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## Review

## Towards circular economy implementation: a comprehensive review in context of manufacturing industry

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## ABSTRACT

The concept of circular economy (CE) is to an increasing extent treated as a solution to series of challenges such as waste generation, resource scarcity and sustaining economic benefits. However the concept of circularity is not of novel as such. Specific circumstances and motivations have stimulated ideas relevant to circularity in the past through activities such as reuse, remanufacturing or recycling. Main objectives of this work are: to provide a comprehensive review of research efforts encompassing aspects of resources scarcity, waste generation and economic advantages; to explore the CE landscape in the context of these three aspects especially when they are considered simultaneously; based on an idea of a comprehensive CE framework, propose an implementation strategy using top-down and bottom-up approach in a concurrent manner. To fulfill this objective a comprehensive review of state-of-the-art research is carried out to understand different ideas relevant to CE, motivation for the research and context of their recurrence. Main contributions of this paper are a comprehensive CE framework and a practical implementation strategy for a regenerative economy and natural environment. The framework emphasizes on a combined view of three main aspects i.e. environment, resources and economic benefits. It also underlines that joint support of all stakeholders is necessary in order to successfully implement the CE concept at large scale. The proposed framework and implementation strategy also identify new avenues for future research and practice in the field of CE.

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## Contents

1. Introduction .....	00
2. Research methodology .....	00
3. Present circular economy research landscape .....	00
3.1. Overview of CE research .....	00
3.2. Related areas to circular economy .....	00
3.2.1. Transformation of economic structures and business rationales .....	00
3.2.2. Regenerative design and critical materials .....	00
3.2.3. Industrial ecology .....	00
3.2.4. Remanufacturing and closed-loop supply chains .....	00
3.2.5. Resource conservative manufacturing .....	00
3.2.6. Governmental CE initiatives .....	00
3.3. Discussion of state of the art research .....	00
4. A comprehensive framework on CE .....	00
5. Practical implementation strategy for CE .....	00
6. Conclusions .....	00
Acknowledgment .....	00
Supplementary material .....	00

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References .....	00
Web references .....	00

### Abbreviations

3R	reduction, reuse and recycling
APRA	automotive parts remanufacturers association
CE	circular economy
EIP	eco-industrial park
EU	European Union
ICT	information and communication technology
LCA	lifecycle assessment
ResCoM	resource conservative manufacturing
PSS	product–service systems
UK	United Kingdom
WEEE	waste electrical and electronic equipment
WW2	world war two

## 1. Introduction

Relationship between industry and environment is crucial for industrial business performance. Environmental impacts have incrementally increased pressure on industrial businesses.

Looking back to the beginning of the industrial revolution, mass production of goods was enabled by new manufacturing methods resulting in products with high availability and low costs. Consequently, due to new consumer societies and staggering growth in industrial activity, emissions to environment, solid waste generation and landfill have become increasingly severe. In addition, due to a growing world population and especially strong middle-class growth the demand for resources is expected to rise rapidly indicating a rising consumption of natural resources. Since planet earth's resources are limited the requirements of exponential economic and population growth cannot be met (Meadows et al., 1972). In this scenario, it is not only the challenge of environmental pollution that is becoming acute but the challenge of global resource scarcity as well. These circumstances confront manufacturing industry to simultaneously cope with the pressure of environmental regulations, challenges of resource price volatility and risks in resource supply, in addition to their daily business. As individual competitiveness is thereby influenced fundamentally, manufacturing companies find themselves in a progressively uncertain position when it comes to resource supplies. Increased competition for access to scarce or critical resources has become another major concern for manufacturing industry (European Commission, 2014b) in addition to fulfilling obligations on environmental legislation at minimum cost.

In the light of the discussed series of challenges and the underlying limitations of a linear economy, i.e. take-make-use-dispose, the concept of a circular economy (CE) is considered as a solution for harmonizing ambitions for economic growth and environmental protection. There are various possibilities for defining CE. In line with eco-industrial development CE is understood as “realization of closed loop material flow in the whole economic system” (Geng and Doberstein, 2008). In association with the so called 3R principles (reduction, reuse and recycling) “the core of CE is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases” (Yuan et al., 2006). Taking into account economic aspects CE can also be defined as “an economy based on a “spiral-loop system” that

minimizes matter, energy-flow and environmental deterioration without restricting economic growth or social and technical progress” (Stahel, 1982). For this paper, the relevant CE definition is the one of “an industrial economy that is restorative or regenerative by intention and design” (Ellen Macarthur Foundation, 2013). This definition is more comprehensive as it considers both the environmental and economic advantages simultaneously under the notion of *regenerative* performance requiring high quality circulation of technical nutrients while ensuring safe entry of bio nutrients in the biological sphere.

The concept of circularity, especially in terms of closed material loops, is not a concept of novelty originating from recent developments, but has been emerging now and then throughout the history: Before the industrial revolution, i.e. in times of craftsmanship and hand production methods, waste as unwanted or unusable material was virtually unknown (Strasser, 2000). A so called ‘stewardship of objects’ has been the prevailing practice with the primary purpose of maintaining possessions by performing reparations, repurposing or recycling leaving disposal scarcely as an option. There is general acceptance that the industrial revolution is responsible for the changing relationship between individuals and the material world (Siegle, 2006; Mathews, 2011; Strasser, 2000). After the industrial revolution disposable products with the explicit purpose of being discarded after use (planned obsolescence) heralded the era of fashion and style hence stimulating throwaway-mindset which is today known as *linear* consumption behavior. Successively, problems of environmental pollution and landfill became severe leading governments around the world to initiate waste reduction and *recycling* programs. Moreover, taking into account mechanization of society through steam engines, railways and electrical equipment a new form of product recovery arose today known as *remanufacturing* in which durable products are restored to a “like new” condition (Steinhilper, 1998). The birth of remanufacturing can be traced to the times of world war two (WW2) when resources became scarce and automotive industry was enforced to perform remanufacturing (Automotive Parts Remanufacturers Association, 2015). However, after times of war the remanufacturing industry experienced continuous growth over the years driven primarily by the economic and competitive advantages. In the beginning of the 2000s, China with its staggering population and rapidly developing industry realized its mismatch between economic development and resulting environmental impacts. As a consequence, the government of China formally accepted the concept of CE as a new development strategy in 2002 and approved the first law “Circular Economy Promotion Law of the People's Republic of China” which took effect in January 2009 (The Standing Committee of the National People's Congress China, 2008). Since the approval of this law major research efforts have been made towards nation-wide implementation of a CE in China. More recently, economic opportunities of CE have been outlined in the European Union (EU) emphasizing advantages for the industrial sector such as reduction of material costs or larger profit pools (Ellen Macarthur Foundation, 2013).

In summary, attempts to respond to challenges of resource scarcity, environmental impact or economic benefits or combinations of these have been made by governments, industries and societies around the world. However, major part of these attempts has been lacking a systematic approach and therefore the CE approach appears not only apposite but also inevitable. In this scenario, the objective of this review paper is to.

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