in different areas of activities including production, consumption, waste management and policies (see Table 3). The set of indicators should account for heterogeneity in different dimensions.

At the lowest level – the micro level -- depending on their characteristics and conditions, different sets of firm-specific indicators are being developed to implement CE in different enterprises. The set of indicators should ideally include a common set across enterprises in an industry and another set that is purely firm-specific. For instance, a set of indicators was developed by Chen et al. (2009) for one iron and steel enterprise. The set included four indicators at the primary level, 12 indicators at the secondary level and 66 indicators at the tertiary level. Some other scholars have focused on indicator systems at the meso or industry level (Du and Cheng, 2009). Du and Cheng (2009) employed the DEA efficiency analysis method with nine input-output indicators and the Malmquist productivity index to assess cleaner production performances of enterprises in the iron and steel industry. Wu et al. (2014) analysed the effectiveness of the CE policy using DEA. Other researchers (for example, Shi et al., 2008) used 22 indicators to estimate cleaner production barriers including policy and market, financial and economic, technical and information and managerial and organizational barriers. Geng et al. (2010b) developed an energy based indicator system to evaluate the overall eco-efficiency of one industrial park and Wang et al. (2008) have looked at interactions among barriers to energy saving.

At the meso level, the two Chinese government agencies NDRC and MEP have published two sets of partially overlapping evaluation indicator systems aimed at eco-industrial parks (EIPs) (Geng et al., 2009, 2012; Li, 2011). NDRC's indicator system has 13 indicators grouped into four main dimensions: resource output rate, resource consumption rate, integrated resource utilization and reduction rate in waste discharge (see Table 4 and Su et al., 2013). The output rate dimension refers to resource productivity, the input rate dimension refer to input use intensity or efficiency, the third dimension examines the reuse rate of industrial waste and finally the last dimension is built on the 3R principle of reuse, reduce and recycling of industrial waste. The MEP indicators system has 21 indicators grouped into the same four dimensions as the NDRC system but it differs in structure and covers economic development, material reducing and recycling, pollution control and administration and management (see Table 5). The MEP system grouped the industrial parks into three sector-integrated groups and designed three sector-specific sets of indicators (Geng et al., 2009a). Dai (2010) also applied the biological theory to develop two indices of eco-connectivity and byproducts and waste recycling in an EIP and Geng and Cote (2003) have suggested the use of an internationally standardized environmental management system.

At the aggregate macro level better data availability allows more assessment studies to be conducted. The NDRC system at the meso level is also employed at the macro level but one more dimension is added here accounting for the importance of recycling materials at the regional level. This added dimension is clearly in line with CE principles and indicates the government's commitment to promoting resource efficiency and conservation in line with CE. Scholars have suggested improving upon the indicator's systems as they have a limited focus on the 3R principles and cover only environmental aspects. A more systematic evaluation system is suggested by several researchers so that indicators of economic and technology development and social aspects can also be incorporated in it (Chen, 2006; Geng et al., 2009a; Jiang, 2010; Jia and Zhang, 2011; Li and Zhang, 2005; Meng and Shen, 2006; Qian et al., 2008; Qin et al., 2009; Wang, 2009; Wang et al., 2006; Yang et al., 2011). Zhu and Zhu (2007) and Zhu et al. (2007) have argued for an eco-efficiency indicator system. They emphasize that productivity in use of materials and waste management should be used in evaluating and planning energy consumption and in the generation of pollutants.

A major limitation of all the indicator systems described earlier is the way in which the individual indicators are grouped into one single dimension or index. The different approaches listed here have been used in computation of indices of development, competitiveness, technology and well-being. These include use of same weights, principal components and factor analyses, analytic hierarchy processes, fuzzy synthesis appraisals, the grey correlation degree method and the full permutation polygon synthetic indicators method (Jiang, 2010 and 2011; Li and Zhang, 2005; Li et al., 2009; Qian et al., 2008; Xiong et al., 2008, 2011; Zhang and Hwang, 2005). A summary of the measurement methods and their findings is presented in Su et al. (2013).

5. DEVELOPMENT OF THE CIRCULAR ECONOMY

5.1 The case of pilot cities in China

Dalian city in China is an important pilot study where the CE strategy was implemented during 2006-10 (see Table 6). The industrial and business area characteristics of the city and the local government's initiatives led to the aspiration of transforming it into a leading environmental friendly city. The strategy had several objectives including further improving resource use efficiency and improving the level of material reuse, recycling and recovering solid waste and waste water (Dalian Municipality, 2006, 2007; Geng et al., 2009b). By comparing data from 2005 and the target and actual data from 2010 Su et al. (2013) assessed how many of the strategy's goals have been achieved. Ten indicators were selected for this purpose and grouped into four aspects: energy and water efficiency, waste discharge, waste treatment and waste reclamation.

As part of the CE strategy, in 2007 the Dalian municipality decided to shut down small scale facilities with high energy use rates and encourage energy saving technologies and production scales instead. Other plans and supply and demand driven policies were also introduced to improve water use efficiency through price incentives and quota management, waste management, waste reporting and tracking systems (Dalian Municipality, 2007; Geng et al., 2009b; Qu and Zhu, 2007; Wang and Geng, 2012). Thus, the policy included close cooperation between the government, enterprises and households. The emphasis was on relationships between energy use, economic size and industrial value added. In an assessment of CE's implementation, Su et al. (2013) found that the goals stated here had been well achieved. Calculated changes in the ten indicators between 2006 and 2010 showed that the CE policies had been successfully implemented in terms of resource use efficiency and waste discharge, treatment and reclamation.

The Dalian pilot study and its successful CE implementation strategy can serve as a success example for other regions with similar characteristics. Su et al. (2013) compare Dalian's performance with three other CE pilot cities (Beijing, Shanghai and Tianjin) using the same ten evaluation indicators system. These cities are economically developed but have different industrial and demographic characteristics. The percentage changes in each indicator for all the four cities between 2005 and 2010 were computed and compared (see Table 7). The relative performance of the cities for each indicator was also calculated (see Table 8). The results show that with a few exceptions all four cities have achieved improvements in all four aspects of the CE strategy. However, the cities' performances differ from one indicator to another and their positions with reference to best practice technology and policy changes also differ. The relative measures also show the degree of success in material use, waste discharge reductions and waste reclamation increase as compared to the best performance used as the benchmark. The numbers indicate evidence of both over- and under-shooting of the pilot cities target levels.

This study based on data covering the four pilot cities in China with different economic and demographic characteristics provides a comprehensive picture of the achievements of implementing CE in China. The results show evidence that the strategy has been implemented effectively and with desired outcomes, in particular in terms of the use and efficiency of resources. Here resources refer to energy, water and land. The positive outcomes seem to be a result of relocation of heavy industries and application of instrument regulations, as well as the four cities' level of development and manpower and technology and financial resources to achieve efficiency in resource use. It is important to mention that the results are based on Chinese official statistics which lack trust and possibly suffer from systematic inaccuracies. The many large percentage positive changes at a time when the environmental conditions in China are deteriorating suggest that the results have been interpreted with caution. This also makes a case for the need to have some other case studies from European countries with lesser uncertainties associated with data quality and estimation of effects of environmental policies.

5.2 Other selected industry cases

The circular economy, or some of its general or specific elements, have been applied or are in the process of being applied by certain industries. This section reviews the outcomes of such implementations. Related Chinese industries include industrial structure, iron and steel, papermaking, emerging industries, process industries, process engineering, leather tannery, mining, chemicals, the construction industry, printed circuit boards industry, circular and eco-agriculture, oil and gas exploitation, electric power, green supply chain and tourism management. A brief summary of these industries and state of their CE implementation is now explained.

Industrial structure, resource efficiency and environment are closely inter-related. Wang and Zhang (2011) analyse the status of industrial structure, resources and environment in Shandong province and discuss the problems and countermeasures for optimizing the agricultural and industrial structure to adjust it to CE's optimal implementation conditions. They discuss the role of the government, science and technology and economic support as well as market mechanisms in adjusting, optimizing and upgrading the industrial structure to guarantee optimal allocation of resources for a sustainably healthy economy. Process engineering is a complex multi-scale discipline which deals with the transformation of mass by energy to products in different industries. Reh (2013) asserts that process engineering plays an important role in CE's implementation. Reh discusses the challenges and progress in recycling in steel and pulp and paper industries. The process industry accounts for a large share of energy consumption in China (see also Li et al., 2008 for a study of energy conservation in China's process industry).

Iron and steel is an energy intensive and highly polluting industry. Ma et al. (2014) investigate the mode of CE in this industry in China. A case study of Wu'an city's private enterprises shows significant improvements but there is much room for additional environmental quality improvements. Another energy intensive and polluting industry is the papermaking industry. Li and Ma (2015) investigate how Guangdong Silver Island Lake Papermaking Park realizes cleaner production and sustainable development by CE through inter-industry resource integration. A study of a phosphorus chemical firm's application of resources and eco-efficiency in industrial metabolism under CE by Ma et al.

(2015) demonstrates that technological progress in mineral processing increases economic benefits and improves resource efficiency. Zhao et al. (2012) discuss the model of mining CE at different levels according to the mineral resource recycling situation in China. As an example they suggest constructing a CE system in coal mine enterprises and in the mineral value chain.

In the European Union (EU) as part of a CE system in the construction industry there is a desire to keep the added value in products as long as possible to eliminate waste. Smol et al. (2015) and Marzena et al. (2015) advocate a transition to a CE which requires changes throughout the value chains. Along the same lines, Wen and Meng (2015) assess industrial symbiosis for promoting CE with a case study of the printed circuit boards industry in China. The industrial chain system's CE performance can be improved by prolonging the production chain. Shen and Qi (2012) suggest that in addition to improving and optimizing traditional linear industries, CE's development should also include strengthening emerging new high-tech industries. These industries will play a decisive and leading role in the socioeconomic development of the nation. Establishing favorable policies, financial support, technology advancements and developing emerging industries are preconditions and countermeasures for developing CE in the western Chinese region.

Energy conservation is a choice with double dividends of reducing energy use and tackling environmental problems. Li et al. (2010) analyse energy conservation in the process industry with emphasis on energy utilization efficiency, energy consumption mode and waste emissions. They studied three cases of developing CE in chemical, metallurgical and electric power industries for enforcing CE and energy conservation. In another study, Li and Su (2012) evaluated CE's development levels in Chinese chemical enterprises. Their analysis shows that the petrochemical industry is in a transitional stage from the traditional development model to the circular mode. The results show that the industry has made notable progress which considered developing new energy saving processes, energy use efficiency, resource utilization and recovery of waste heat. They point out that for energy conservation more attention should be paid to process intensification and system integration (see Table 9). The leather industry also leads to tremendous environment pollution and to the destruction of biological chains. Hu et al. (2011) investigate the ecological utilization of leather tannery waste with a CE model for improving resource productivity and eco-efficiency and alleviating waste. They suggest developing tannery company level CE processes.

Agriculture's close connection with the natural eco-system allows for a harmonious process whereby material can circulate in the natural eco-system. Successful development of eco-agriculture achieves a circular flow between material and energy. As measures of constructing CE, Han and He (2011) suggest improving community awareness about environmental protection and resource conservation, environmental certification of products and establishing an overall plan for CE and its implementation. Li et al. (2011) also express urgency in implementing an agro-circular economy in the Erhai Lake Basin to achieve comprehensive energy utilization, ecological breeding, comprehensive utilization of agricultural waste and agricultural eco-tourism patterns. Modern eco-agriculture is central to realizing the sustainable development of circular and low-carbon agriculture.

Cao et al. (2011) studied the role of modern eco-agriculture in constructing a rural CE in Shandong province. They found several restrictive factors in the sector including the aggravated contradiction between land and population, shortage of water and biology resources, ecological environmental deterioration, lagged technology development, low education and technical capabilities of farmers and imperfect service systems. They suggest policy systems for technology development, support and incentive measures for developing sustainability of eco-agriculture and circular agriculture. Huang (2011) has also studied models of CE in agriculture.

In the energy area, CE has been a successful practice in the oil and gas industry in some developed countries. Huang and Zhang (2011) suggest that the achieved practical development modes can influence CE strategies so as to achieve harmonious development of the oil and gas exploitation industry and also for the ecological environment in China. They recommend enterprise-society-government collaborations, developing an industry chain strategy, innovation strategy and improving energy efficiency and CE support systems to push forward the CE development mode of the industry. In another related study, Zhang and Huang (2011) present an early-warning method and its application of complex CE systems for exploiting oil and gas. The proposed early-warning index system accounts for different warning grades (economic, social, ecological and resource sub-systems) and warning degrees (no, micro, middle, heavy and violent). The systems in-decision analyses can guide the formulation of regulatory policies to achieve long-term sustainable development.

The coal-based energy structure is a main source of CO_2 and pollutant discharges and it is increasing with economic growth. Promoting low-carbon development of electric power generation is important. In this regard, Zeng and Zhang (2011) employ the DEA method to promote the electric power industry from the perspective of benchmarking CE efficiency. The input-output index system that they use reflects the 3R principles for measuring efficiency of coal-fired power plants. The benchmarking helps choose the best efficiency benchmark of CE in the power industry's environmental management to reduce, reuse and recycle pollutants (see also Li, 2012). In another study, Long and Zhang (2009) discuss CE development countermeasures in a coal mining area. Their analysis of an example led them to conclude that the development of CE and the introduction of negative entropy flows could promote the balance of the eco-system. Hao et al. (2009) and Ren (2011) discuss the index system of cities' sustainable development based on CE.

The difference between green and traditional supply chain management is analysed by Jiang and Zhou (2012). They find that the implementation of green supply chain management maximizes resource utilization, reduces resource consumption and enhances image, operational performance and compatibility, and thus helps in achieving sustainable development. The information management system has been developed significantly. In developed countries appropriate infrastructures are in place. The knowledge can be used in the supply chain of tourism management to enhance supplies and customer relationships and satisfaction conducive to CE. Guo et al. (2011) find that China has the potential of becoming a major node in global supply chain networks for tourism management by bridging Europe and USA (see also Hua, 2011).

5.3 Entrepreneurship and CE

Entrepreneurship is the process of starting a business, a startup company or an organization. In the process, an entrepreneur develops a business plan and acquires required resources and is fully responsible for the outcomes. It has dimensions such as social, political and knowledge entrepreneurships. Small businesses and entrepreneurships are considered major drivers of economic growth, breakthrough innovations and job creation. In order to promote risk-taking and entrepreneurship, governments fund different agencies and invest in establishing business incubators and science parks to support entrepreneurial-related activities and potential entrepreneurs and their successful innovations. Literature on the relationship between entrepreneurship and CE is in its infant stage. However, several studies (for example, Edler and James, 2015; Hall et al. 2010; Iyigun, 2015; Pacheco et al., 2010; Stefanescu and On, 2012; Uslu et al., 2015) elaborate on entrepreneurship and sustainable development as a broad social goal which is the subject of this section. Parker (2012) provides a comprehensive survey of the theories of entrepreneurship, innovation and business cycles, while Köhler (2012) compares the neo-Schumpeterian theory of Kondratiev waves and the multi-level perspective on environmental innovation and societal transitions.

As mentioned earlier, at the micro level (which is relevant for entrepreneurship), depending on their characteristics and conditions different sets of firm-specific indicators and regulations are being developed for implementing CE at the enterprise level. This has led to challenges for existing firms and opportunities for new enterprises. A set of indicators assessing the progress made by CE's implementation should ideally include a common set across enterprises in an industry and another set that is purely firm-specific. The use of existing sets of indicators suggested in various studies (for example, Chen et al., 2009; and Du and Cheng, 2009 for iron and steel enterprises) will help shed light on their effects on entrepreneurship. Other researchers (for example, Shi et al., 2008) have used indicators to estimate cleaner production barriers including policy and market, financial and economic, technical and information and managerial and organizational barriers which add value to guidelines aimed at easing entrepreneurship and new entries adapting to the implementation of CE.

As a result of technological developments, expansion in knowledge, globalization and flow of resources and evolution of new societies, entrepreneurial activities have been an important source of social and ecological sustainability. The *Journal of Business Venturing* (JBV) (Volume 25, Issue 5) has published a special issue on '*Sustainable Development and Entrepreneurship'*. Hall et al. (2010) reviewed emerging research concerned with sustainable development and entrepreneurship. They state that entrepreneurship is a major channel for sustainable products and processes and a possible solution for many social and environmental concerns. They discuss uncertainties regarding an entrepreneurship's role and present suggestions for future research. Sustainable development is defined in the *Brundtland Report* of the World Commission on Environment and Development as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED, 1987). This research is of great value considering the relationship between entrepreneurship and circular economy.

Based on support from recent research, York and Venkataraman (2010) view entrepreneurship as supplementing the efforts made by governments, NGOs and existing firms so as to provide solutions to rather than the causes of environmental degradation. Entrepreneurs can contribute to solving environmental problems by helping institutions to achieve their goals and by creating environmentally sustainable products, services, processes and institutions. The authors present a model using which they illustrate how entrepreneurs can address environmental uncertainty, provide innovation solutions and engage in resource allocations to address environmental degradation. An entrepreneurship's efficacy in the process of transforming from a linear to a circular system will certainly depend on the nature of market incentives that are provided. Pacheco et al. (2010) call this limitation a 'green prison' where entrepreneurs are compelled to environmentally degrading behavior attributed to the divergence between individual rewards and collective goals for sustainable development. The state plays a key role in facilitating entrepreneurs moving from the green prison by creating or altering conditions for competitive games. Pacheco et al. (2010) provide evidence of such actions and discuss their implications.

York and Vankataraman (2010) and Pacheco et al. (2010) suggest a two-way causal dependency between the state and entrepreneurship when it comes to the environment. The pattern of how incumbents and new entrants engage in sustainable development is illustrated in a model proposed by Hockerts and Wustenhagen (2010). They suggest that new entrants' engagement with sustainable entrepreneurship activities influences the incumbents positively to pursue sustainability-related opportunities and the compounded impact promotes the industry's sustainability transformation. Meek et al. (2010) add another dimension to the state-incumbent-entry relationship with development sustainability, namely the potential effects that social norms can have on the effects of a state-sponsored policy aimed at encouraging entrepreneurships' environmentally responsible economic activities. Parrish (2010) focuses on sustainable development as a broad social goal. He sees entrepreneurship as a dynamic force of change contributing to this goal. Parrish investigates an organization's design expertise necessary for sustainability-driven entrepreneurs to succeed in a competitive market context. He identifies divergences from conventional principles of entrepreneurship and also links these to values and motives. Kuckertz and Wagner (2010) find that business experience affects the influence sustainability orientation of entrepreneurial intentions.

The European resource efficiency platform, manifesto and policy recommendations provide the basis for action for a resource efficient Europe and provide ways towards a resource efficient and circular economy (EC, 2012). The importance of entrepreneurship and sustainable development for social-economic development is well recognized. The 2008 international economic crisis has affected national economies in different ways and with different intensities. Stefanescu and On (2012) analyse the correlations between the indicators of entrepreneurial activities and sustainable development before and after the crisis in European countries. The principal component analysis (PCA) results show evidence of heterogeneity where most of the innovation-driven economies are grouped together, while efficiency-driven economies are placed at a distance from other the countries. An understanding of the changes in entrepreneurial and social-economic indicators of sustainable development and the position of the economies provides a useful information base for national economic policies.

Recent research on entrepreneurship and sustainability adds to existing knowledge on a number of dimensions. In many instances entrepreneurship is seen as an alternative to unemployment and poverty. It can serve as a source of renewal and also an influence on the performance and growth of the market economy. Using a corporate social responsibility approach, Iyigun (2015) attempts to reveal the motivations for sustainable development and discusses the possible underlying dimensions in decision making and entrepreneurships contributing to sustainable development. An increase in entrepreneurship, environmental deterioration and corporate social responsibility brings about an opportunity for improving the green entrepreneurial eco-system. In this regard, various inventive programs have been introduced to provide support to green businesses and local entrepreneurs with application of green entrepreneurship in Turkey. Uslu et al. (2015) propose a number of policy recommendations including support to environmental friendly products and increased green awareness through social responsibility projects, collaboration between national and foreign firms, universities and industry, access to low cost technology by green entrepreneurs and desired levels of regulation. Vaghefpour and Zabeh (2012) emphasize the role of cooperation in entrepreneurship development for creating new opportunities and entrepreneurship in the area of renewable energy to transit to a sustainable energy system. Abolhosseini and Heshmati (2014) and Heshmati et al. (2015) discuss the development of renewable energy sources and their significance for the environment. They also outline the main support mechanisms for financing renewable energy development.

6. Challenges and Barriers to implementation of a Circular Economy

6.1 From a general perspective

An assessment of the four pilot cities and diverse industry studies in China described earlier suggests a promising future for the implementation of CE at broader industrial, regional and national levels. However, the quality of the data casts doubts on the accuracy of the achievements. A majority of the pilot cities in China are mega-cities. However, CE at the levels mentioned earlier but on a smaller scale is equally possible to implement at firm, industry and city levels in Sweden and elsewhere. A number of challenges and barriers that may prevent or slow down the implementation of CE have been recognized in literature. For instance Su et al. (2013) stress the importance of lack of reliable data and information, shortage of advanced technologies, weak or absent economic incentives, poor enforcement of legislations, poor leadership and management of the development strategy, lack of public awareness about the necessity and promises of CE and lack of a comprehensive standard system for assessing CE's performance. We now elaborate on these and other important aspects to help remove barriers to CE's implementation.

In general there is low trust on the accuracy of Chinese official statistics. Despite decades of openness and increased data collection and improved research capacity there are doubts that the data collected and the information released are not independent from state interventions and as such they are aimed at fulfilling certain political purposes. In this regard Geng and Doberstein (2008a) discuss the importance of internal, industry level and external information for enterprises so that they are able to plan, design and undertake firm-specific optimal reductions and reuse and recycle activities in line with larger industrial, macroeconomic and environmental policies. Therefore the quality of information and its quantity and flow through an efficient information system that deals with resource use, production and consumption is crucial for decision making. Multiple agencies and channels providing different information further complicate the issues of information reliability and decrease efficiency in information exchanges.

Technology in its advanced stages along with technological capabilities are key factors in the successful implementation of CE's principles at different levels and in different areas. A combination of advanced technology, skills, management, finances, policy and governance is required to develop the CE strategy and to update production facilities and equipment. Conditions in China with regard to these factors and their inter-relations are assessed to be insufficiently developed to support multidimensional and simultaneous development programs within the area of environment. Currently there are a few incentive programs that encourage a large number of SMEs to participate in the process of CE implementation. Shi et al. (2008) explain their lack of interest because of high costs associated with such participation and little direct benefits to the firms associated with such transformation. Xing et al. (2011) view importing technology as a solution to the low speed at which indigenous technology is developing in the transition to CE. However, there is fear that such a policy may lack effect as it will be dependent on foreign experts to operate and resolve technological failures.

Public incentive programs for finance, technology, regulatory and administrative support are required to support enterprises so that they can access financial and tax incentives and engage in innovative activities so as to be able to develop and implement environmental friendly technologies and solutions. A low level of public intervention in the areas mentioned earlier acts as a constraint; this is strengthened by interventions with opposite effects. For instance, active public interventions for maintaining factor prices like energy and water at a low level reduces firms' and households' incentives to implement CE strategies to utilize the reduce, reuse and recycle of energy, materials and water resources. In general, public policies have been biased towards heavy industry, infrastructure investment and energy intensive manufacturing industries thereby limiting the general flexibility in the CE transition process. In addition, in the absence of effective regulations there is a possibility that producers transfer the higher costs of resource saving measures to consumers through pricing thus reducing their incentive to introduce costly and advanced production and distribution technologies. The environmental policy, and in particular the government's price policies, are expected to be linked to macroeconomic policies and be targeted at low income groups' welfare policies.

Enforcement of legislations in general and environmental and labor market related legislations in particular and their progressive development elsewhere have been lagging far behind in China. This is so as to not harm Chinese firms' competitiveness in the international market. According to Wang (2007) added to this problem is the poor performance of legislations and their drawbacks due to superficial enforcement, the time lag between non-compliance and enforcement, inadequate punishments for non-compliance, low levels of compensation paid to harmed parties and the use of limited administrative punishments instead of appropriate criminal punishments. All these have created an atmosphere of corrupt and non-optimal functioning environmental conditions.

Deficiencies in legislations are a part of the Chinese government's management system that is questioned about its complex structure of agencies at the national level and lack of transparency and poor accountability at the local government levels as well as the widespread corruption in society. Ma and Ortolano (2000) are of the view that for implementing CE over a sustained period an integrated management effort is required. Ideally this should include the proactive participation of all major public and private sector actors and transparency and predictability in administrative and policy instruments. The deficiencies mentioned earlier explain to a large extent the failures in the management of energy, materials and the environment in China.

Germany and Japan are among the few successful country case studies of CE implementation and its further development. The two countries' success is attributed to the general public's awareness and participation in the strategy's implementation. Geng and Doberstein (2008a) identify the complex nature of the concept, the large and diverse populations and the lack of human and institutional capabilities as the main contributors to existing deficiencies in China's environmental management programs, low rate of public awareness and poor understanding of participation in CE programs. The limited progress in pilot cities with more homogenous structures is mostly attributed to the leadership's vision rather than institutional capacities and public awareness (see also Liu et al., 2009; Xue et al., 2010). In order to reduce CE's risks, Bilitewski (2012) illustrates with examples that a CE trade in a global dimension is not acceptable without globally-agreed risk assessments for existing and newly developed chemicals and products. Liu (2012) suggests re-writing economics on the condition that every resource including water, sunlight and fresh air are valuable. Knowledge about the living system that is followed by the traditional Hakka people in southern China should thus be applied in developing a modern circular economy.

Given this discussion, in order to succeed it its mission it is obvious that the Chinese government needs to build a more complete system of formulating a strategic CE policy and also build on its legislative and administrative capacity. It is inevitable that serious efforts will have to be made to design a complete system for performance assessment and for standardizing the process of data collection covering all relevant levels including firms, industry, local and central governments and areas of production, consumption and energy, materials and environmental management and specific quantitative goals at local government levels (Geng et al., 2012). Unbalanced economic and social development, poor resource endowment, low technology levels and public awareness on CE suggest that a region-specific CE policy needs to be designed and the standards that are set need to be more realistic. This will help reduce discrepancies in statistics to fit different political purposes (Geng, 2011; Liu and Bai, 2014).

6.2 From an entrepreneurial perspective

As already mentioned entrepreneurship is the process of starting a business or organization. The development process has many dimensions such as management, social, political, knowledge, technology, legal, financial, manpower and economics. Each of these can be seen as a challenge; entrepreneurs also face many barriers. A number of public measures like establishing business incubators and science parks are aimed at supporting entrepreneurship and their operations, survival and success.

A number of studies look into the relationship between entrepreneurship and sustainable development. Hall et al. (2010) provide a comprehensive review of emerging research in the field, past contributions and future directions. The authors view entrepreneurship as a major conduit for sustainable products and processes, and as a panacea for social and environmental concerns. However, uncertainty regarding the nature of entrepreneurship and its role remains. Iyigun (2015) asks what could entrepreneurship do for sustainable development? He uses a corporate social responsibility-based approach. Sustainable entrepreneurs are expected to have a clear vision of the direction including sustainable development that balances social, economic and environmental impacts. These act as catalysts for transitioning from a current linear economy to a sustainable economy and as such entrepreneurs face various forms of risks, challenges and barriers. Iyigun maintains that beyond entrepreneurial will, socio-cultural conditions and institutional realities could affect CE adoption practices by SMEs. Schaltegger and Wagner (2007) focus on the types of sustainable entrepreneurship and conditions for sustainable innovations. Their focus is on the administration of technical challenges to the management of opportunities. They see management as a challenge to comply with regulations and tight regulatory frameworks and requirements for business. Business leaders play a role in creating market innovations and in their promotion and implementation.

Heshmati (2014b) in an empirical survey reviews the ramifications of a green economy and Uslu et al. (2015) point out the advantages and disadvantages of transitioning to a green economy and green entrepreneurship in Turkey. The disadvantages which form the challenges and barriers are related to low levels of activity, limited support programs, lack of green capacity, access to private capital, the educational system, cultural norms, implementation and control deficiencies, newness of green entrepreneurship, lack of public awareness and lack of purchasing green products. In a related study, Vaghefpour and Zabeh (2012) talk about the role that cooperation plays in entrepreneurship development in the area of renewable energy. They see the creation of fundamental innovations in this field and the formation and development of an entrepreneurship culture and the creation of required mechanisms as challenges. These are regarded as effective solutions in the process of commercialization of new innovations.

The European resource efficiency platform through its manifesto in December 2012 (EC, 2012) called on business, labor and society leaders to support resource efficiency and move to CE. In response to key policy challenges it recommends the creation of growth and jobs; provision of incentives to overcome barriers and for improving resource efficiency; valuation of resources; provision of information and progress measures; and promoting new business models. The recommendations to be taken forward by individual members include setting objectives, measures and reporting on progress; improving information about the environment and resource impacts for decision making; phasing out environmentally harmful subsidies; moving towards a CE and promoting high-quality recycling; improving resource efficiency in business-to-business relations; taking forward a coherent, resource efficient product policy framework; delivering a stronger and more coherent implementation of green public procurement; and developing instruments for SMEs. The barriers emphasized in EC (2012) include those that stop entrepreneurs from innovating; legal, financial and institutional barriers to new business models; barriers to private financing; and barriers to accounting systems to guide investments. Edler and James (2015) argue for an understanding of the emergence of new science and technology policies in the context of the European Framework Programme. Altvaater (2009) discusses the trilemma of the world economy, the financial crisis and ecological sustainability. The trilemma includes labor productivity growing faster than GDP, the real interest rate exceeding the real growth rate of GDP and an increase in real GDP growth violating the conditions of ecological sustainability. In an up-to-date assessment, Stepanescu and On (2012) consider entrepreneurship and sustainable development as two key factors for social-economic development. They study the correlation between the two factors in European countries before and during the global economic crisis and compare efficiency-driven and innovation-driven economies.

The special issue of JBV edited by Hall et al. (2010) contains six articles on sustainable development and entrepreneurship. They are a mix of theoretical and empirical studies, case studies and econometric analyses of data, and focus on individuals and institutions. They share a common interest -- drivers of sustainable entrepreneurship and their importance for development policy. The first study by York and Venkataraman (2010) using canonical entrepreneurship theories proposes a model outlining how entrepreneurial actions can address environmental degradation representing opportunities and for-profit new ventures as a supplement to regulation, corporate social responsibility and individuals' environmental activism to find solutions to environmental degradation. The second study by Pacheco et al. (2010) employs a game-theoretic approach to examine sustainability choices in which the cost of pursuing sustainability before competitors and before establishing norms, regulations and institutions play a key role. The third study by Hockerts and Wustenhagen (2010) models the entry of sustainable entrepreneurs (called emerging Davids) that influence incumbents' (called greening Goliaths) sustainable practices during the transformation of the industry. The survival and successful transformation of the industry will depend on the interplay of entrepreneurial entry and transformation of incumbent players. In the fourth study Meek et al. (2010) look at how institutional context, in particular the role of social norms and government incentives, influence the incidence of sustainable entrepreneurship. Social norms favorable to sustainability objectives in the US solar energy sector have led to higher levels of entrepreneurial findings. The fifth study by Parrish (2010) in an attempt to explore the motivation of entrepreneurs to pursue sustainable ventures highlights the difference between opportunity-driven and sustainable-driven entrepreneurs. Here the entrepreneurs' primary objectives are to build profitable ventures and contribute to profitable sustainability. Drawing in four cases of sustainability-driven entrepreneurs, the author finds that by placing a higher weight on resource-efficiency, sustainability organizations differ from traditional forms of entrepreneurships. Finally, the 6th study by Kuckertz and Wagner (2010) investigates the relationship between individuals' sustainability orientation and their entrepreneurial intentions. Results based on university student data show that sustainability orientation influences entrepreneurial intentions for certain groups but business experience cancels out the positive relationship.

6.3 From an innovation perspective

In their executive summary of the JBV special issue on the relationship between sustainable development and entrepreneurship, Hall et al. (2010) outline emerging research concerned with sustainable development as a less controversial concept in business and policy. They state that by now it is recognized that a fundamental transformation of the economy is needed to reduce the detrimental and social impacts of unsustainable business practices. They draw a number of conclusions. First, in this context entrepreneurship is seen as a conduit for bringing about transformation in sustainable products and processes to meet social and environmental concerns. It is a vehicle for exploiting opportunities to meet social needs. Second, research is needed to address the rather prescriptive relationship and gaps in knowledge about the transition process. There remain gaps in knowledge regarding the extent to which entrepreneurs have the potential for creating sustainable economies, about their motivation and how to incentivize them, the presence of structural barriers, how to capture economic rents and exploring public policy and how to enhance its influence on sustainable entrepreneurship. Third, research is needed to explore the conditions for providing sustainable products and processes by entrepreneurial ventures rather than incumbent firms and the welfare-creation and welfare-destruction effects as well as unsustainable rent-seeking by entry into dirty businesses. Finally, research about conditions to simultaneously create economic growth, advance environmental objectives and improve social conditions for impoverished communities – a hindrance for environmental improvements. These conclusions regard innovation as a key to the transition process.

Sustainable development implies use of renewable resources whenever possible and using non-renewable resources under conditions of reduce, reuse and recycle to extend their viability for future generations. Conflicts in objectives and in weighing economic, social and environmental concerns arise in cases such as trade-offs between economic growth and resources degradation. In order to avoid devolution of development to achieve sustainability, large-scale societal and economic transformations might be achieved through innovation. This panacea hypothesis believes that green, clean and low-carbon entrepreneurs will be a driving force behind innovation and delivering sustainable products and services. Despite the premise of entrepreneurship for fostering sustainable development, there remains uncertainty regarding entrepreneurship's role and its possible outcomes. The expectation is based on the role that entrepreneurship has played in the developmentally non-sustainable societal transformations in the past. There is little or no evidence on how entrepreneurs will discover and develop opportunities to achieve sustainability goals. Sustainable development is not researched within entrepreneurship literature. Thus, there remain gaps in knowledge about how the process will unfold; this is a major constraint. The special issue of the *Journal of Business Venturing* (Hall et al., 2010) was aimed at addressing this gap. It reviewed literature and explored the role of entrepreneurship in sustainable development. The overview of the studies included in the special issue help to get a better understanding of the gaps and suggest further research on the entrepreneurship-sustainable development nexus.

Corporate social responsibility and its linkage to sustainable development has become a corporate strategy. A majority of the large firms apply some form of the corporate sustainability policy. Universities have also responded with new faculties and educationally green and sustainability programs. Well-known journals in diverse research fields have been actively publishing research on corporate and university sustainability. However, a majority of the published research is related to established firms' efforts to reduce environmental impacts by going green and their effects on competitiveness. Hall et al. (2010) by referring to Amber and Lanoie (2008) report the financial benefits of sustainability investments in being green including better access to certain markets, differentiated products, revenues from selling green technology, better risk management, lower cost of resources, lower cost of capital and lower cost of labor. However, sustainable development from entrepreneurship orientation has not been researched much. The existing slowly developing sustainability-driven entrepreneurial economics and management literature offers limited insights into how entrepreneurship is expected to create new productive opportunities to correct social and environmental related market failures and how they also unproductively destroy technologies.

Further research and development of institutions is needed to support efficient allocation of scarce resources and profitability of environmental friendly innovations and sustainability oriented production activities. A related stream of literature on social entrepreneurship summarized by Zahra et al. (2009) encompasses activities to discover and exploit opportunities inherent in environmentally market failures. The aim is to enhance social wealth through the creation of new ventures and existing organizations. Cohen and Winn (2007) stress that yield opportunities for sustainability entrepreneurs are a result of specific market imperfections. Considering the two-way causal relationship between environmentalist and sustainable development entrepreneurs, it is unclear how sustainability intentions influence entrepreneurial intentions (Kuckertz and Wagner, 2010).

7. The Future Development of Circular Economy

7.1 CE as part of an entrepreneurial strategy

This review which is based on existing literature establishes that sustainable development is not a reversal path. Hall et al. (2010) provide a foundation for potential future research directions in the field of sustainable development and entrepreneurship. Current research has been more prescriptive and optimistic. Future research should be descriptive and provide answers to the extent to which entrepreneurs have the potential for creating sustainable economies which require insights into at least five related issues. First, the conditions under which entrepreneurial ventures rather than incumbent firms or their combinations transform economies into sustainable systems providing sustainable products and services. Second, incentivized conditions leading to entrepreneurs pursuing sustainable ventures. Here the key factors are developing the theory, removing structural barriers to capturing economic rents, differences among sustainability-oriented and traditional entrepreneurs and differences in behaviors and risk preferences. Third, the conditions under which entrepreneurs can simultaneously create economic growth, while advancing social and environmental objectives. It should be noted that entrepreneurial dynamics for sustainable development in impoverished communities within developing and emerging economies can be a hindrance to environmental investments. Fourth, conditions that factor in all externalities in entrepreneurship welfare-creation versus welfare-destruction should be considered. The key factors are possible negative externalities, unanticipated problems, newly created social and environmental challenges and potential unsustainable rent-seeking by entrepreneurs. Finally, the conditions under which public policy can positively influence the incidence of sustainable entrepreneurship. The policy and practice should provide answers to all the questions raised here. Depending on the drivers of entrepreneurs to adapt sustainable orientation, it is important to introduce an optimal combination of policies of allocation of innovation support to incumbents or to new ventures, heterogeneity in the support being provided by the sector, industry structure and dynamics and provision of demand-side tax and supply-side R&D subsidies. The interplay and trade-offs between competing social, environmental and economic objectives will determine the optimal mixture of sustainable entrepreneurship policies.

Hockerts and Wustenhagen (2010) have theorized about the role of incumbents (greening Goliaths) and new entrants (emerging Davids) in sustainable entrepreneurship. The two types of players are characterized by age, size and objectives. Sustainable entrepreneurship is defined as the discovery and exploitation of economic opportunities linked to market failures in the process of generating market equilibrium. The objective is to transform industries into environmentally and socially sustainable states. Thus, sustainable entrepreneurship describes activities that represent disruptive rather than incremental innovations. Incumbent and large firms engage in incremental environmental or social process innovations such as introduction of sustainability management systems, eco-efficiency or corporate social responsibility initiatives (Schaltegger, 2002). On the other hand, the new entrants are 'sustainable entrepreneurs' or 'bioneers' or 'social bricoleurs'. The diffusion of sustainable products and services is a traditional case S-shape and includes the stages of introduction, early growth, take-off and maturity. The two forces evolve over time. The co-evolution of sustainability start-ups and market incumbents towards the sustainability transformation of an industry is from different initial positions. Emerging Davids by having a sustainability niche have high environmental and social performance but low market share, while the greening Goliaths have low environmental and social performance but a high market share. They both target high environmental performance and market share as an outcome of the sustainability transformation of the industry in the maturity stage. Regulations, environmental and health awareness and various sustainable innovation policy incentive programs will influence the speed and outcome of the transformation and the allocation of market share. Examples of such markets are organic retailer whole foods markets, solar cell production, smart cars, electric vehicles and clean power production which provide some basic information about the transformation process, the interplay between firms in the market and effects of various public policies, as well as potential negative externalities.

7.2 CE as an innovative national level development strategy

A report published by the Swedish government's offices titled 'Sweden's national strategy for sustainable development' (ME, 2002) defines sustainable development as the overall objective of the government's policy. The strategy brings together social, cultural, economic and environmental priorities in a shift towards more sustainable development in Sweden. The report describes the government's efforts in the form of objectives, measures and strategies adopted and reflected in policy towards sustainable development. Sustainable development strategies have also been formulated by EU, OECD, the Nordic Council of Ministers and several other organizations and countries. In a recent study Wijkman and Skånberg (2015) explore the potential for a significant increase in resource efficiency and assess benefits for society in the form of carbon emissions and employment gains. The modelling exercise shows significant emission reduction and positive employment and trade balance effects from renewable, energy-efficient and material efficiency sources. Using the Swedish economy as a case, the authors recommend lowering taxes on work and increasing taxes on the use of natural resources and white certificates as policy measures to promote the move towards CE and increasing its benefits for society. Glomm et al. (2008) examine the double dividend from revenue neutral green (gasoline) taxes in the form of consumption efficiency and environmental quality dividends. Positive net employment effect is found in Cai et al. (2011) who studied the relationship between the green economy and green jobs in China's power generation. Mehmet (1995) too studied employment creation and the green development strategy. By highlighting the jobs versus environment dilemma for densely populated developing countries Mehmet suggests that the North should finance job creation in the South using funds raised through eco-taxes and levies on international trade. Samet (2013) also discusses circular migration between the North and the South.

The Swedish national level sustainable development strategy defines the long-term vision of a sustainable society and its foundation of values and specifies policy instruments, tools and processes necessary to implement the change process, as well as the monitoring and evaluation of its implementation. Different players are called to join in the broad participation which is based on public consultations. The national level development strategy is expected to include all three dimensions of sustainability -- ecological, social and economic -- and to make prudent use of, conserve and invest in human and environment resources. The sustainable development strategy is based on a democratic system of government institutions that promote resource-efficient production and consumption patterns and learning and collective public goods comprising knowledge, health and the environment. A balanced combination of social welfare, economic development and a sound environment is at the heart of the Swedish vision and policy of sustainable development. The Swedish government has prioritized eight strategic core areas encompassing the important elements of a sustainable society: the future environment; limitation of climate change; population and public health; social cohesion, welfare and society; employment and learning in a knowledge society; economic growth and competitiveness; regional development and cohesion; and community development. Each core area is presented and some general objectives and measures provided (see GO-ME, 2002: 21-35).

Environmental degradation is not only a national problem but a global one. The challenge of the 21st century is facilitating and strengthening democratic cooperation on sustainability at the international level to promote the environment, human health and well-being. Since 2001 the European Council has been urging members to formulate their national sustainable development strategies so that in cooperation with the UN system this can lead to worldwide development of a sustainable development strategy. Sweden is a major contributor when it comes to integrating ecological, economic and social sustainability. This is achieved by joint responsibility in creating sustainable sectors of special needs including industry, working conditions, regional development, agriculture, forestry, fisheries and a good built environment. The three aspects of sustainability are protection of natural resources, sustainable management of resources and improved efficient use of resources. These account for social and economic sustainability and provide a good picture of the national sustainability strategy and its scope. Sustainability in family and working life is among the great future social and economic challenges. Sweden as a technologically developed nation with a strong innovation capability in the area of environmental regulations, green taxes and standards, could explore the entrepreneurial/business opportunities which Swedish firms could participate in for transferring advanced waste management and technology. Waste management is an old but aggravated challenge that requires new solutions in the form of public investments in cleaner and more efficient waste-removal systems to build a sustainable and intensified urbanization environment. An example of successful entrepreneurial firms trying to use the opportunities of developing new technologies and approaches based on the circular economy, such as the quantum system technology, is the Swedish company Envac (Törnblom, 2014).[1]

Implementing a sustainable development policy requires a number of tools and incentives (GO-EM, 2002). These include environmental legislations to support efforts towards a sustainable society, the role of spatial planning of communities, synergies in mutually supportive economic, environment and social actions and programs and having an integrated product policy for life cycle management of good and services. Economic instruments are the drivers of the development. The main component, tax on harmful

[1] Envac is a global leader in the vacuum waste collection industry. It has 40 offices across Europe, North and South America, the Middle East and Asia. The company invented the automated underground vacuum waste system. The system can now be found all over the world in residential areas, business premises, town centres, industrial kitchens, hospitals and airports (http://www.worldfinancialreview.com/?p=2890).

activities, promotes both economic and ecological sustainability. An evaluation of the impact of policies at different levels provides a better basis for decision making. Progress in creating standards for regular monitoring and evaluations have in general been slow. Efforts at getting a national sustainable development strategy indicators system continue. Research and development, education, information dissemination and dialogue between actors are essential elements of a sustainable society. Finally institutional capacity is crucial for integrating development issues in all policy areas and at all decision making levels. Effective coordination and the complex task of combining short- and long-term processes is a challenge that calls for active leadership in achieving the goal of CE as an innovative national level development strategy.

The responsibility for sustainable development lies with the individual state, although climate, environmental degradation and globalization have increased the states' mutual dependence. Thus, sustainable development calls for measures at local, national, regional and global levels. The key international organizations are the UN, EU, OECD, WTO, the Nordic Council of Ministers and other environmental organizations such as the Stockholm Environmental Institute (SEI)[2] and the recently established Global Green Growth Institute (GGGI).[3] One of the eight millennium development goals is ensuring environmental sustainability. Development of environmentally sustainable energy systems and efficient transportation systems that reduce emissions and greenhouse gases are important sustainable consumption and production measures. Agreements have been reached under the UN Framework Convention on Climate Change to support the developing countries in their transition economically and technologically. Global water partnership, peace and security, EU and OECD sustainable development strategies, in addition to local and nation level activities are among other initiatives that are essential to global sustainable development. OECD Green Growth Studies (OECD, 2014) has developed a green growth framework and indicator set to monitor progress towards green growth. Green growth aims at fostering economic growth and development while ensuring that natural assets continue to provide the resources required for enhancing our well-being. The set contains indicators covering the socioeconomic context and characteristics of growth, the environmental and resource productivity of the economy, the nature of the asset base, the environmental quality of life and economic opportunities and policy responses. The indicators are useful for designing and evaluating policies. A full summary of the indicators is provided in Appendix B.

7.3 General policy recommendations

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[2] SEI is an independent international research institute established in 1989 by the Swedish Government. SEI has been engaged in environment and development issues at the local, national, regional and global policy levels. Its goal is to bring about change for sustainable development by bridging science and policy by providing an integrated analysis that supports decision-makers (http://www.sei-international.org/).

[3] GGGI is an international organization established in 2012. It is dedicated to supporting the transition of its member countries towards a strong, inclusive and sustainable green growth model by developing and implementing strategies that simultaneously achieve poverty reduction, social inclusion, environmental sustainability and economic growth (http://gggi.org/).

Literature on the evaluation of CE is not yet well developed and gained experience from the four Chinese pilot cities provides limited guidelines on CE implementation at the macro level. Various methodologies of index numbers are used to aggregate individual indicators into composite and multidimensional indices to measure CE's performance in various recognized dimensions and levels. As in other areas of development research the issue of an optimal weighting in aggregation of the indicators is far from being resolved. Other challenges include lack of reliable information, shortage of advanced environmental technology, enforcement of legislations, weak economic incentives, poor management and lack of public awareness. This review attempted to define standardized quantitative measurements and goals so as to provide a clear picture of where China and some European countries stand in the CE adaptation process. We suggest the deployment of a range of policies to overcome these challenges and provide a guide for designing an optimal future direction of the development strategy to prevent a reversion to old practices and standards. An assessment of China's 12^{th} five-year plan (2011-15) when data becomes available will help shed light on the old and new challenges which will possibly require a changed set of policies.

One of the key challenges listed earlier is lack of reliable information and data. Provinces in China have a relatively high degree of autonomy. In recent years a number of comprehensive surveys and databases have been created and generously made available to researchers without much restriction on their access. This openness applies to a large number of areas including collection and dissemination of statistics. However, data in general is collected by the National Statistical Agency. In parallel, provinces and major municipalities also collect and publish local statistics. The way data is collected, processed and made available for research is still managed and controlled in the old fashioned way where the state has a strong influence on the content and the way it is presented and disseminated. Radical changes are needed to improve the general public's trust in the accuracy and quality of the data. New standardized databases covering all levels and provinces need to be collected and used in assessing CE's implementation. This applies to all countries with an increased focus on environment. The OECD (2014) Green Growth Studies has suggested a measurement framework and provides a range of topics and indicators.

China has industrialized at a very rapid pace. The level of technological capabilities has developed significantly but not homogenously across different sectors and locations. Shortage of advanced technologies is one key limitation in the efficient management of the environment and for coping with the rapidly deteriorating environmental conditions in the country. Developing such technologies is not feasible given the current relatively low indigenous technology levels. Improved global awareness about the environment and climate change has developed channels and mechanisms to facilitate related and advanced technology transfers to developing countries. Through such cooperative channels and its own joint venture regulations for corporations to gain access to the Chinese market, China has been able to facilitate transfer of needed technology. It is worth mentioning here that current technology levels are short of the optimal level and investments in environmental technology innovations are necessary for developing the needed technologies. This will further increase the cost of production and in general it is considered harmful to firms' competitiveness. However, it promotes energy and material savings in production and green trade as dividends. The new and advanced environmental technologies adapted to CE's 3R principles should be a priority for central and regional governments and for municipalities in China.

Sweden is a technologically developed nation with strong innovation capabilities and is a major donor for international development aid. The Swedish state and municipalities with strong capabilities in areas of environmental regulations, green taxes and development of standards, could encourage entrepreneurs and business corporations to participate in the implementation of the advanced waste management and technology development in China and elsewhere. Scandinavian gained experience in data collection, grassroots participatory decision making and solidarity in sharing welfare and responsibility are among potential exportable services that place Sweden and its corporations at the forefront of practitioners of environmental concerns. This is in line with the green wave and the Nordic view of environmental justice (see Lehtinen, 2007).

There are no intended public restrictions on development and introduction of production and consumption technologies considering their positive environmental and climate impacts. Such interventions as in the case of medicines and their health and side effects could be developed. Legislations are being introduced to cope with polluting technologies regardless of their type and source. However, legislations are often introduced long after the technologies have been developed and introduced in the market. Thus, their introduction is more or less an issue of repairing damages that have already happened and their sources may not be within the range of the law. Even if legislations are introduced to prevent harm to the environment, their efficient enforcement is a precondition for successful implementation of environmental and advanced costly technology use regulations.

The main focus of the central and provincial governments in developing countries in general and in China in particular has been on investments for developing infrastructure. Costly environmental considerations and their negative effects on competitiveness have not been priorities. Thus few resources have been allocated in the form of economic incentives to promote development and implementation of CE. International practices reveal that public economic incentives remain an effective means of conserving resources and the environment. Economic incentive policies stimulate the behavior of producers and consumers to bring them in line with the 3R principles of CE. Examples of economic incentive policies include public R&D and innovation support, pricing and tax policies, environmental damage and health policies and insurances, cap and trade systems, support to research in the fields of energy saving, renewable energy alternatives, recycling of materials and green and environmental labeling of products.

Business and methods of operation and management are developed globally. Transfer of finances, management, skills and technology is much easier and faster than design and implementation of environmental regulations. Such soft knowledge is often developed indigenously and with long lags and in response to market failures. This phenomenon combined with issues such as corruption lead to poor management of the public sector and its responsibilities. There is a desire to attract enterprises' establishment and operation for reasons such as creating employment opportunities. These limit the effects of regulations. Improvements regarding the enforceability of legislations and the management system along with the government and corporate governance system, reform of judicial management mechanisms, a transparent monitoring and auditioning mechanism and accountability are required. Green political parties, civil society and NGOs' participation in inclusive decision making processes and rich policy experience from the traditional market economy in developed nations ease the implementation of a green growth strategy and sustainable development.

Like enhancing business awareness about the environment, public awareness in the capacity of business owners, employees and consumers is equally important as components of production, consumption and waste management; this is also needed in the implementation of regulations. Countries differ by level of education and general awareness about the environment. A transition from socialism to the market economy in China has created space for experimentation. However, the unlimited desire to produce, export and accommodate in an unsustainable way and under minimum regulations has been extremely harmful to the environment. Achieving an optimal level of public education and increasing awareness require enormous resources. Significant investments at all levels and inn all areas are necessary for achieving the desired level of awareness that is conducive to the environment. Media channels can be used for facilitating close cooperation between producers, consumers and regulators in the field of environment and material management.

8. SUMMARY AND CONCLUSIONS

CE as a concept was introduced in 1990 with its 3R principles of reducing, reusing and recycling energy, materials and waste. CE is seen as offering a viable alternative development strategy to ease tensions between desired national economic development and environmental concerns. It also helps address existing resource scarcity and pollution problems and enables enterprises and industries to improve their competitiveness by removing green barriers in their international trade relations. China's rapid industrial development and persistent high rate of economic growth since its open door policy at the end of the 1970s have led to increased awareness about China's resource scarcity and environment degradation. CE is viewed as a viable solution to countries' resource scarcity and environmental problems.

A growing body of literature has emerged during the last two decades on various theoretical, methodological and empirical aspects of CE and its implementation. China has made serious efforts to intensively and on a large scale implement CE with the objective of providing long term and sustainable solutions to its severe resource scarcity and environmental degradation problems.

This review provided an overall review of literature on the circular economy in China and the sustainable development strategy elsewhere. The current practice of the strategy is being carried out at the micro, meso and macro levels covering production, consumption, waste management and various public support programs to promote, regulate, monitor and evaluate CE's successful implementation.

The review's results show that research resources in China as a main practicing country of CE are allocated in a fragmented way and research is not organized and conducted effectively for unified effort and progress. Two sets of assessment indicator systems are suggested by two Chinese agencies to evaluate implementation of CE. Their focus is on the realization of the 3R principles. In addition, one of the indicator systems considers the impact of eco-industrial parks on the economy and the environment. Results using a combination of the assessment indicator systems from the pilot city of Dalian compared with three other pilot cities of Beijing, Shanghai and Tianjin show evidence of CE's implementation and quantified positive effects. The empirical results presented and summarized in this review show evidence of significant heterogeneity among the pilot cities and in the establishment and industry case studies with respect to the performance of the circular economy's 3R principles.

Like circular economy a set of indicators for assessing practices of the sustainable development strategy in Europe and elsewhere is also being developed. Again the evaluation systems are highly fragmented and far from being standardized. A coordination of efforts in harmonizing and standardizing the evaluation systems for micro, meso and macro levels accounting for industry heterogeneity and country specificity conditions is desired. This will facilitate a comparison of resource use and environmental performance across firms, industries, regions and countries. The United Nations Environmental Protection Agency and other organizations like the EU Environment Agency, the Stockholm Environmental Institute and the Global Green Growth Institute in cooperation with academia could coordinate efforts to develop general systems for evaluating the circular economy, sustainable development and green growth strategies. These multidimensional composite indices and outcome oriented indicators, like human development and environmental sustainability indices, will help track elements of CE and the progress being made in its implementation. This information can be of great value to policymakers, resources and environmental scientists, agencies and organizations as well as to the general public.

The Swedish national sustainable development strategy clearly defines the long-term vision of a sustainable society and its foundation of values and specifies various policy instruments, tools and processes necessary to implement the change process, as well as for the monitoring and evaluation of its implementation. As a result significant knowledge about the environment and its preservation has been developed. Therefore, Sweden as a technologically developed nation with strong innovation capabilities in the areas of environmental regulations, green taxes and in developing standards, could explore entrepreneurial/business opportunities in which Swedish firms and municipalities could participate in implementing advanced waste management and technology development in China, India and elsewhere. This is consistent with the new orientation in development aid provision with a strong focus on local education and research capacity building and promotion of entrepreneurship in receiving countries in recent years.

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Table 1. Benchmarks for Sweden, Stockholm and Gothenburg (all per capita except for area)

Indicators	Sweden	Stockholm	Gothenburg
Area (km^2)	450,295	6,526	3,695
Population density (km^2)	22.6	305	246
Disposable income (1,000 SEK)	230	260	246
Tertiary education	0.31	0.39	0.37
Number of personal cars	0.41	0.31	0.37
Residential floor area (m^2)	44.1	40.8	42.7
Domestic material consumption/capita (tonnes)	18.5	10.3	10.9
	Sweden (2011/2000)	Stockholm (2011/1996)	Gothenburg (2011/1996)
Population	1.07	1.20	1.14
Resources consumption:			
Fossil fuels	0.99	0.63	2.08
Metals	1.00	1.29	1.80
Non-metallic minerals	1.11	1.61	1.88
Biomass	0.98	1.09	2.22
Chemical and fertilizers	1.28	2.77	2.34
Others (fibers, salts, etc.)	0.91	1.93	1.81
Total domestic mineral consumption (DMC)	1.05	1.31	1.97

Source: Adapted from Kalmykova et al. (2015). 'Resource consumption drivers and pathways to reduction: economy, policy and lifestyle impact on material flows at the national and urban scale', *Journal of Cleaner Production:* Table 1.

Table 2. Relationship between GDP by sector and main material categories' consumption

Indicators	Domestic Material Consumption	Fossil Fuels	Metals	Non-Metallic Minerals	Biomass	Chemicals and Fertilizers
Sweden:						
GDP	0.69	0.14	-0.53	0.82	0.55	0.62
Industry	0.74	0.02	-0.44	0.85	0.57	0.77
Services	0.63	0.23	-0.56	0.77	0.49	0.53
Stockholm:						
GDP	0.85	-0.53	0.73	0.85	0.67	0.90
Industry	0.80	-0.56	0.72	0.80	0.43	0.90
Services	0.84	-0.69	0.54	0.89	0.36	0.91
Gothenburg:						
GDP	0.78	0.26	0.39	0.90	0.67	0.85
Industry	0.78	0.43	0.51	0.85	0.63	0.66
Services	0.75	0.19	0.32	0.88	0.67	0.89

Source: Adapted from Kalmykova et al. (2015), 'Resource consumption drivers and pathways to reduction: economy, policy and lifestyle impact on material flows at the national and urban scale', *Journal of Cleaner Production:* Supplementary Table 1.

Note: GDP is measured at 2011 fixed prices.

Table 3. Structure of the circular economy practice in China

Areas\Levels	Micro (Single object)	Meso (Symbiosis Association)	Macro (City, Province, State)
Production	Cleaner production Eco-design	Eco-industrial park Eco-agricultural system	Regional eco-industrial network
Consumption	Green purchase and consumption	Environmentally friendly park	Renting service
Waste management	Product recycle system	Waste trade market Venous industrial park	Urban symbiosis
Development support	Policies and laws, information platform, capacity-building; NGOs; applicable to all micro, meso and macro levels.		

Source: Adapted from Su et al. (2013), Table 1.

Table 4. NDRC evaluation indicator system for the circular economy at the meso level

Group dimensions	No.	Indicators
1. Resource output	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	2.1	Energy consumption per unit of production value
	2.2	Energy consumption per unit of production in key industrial sectors (iron, copper, aluminium, cement, fertilizers and paper)
	2.3	Water consumption per unit of production value
	2.4	Water consumption per unit of production in key industrial sectors
3. Integrated resource utilization	3.1	Utilization rate of industrial solid waste
	3.2	Reuse ratio of industrial waste water
	3.3	Recycling rate of industrial waste water
4. Reduction in waste generation	4.1	Decreasing rate of industrial solid waste generation
	4.2	Decreasing rate of industrial waste water generation

Source: Adapted from Su et al. (2013), Table 2.

Note: NDRC: National Development and Reform Commission.

Table 5. MEP evaluation indicator system for the circular economy at the meso level

Group dimensions	No.	Indicators
1. Economic development	1.1	Industrial value added per capita
	1.2	Growth rate of industrial value added
2. Material reducing and recycling	2.1	Energy consumption per industrial value added
	2.2	Fresh water consumption per unit of industrial value added
	2.3	Industrial waste water generation per unit of industrial value added
	2.4	Solid waste generation per unit of industrial value added
	2.5	Reuse ratio of industrial water
	2.6	Utilization rate of industrial solid waste
	2.7	Reuse ratio of recyclable treated waste water
3. Pollution control	3.1	Chemical oxygen demand loading per unit of industrial value added
	3.2	SO_2 emission per unit of industrial value added
	3.3	Disposal rate of dangerous solid waste
	3.4	Centrally provided treatment rate of domestic waste water
	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
4. Administration and management	4.1	Extent of establishment of the information platform
	4.2	Environmental report release
	4.3	Extent of public satisfaction with local environmental quality
	4.4	Extent of public awareness about eco-industrial development

Source: Adapted from Su et al. (2013), Table 3.

Note: MEP: Ministry of Environmental Protection.

Table 6. Key circular economy indicators in Dalian in 2005 and 2010 and goals set in 2006

Dimensions	Indicators	Actual 2005	Actual 2010	Goals by 2010	% change in goals	% change in actual
Resource efficiency	Energy consumption per GDP (standard coal, tons/10^4 RMB)	1.0	0.8	0.8	-21	-21
	Energy consumption per unit of industrial value added (standard coal, tons/10^4 RMB)	1.6	1.2	1.2	-27	-27
	Water consumption per unit of industrial value added (tons/10^4 RMB)	37.5	18.0	26.2	-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 waste water treatment, %	73	90	90	17	17
	Rate of safe disposal of municipal solid wastes, %	80	100	98	18	20
Waste reclamation	Rate of treated waste water recycling, %	10	42	35	25	32
	Rate of industrial solid waste reclamation, %	62	96	75	13	34

Source: Dalian Municipality (2006, 2011); The Liaoning Statistic Yearbook (2006, 2011); Adapted from Su et al. (2013), Table 4.

Note: Municipal waste includes waste from both industrial and residential sources.

Table 7. Per cent actual changes in key circular economy indicator in four cities (2005-10)

Dimensions	Indicators	Beijing	Shanghai	Tianjin	Dalian
Resource efficiency	Energy consumption per GDP (standard coal, tons)	-62	-31	-21	-21
	Energy consumption per unit of industrial value added (standard coal)	-66	-36	-76	-27
	Water consumption per unit of 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 waste water treatment	3	-8	31	17
	Rate of safe disposal of municipal solid wastes	15	10	14	20
Waste reclamation	Rate of treated waste water recycling	45	-5	5	32
	Rate of industrial solid waste reclamation	16	21	27	34

Source: Data collected from the statistical yearbooks of Beijing, Shanghai, Tianjin and Dalian in 2006 and 2011; Adapted from Su et al. (2013), Table 5.

Table 8. The relative performance of four cities in 2005 and 2010 for resource and waste indicators

Dimensions	Indicators	Beijing		Shanghai		Tianjin		Dalian	
		2005	2010	2005	2010	2005	2010	2005	2010
Resource efficiency	Energy consumption per GDP (standard coal, sc)	2.58	1.00	2.06	1.42	1.88	1.48	2.02	1.60
	Energy consumption per unit of industrial value added (sc)	3.03	1.03	1.67	1.06	4.09	1.00	1.82	1.33
	Water consumption per unit of 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 waste water 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 waste water 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

Source: Adapted from Su et al. (2013), Table 6.

Note: The relative performance is obtained by dividing each row's data by the best performance for each indicator. The benchmarks are shaded.

Table 9. The evaluation index system on the development level of a circular economy in chemical enterprises

Target level	Criteria level	Index level	Current value	Standard value
The development level of a circular economy:	X1 Economic development	X11 Rate of output per unit of land area	0.39	1.26
		X12 Per capita GDP	5.7	5.5
		X13 Rate of return on common stockholders' equity	50	200
		X14 Annual growth rate of industrial added value	6	8
	X2 Exploiting resources	X21 Water consumption per unit of industrial output	9.5	1.2
		X22 Energy consumption per unit of industrial output	3.5	1.2
		X23 Comprehensive utilization of industrial solid waste	30	75
		X24 Recycling rate of industrial water	70	75
	X3 Pollution reducing	X31 Emission reduction rate of industrial waste water COD	44	66
		X32 Emission reduction rate of SO2	89	100
		X33 Rate cut of industrial solid waste generation	60	80
	X4 Ecological efficiency	X41 Waste water emissions per unit industrial output	4.02	0.58
		X42 SO2 emissions per unit of industrial output	5	10.2
		X43 Solid waste emissions per unit of industrial output	166.6	135
		X44 Net profit / environmental investment	187.5	300
	X5 Develop-mental potential:	X51 The proportion of technology investment to total industrial output	1	2.5
		X52 Capital accumulation rate	8	30
		X53 Rate of sales growth	10	20

Source: Adapted from Li and Su (2012), *Evaluation of the circular economy development level of Chinese chemical enterprises*, Table 4.

Appendix A. Chronological summary of selected empirical studies on CE and sustainable development and entrepreneurship

Author(s)	Topic of research	Study period	Dimensions (number of indicators)	Method of estimation/ computation	Summary of findings and conclusion
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 its sustainable and all-round development.
Peng et al. (2005)	Promotion of clean technology in SMEs in China.	2002	20 barriers are grouped into four major categories: policy and market, financial and economic, technical and information, managerial and organizational barriers.	Analytic Hierarchy Process (AHP).	The exterior policy and financial barriers should be stressed rather than the inner technical and managerial barriers. Absence of incentives, lax enforcement of regulations and high initial capital costs were the most important barriers to adoption of clean technologies in China.
Zhang and Huang (2005)	Research on the 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 2002-07 the goal was to focus on reducing pollution and resource consumption; in 2008-2010 the goal was to focus on eco-environment protection, reducing pollution and management; in 2011-20 the goal is to control for balanced development among all aspects.
Chen (2006)	Evaluation of CE for 3 different cities of Shanghai, Yinchuan and Rizhao.	Experience and consulting	Economic development; living environment; structure features; resource utilization social development (38).	Analytic Hierarchy Process (AHP).	Shanghai (metropolitan) scored 93, Yinchuan (big city in the west) scored 76, Rizhao (medium sized city in the east) scored 65.
Meng and Shen (2006)	Research on CE's evaluation of Central Plain cities.	2003	Economic development; green development; social development (25).	Principal Component Analysis (PCA).	Economic development has proposed the most influence on CE, followed by reduction of resource usage and social development.
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 (AHP).	The analysis showed that CE is developing at a steady speed. According to the trend of development in 1986-2003, the official goal will not be achieved until 2022.
Wang et al. (2006)	Evaluation and diagnosis of obstacles for CE in Jiangsu's	1985-2003	Social and economic development; resource reduction; recycle and reuse;	Analytic Hierarchy Process (AHP)	The results showed ten obstacles that are impeding CE's development in Jiangsu's industrial sector. Energy efficiency was the

	industry sector.		waste reduction; safety of resources and environment (35).	and obstacle analysis.	biggest obstacle. The average growth of CE indicators: in general (10.2%), waste reduction (17.6%), resource reduction (9.6%), and recycle and reuse (3.0%).
Zhu and Qiu (2007)	Analytical tool for urban CE planning and its application.	1990-2004	Productivity of resources 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.
Qian et al. (2008)	Assessment of CE's development levels.	Recent year data	Resource efficiency; environmental impacts; social development (28).	Analytic Hierarchy Process (AHP).	The comprehensive index of CE development of Qingdao city is 0.73, i.e. the mid-circular state; identifying the bottlenecks in the development of CE. Development countermeasures are put forward.
Xiong et al. (2008)	Comprehensive evaluation of CE development.	1998-2004	Resource reduction; resource efficiency; waste generation; resource reuse and recycle; economic aspects (19).	Principal Component Analysis (PCA).	In 1998-2004, CE's performance in Shaanxi has improved gradually. Waste per produced unit of GDP decreased and utilization of solid waste improved.
Zhu and Qiu (2008)	Eco-efficiency indicators and their demonstration as a measure of CE.	1990-2005	Productivity of resources and waste (7).	Eco-efficiency.	The eco-efficiency of natural resource inputs in China increased during1990-2005. It is not enough for China to decouple economic growth from natural resources.
Du and Cheng (2009)	Evaluating CE efficiency in 47 iron and steel industry establishments.	2003-06	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 (DEA) and Malmquist Productivity Index (MPI).	The CE efficiency of the iron and steel industry in China on the whole is not high, but it shows a positive trend. The main factor that affects the enhancing of CE efficiency of the iron and steel industry is technical efficiency.
Geng et al. (2009)	Review of progress in implementation of CE at the regional level.	2005 and 2010 goal	Comparing key CE indicators for Dalian, Beijing, Shanghai and Tianjin in 2005. The indicators cover resource consumption, waste discharge, waste treatment and waste reclamation (10).	Simple descriptive statistical analysis.	Identifies several responses by Dalian municipality to overcome the challenges: pricing and tax reforms serve as conservation incentives, provision of financial support and the organization of CE training programs. More is possible and more is needed before Dalian can be designated a true 'eco-city'.
Hao et al. (2009)	Design of the 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 and assistant index systems.

Li et al. (2009)	Measurement indicators and an evaluation approach for assessing urban sustainable development.	Plan for 2004-20	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. According to the ecological plan for 2004-20, the indicator will improve to 0.45 in 2007, 0.62 in 2010 and 0.90 in 2020.
Liu et al. (2009)	Analysis of public awareness and performance for promoting CE.	2006	The data used was collected by distributing questionnaires randomly in 6 urban districts in China and interviewing 600 respondents.	Descriptive statistical analysis of survey data.	The results indicate that the residents have limited awareness and a poor understanding about the CE program. People's awareness has a positive correlation with their educational levels, whereas their pro-environmental and resource conservation behavior has a positive correlation with the age of the respondents.
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 development (23).	Obstacle analysis.	Different status of development in 21 cities in Guangdong owing to dissimilarities in natural and environment conditions as well as on a social and economic basis.
Wang (2009)	Evaluation of CE in 29 Chinese cities.	2006	Economic development; reuse and recycle; resource reduction; emission reduction; social development (10).	Principal Component Analysis (PCA).	16 cities' comprehensive scores show that their CE development is more balanced than others in all aspects; 12 cities' shows gaps in their CE goals. Also pilot cities scored lower than non-pilot cities.
Jiang (2010)	Empirical analysis of regional CE development in provinces Jiangsu, Heilongjiang and Qinghai.	--	Resource consumption; Environmental disturbances; recycling; social development (16).	Fuzzy synthesis appraisal; comparison evaluation method.	Jiangsu had higher development in CE than Heilongjiang and Qinghai provinces. Heilongjiang needed to adopt energy conservation. CE development and efficiency in recycling needs powerful economic security.
Kockerts et al. (2010)	The influence of sustainability orientation on entrepreneurial intentions.	2007, cross-section of individuals	Determinants of science and engineering, business students and their alumni's intentions about becoming self-employed.	Ordinary Linear Regression Model (OLS).	The findings suggest that the positive impact of sustainability orientation vanishes with business experience. Suggests measures to nourish an evidently existing potential for sustainable entrepreneurship.
Meek et al. (2010)	The impact of social norms on	Sample of 45 USA states	Estimates models of a number of new solar energy firms by	Fixed effects panel data.	The findings suggest that the efficacy of state-level policies in the sponsoring of

	entrepreneurial action.	funding solar firms, panel data	firms, state and regulations and their interaction variables.	Model.	entrepreneurial growth is dependent on the social norms that prevail in the entrepreneur's environment. Demonstrates the integral role that social norms play in influencing the creation of new firms and illustrates the potential effect that social norms have on the effect of environmental policies.
Xue et al. (2010)	Officials; awareness on CE development in China.	Municipal and country level survey data in 2008	The questionnaire targets a stratified population by age, income and educational levels. The questions are related to: understanding CE development, attitude and performance towards promoting CE development.	Simple statistical analysis of data.	Most of the officials working at municipal and county levels have higher awareness and understanding of the CE concept. Nearly 16.70% need to further improve their CE awareness. The main barriers are weaknesses in public awareness and lack of financial support. Willingness to pay for green products is low.
Zhu et al. (2010)	Integrated management to resource depletion and pollution problems.	Survey	Measurement items for evaluating environmental oriented supply chain cooperation, measurement items for evaluating CE practices and measurement items for evaluating CE targeted performance (46).	Factor Analysis (FA) and Multi-Hierarchical Clustering Method (MHCM).	The cluster analytic results with a multivariate analysis of variance among four types of Chinese manufacturers varying in environmental-oriented supply chain cooperation highlight the importance of intensifying cooperation with upstream and downstream supply chain partners for a CE initiative to succeed.
Jia and Zhang (2011)	Evaluation of regional CE.	2006	The regional CE index system and quality grades include reduce, recycle and reuse as rule layers. The layers include energy and water consumption, water and waste emissions and recycling and treatment.	Fuzzy mathematic and the matter element model.	The model applied to evaluate the development of CE in Beijing, Anhui and Sichuan shows that the quality grade of Beijing is good, Anhui is middle and Sichuan is in the basic circle. The proposed method proved to be reasonable and reliable, and can be widely used in evaluation problems.
Jiang (2011)	Evaluation system for regional CE	--	Resource consumption; environmental disturbances; recycling; and social development (16).	Fuzzy Comprehensive Evaluation Method and Comparison Evaluation Method.	It enhances ability in the evaluation model and evaluation method of CE developing level in Jiangsu, Heilongjiang Qinghai Province.

Li (2011)	Construction of an evaluation index system and evaluation results for eco-industrial parks.	--	Element; environment; economy; social; and management (20).	ANP and AHP to evaluate multi-attribute network with feedback.	Empirical research on Jiangsu eco-industrial parks illustrates the feasibility and rationality of this approach. The method can provide more scientific information to enhance their performance and basis for decision making.
Qing et al. (2011)	Integrative evaluation of development of CE.	2004-08	Social and economic development; resource efficiency; resource recycling and use; environmental protection; and pollution reduction (26).	Principal Component Analysis (PCA) and Analytic Hierarchy Process (AHP).	The results show that CE development in Shaanxi province is steadily moving upward. Advices for accelerating CE development of Shaanxi.
Xiong et al. (2011)	Evaluation of CE's development efficiency.	1999-2008	Takes labor, resources and capital as input elements of CE development and takes economic growth, social development, industrial discharge treatment compliance rates and the comprehensive utilization rate as output to construct the efficiency evaluation index system of CE development.	Data Envelopment Analysis (DEA).	Need to improve the utilization of input factors and productivity of output indicators in Jiangsu province. Need to improve the utilization of input factors of those enterprises with high water and energy consumption to fully use resources.
Yang et al. (2011)	Integrative evaluation of the development of CE in Shaanxi.	2004-08	Economic development; resource efficiency; resource recycling and reuse; environment protection; pollution reduction (59).	Principal Component Analysis (PCA) and Analytic Hierarchy Process (AHP).	The results show that CE's development in this province is steadily moving upwards. Different indicators have different trends.
Zhang and Huang (2011)	Early-warning method and application of a complex system of CE.	2007-10	Economic sub-system; social sub-system; ecological resources sub-system; and resources system (20).	Fuzzy ISODATA cluster analysis.	The fuzzy ISODATA cluster analysis based on early warning systems and decision analysis is practicable when applied to a complex CE system for oil and gas explorations.
Zeng and Zhang (2011)	Benchmarking CE efficiency of coal-fired power plants.	--	8 input and 4 output indicators in measuring CE efficiency for 24 coal-fired power plants.	Data Envelopment Analysis (DEA).	Though measuring, improving and benchmarking, the carbon dioxide emissions and pollutant discharges will be continuously reduced, reused and recycled, hence the low-

					carbon development of electric power industry can be achieved.
Geng et al. (2012)	National CE indicator system.	-	The evaluation indicator system at the macro level: resource output and consumption rates, integrated resource utilization rate, waste disposal and pollutant emission and at the industry park level. At the micro level 22 calculation formulas are suggested.	Single indicators and composite index methods.	Introduce a national CE indicator system. Certain benefits can be gained, but substantive revision is also needed due to lack of a comprehensive set of indicators which should include social, business indicators, urban/industrial symbiosis, absolute material/energy reduction and prevention-oriented indicators.
Li (2012)	Quantitative evaluation of enterprise's CE.	--	Inputs are from different departments, resources and general products, departments outside the area and waste input. Inputs include production area, pollution eliminated, waste remains in production and consumption areas and total waste output.	Waste input-output analysis.	With a system analysis of the development and principles of CE based on the input-output analysis tools, builds a table and the basic evaluation model of CE in enterprises. The model still has some flaws and weaknesses.
Li and Su (2012)	Evaluation of the CE development levels in Chinese chemical enterprises.	Enterprises' confidential data	Economic development, resources exploiting, pollution reducing, ecological efficiency, development potential. (18)	Weighted sum model.	An analysis of CE development of Beijing Petrochemical New Material Base indicates that the CE development in this base is in a transitional stage from transitional development to the circular mode. In the future more importance should be attached to the efficiency of exploiting resources and their potential development to raise the level of CE development.
Stefanescu and On (2012)	Analysis of entrepreneurship and sustainable development in Europe.	2006-09	Indicators of entrepreneurship and sustainable development. The countries are divided into innovation-driven and efficiency-driven groups.	Principal Component Analysis (PCA).	The hypothesis was confirmed by the results, that is, most of the innovation-driven economies are grouped together, meanwhile efficiency-driven economies are placed at some distance from the others countries.
Li et al. (2013)	Reutilization-extended material flows and CE.	2000-10	Total generation flows divided into: material reutilized (agriculture and industry),	Economy-wide material flow analysis (EW-	By 2010, about 60% of the overall solid waste generation had already been reutilized, and more than 20% of the total resource

			recycled and recovered materials (construction, municipal solid waste, scrapped vehicles, waste electronic equipment) and second hand products. Each is divided into a number of waste categories.	MFA).	requirements had been reutilized. Interpretations of resource reutilization-related laws and regulations of CE are provided and corresponding policy suggestions are proposed based on the results.
Liu and Bai (2014)	Firms' awareness and behavior of CE's development.	Questionnaire firm survey	The 10 questions asked are grouped into: awareness and behavior towards CE development. The firms are grouped into 15 industry groups. Barrier categories are: structural, cultural and contextual.	Analysis of variance between and within groups (ANOVA).	Results indicate that the firms had a relatively good understanding about CE and its values and had a strong willingness to operate a CE, but this was not indicative of enthusiastic behavior. Gap exists between a firm's awareness and its actual behaviour in developing a CE. Reasons for the gap are explored and recommendations for overcoming them suggested.
Liu et al. (2014)	Constructivism scenario evolutionary analysis of zero emission regional planning.	--	Types of scenarios: natural environment; social economy system; human.	An evolutionary analysis and multi-objective programming model of CE.	The model provides solutions to the optimal expected output levels of main chemical products and minimal quantity of pollution treatment facilities. The results of the paper will have important policy implications for regional development planning in China.
Ma et al. (2014)	A historical perspective on the inherent CE mode.	2007-10	Four main indicators at the level of: equipment used; utilization of materials; slag and converter slag; and pollutant emission.	Established a bespoke evaluation system.	Although the implementation of a CE has greatly enhanced China's iron and steel industry with respect to reducing pollution, further measures such as improving the utilization rates of coke oven gas, converter gas and converter slag, and reducing sulfur dioxide emissions, are urgently required.
Wu et al. (2014)	Effectiveness of the CE policy.	2005-10	The specific efficiency of three sub-systems: resource saving and pollutant reducing, waste reusing and resource recycling and pollution controlling and waste disposing are assessed along with rank comprehensive CE efficiency. Each sub-system	Data Envelopment Analysis (DEA).	The difference in regional efficiency of the three sub-systems reflects the difficulty of carrying out a CE policy in China, that is, promoting the adaptability of regional policy for local governments and enhancing the coordination among various policies for China's central government are the key concerns for realizing sustainable

			has inputs and outputs.		development.
Kalmykova et al. (2015)	Analysis of material flows to study the dynamics of resource consumption.	1996-2011	Resource consumption: fossil fuels, metals, non-metallic minerals, biomass, and chemicals, fertilizers and others in Sweden, Stockholm and Gothenburg.	Descriptive statistical analysis.	In recycling, waste-to-energy is growing faster than material recycling, which impedes the development of CE. The main limitation of the policies implemented to date is that they only address efficiency of use, but do nothing to reduce the demand for resources.
Li and Ma (2015)	Cleaner production and sustainable development by developing CE.	2013	Dimension: resource consumption rate (energy and water), resource comprehensive utilization rate (recycling of solid waste and water), reduction rate in waste discharge (pollutant) and disposal rate of dangerous solid waste.	Simple statistical analysis of the data.	The GSIL papermaking park constructs a CE industrial mode by recycling energy, water and materials. The CE plan has integrated the resources of the papermaking and power industries horizontally. Resource consumption, resource utilization and pollutant emission indexes of the park have reached an advanced level in the papermaking industry in China.
Ma et al. (2015)	Application of resource efficiency and eco-efficiency in industrial metabolism under CE.	-	Economic benefits; resource efficiency; recycling efficiency; eco-efficiency.	Optimization of resource efficiency.	Demonstrates that technological progress in mineral processing and the production of associated products is the endogenic motivation to increase economic benefits and for improving resource efficiency.
Wen and Meng (2015)	Assessment of industrial symbiosis for the promotion of CE.	Questionnaire 2010	Input (water, sludge containing copper, waste copper foil and waste etching solution) and output (regenerated copper, regenerated etching solution and loss of copper).	Substance flow analysis (SFA) and resource productivity indicator (RP).	RP is enhanced by prolonging the industrial production chain and RP under the excluding waste utilization scenario is higher than the waste utilization scenario for the same chain, which can be achieved through greater industrial symbiosis. Finally proposes further implications on developing CE in eco-industrial parks.

Note: study period is not indicated (--)

Appendix B. OECD Green Growth Indicators

Indicator group	Theme	Topics	Proposed indicators
A. Environmental and resource productivity of the economy	A1. Carbon and energy productivity	1. CO_2 productivity	1.1. Production-based CO_2 productivity. GDP per unit of energy-related CO_2 emitted.
			1.2. Demand-based CO_2 productivity. Real income per unit of energy-related CO_2 emitted.
		2. Energy productivity	2.1. Energy productivity (GDP per unit of TPES).
			2.2. Energy intensity by sector (manufacturing, transport, households, services).
			2.3. Share of renewable energy sources in TPES, in electricity production.
	A2. Resource productivity	3. Material productivity (non-energy)	3.1. Demand-based material productivity (comprehensive measure; original units in physical terms) related to real disposable income. • Domestic material productivity (GDP/DMC) - Biotic materials (food, other biomass). - Abiotic materials (metallic minerals, industrial minerals).
			3.2. Waste generation intensity and recovery ratios by sector, per unit of GDP or value added, per capita.
			3.3. Nutrient flows and balances: Nutrient balances in agriculture (N, P) per agricultural land area and change in agricultural output.
		4. Water productivity	Value added per unit of water consumed, by sector (for agriculture: irrigation water per hectare irrigated).
	A3. Multifactor productivity	5. Multifactor productivity reflecting environmental services	Comprehensive measure; original units in monetary terms.
B. The natural asset base	B1. Natural resource stocks	6. Index of natural resources	Comprehensive measure expressed in monetary terms.
	B2. Renewable stocks	7. Freshwater resources	Available renewable natural resources (groundwater, surface water) and related abstraction rates (national, territorial).
		8. Forest resources	Area and volume of forests; stock changes over time.
		9. Fish resources	Proportion of fish stocks within safe biological limits (global).

	B3. Non-renewable stocks	10. Mineral resources	Available (global) stocks or reserves of selected minerals: metallic minerals, industrial minerals, fossil fuels, critical raw materials; and related extraction rates.
	B4. Biodiversity and ecosystems	11. Land resources	Land cover types, conversions and cover changes from natural state to artificial state: • Land use: state and changes.
		12. Soil resources	Degree of topsoil losses on agricultural land, on other land: • Agricultural land area affected by water erosion, by class of erosion.
		13. Wildlife resources (to be further refined)	• Trends in farmland or forest bird populations or in breeding bird populations. • Species threat status: mammals, birds, fish, vascular plants in per cent species assessed or known. • Trends in species abundance.
C. Environmental dimension of the quality of life	C1. Environmental health and risks	14. Environmentally induced health problems and related costs	For example, years of healthy life lost from degraded environmental conditions. • Population exposure to air pollution.
		15. Exposure to natural or industrial risks and related economic losses	
	C2. Environmental services and amenities	16. Access to sewage treatment and drinking water	16.1. Population connected to sewage treatment (at least secondary, in relation to optimal connection rate).
			16.2. Population with sustainable access to safe drinking water.
D. Economic opportunities and policy responses	D1. Technology and innovation	17. R&D expenditure's importance for green growth	- Renewable energy sources (% of energy-related R&D). - Environmental technology (% of total R&D, by type). - All-purpose business R&D (% of total R&D).
		18.Patents for importance to green growth	(% of country applications under the Patent Cooperation Treaty): - Environment-related and all-purpose patents. - Structure of environment-related patents.
		19. Environment-related innovation in all sectors	

	D2. Environmental goods and services	20. Production of environmental goods and services (EGS)	
		21. Gross value added in the EGS sector (% of GDP)	
		22. Employment in the EGS sector (% of total employment)	
	D3. International financial flows	23. International financial flows of importance to green growth	% of total flows and % of GNI.
		24. Official development assistance	
		25. Carbon market financing	
		26. Foreign direct investment	
	D4. Prices and transfers	27. Environmentally related taxation	- Level of environmentally related tax revenue (% of total tax revenues and in relation to labor-related taxes). - Structure of environmentally related taxes (by type of tax base).
		28. Energy pricing	Share of taxes in end-use prices.
		29. Water pricing and cost recovery (tbd)	To be complemented with indicators on: environmentally related subsidies, environmentally related expenditure: level and structure.
	D5. Regulations and management approaches	30. Indicators to be developed	
E. Socioeconomic context and characteristics of growth	E1. Productivity and trade		
	E2. Labor markets, education and income	Training and skill development	31. Indicators to be developed.
	E3. Socio-demographic patterns		

Note: Adapted from OECD green growth indicators (2014), Table 1.1 and various tables from Chapters 4 to 7.