1. Introduction and overview

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INTRODUCTION

During the last decade, the circular economy has increasingly caught the attention of policy-makers, academia and industry. The logic of the circular economy is straightforward: that is, the linear material flows of global production and consumption systems cannot continue on their current trajectory. On one hand, the finite nature of non-renewable resources, such as land, fossil fuels and other materials (for example, minerals), makes it clear that current extraction rates cannot be sustained indefinitely. On the other hand, the sheer levels of waste generation and emissions have highlighted the limited capacity of the environment to cope with the wastes of current unsustainable production and consumption systems, which aim at satisfying the satieties of increasingly wealthier and demanding societies.

Changing this trajectory raises a number of difficult challenges that must be solved. In a more sustainable society, resources must be used much more efficiently and effectively, so as to provide societal value over a longer time period and with minimized environmental impact. The challenges lie with designing and implementing technologies, policies, business models and new modes of production and consumption that are based on a very different paradigm to that of the current regime.

As world leaders grasp this concept and understand the need for a paradigm shift in production and consumption systems, action plans for a circular economy have been adopted in several countries, including political unions such as the European Union. Despite the general acceptance in policy circles, the direction of, and the ways in which, production and consumption systems should change remain unclear. Several academic fields can contribute to making the circular economy a reality, or, at least, to give it intellectual rigour. Ecological economics, industrial ecology and life cycle assessment (LCA) are three examples of fields that have increased the robustness of the concept.

This *Handbook* endeavours to shed light on a topic that has gained much notoriety, and has become more mainstream: the (relatively) new and rapidly emerging concept of the circular economy. Its purpose is to provide an authoritative and consistent approach to the circular economy as a concept, as well as its application in policy and business contexts, and assessment tools. It is timely to synthesize and consolidate the myriads of interpretations and applications of the concept that have taken place, with the goal of providing a comprehensive *Handbook* that can guide consumers, producers, policy-makers, teachers and students. It includes contributions from world-renowned experts on topics ranging from agriculture to waste management, from national action plans to product service systems.

We hope that the *Handbook* can bring clarity, in an intellectually and scientifically rigorous manner that can guide robust decisions in the transition towards sustainable development that is so needed. Like the topic, the scope of this book is large: it targets

anyone who may be interested in the circular economy, from the layman to the expert. It covers several of the key sectors of the economy. Similarly, it gives an overview of how the concept has made its way into policy, and offers case studies. The *Handbook* provides a thorough representation of the topic in terms of both breadth and depth, and puts it in a scientific context.

OVERVIEW OF THE *HANDBOOK*

The chapters within this book are structured around five thematic parts.

Part I: Fundamentals of the Circular Economy

Part I provides an overview of the basic concepts and some strategies for thinking about the circular economy. Chapter 2 by Lazarevic and Brandão provides a general introduction to the circular economy: what it is and what it aims to achieve. The circular economy is discussed as a decoupling strategy to reconcile economic growth with the unsustainable use of natural resources and the negative environmental impact of today's production and consumption systems.

In Chapter 3 by Korhonen the circular economy is presented as a complex adaptive system. The chapter examines four properties relevant to the circular economy: material cycles (and energy cascades), diversity in the actors involved, interdependency in their relations and locality in the system's spatial reach, and products' life cycles. Through an understanding of the relationships between complex adaptive system development and the circular economy, the risks of problem displacement and shifting can be better recognized in strategy development.

Design is one of the most important phases of a product or service system's life cycle, as it has the greatest influence on its subsequent environmental performance. Chapter 4 by Andrews explores the role of design and its influence on current production and consumption systems and the circular economy, discussing its role as both a barrier to and an enabler of the circular economy. Moving from design to production, in Chapter 5, Martin provides an overview of industrial symbiosis, whereby firms collaboratively exchange energy, materials or services for mutual benefits as a strategy to improve resource efficiency. Chapter 6 by Lingegård outlines product service systems as a promising business model for achieving more efficient resource use by reducing the resources consumed for products without reducing their function, achieved by cooperation, and a focus on functions, material and energy use reductions and value. Moving from the production side, Chapter 7 by Camacho-Otero et al. provides an overview of the often overlooked role of consumption in the circular economy. The authors examine factors which influence the acceptance and adoption of circular products and services, and discuss strategies and concepts for introducing circularity to consumers.

Part II: Assessing the Impacts of a Circular Economy

Part II includes chapters that discuss the applicability of various tools to measure and assess the impacts of circular economy interventions. At the core of the circular

economy is the recirculation of material within the economy. Chapter 8 by Schmidt and Laner demonstrates the use of material flow analysis as a tool to determine the amount, composition and fate of materials in waste management and secondary production processes. Extending the fundamentals of material flow analysis to the elemental scale, Chapter 9 by Sinha et al. introduces and illustrates element flow analysis as a tool to track and understand resource metabolism, exploring gold flows in the global mobile phone product system.

Life cycle assessment is a commonly used tool to analyse the environmental impacts of a product or service system. In Chapter 10, Ekvall and Brandão review 12 different methods for modelling material recycling in LCA. Their findings indicate that the selection of different methods implies a trade-off between modelling feasibility and accurate representation of the consequences of recycling, and that the LCA results are highly sensitive to the methods applied. Chapter 11 by Andersen and Martinsen combines environmental economic assessment and life cycle assessment that can be used to analyse the performance of novel circular technologies from a sustainability perspective. The assessment includes external costs related to the environmental burdens in a welfare economic analysis of an integrated biorefinery.

In Chapter 12, Skånberg et al. take a macroeconomic perspective by using an environmentally extended input–output model for carbon dioxide (CO₂) emissions, employment and the trade balance of circular economy strategies in eight European countries. In Chapter 13, Pitkänen et al. turn their attention to the social impacts of the circular economy. They point out the imbalance between the many positive social impacts of the circular economy and discuss whether these statements can be assessed based on a review of the different social impact-assessment methods available.

Chapter 14 by Wiedenhofer et al. outlines a multi-level system-wide circular economy monitoring framework that encompasses the biophysical dimensions of the circular economy and integrates nested actor-oriented perspectives. The framework provides relative and absolute performance indicators that are applicable at different spatial and temporal scales, enabling the assessment of the potential contributions of circularity strategies. Chapter 15 by Maier et al. covers the all-important aspect of the rebound effect. The chapter explains the mechanisms behind displaced production and circular economy rebound, presenting methods available to quantify effects, and discusses potential tools and approaches to avoid, or at least reduce, circular economy rebound effects.

Part III: Governing the Circular Economy

Part III contains chapters that focus on various aspects related to the governance of the circular economy. In Chapter 16, Kautto and Lazarevic provide an overview of the European Union's circular economy policy goals and different policy instruments available to Member States to steer change towards a more circular economy. The chapter shows that whilst there are many policy instruments available to address the fundamental socio-economic metabolic changes required, key policy failures need to be addressed in order to make real progress toward the circular economy. Turunen, in Chapter 17, focuses on the question of regulation in the circular economy. Taking the European Union as a case study, the chapter investigates the systematic mismatches between regulatory approaches at the interface between waste and chemicals legislation.

The transition to a circular economy not only needs well-functioning policy and regulation, but also a well-functioning ecosystem of intermediary actors who can broker knowledge exchange and collaboration between different societal systems and geopolitical scales. In Chapter 18, Barrie and Kanda look at how ecologies of intermediary actors can be nurtured in order to facilitate the transition to a circular economy.

Business models will play a key role in the transition to a circular economy and are the focus of the next two chapters. Chapter 19 by Bocken and Short focuses on the question of a ‘sufficiency-based’ circular economy, addressing the problems of a rise in overall consumption. Presenting examples of sufficiency-based business models in the food and clothing sector, they present a framework to understand how industry, society and policy-makers could collaborate in designing and implementing long-term initiatives for a sufficiency-based circular economy. Chapter 20 by Corvellec et al. complements the previous chapter by providing a case study on a small Swedish sign company. Drawing on actor network theory, it illustrates how circular business model innovation is a collective effort that brings together a large array of actors in development processes that are hesitant, imprecise, provisory, contingent and reversible. They argue that policy support for linear business models needs to be reduced if circular business models are to successfully translate circular ambitions into circular business practices.

Chapter 21 by Aid and Lazarevic investigates the role of waste management in a circular economy. The chapter discusses barriers identified by industry, including circulation costs and resource valuation issues, when aligning waste management practices with the new objectives of the circular economy.

The next three chapters are based on national-level case studies. The purpose of these case studies is not to provide an account of current circular economy policies, but rather to explore issues related to the implementation of circular-economy policies and strategies. In Chapter 22, Gerasimenko et al. provide an interesting historical perspective of the circular economy by detailing a case study of the former Soviet Union’s industrial policies. This analysis shows that these policies were based on a number of key concepts which could be found in any contemporary circular economy strategy: rationalization of the production processes including standardization and unification, territorial–production complexes, secondary resources and recycling, inventories of material flow systems and zero-waste technologies. The authors also point to recent challenges in governmental priorities that are implementing a ‘refurbished’ circular concept. Buclet, in Chapter 23, provides a contemporary account of how French institutions have adopted the circular economy concept and in doing so have modified the meaning of industrial ecology and how it is implemented in France. The French case study illustrates how original references to creating industrial systems based on ecological principles are substituted by objectives of optimizing existing systems. In Chapter 24, Borrego et al. provide a case study on the mobilization of urban and regional metabolism to support regional policy-makers and governance services implementing the Portuguese Action Plan for Circular Economy, by identifying flagship sectors, business opportunities and circularity potential.

Part IV: Sectoral and Business Case Studies

Part IV draws together sectoral case studies. Due to the breadth of the circular economy, potentially affecting all sectors of the economy, a comprehensive coverage of all sectors is

not practical. In this section, case studies focus on some key application areas of the circular economy: products manifesting linkages to the bioeconomy, touching upon nutrient recycling, forestry, bioenergy and bio-based products, the built environment and mining.

The first two chapters in this section focus on product and manufacturing systems. Chapter 25 by Tillman et al. provides guidelines on measures for resource efficiency for products with different characteristics. The guidelines are based on the premise that product characteristics are the more appropriate basis for the identification of resource efficiency strategies. Chapter 26 by Rashid et al. outlines closed-loop manufacturing systems and circular manufacturing systems, and provides comparative case studies of industrial circular manufacturing systems in terms of their business models, product design, supply chain and mobilization of information and communication technologies.

The following chapters relate to different aspects of the bioeconomy. In Chapter 27, Valve et al. turn their attention to nutrient recycling, arguing the benefits of transitioning away from virgin nutrients to nutrient recycling, and provide an overview of the technological, practical and institutional dimensions critical for such a change. Chapter 28 by Klitkou investigates forest-based value chains, providing an overview of important forest-related residues and side streams, and examples of their valorization. Through case studies of three forest-industry clusters in Norway, the challenges related to the development of pathways to valorize different forestry residues and side streams are analysed. Chapter 29 by Cowie investigates bioenergy from a circular economy perspective. It discusses both the role bioenergy can play in achieving circular economy objectives, and how circular economy principles can be translated for application to bioenergy, providing guidance for the design of bioenergy systems. In Chapter 30, Brandão provides a critical analysis of bioenergy systems, illustrating through LCA that they are not always, from a climate change perspective, preferable to incumbent linear fossil-based systems; demonstrating the importance of applying hard-systems approaches to elucidate the merits or otherwise of alternative production systems. In Chapter 31, Hoge and Brandão undertake a critical assessment of the move to limit single-use plastic drinking straws. Through LCA, the chapter shows that the consequences of replacing plastic straws with kraft paper drinking straws could potentially include a significant increase in greenhouse gas emissions, thus critically highlighting the need for such assessments in order to recognize the consequences of decisions, which differ for different impact categories.

Chapter 32 by Malmqvist et al. investigates circularity in the built environment. They demonstrate some of the problematic issues of how the scope of certain decision support tools, such as LCA, can limit the identification of circularity measures. Chapter 33 by Mendoza et al. provides a case of universities as key arenas for implementing and testing circular economy strategies. It provides a case study of the barriers and opportunities for the implementation of circular thinking in campus management, and the application of an action-led approach for building a business case for circular economy strategy development.

The next two chapters relate to mining, at the very start and end of a material life cycle. Chapter 34 by Joyce and Björklund investigates resource recovery in high-volume extractive industries, presenting the case of bauxite residue valorization. Using a set of semi-quantitative and quantitative approaches to assess resource recovery processes from a life cycle perspective, they show how possible inputs which have the greatest potential to lead to significant environmental issues in later processes can be identified. In Chapter 35,

Krook et al. look at the urban mining of wire-based infrastructure systems in two Swedish cities, presenting an overview of identified accumulation processes for disconnected subsurface infrastructure. An approach for performing contextualized assessments of the feasibility of urban mining is presented, and the challenges connected to making recycling an integral part of infrastructure management are discussed.

Part V: Prospects

The final section of the *Handbook* critically discusses the prospects for transitioning towards a more circular economy. In Chapter 36, Hobson critically examines the role of the consumer in the circular economy. The chapter examines the framing and treatment of the ‘consumer’ in circular economy discourse, which may limit the reach and impact of the concept. The author calls for space to debate modes of consuming, being and collectivizing that allow society to rethink its relationships with its material and ecological environments. Chapter 37 by Ghisellini and Ulgiati provides an overview of the scale of changes required for the transition to a circular economy, highlighting the substantial changes in economic subsystems required for the adoption of more sustainable models of production and consumption and discussing different approaches, strategies and policy instruments for managing the transition. Finally, Chapter 38 by Brandão et al. summarizes the findings presented throughout the *Handbook* and critically discusses the prospects for the circular economy’s implementation.