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The history and current applications of the circular economy concept



K. Winans*, A. Kendall, H. Deng

Department of Civil and Environmental Engineering, University of California, One Shields Avenue, Davis, CA 95616, USA

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ABSTRACT

The challenges of balancing industrial development, environmental and human health, and economic growth in China and elsewhere in the world are drivers for recent resource use and low-carbon development strategies that include the application of the circular economy (CE) concept. A central theme of the CE concept is the valuation of materials within a closed-looped system with the aim to allow for natural resource use while reducing pollution or avoiding resource constraints and sustaining economic growth. The objectives of this study are (1) to review the history of the CE concept to provide a context for (2) a critical examination of how it is applied currently. Thematic categories are used to organize the literature review of current applications including policy instruments and approaches; value chains, material flows, and products; and technology, organizational, and social innovation. The literature review illustrates the variability in CE project success and failure over time and by region. CE successes, key challenges, and research gaps are identified. The literature review results provide useful information for researchers as well as multi-stakeholder groups who seek to define the CE concept in practical terms, and to consider potential challenges and opportunities it presents when implemented.

1. Introduction

In response to the United Nations Framework Convention on Climate Change, 196 participating countries created strategies for low-carbon development. Of these countries, China emits higher amounts of greenhouse gas (GHG) per year compared to any other country in the world, yet contributes less carbon dioxide (CO₂) emissions per capita compared to Russia and 68% of the Organization for Economic Cooperation and Development countries [1]. China produces the greatest amount of manufactured goods and has a historically rapidly growing economy. This pace of growth and consequential environmental damage, human health effects from pollution, and social justice issues in China and elsewhere in the world are drivers for recent low-carbon development strategies, including the application of the circular economy (CE) concept [2–5].

The CE concept was popularized in China in the 1990s in response to economic growth and natural resource limitations [6–8]. The main point of the CE concept is to capitalize on material flow recycling and to balance economic growth and development with environmental and resource use [9]. Today, the concept of CE has been adopted more widely and organizations across the world such as the European Commission and the Ellen MacArthur Foundation are promoting certain aspects of it, including materials design and flow assessment

[10], among others.

The objectives of this study are (1) to review the literature considering the history of the concept of CE to provide a context for (2) a critical examination of how it is applied currently. To narrow the scope and for purposes of this literature review, the following thematic categories are used to organize the results: policy instruments and approaches; value chains, material flows, and products; and technology, organizational, and social innovation. These thematic categories were in part selected based on the *Economie Circulaire dans l'Union Européenne Resume Analytique* [11] and World Bank [12] findings and recommendations for applications of the CE concept. The literature review was conducted using searches of the journal databases Scopus and ScienceDirect as well as Google Scholar, and keywords including, but not limited to, industrial symbiosis, eco-industrial park, material flow analysis, and circular economy. Close to 1500 relevant papers were identified, over 150 of which were selected for inclusion in the review, covering a geographic scope of 20 different countries.

2. History of the circular economy concept

There is no clear evidence of a single origin or originator of the CE concept, but contributors include U.S. professor John Lyle; his student William McDonough; the German chemist, Michael Braungart; and,

Abbreviations: CO₂, Carbon dioxide; CE, Circular economy; GHG, Greenhouse gas

* Corresponding author.

E-mail address: kswinans@ucdavis.edu (K. Winans).

architect and economist, Walter Stahel [13]. The CE concept may also have been inspired by Rachel Carson's *Silent Spring* [14], the 'limits to growth' thesis of the Club of Rome in the 1970s, the 'spaceship earth' metaphor presented by Barbara Ward and Kenneth Boulding, and work by eco-economist Herman Daly [8]. Pearce and Turner developed conceptual frameworks for the CE concept such as the resource-products-pollution mode [15]. The principles of the CE concept include the 3Rs (reduce, reuse, recycle) [2] and the 6Rs (reuse, recycle, redesign, remanufacture, reduce, recover) [16].

The CE concept is interwoven with various other concepts, some of which predate it, like industrial symbiosis [17–19]. Eco-city is a CE related concept that is rapidly evolving in Japan, Singapore, and elsewhere [20]. In industrial ecology and systems theory, the CE concept is associated with a broad range of subjects such as thermodynamics and ecological economics. Important to note is the CE concept does not work for thermodynamics, in particular because no system can be 100% circular (or closed) due to the entropy law [8,21]. In systems theory and according to thermodynamics, application of CE concepts influences the production and consumption models in a way that causes a 'degrowth phase' not a 'growth-oriented phase' of the economic system [22–24].

The CE concept evolved differently in light of diverse cultural and social and political systems [25]. In Germany, in the early 1990's, the CE concept was introduced into environmental policy with the intent to address issues associated with raw material and natural resource use for sustained economic growth [26]. In China, in the late-1990's, an eco-industrial park model was promoted, and in the mid-2000's, the application of the CE concept was introduced in line with Hu Jintao's concept of a "harmonious society," which was later implemented with emphasis on waste recycling post consumerism and the development of waste-based closed loops within a company or among different processor and consumer groups [27]. In China, the concept of CE is used as a mechanism for profitable product development, new technology development, upgrading equipment, and improving industry management [28]. The CE concept is applied in the UK, Denmark, Switzerland, and Portugal for waste management, primarily, although there are also business models that apply material circular use (or reuse) concepts [29]. Some CE-related initiatives aim to increase consumers' responsibility for material use and waste, which is evident in some parts of Korea and Japan [30,31]. In North America and Europe, corporations apply the CE concept with the aim to enhance reduce, reuse, and recycle programs, and to conduct product-level life cycle studies [32,33]. In the past decade, a range of government top-down, e.g., material flow analysis frameworks, and bottom-up, e.g., harmonious society, approaches emerged that include the CE concept and tools for quantitative assessment of new CE initiatives [12,34,35]. In Serbia, implementation of the CE concept is investigated to explore potential for and benefits of new CE initiatives [36]. With emerging CE initiatives, various tools are evolving to assess, e.g., material flows [37,38], and many of these tools do not evaluate the social or community context in which the initiatives occur [39].

3. Current applications of the circular economy concept

The three thematic categories used to organize the literature review results include (1) policy instruments and approaches; (2) value chains, material flows, and product-specific applications; and (3) technological, organizational, and social innovation.

3.1. Policy instruments and approaches

Policy instruments are regulatory and economic instruments implemented to achieve an effect that will not occur in the absence of governmental intervention. Note that there are different approaches to policy including but not limited to policy instruments, policy frameworks or top-down approaches, and government programs or bottom-

up approaches. In the following sections, applications of the CE concept are presented along with the main objects or ideas, actors, and practices of each, which are the essential components of policy as defined by Jiao and Boons [40,41].

3.1.1. Eco-industrial park, eco-industrial network, and industrial symbiosis

Eco-industrial park initiatives include the exchange of water, energy, information, and or materials "to minimize energy and raw materials use, reduce waste, and build sustainable economic, ecological, and social relationships" [42,43]. Eco-industrial networks or industrial symbiosis networks also evolved with the same idea as eco-industrial parks but cover a broader geographic area within a region, a province, or a country. Sometimes the terms industrial symbiosis, eco-industrial network, and eco-industrial park are used in the literature synonymously. It is necessary to make a distinction between these terms, however, because the scale and scope of the objectives, actors involved, and practice are different, as are the potential synergies that may exist for each initiative. [44]. A critical point is that the spatial relationship, i.e. the distance between industries, influences energy and material flows between entities [45].

Eco-industrial park developments are the first manifestation of industrial symbiosis, occurring for the first time in the 1960's in the eco-industrial park in Kalundborg, Denmark [46]. Today, there are several examples of eco-industrial parks around the world— in India, Australia, Korea, Japan, Canada, the United States, and Europe— that build upon existing and potential linkages within a region [47,48]. Many of these eco-industrial park developments are supported by policy to encourage material and information interchanges [47,48]; however, some eco-industrial parks evolved without government intervention.

The eco-industrial park in Kalundborg, Denmark exemplifies natural physical linkages of material flow exchange between industries within a region. This eco-industrial park self-organized in that its economic feasibility resulted from bilateral agreements among industries without the participation of external forces [49,50]. The park continues to evolve and acts as a model system for new industrial symbiosis developments elsewhere in the world [49,50]. The eco-industrial park in Ostergotland (a region of Sweden) is another self-organized system that supports material flow and linkage between a sawmill, a pellet production plant, a pulp mill, and several municipality actors for purposes of reuse of and reduced waste of CO₂, heat, and power within biofuel applications [51]. The Industrial EcoSystem project Rotterdam Harbour Industrial Ecology Project in the Netherlands started from the bottom-up, initiated by industry actors' interests in the socio-economic welfare of new employees [52]. The Project culminated in 1994 with 69 industries involved, and now includes stakeholders from the government and academic sectors, as well as community members who are collaborating with the aim to reduce heat and CO₂ waste [52].

Most eco-industrial parks or networks and industrial symbiosis initiatives are not self-organized and are instead inspired and supported by policy. In Italy, the eco-industrial park concept was introduced in 1997 under Italian law *Area produttiva ecologicamente attrezzata*, Law No. 57/1997 (article 26), entrusting regions to develop industrial zone initiatives according to the definition "industrial zones equipped with infrastructure and systems able to guarantee health, safety and environment protection" to which 15 regions responded. One region (Emilia-Romagna) instituted a regional law (Planning Law no. 20/2000) to develop the eco-industrial parks with sustainability principles [53]. Within Emilia-Romagna region, the Raibano eco-industrial park has been assessed by Conticelli and Tondelli [53] using a strategic environmental assessment, but the project has not been implemented to date. In the United Kingdom, several eco-industrial programs started under the banner of the National Industrial Symbiosis Program [54], a program which is now an independently owned commercial enterprise [55].

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