

Communication

The Socio-Economic Embeddedness of the Circular Economy: An Integrative Framework

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Abstract: Global economies have been characterised by a large dependency of material inflows from natural stocks, an exponential growth of material stock-in-use in the built environment, and the extensive disposal of waste material outflows to anthropogenic sinks. In this context, the concept of the circular economy has emerged, promising to circulate the stock-in-use of materials and transforming output waste material flows back into useful resources while promoting job and value creation. These promises have drawn the attention and interest of policymakers and industry, and gained popularity across society. Despite its apparent emergent legitimacy and diffusion, a few essential adjustments still need to be addressed so that circular economy initiatives can actually deliver on their promises without leading to negative unintended effects. First, a complete entanglement with the existing formal economy is fundamentally needed; this implies valuing the preservation of natural stocks and pricing material input flows adequately. Secondly, a recognition of its socio-economic embeddedness is essentially necessary. The decision-making of societal actors affects material configuration, which in turn affects societal actors; this important feedback loop needs to be explicitly taken into account in circular economy initiatives. The aim of this short communication paper is to explore these pervasive challenges in a broad context of sustainable physical resource management. An integrative framework for recognising the socio-economic embeddedness of the circular economy in practice and the role of the formal economic system in realising its ambitions is proposed.

Keywords: circular economy; stocks and flows; socio-economic embeddedness; sustainable physical resource management; integrative framework

1. Introduction

The circular economy concept is expected to deliver multiple benefits of improved resource efficiency, reduced primary resource demand, and the provision of new sources of income and

job creation [1]. Consequently, there has been exponential interest in circular economy initiatives branded under the circular economy tag in business in the past few years [2]. This movement has gained considerable traction because of the tireless efforts of the Ellen MacArthur Foundation [3]. Nevertheless, there are claims that beyond recycling [2], the circular economy concept has only rarely and fragmentally been adopted by business [4]. Conversely, a significant number of barriers to the implementation of the circular economy have been identified [4]. Interestingly, these barriers refer mostly to socio-economic aspects and decision-making at multiple levels—e.g., product design, integration into production processes, perception of sustainability, risk aversion, and unclear responsibility distribution [4].

In the preparation of this contribution, we have started to scrutinise the literature on the circular economy concept. In doing so, we have been impressed by the width and ambition of the concept. However, we have also found that its priorities and its practices have been hitherto largely decoupled from (1) the socio-economic context and (2) the existing formal economy. We would like to highlight this further in this short communication. We close this article by delineating an integrative framework for recognising in practice the socio-economic embeddedness of the circular economy, based on a rich exchange of experiences and knowledge between us authors (see Appendix A).

2. Conceptualisation of the Global Economy's Material System

The circular economy is grounded on the concepts of zero waste and industrial symbiosis. There is no consistent delimitation for this emerging concept. A recent study synthesised 45 circular economy strategies of varied scope at practical and technical levels [5]. Other previous studies [5–13] have broadly analysed circular economy strategies in contexts such as resource productivity, waste hierarchy, resource recovery, and sustainability-driven business models. These strategies are not individually new, but the concept of the circular economy offers a new framing of these strategies and their interrelationships [8].

According to an industrial ecology perspective, the circular economy can be defined as closing the material flow loop efficiently (cf. eco-cycle concept in Sinha et al. [14]) where materials or resources continuously circulate within the socio-economic system with low or no leakage (e.g., emissions, flows going out of the system). In contrast, physical resource management strategies predominantly focus on the outflows from the socio-economic system; to date, global economies are characterised by significantly large inflows and outflows. However, in the present communication, we propose to focus on inflows, outflows, stocks, and studying the overarching efficiency in the use of resources in the system, as illustrated in Figure 1. By expanding the focus from the outflows to inflows and stocks, flows are expected to be reduced, and stocks are expected to be circulated in the formal economic system, allowing society to lessen the pressure on the environment by increasing the magnitudes of the closed loops (see the curved arrow in Figure 1).

Figure 1 shows that the formal economy is the driver of societal activities and thus defines the magnitude of inflows, outflows, stocks, and efficient use of resources within the socio-economic system. Therefore, the paper proposes establishing indicators for the circular economy linking the formal economy to the physical resource flows and use.

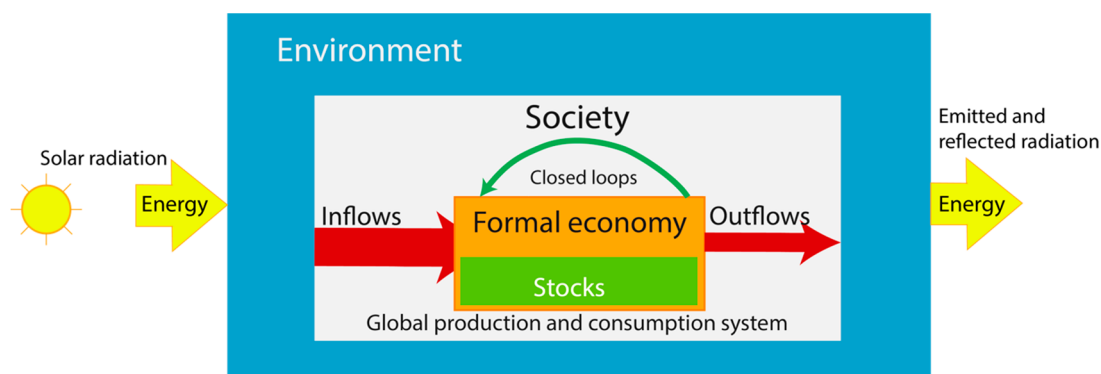


Figure 1. Conceptual model of the current physical resource metabolism in the global production and consumption system. The white rectangle represents our society, where production and consumption take place. The outer blue rectangle represents the environment. The thicker of the two red solid arrows shows the physical resource flows from the environment to the production and consumption, while the thinner solid red arrow represents the outflow from the production and consumption systems to the environment. The inner green rectangle represents the stocks of physical resources under the formal economy (orange rectangle). The thinnest green curved line with an arrowhead shows the reuse, repair, refurbishment, remanufacture, recycling, and recovery of resources. The yellow arrows show energy flow, illustrating that the environment and our planet Earth are open to energy flows.

3. Socio-Economic Embeddedness in the Material System

The circular economy has delivered much hope for potential economic benefits and new business opportunities. The expression “circular economy” is appealing to companies, innovators, and entrepreneurs struggling to create new businesses and hoping to do so under pressure to improve environmental performance and social acceptance [13].

However, circular economy strategies do not necessarily result in the decoupling of an inextricable link of economic growth and resource consumption [15,16]. Indeed, the circular economy could lead to increased environmental impacts due to an overall increase in production and the use of products, which is described by Zink and Geyer [15] as the circular economy rebounds. The circular economy rebounds can partially or fully offset the environmental gains of circular economy by increasing the overall demand because of: (1) the insufficient substitutability of secondary products over primary products, in the case of technologically advanced products with rapid innovation cycle, leading to additional consumption as a result of reduced prices. For example, uncompetitive refurbished mobile phones merely lead to a reduction in the manufacturing of new phones [17–19]; (2) rebounds as a result of a net reduction in the prices of the product and their substitutes when the suppliers compete for the buyers in the markets. This leads to the income effects and the substitution effect [15]; and (3) economy-wide and transformational effects due to changed consumer behaviours and changes in market structures [20]. Therefore, achieving an absolute reduction in resource consumption demands a concerted effort involving processes of decision-making and agreed actions by actors across globalised supply chains. These processes should focus on developing mechanisms to create competitively fair markets for all of the suppliers by eliminating the ‘free-riders’. Nonetheless, currently, the circular economy strategies appear to take these processes for granted and focus on including actors that are only immediate to the value chain.

Further, the key promises of the circular economy to slow and close material loops as well as the use of renewable energy may be unrealistic due to technological limits and socio-economic constraints. For instance, the 100% recyclability and use of renewable energy to drive resource productivity depends upon the availability of technological solutions and their economic and environmental viability. Nonetheless, current projections for the expansion of renewable technologies to meet such demand are directly in conflict with resource scarcity concerns related to rare-earth

metals. Further, expected higher consumer costs and or the unavailability of the consumer market may hamper the adoption of longer lasting products with less environmental impacts overall, as required in a circular economy (due to slow material cycles). Indeed, current norms of consumerism characterised by faster technological innovations coupled with fashion-oriented socio-cultural values [21], market competition [22], and businesses' demands for rapid turnover [23], especially in the industrialised countries, are some of the key challenges confronting the businesses aspiring towards the circular economy. These pose tremendous barriers to create value from (re-)circulating resources through repairing, remanufacturing, and component recovery, which demand a fundamental shift in consumer behaviours and expectations. Subsidised energy and virgin material resources due to government policies focusing on driving economic growth, especially in the developing countries, further escalate these challenges. In addition, in the current economic system, the social and environmental externalities go unaccounted for, which worsens these challenges.

Further, some of the unaddressed systemic challenges to the circular economy include a lack of consumer interest and awareness, hesitant company culture, regulatory, incompatible current market structures, and slow technological progress towards recovering/recirculating resources [24]. Due to these interrelated challenges, the current scope of the circular economy implementation includes only selected products, materials, and sectors [5]. This is invariably due to the current economic structures and institutions that allow (monetary) value creation and recovery from some selected materials, products, and sectors, but not from others. However, a sustainable management of physical resources will require a revaluation of externalities to the formal economic system and change monetary incentives. In our mind, the circular economy in its current approach does not address this systemic challenge.

This fundamental challenge clearly relates to the formal global economy domain. It raises an important question as to whether the promises of the circular economy could be realised without its integration within the formal economic system. Indeed, driving a positive technological, social, and economic change towards a transition to a circular economy requires the collaboration of stakeholders across society, addressing business concerns and incorporating sustainability demands [13]. Therefore, it is imperative to align the ambitions of the existing formal economy with the concept of the circular economy. The concept in its current form lacks a necessary strong link to and acceptance by formal economists and lacks embedding the material system in the formal economy.

4. Circular Economy as an Essential Bridge for Linking Material and Socio-Economic Systems

According to Korhonen et al. [7], the context of the unit of analysis of the circular economy initiatives in industrial production systems and networks can be divided into two levels: the organisational culture, learning, responsibility, and the overall worldviews and visions are the themes of the first level; and the empirical physical flows of materials and energy make up the second level. These could also be seen as material and socio-economic aspects of the circular economy initiatives, and they are reflected in the definition of the circular economy concept by Korhonen et al. [7]: “circular economy is a sustainable development initiative with the objective of reducing the societal production–consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system . . . ” (material structure); “ . . . the circular economy promotes high-value material cycles alongside more traditional recycling, and develops systems approaches to the cooperation of producers, consumers, and other societal actors in sustainable development work” (socio-economic structure).

From a systems thinking perspective, there is not only a causal link from the socio-economic to the material aspects of the circular economy implementation, but also a feedback loop in this relation—the institutional aspects affect the material aspects that in turn feed back to the institutional aspects. In cases in which the circular economy initiatives fail or are poorly implemented, it appears to be missing an important link between the material and the institutional aspects, which needs to be explicitly accounted for by different stockholders in order to harness the full potential of the circular

economy. In other words, connecting material flows and the socio-economic drivers that result in changes to these flows would allow for an effective implementation of the circular economy initiatives.

In this context, a few aspects remain unclear: which physical parameters are affected by the decision-making process relevant for specific circular material flows, and how? Which agents have a stake in the implementation of the circular economy initiatives? How do/should they interact? How do they act and affect the implementation of the circular economy initiatives? What are the rules and indicators that are used to make decisions in the implementation of the circular economy initiatives? What new interactions, important causal and feedback loop mechanisms, and implications—social, economic, and environmental—arise in the circular economy initiatives?

In order to address these questions, the circular economy should be developed as a solution of systems integration. The institutional system affects and is affected by the material system, and these feedback loop interactions are governed by decision-making rules (see Figure 2). This premise is grounded on Giddens' structuration theory [25]. In this sociological theory, social structures (e.g., legislation, culture, and the economic system) affect human action, but human action itself also changes or perpetuates the present social structures (whether intended or unintended). Understanding this interaction and the feedback between social structures and human action can improve physical resource management [26]. Thus, making an explicit link between the institutional drivers of material change and material (stocks and flows) aspects would allow for increasing the effectiveness of the circular economy initiatives.

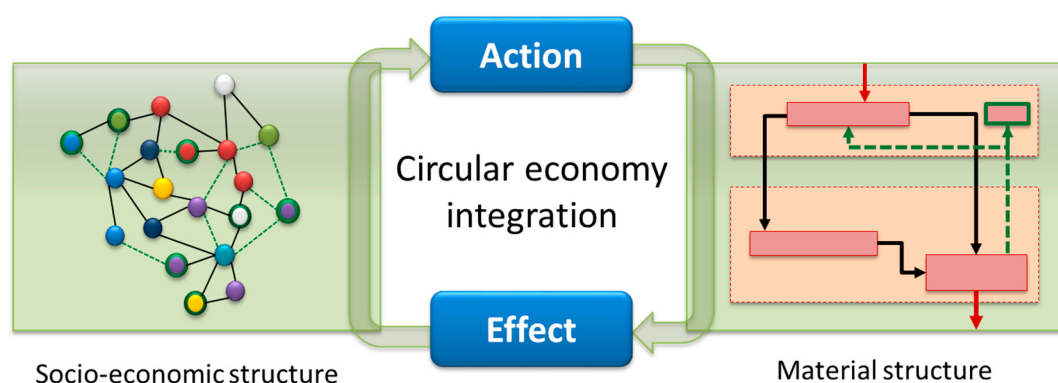


Figure 2. The circular economy concept for systems integration, where socio-economic and material structures incorporate new actors and systems (with the green border), and support new interactions among them (in the green dotted lines) and new processes (with the green border). Adapted and modified from Binder [27].

Material flow analysis can be combined with structural agent analysis [26] for the integration of seemingly disconnected areas such as organisational transition, product design, and business model innovation. This can provide inputs for supporting the management of circular material flows in companies. The purpose is to put the material perspective of the circular economy into the larger institutional context in which the former is embedded for improved circular material flow management.

5. Final Remarks: A Way Forward

In this communication, we argued that the social and material (physical resource) systems have hitherto been treated in isolation in the conceptual development of the circular economy. Integrating these two systems as well as internalising environmental and social externalities into the formal economy is of fundamental importance for realising the full promises of the circular economy for sustainable development [20]. The purpose is to put the material perspective into a larger socio-economic system in which the circular economy is embedded for improved physical resource management (see Figure 3).

The main key message of this short communication is trying to fill the gap of current knowledge and practice, arguing that the circular economy shall be:

- (1) used as a concept for integrating seemingly disconnected areas such as stakeholders' decision-making at different societal levels (producers, recyclers, collectors, consumers, authorities, etc.), product design and development, business model innovation, and policy instruments. This is because in order to reduce the specific metabolic activity of physical resources (energy and materials), i.e., inflows to and outflows from the formal economy per unit of economic output, new means of cooperation and interaction between institutions, social actors, and individuals are essential.
- (2) legitimated as a fundamental part of the formal economy, fine-tuning a rather well-functioning economic system while taking into account the unheard voices of those at stake (Earth's natural system, future generations, etc.). Thus, it will be increasingly important to monitor and follow up ongoing economic activity and their connected physical resource flows (by means of accounting). Such accountings will have to include inflows, outflows, and stocks in the material loops, and embed these into the formal economy (i.e., to internalise externalities). This embedding can be done by means of combining physical resource accountings with negotiated prices for leakages in different material systems. This integration of physical resource accountings in the formal economy is yet to be developed, and would become a key step towards a true circular economy.

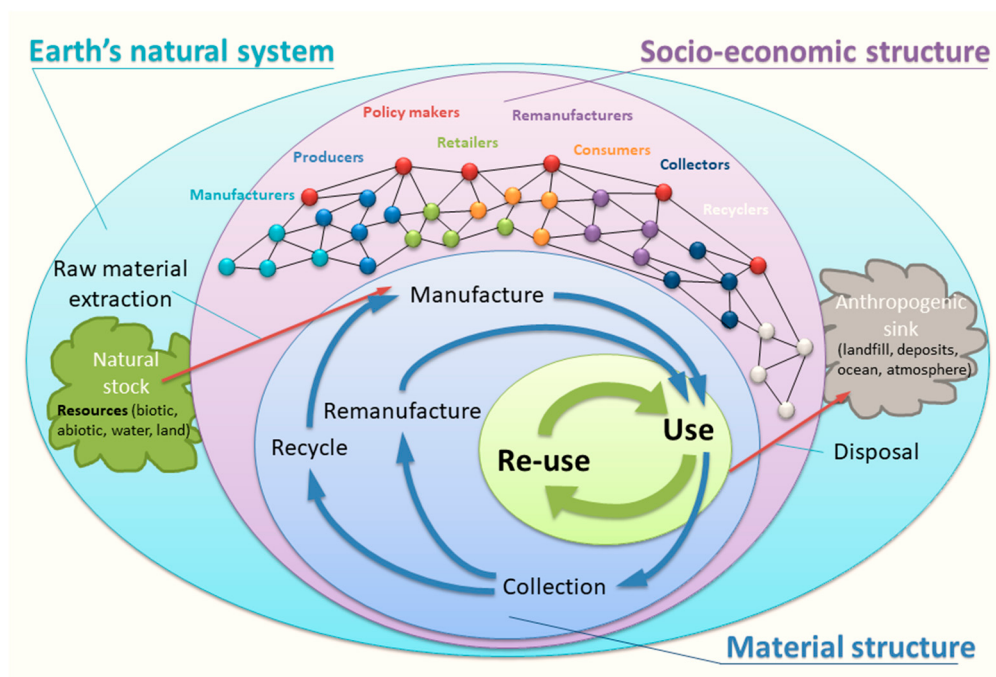


Figure 3. The socio-economic embeddedness of the circular economy.

Incorporating these three arguments as a guide in the journey towards the circular economy may substantially foster its development and success. It would allow the current practice and knowledge to come into clinch with the real challenges of establishing a circular economy that could live up to its promises.

Finally, in order to operationalise our vision into practice, we outline a framework with three iterative steps (see Figure 4), based on previous research [26].

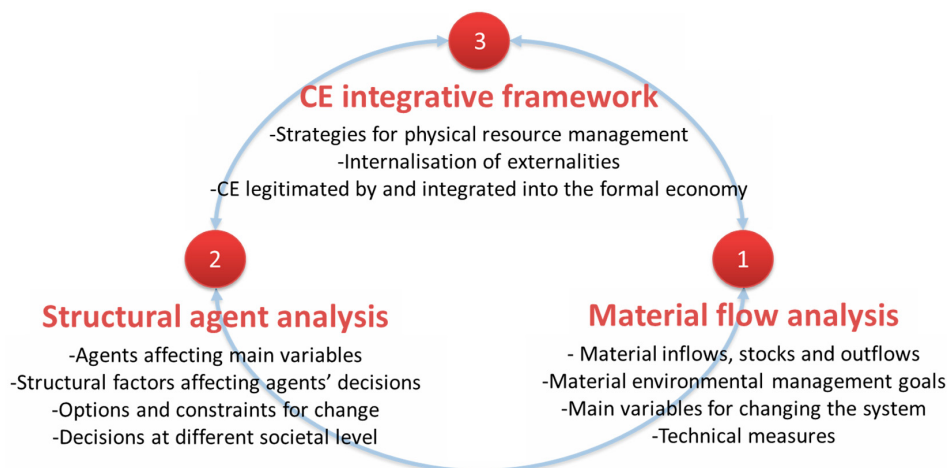


Figure 4. An integrative framework for the circular economy (CE) initiatives.

Material Flow Analysis

Material flow analysis (MFA) are conducted for circular economy initiatives (accounting inflows, stocks, and outflows of physical resources). The goals/needs for material flow management are defined from MFA [28]. Life cycle assessment (LCA) investigations can accompany and complement the MFA results [23,29]. The main aspects where the material flow system could be optimised are defined using a consensus building process among the decision-making and potentially affected agents [30]. This includes both the variables that would yield the most effective material flows if changed, and the potential technical and non-technical measures that would be required in order to achieve the preferred material goals. Sustainability assessment tools can be used in this latter step [31].

Structural Agent Analysis

The results from the material flow analysis feed into structure agent analysis, where agents directly and indirectly affecting the main variables are determined, as well as the structural factors affecting their action by using agent network analysis and interviews [32]. Options, constraints, and facilitators for successful material flow management, as well as interferences among agents, are identified from the impact of the structural factors on the agents. Decisions at different societal levels taken from stakeholders are also mapped.

CE Integrative Framework

The results from the material flow analysis and structural agent analysis are consolidated into a circular economy integrative framework. The potential effect of agents' actions on material flows and stocks can be organised in stock and flow diagrams [33] or causal loop diagrams [23]. Strategies for physical resource management achieving the depicted material flow goals are developed. Mechanisms and policy instruments for internalising social and environmental externalities are considered. Finally, the legitimacy of the circular economy initiative into the formal economy is sought.

We hope that this short communication paper triggers a constructive discussion with businesses and academia on the fundamental importance of recognising the socio-economic embeddedness of the circular economy.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

At the KTH Royal Institute of Technology in Stockholm, a research group working on sustainable production/consumption systems was established in 2011 as part of the Division of Industrial Ecology. The group comprised the Ph.D. students Rafael Laurenti from Brazil, Jagdeep Singh from India, and Rajib Sinha from Bangladesh under the supervision of Professor Björn Frostell. The three students were assigned research tasks as follows and according to their interests: Rafael Laurenti worked with sustainable design, Jagdeep Singh worked with sustainable waste management, and Rajib Sinha worked with the systems modelling of production–consumption systems. For almost five years, the group worked together with joint research advisory meetings with a common focus on systems thinking [34–37] and life cycle thinking [38]. A common focus for the whole group gradually became something we named physical resource management. Physical resource management we defined as the understanding and control of flows and stocks of energy and materials in different system scales in the global economy, from individuals to the global economy itself. The research efforts resulted in three individual, but connected Ph.D. theses [39–41].

Gradually, encountering the emanating concept of the circular economy, the group has been struck by the similarities in the aims, objectives, and approaches between the concepts of physical resource management and the circular economy. It is almost so that the two concepts could be placed above one another, but for one thing. The approach that has been used here had a specific objective of quantifying physical resource flows and stocks at different system scales in the global economy. This in order to facilitate an evaluation of different approaches in order to improve the performance of the physical resource metabolism in different subsystems of the economy. Here, we had a vision of connecting physical resource accountings to the formal economy and thus influencing the prioritisation of different modes of action.

In 2017, Dr. Laurenti was offered a postdoc position in the research group of Professor Claudia Binder at the École polytechnique fédérale de Lausanne (EPFL). Her research interests had also for many years been devoted to the physical resource metabolism of cities. A special interest of Professor Binder was something she named social MFA, which examined the interdependency of the physical resource metabolism of socio-ecological systems and its social expressions [26,27,42]. This contribution has been shaped by the discussions among these researchers.

References

1. Webster, K. What might we say about a circular economy? Some temptations to avoid if possible. *World Futures J. Gen. Evol.* **2013**, *69*, 542–554. [[CrossRef](#)]
2. Bocken, N.M.; Ritala, P.; Huotari, P. The Circular Economy: Exploring the Introduction of the Concept among S & P 500 Firms. *J. Ind. Ecol.* **2017**, *21*, 487–490. [[CrossRef](#)]
3. Lazarevic, D.; Valve, H. Narrating expectations for the circular economy: Towards a common and contested European transition. *Energy Res. Soc. Sci.* **2017**, *31*, 60–69. [[CrossRef](#)]
4. Ritzén, S.; Sandström, G.Ö. Barriers to the Circular Economy—Integration of Perspectives and Domains. *Procedia CIRP* **2017**, *64*, 7–12. [[CrossRef](#)]
5. Kalmykova, Y.; Sadagopan, M.; Rosado, L. Circular economy—From review of theories and practices to development of implementation tools. *Resour. Conserv. Recycl.* **2018**, *135*, 190–201. [[CrossRef](#)]
6. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [[CrossRef](#)]
7. Korhonen, J.; Nuur, C.; Feldmann, A.; Birkie, S.E. Circular economy as an essentially contested concept. *J. Clean. Prod.* **2018**, *175*, 544–552. [[CrossRef](#)]
8. Blomsma, F.; Brennan, G. The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. *J. Ind. Ecol.* **2017**, *21*, 603–614. [[CrossRef](#)]
9. Singh, J.; Ordoñez, I. Resource recovery from post-consumer waste: Important lessons for the upcoming circular economy. *J. Clean. Prod.* **2016**, *134*, 342–353. [[CrossRef](#)]

10. Rammelt, C.F.; Boes, J. Galtung meets Daly: A framework for addressing inequity in ecological economics. *Ecol. Econ.* **2013**, *93*, 269–277. [[CrossRef](#)]
11. Gharfalkar, M.; Court, R.; Campbell, C.; Ali, Z.; Hillier, G. Analysis of waste hierarchy in the European waste directive 2008/98/EC. *Waste Manag.* **2015**, *39*, 305–313. [[CrossRef](#)] [[PubMed](#)]
12. Bocken, N.M.P.; Bakker, C.; Pauw, I. De Product design and business model strategies for a circular economy. *J. Ind. Prod. Eng.* **2016**, *33*, 308–320. [[CrossRef](#)]
13. Kiørboe, N.K.; Sramkova, H.; Krarup, M. *Moving towards a Circular Economy: Successful Nordic Business Models*; Nordic Council of Ministers: Copenhagen, Denmark, 2015; ISBN 9789289343305.
14. Sinha, R.; Laurenti, R.; Singh, J.; Malmström, M.E.; Frostell, B. Identifying ways of closing the metal flow loop in the global mobile phone product system: A system dynamics modeling approach. *Resour. Conserv. Recycl.* **2016**, *113*, 65–76. [[CrossRef](#)]
15. Zink, T.; Geyer, R. Circular Economy Rebound. *J. Ind. Ecol.* **2017**, *21*, 593–602. [[CrossRef](#)]
16. Kjaer, L.L.; Pigosso, D.C.A.; Niero, M.; Bech, N.M.; McAlloone, T.C. Product/Service-Systems for a Circular Economy: The Route to Decoupling Economic Growth from Resource Consumption? *J. Ind. Ecol.* **2018**, *58*, 523–533. [[CrossRef](#)]
17. Geyer, R.; Doctori Blass, V. The economics of cell phone reuse and recycling. *Int. J. Adv. Manuf. Technol.* **2010**, *47*, 515–525. [[CrossRef](#)]
18. Skerlos, S.J.; Morrow, W.R.; Chan, K.Y.; Zhao, F.; Hula, A.; Seliger, G.; Basdere, B.; Prasitnarit, A. Economic and environmental characteristics of global cellular telephone remanufacturing. In Proceedings of the 2003 IEEE International Symposium on Electronics and the Environment, Boston, MA, USA, 19–22 May 2003; pp. 99–104.
19. Thomas, V.M. Demand and Dematerialization Impacts of Second-Hand Markets. *J. Ind. Ecol.* **2003**, *7*, 65–78. [[CrossRef](#)]
20. Laurenti, R.; Singh, J.; Sinha, R.; Potting, J.; Frostell, B. Unintended Environmental Consequences of Improvement Actions: A Qualitative Analysis of Systems' Structure and Behavior. *Syst. Res. Behav. Sci.* **2016**, *33*, 381–399. [[CrossRef](#)]
21. Miles, S. *Spaces for Consumption*; SAGE: New York, NY, USA, 2010; ISBN 1412946662.
22. Tang, J. Competition and innovation behaviour. *Res. Policy* **2006**, *35*, 68–82. [[CrossRef](#)]
23. Laurenti, R.; Sinha, R.; Singh, J.; Frostell, B. Towards Addressing Unintended Environmental Consequences: A Planning Framework. *Sustain. Dev.* **2016**, *24*, 1–17. [[CrossRef](#)]
24. Kirchherr, J.; Piscicelli, L.; Bour, R.; Kostense-Smit, E.; Muller, J.; Huibrechtse-Truijens, A.; Hekkert, M. Barriers to the Circular Economy: Evidence From the European Union (EU). *Ecol. Econ.* **2018**, *150*, 264–272. [[CrossRef](#)]
25. Giddens, A. *New Rules of Sociological Methods*; Hutchinson: London, UK, 1978.
26. Binder, C.R. From material flow analysis to material flow management Part II: The role of structural agent analysis. *J. Clean. Prod.* **2007**, *15*, 1605–1617. [[CrossRef](#)]
27. Binder, C.R. Concept and Models on Material Stocks and Flows in Human-Environment Systems: A Contribution to Transitions towards Sustainable Development. Habilitation Thesis, Swiss Federal Institute of Technology, Zurich, Switzerland, 2005.
28. Brunner, P.H.; Rechberger, H. *Practical Handbook of Material Flow Analysis*; Lewis: New York, NY, USA, 2004.
29. Lavers, A.; Kalmykova, Y.; Rosado, L.; Oliveira, F.; Laurenti, R. Combining Material Flow Analysis and Life Cycle Assessment to Identify Environmental Hotspots of Urban Consumption. **2018**. submitted.
30. Cormick, G. *Building Consensus for a Sustainable Future: Putting Principles into Practice*; National Round Table Series on Sustainable Development; National Round Table on the Environment and the Economy: Ottawa, ON, Canada, 1996.
31. Korhonen, J. Industrial ecology in the strategic sustainable development model: Strategic applications of industrial ecology. *J. Clean. Prod.* **2004**, *12*, 809–823. [[CrossRef](#)]
32. Scott, J. *Social Network Analysis: A Handbook*; Sage: London, UK, 2000.
33. Sterman, J.D. *Business Dynamics: Systems Thinking and Modeling for a Complex World*; No. HD30. 2 S7835; McGraw-Hill Education: New York, NY, USA, 2000.
34. Skyttner, L. *General Systems Theory: Problems, Perspectives, Practice*, 2nd ed.; World Scientific Publishing Co., Pte. Ltd.: Singapore, 2005; ISBN 978-9812564672.
35. Churchman, W. *The Systems Approach*; Delacorte Press: New York, NY, USA, 1968.

36. Checkland, P. Systems thinking, systems practice: Includes a 30-year retrospective. *Syst. Res.* **1999**, *17*, 11–58. [[CrossRef](#)]
37. Meadows, H.D. *Thinking in Systems*; Earthscan: London, UK, 2008; ISBN 9781844077267.
38. Frostell, B. Life Cycle Thinking for Improved Resource Management: LCA or? In *Handbook of Sustainable Engineering*; Kauffman, J., Lee, K.M., Eds.; Springer: Berlin, Germany, 2013; p. 1298, ISBN 978-1-4020-8939-8.
39. Sinha, R. Systems Modeling Approaches to Physical Resource Management: An Industrial Ecology Perspective. Ph.D. Thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2016.
40. Laurenti, R. The Karma of Products: Exploring the Causality of Environmental Pressure with Causal Loop Diagram and Environmental Footprint. Ph.D. Thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2016.
41. Singh, J. Beyond Waste Management: Challenges to Sustainable Global Physical Resource Management. Ph.D. Thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2016.
42. Binder, C.R.; Hinkel, J.; Bots, P.W.G.; Pahl-Wostl, C. Comparison of frameworks for analyzing social-ecological systems. *Ecol. Soc.* **2013**, *18*, 26. [[CrossRef](#)]



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