CONSTRUCTING A GREEN CIRCULAR SOCIETY

Edited by Munjur E. Moula, Jaana Sorvari, Pekka Oinas

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Foreword

Editors

This book focuses on the comprehensive economic model *Circular Economy* to take the present world more sustainable green society for the next generation. Because, for the shortcomings of global economy for centuries, the current society is passing through a mediocre unrest. Poverty, inequality, opacity, drought, floods, politics and diplomacy with the reality that barriers to the formation of environmentally friendly society, fighting, violence, unrestrained people, etc. are unacceptable, and unexpected words are hurting our daily living environment directly and indirectly. The sustainable society in the sense of social justice is now questioned. This means that our targeted sustainable development has been challenged by the global challenges (climate crisis, raw material scarcity crisis, toxicity crisis, energy crisis, etc.). In this book, it can be seen in the context of how the global challenges can be tackled through timely or timely steps. Here is a timely or timely move to say the new economic model *Circular Economy*. Because the dead address addressed to the circular economy society problem in creating a sustainable green society system, with the eye which is seen by the rest of the mankind.

This book also maps circular economy's broader benefits. Our preconceived idea is that, 200 years from now, the world-wide structural benefits of this circular economy will be sung by the great people like those who have made outstanding contributions to this book today and are working day and night to see the 'Sustainable Green Society'.

Moreover, the book *constructing a green circulary society* will convey novel ideas and inspiration, benefitting policy makers, researchers, student and companies alike. It consists of nine chapters, each approaching the topic green circular society from a different perspective. The results of this book are an outcome of work done by diverse set of tallented both young and old scientists ranging from Bangladesh, Belgium, Finland, Germany, Malaysia, Mexico, the Netherlands, Sweden and Turkey. We apologies in advance for any unforeseen shortcomings.

We would like to thank the authors for their contribution and the reviewers for their constructive feedback. Our thanks also go to the following for their invaluable help/inspiration during the preparation of this book: Jahanara Ferdous Suborna, Mesbaul Islam Anindo, Nasrullah Mohammed, Hamdy Mohammed, Abdul Mannan Pappu, Voitto Kotiaho. A special word of thanks to *Children's Dream* to support for the printing of the book. We would also like to extend a particular warm thanks to Faculty of Social Sciences, University of Helsinki, Finland.

Helsinki, Finland, November 2017

Chapter 1

INTRODUCTION

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How can circular economy help to construct a more sustainable green circular society?

Global economy is unprecedented to build a more sustainable green circular society, where people are committed to solving societal challenges and building a healthy and sound future for the mankind. This book provides guidelines on how to construct a green circular society by engaging societal stakeholders, promoting moral norms, educating the public about the limitations of linear economy and the benefits of circular economy. The circular economy can tackle the global main challenges such as jobs and growth, climate crisis, raw material scarcity crisis, toxicity crisis and energy crisis, social agenda with industrial innovation.

From theoretical point of view, this book provides the answer to the question: 'Are we unknowing prisoners of our own conceptions about global sustainable society? In these lines of thought, a green circular society requires societal movement from a linear philosophy of traditional industrial processes raw materials, products, wastes to a novel circular economy model in industrial sector. From integrated and transdisciplinary perspective, circular economy is an alternative pathway to make a more sustainable society, which is taken many strategies including renewable resources, increased resource efficiency, enhanced reuse and recycling, resource loop closing, innovative technologies and business models. A simple question can now be born in our mind is that *how to move from linear to circular economy*? This crucial epistemological question discusses by the authors of the different chapters of this book titled 'Constructing a green circular society'. The hypothesis of this book is about a green circular society in which human-friendly environment, fundamental basic needs, freedom, openness, democracy and creativity are aliened.

The starting assumption here is that the processes, functional rules and regulations for the orderly development of the whole chain of linear economy system has an inevitable recipe to create unprecedented divisions between developed and developing countries. A fifth of the world's population, for example, 'live in the richest countries and account for 86 percent of the world gross domestic product' (Javed Maswood, 2006). Much of the urban world, as a result, is rushing backwards to the age of Dickens (Davis, 2004). More preciously, through the lens of theory of social justice we might be able to grasp the novelty of a true global residuum that is perhaps created by the whole chain of linear economy system. Thus, despite some success stories, the linear economic activity creates a new window to see the world war between capital and labor!

Borrowing on the report of COP21 'Paris climate change conference 2015', for example, we argue that climate change, in general, clearly focused on the necessities to stop our current irresponsible linear activities that create 'pressures on the earth's systems are having serious consequences and threatening critical, global, and local thresholds' (Riedy, 2013). Hence the paucity of benefits from linear economic structures lead, legitimately, to questions of 'whose sustainable development? These and other indicators, are discussed in different chapters of this book, are common enough to construct a green circular society that prioritizes people over happy. More specifically, avoiding existing under 'sun' economic approaches, green circular society, a more sustainable society, focuses on comprehensive circular economy approach that ensures labour laws and human standards, and enables 'people to assess their benefits of various development, social and environmental impacts' (Sen, 2009). In addition to this, the implementation of circular economy is based on sustainability science that creates 'an opportunity to consider the interests of all sectors in a win-win situation' (Villela, A., Martins, L.C., 2008; Moula, et al. 2015). Hence the discussions on circular economy focus on 'pervasive demands for participatory living in which human life have the same value' (Sen, 2009).

Moreover, the concept of circular economy is a combination of disciplines which provides a new train of thought on how circular economy takes a closer look at the question of social justice which is the central part of sustainable social development. Questions remain: how to design the whole chain of circular economy? Methodological discussions of this book clearly focus this key concern to a construct green circular society. Let us walk with this concern through the discussion of 'fundamental relationship between circularity approach and green circular society'.

Many chapters highlight that design plays an important role in every aspect in our society, innovations and in business related areas, which is deeply rooted in our culture. Taking these into account, this book stresses on societal acceptance in terms of designing holistic circularity approach which is primarily based on our general wisdom. Design of circularity, therefore, plays a crucial role to address the societal acceptance of circular economy in the framework of sustainability science. The philosophy of the circularity approach is that a truly green circular society can be constructed by combining individual's experience and their tacit knowledge, by considering a combination of views from different disciplines, by using –technical expertise of the company, by integrating local choices (local welfare and social welfare) that often have global ramification, and by incorporating sustainability principles in natural resource management and public policies. Hence different chapters of this book provide insights to design holistic circularity approach, and to understand the notion of a green circular society.

Moreover, chapters of this book indirectly/directly focus more about contemporary economic globalization which has hiatus relations with the whole chain of linear economy system.

Discussions on global economy invite green circular society to provide the answers to the questions of (1) How to think environmental challenges in the contemporary world? (2) How to link our asymmetry of economic power with our responsibility for the powerless other species? Thus, the outcome of this book holds promises as a response to the global challenges and the problems of sustainability.

Chapter 2 discusses the linkages of the circular economy concept to the related concepts of industrial ecology and supply chain management. Ecological issues have traditionally been in focus when assessing the sustainability in the latter two disciplines. In reverse logistics systems and closed loop supply chains based on consumer returns, the economic aspect can also be determinant, however. Whereas industrial ecology is merely focused on material and energy flows and commercial aspects are ignored. Circular economy broadens the scope of both of these, resource management focused, related disciplines by introducing new aspects and means to attain circularity, such as upcycling; sharing and renting instead of complete ownership; and upgrading/maintenance/ repair instead of production. Consumers have a key role in the implementation of circular economy. Unfortunately, several problems remain that affect their purchasing behavior, particularly excessive information flow related to products and need and desire for novelty.

Moving from linear economy towards circular requires various changes and deliberate actions of different actors - a societal transition that is time-consuming and stepwise. Chapter 3 highlights these issues using clothing as an example. ―Production of clothing causes considerable consumption of water, land and energy, and includes social issues (child labor, underpaid workers etc.), and economic aspects (e.g., turnover and its loss). To turn such a system circular is challenging and requires complex, dynamic and uncertain processes. Climate change will increase the severity of environmental effects while geopolitical issues generate instability of product prices. New production technologies, particularly 3D printing, cause overconsumption and creates unemployment in developing countries. Concepts of added value are thus needed, e.g., modularity and durability in product design, move from selling to leasing, integrated supply chains and collaboration. Regulation can provide means to these changes, as long as it will not create an unwanted trade-of system.

Chapter 4 summarizes the exiting and forthcoming policy instruments that aim to support circular economy. These include targeted product-oriented and consumption-oriented instruments and holistic instruments. Eco-design and extended-producer responsibility are EU-wide product-oriented policy approaches, which are currently undergoing updating. In the consumption-oriented approach, the authors highlight the role of green public procurement, EU-wide quality standards for reused and refurbished products, and creation of reuse networks. Financing and targeting public investments to support innovations of new business models are more holistic means. The authors present several "good practice" examples and conclude that waste levies are the most common economic instruments. Several countries have also successfully adopted information-oriented instruments, e.g., awareness rising campaigns related to waste prevention. The authors state that in circularity, the focus is still too much on waste management and that all actors in the product's life cycle should work together to find the optimal solutions leading to circularity.

Many researches on how to move towards circular economy show that there are systematic challenges related to institutional change within university and society. Chapter 5, therefore, looks at the questions of *How to tackle these challenges by developing a curriculum for teaching on circularity and resource-efficiency?* Chapter 5 presents a study that developed a curriculum for teaching BSc level students of architecture on circularity and resource-efficiency. This curriculum is based on a studio comprising full-scale design projects which should follow the given design principles accordant with the resource-efficiency and circularity paradigm. Testing with 30 students showed that the participating students had improved their knowledge, skills and attitudes on the implementation and importance of circularity and resource-efficiency in architectural design. The new curricula particularly support the understanding of design errors, and how they should be addressed and communicated further. Some challenges in teaching on circularity and resource-efficiency remain, however, particularly related to the limited resources for teaching owing to the novelty of the circularity paradigm. The fragmentation of expertise and higher education at universities in disciplines also prevents the construction of truly holistic and interdisciplinary curriculum needed for adequately address the circularity and resource efficiency.

Chapter 6 focuses on resource-light business models as means to attain circularity. The authors highlight minimization of waste disposal, use of clean water and sharing instead of ownership as essential elements of circularity. They give several practical examples of sharing economy -based business, e.g., car pooling and Wikipedia, and bring forward the need for economic incentives, e.g. tax relieves, to increase the market of recycled products. In the case of water, this means putting the true price for its use. Additionally, EU-wide quality standards for reuse of wastewater could serve as a suitable policy instrument. Greater producer responsibility, i.e. extension of product liability from the current 05 to 2 years, could also enhance circularity. Public sector has an important role and it should lead the way towards circularity by providing an example in its procurements. To conclude, supporting of circularity clearly requires several parallel measures.

Chapter 7 raises the conversion of waste biomass, e.g. residues from forest industry, to different commodities as one means to attain circular economy. Various organic wastes are in fact suitable for conversion to chemicals, fuel or energy, by biological, thermal or hydrothermal recovery processes. Each process has its pros and cons, e.g., scalability, sensitivity to variation of raw material, need for pre-treatment, energy-efficiency, residence time, costs, purity of and market for end products, that need to be considered. Hence, the characteristics of the feedstock and desired products determine the optimal conversion process, which should also be adaptable and flexible to changes. Then, varying optimization models can be used in designing the whole supply chain network. An integrated biorefinery with a sectoral integration structure, where biomass is pre-treated on site and then transported to regional conversion plants, is in fact the most sustainable solution.

Chapter 8 evaluates the existing industrial applications of solar energy from the viewpoint of costs, technical feasibility and reliability. Solar radiation can be transformed to heat and trapped in water or steam to be used, i.e., in washing, cleaning, sterilization, desalination; used as a direct heat source in dehydration and drying; or converted to electricity in photovoltaic (PV) power systems. Passive open-air solar driers are an economical means of drying crop in developing countries, the uncertainty of results, pests and crop loss being drawbacks. -In air-conditioners and refrigerators solar radiation provides a feasible means to save energy and eliminate emissions. PV systems are successfully used in so-called zero-emission buildings. Desalination of water in areas lacking clean water is a promising application with some shortcoming, however (high investment costs, need for land space, sensitivity to weather conditions).

Chapter 9 focuses on the biofuel industry throughout the transformation journey from investing in waste disposal services to discovering added value in waste by using a circular economy model. Increased urbanization all over the world increases energy consumption (mainly from fossil fuels) as well as waste generation. The depletion of the energy resources reserves is inevitable and when this occurs, biofuels could potentially be the ones to satisfy their demand. Despite of that, the biofuel industries along with certain economic models, are not necessarily green or sustainable. Biofuel industries generate waste such as water, food scraps, glycerine and methanol, just to mention a few, which force these industries to pay for final disposal services.

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Chapter 2

CIRCULAR ECONOMY VS. CLOSED LOOP SUPPLY CHAINS: WHAT IS NEW UNDER THE SUN?

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Abstract

The circular economy is both a prominent concept, an industrial trend, and a policy instrument. There is a promise of economic growth without further pollution and resource extraction, of a smarter way to use and reuse extant resources, and of innovation. This chapter evaluates the concept in contrast with other related concepts that have been used in other disciplines such as in industrial ecology and in supply chain management, in order to understand what is novel, and how the circular economy extends or combines previous streams of literature.

Keywords: circular economy, closed loop supply chain, reverse logistics, industrial ecology

1. Introduction

The circular economy is both a prominent concept, an industrial trend, and a policy instrument. There is a promise of economic growth without further pollution and resource extraction, of a smarter way to use and reuse extant resources, and of innovation. Arguably, none of this is really new. Before a throw-away consumerist society, people reused, refurbished, and repurposed most of their possessions. Yet for a long time it was consumerism that fueled economic growth, together with ever shorter technology and innovation cycles, creating new "needs" and feeding the curiosity of consumers. The sustainability of such behavior has long been questioned.

The circular economy concept is one of the much-discussed potential answers to these problems. It combines many elements and streams of previous sustainability endeavors. This chapter evaluates the concept in contrast with other related concepts that have been used in other disciplines such as in industrial ecology and in supply chain management, in order to understand what is novel, and how the circular economy extends or combines previous streams of literature.
The chapter is structured as follows: It starts by revisiting other related concepts, primarily borrowing from industrial ecology and from sua\wepply chain management literature. It then comes back to examining the concept of the circular economy in contrast to these, before presenting its conclusions.

2. From reverse logistics to closed loop supply chains

Sustainable supply chain management has been rather preoccupied with the ecological dimension of sustainability, to the extent that it has just fairly recently started to discover other topics as well – ranging from ethics to health and safety to labor and employment to gender, marginalization, minority development, and other societal questions (Seuring & Müller, 2008, Yawar & Seuring, 2017). The good news is that there is an abundance of ecological considerations in sustainable supply chain management, therefore often also called either environmental supply chain management, or green supply chain management.

Originally, the question evolved around what to do with material waste. In the supply chain, material waste could occur at any point, either as materials or energy that were the bi-product of manufacturing, or items that expired, didn't sell well, or went out of fashion, not to speak of defects (i.e. products with quality problems), and product returns. The latter even captured the interest of marketers, both as they constituted a problem for further sales, but eventually also as the ease of returning a product would become a sales promise. Conceptually, the focus was either on "product returns" (in marketing) or "reverse logistics" (in logistics and supply chain management). Eventually, the two were combined into the "returns management process", one of the eight main processes that are outlined in the supply chain management framework (Rogers et al., 2002).

Consumer returns underlie all sorts of regulations, and there are legal differentiations between product recalls, warranty returns, returns systems for particular materials (primarily packaging materials such as glass bottles, metal cans, cardboard etc.), and "other" returns. Interestingly, not even the focus on "other" returns is unique to the circular economy: Furniture manufacturers as well as technology firms have for a long time embraced the delivery of old furniture or e.g. white goods when buying a new one – primarily as this would increase their sales and reduce sales cycles, but also, to examine end of use products for usage patterns and durability and incorporate this learning in the development of new ones (Herold & Kovács, 2005). And which consumer wouldn't prefer someone taking away their old couch or washing machine at the time of delivering a new one? Also to date, making returns easy is an important promise fuelling especially online clothing sales, to the extent that customers are segmented based on their returns behavior. It even turns out that those customers returning most clothing are the most profitable ones for e-commerce to focus on (Hjort et al., 2013; Lantz & Hjort, 2013).

Overall, there are various narrow vs. wide definitions of product returns and also reverse logistics. A first important distinction can be made whether the focus is on the commercial or the ecological aspect of the concept. Already Rogers and Tibben-Lembke (2001) distinguished between the commercial vs. ecological aspects of greening the supply chain, listing overlaps between the two approaches to consist of recycling, remanufacturing, and reusable packaging; but indicating that from a commercial perspective, reverse logistics would extend this focus to product returns, marketing returns, and even finding secondary markets for products, whereas the ecological dimension would be more concerned with reducing packaging, air and noise emissions, and even extend to other related aspects of logistics such as transportation mode selection. This is not a trivial distinction, as the example of furniture or white goods demonstrates. If the main idea is to increase sales, or reduce costs, the solution is not necessarily an ecological one. The above example definitely increases sales, but does not guarantee the further use of the returned item in any way.

From an ecological perspective, the focus of reverse logistics is much in line with the inverse pyramid of resource reduction and recovery options (Carter & Ellram, 1998). Reverse logistics thus comprises activities involved in the collection, disposal of products and materials, their recycling, remanufacturing, refurbishing, reuse and reselling, but also resource reduction (Rogers & TibbenLembke, 1998; Thierry et al., 1995). Yet before any of such activities incur, an important decision in reverse logistics is that of gatekeeping, that determines what is to be collected in the first place – and the very avoidance of returns. The latter point is again a divisive one, as reverse logistics is either defined narrowly as to focus on any "backwards" material flow in the supply chain, or more widely to denote also questions of resource reduction, dematerialization, design for disassembly and ecological product development. But as the very term "reverse" logistics may not easily lend itself to denote also "forward", regular material flows, the concept of "closed loop supply chains" (CLSC), and closed loop supply chain management was coined. Indeed, depending on whether reverse flows are used in the original or in secondary supply chains and/or involve new auxiliary channel members, one can even distinguish between closed, and open-loop ones.

Both concepts, reverse logistics and closed loop supply chains, can also be examined from a business perspective; as Stock et al. (2002) early emphasized the competitive advantage stemming from returns. There are three main aims of reverse logistics from the commercial perspective: cost avoidance, cost reduction, and an increase of demand. The cost avoidance perspective prevails in industries in which their waste, used or expired goods would otherwise create health hazards. These tend to be heavily regulated. Not surprisingly, pharmaceuticals and other medical items, contaminated food remains, but even the waste from nuclear power plants, are collected back to be able to process them in a controlled manner. The cost reduction perspective extends to all sorts of technical issues, from network design to shop floor control and even inventory control (Guide & van Wassenhove, 2001; Srivastava, 2008; Tan & Kumar, 2008). But as shown with product returns to increase sales, returns can also be used to improve customer loyalty, profits and enhance the brand or firm's public image (Rogers et al., 2002). Interestingly, remanufactured goods at times sell with higher profit margins or reach a more profitable secondary market than original ones (Stock et al, 2002). This is the very idea behind antique and vintage markets, for example.

Yet when it comes to the valorisation of biproducts, inventory, and dead stock (Kovács, 2014), the processes involved quickly require an understanding of other disciplines such as green chemistry (Zhang et al., 2013), or conservation (Jeguirim et al., 2012). This is the more emphasized in industrial ecology.

3. Closed loop supply chains vs. industrial ecology

Sarkis (2001) has described environmental supply chain management as the operationalization of industrial ecology. Indeed, closed loop supply chains encompass the cradle-to-grave, as well as cradle-to-cradle notions of life cycle assessment alongside the holistic view of industrial ecology. Industrial ecology, not unlike the circular economy, has been defined as a “new system for describing and designing sustainable economies” (Ehrenfeld, 1997, p.87). Of course not every aspect of industrial ecology necessarily focuses on the supply chain. Commercial aspects and business relationships in a chain are not the core here, rather, the focus is a holistic one on the physical flows of matter and energy (Korhonen, 2004; Korhonen et al. 2004) with regards to industrial processes and products. The main aim is an ecological one, to reduce environmental impacts within an industrial system (Seuring, 2004). This industrial system can be defined in three main ways: within an industry, bound to a geographical location, or following a product from cradle to grave (Boons & Bas, 1997).

The within-industry view is a sectoral one, often defined by a common product, resource or raw material. This view helps to formulate and achieve common aims to an industry; whether to propagate the use of clean(er) technologies, to set standards with regards to emissions and/or target recovery rates for various materials, or to eliminate the use of disputed materials altogether. The elimination of hazardous materials is particularly of interest when it comes to conflict minerals, materials intrinsically linked to child labor (e.g. particular metals), or hazardous materials. The sectoral view thus easily lends itself to legislation.

The geographical perspective is particularly apt in highlighting the interrelations of industries as an industrial ecosystem. Here the biproduct of water from one factory can be used in the cooling system of another co-located one, the heat from another factory can be used as energy input, and/or one another’s biproducts are of relevance to various industries. This can lead to the conscious co-location of industries in eco-industrial parks based on industrial symbiosis.

It is the third view that follows the “product chain” that is most akin closed loop supply chains. This view focuses on the processes related to a material, whether with the aim of dematerialization, or materials flow analysis (Erkman, 1997; Harper & Graedel, 2004). This stream is even called “integrated chain management” (Ehrenfeld, 1997), and not surprisingly, has as such been embraced by supply chain management scholars as well (Sarkis, 2001; Seuring, 2004), and there is a considerable cross-fertilization of research across the two domains. As distinct to supply chain management, integrated chain management follows the product chain (only), ignoring other process, technology, and service providers that are relevant to the supply chain (Kovács, 2008). Yet the same could be said of closed loop supply chains.

4. The novelty of the circular economy

There is an abundance of industrial approaches, and of research, that focus on resource management and resource reduction, way beyond the two main streams illustrated above. There is much related research in specific sectors, particularly in the resource extraction industries such as mining and agriculture. All industries like to pursue resource reduction approaches if they come with efficiency or effectiveness gains. So, what is new to the circular economy?

> In the European Union, the following definition of the circular economy has been adopted: "A transition to a circular economy shifts the focus to reusing, repairing, refurbishing and recycling existing materials and products. What used to be regarded as 'waste' can be turned into a resource… Products are intentionally designed to fit into material cycles, and as a result materials flow in a way that keeps the, value added for as long as possible – and residual waste is close to zero" (European Commission 2014, p.1).

Winans et al. (2017) maintain that the circular economy concept is a political one; but they also highlight its roots in industrial symbiosis and closed loop systems. Looking for the relations between circular economy, industrial ecology, and closed loop supply chains is perhaps not far-fetched.

Sustainability in management has for a long time maintained that consumers will vote with their feet and demand more ecological products; though the reality of this has been much disputed. There are strong consumer movements in this direction, but apart from particular scandals, even if consumers had such power, consumers find it difficult to follow the complexities of industrial processes and supply chains. This is not necessarily a matter of an information gap; often the opposite is true and the abundance of information overwhelming, and complicating decisions even more. Ethical, and ecological consumerism has though benefited from the rise of technological developments that brings and summaries important parts of information in apps that can tell whether a particular fish is endangered, or a particular cosmetic product contains any unwanted materials.

Yet the degrowth movement notwithstanding, demand for new products, and for novelty continues to grow in most industries. Politically, the aspect of economic growth through the circular economy is an attractive one, at least as long as growth is measured in GDP. Not surprisingly, policy documents have defined and outlined what they call "growing green economy sectors" (Jäppilä & Heliölä, 2015).

For example, in the clothing and fashion industry, one of the biggest challenges also to circular economy approaches is the consumers' constant need for novelty. Clothing choices are strongly linked identity building, and consumer needs with regards to appearance and aesthetic preferences change continuously (Niinimäki & Hassi, 2011). The "need" for clothing cannot be reduced to a physical one in protection from the elements, thus cannot be answered by higher quality and durability alone.

The design of new “product-service-systems” – the concept itself stemming from industrial ecology – emphasize dematerialization and eco-efficiency. Examples of novel product-service-systems in the fashion industry focus on upgrading, modifying and lending services. The idea is for companies to be able to adapt their business offering even to consumers who are ready to decrease their fashion consumption (Armstrong et al., 2015). In other words, they emphasize some important trends in the circular economy: upcycling, the sharing economy, and servitisation.

Upcycling as a “circular product design strategy” (Bocken et al., 2016) is an interesting aspect of sustainable innovation. It not only reduces the needs for primary resources but caters to the political need of economic growth, the industry need of higher profit margins, and the consumer need of novelty. Upcycling has further been linked to other trends, such as grassroot innovation, or been linked to technology developments such as the use of 3D printing. Apart from upcycling, also technological, organizational, and even social innovation are important to the circular economy (Winans et al., 2017).

The sharing economy, sometimes even called “post-ownership sustainability” (Belk, 2014), can be seen as a social innovation. To return to the example of clothing, there are clothing clubs where consumers can borrow a certain number of garments each month; through other examples are more prominent when it comes to sharing apartments, cars, and car rides, or all sorts of machinery and equipment.

The servitisation trend turns the focus from the product itself to the function of the product, or the experience of the product. Thus, rather than buying certain products, they can be rented and replaced. This is another part of post-ownership. Users or consumers can focus on mobility as a service rather than the ownership of a car; the use of a leased carpet that is maintained and cleaned rather and plants that are landscaped and watered rather than their ownership and need for maintenance. Interestingly, even cities have adopted this trend alongside the sharing economy in their adoption of circular economy approaches.

5. What next? Beyond the circular economy

The circular economy concept has embraced many of the important aspects of both industrial ecology and closed loop supply chains, and combined these with current trends; from upcycling, to the sharing economy, to servitisation.

Interestingly, the circular economy does not only share its focus but also its oversights with closed loop supply chains and industrial ecology: the strong product focus easily distracts from other environmental problems, e.g. the one of increased transportation needs, and thereby increased transportation emissions. Furthermore, the sole attention to eco-efficiency can itself be counterproductive. Hertwich (2005) even talks of a “backfire effect” when efficiencies have resulted in cheaper prices, fueling an actual increase in demand, more consumption, and more waste. The potential to extend the life spans and intensify the utilization of products is key not only as an answer to this problem, but also to enable their sharing. At the same time, it is a question of societal acceptance, which innovations, and which sharing models prevail (Kramer & Belz, 2008). But even when it comes to upcycling, the question is whether the new upcycled products cannibalize the use of old ones. In other words, new trends open up to new questions and new criticisms as well. For example, aspects of the sharing economy are already under fire from the perspective of taxation, and even the potential discrimination of users.

Despite the circular economy embracing many societal trends, yet another criticism prevails across closed loop supply chains, industrial ecology, and the circular economy: Due to their strong emphasis on the ecology, they tend to be detached from their social and community contexts (Winans et al., 2017).

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Chapter 3

TRANSITIONING FROM A LINEAR ECONOMY TOWARDS A CIRCULAR ECONOMY: THE CASE OF THE APPAREL INDUSTRY

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Abstract

This chapter describes and illustrates potential benefits and challenges of a transition from the traditional, linear, organization of economic processes towards an organization of such processes based on circularity. A view is elaborated based on notions and theoretical concepts that apply to the idea of a circular economy, followed by an exploration of the main challenges and obstacles for a significant shift towards circularity. An illustrative case of a substantial shift towards circularity in the apparel industry is presented. The chapter ends with an agenda for further research and policy making.

Keywords: circular economy; transition process; apparel industry

1. Introduction

Introduction

In the past decade, the debate regarding the need to change the dominant traditional linear way of working in basic economic processes towards a more circular organization of these processes has been intensifying. The need for a transition towards what is referred to as ‘a circular economy’ has been advocated by many researchers and policy makers (e.g., Ellen, 2013; Van Buren et al., 2016), and new business models have been proposed (e.g., Jonker, 2011; Lewandowski, 2016). Furthermore, innovative solutions have already been implemented in various domains (e.g., Jonker, 2013), and supportive policy agendas have been launched (e.g., European Commission 2015).

Although these events might suggest an accelerating large-scale transition, the required structural change of economic and business practices appears to be extremely challenging. Changing the system is a matter of many small steps and endurance. The promising theoretical perspectives on the benefits of a circular economy with respect to economic, social and environmental dimensions of society, and hence a more sustainable development, often appear insufficient to overcome various technical, institutional, economic and social barriers to a large-scale transition.

The present chapter aims to describe and illustrate potential benefits and challenges of a transition from the traditional, linear organization of economic processes towards a circular organization of such processes. Since this subject is so encompassing and complex, we have to limit ourselves. We will, in the next section, first elaborate our view on basic concepts associated with a circular economy. Next, the main challenges and obstacles to a significant shift towards circularity will be explored. In the fourth section, an illustrative case of attempts to shift apparel industry towards circularity is analysed. The final section draws some conclusions.

2. Demarcation of linear and circular economy

Circular economy is a term that has been coined as opposed to the concept of a linear economy, a generally used label for traditional economic business processes. These labels require further explanation to understand the essential differences between the two, and to identify the challenges anyone desiring a transition may encounter.

The dominant practice of business processes in production industries has long been based on the sequence of (a) producing and procuring raw materials essential for production, (b) using these raw materials for producing the goods, (c) branding, marketing and selling the product, (d) use and maintenance, and (e) disposal of the product as waste. Generally, in the first three steps, economic value is added to the end products. The market price is an expression of the buyers' willingness to pay for owning and using the product. In step (e), basically, the economic value of waste is considered negative (waste treatment costs money), or at its best considered (near to) zero. In its simplest form, in this linear view on the production –consumption process, the value chain is considered a pipeline, where raw materials enter and waste results at the end. With a growing world population and increasing welfare, and with a growing dependency on energy use per capita, the amount of raw materials produced and consumed (including fossil resources) has grown exponentially over de past decades. Increasingly, less-accessible locations for mining have to be explored, causing significant negative impact on the social and natural environment. Geopolitical strategies harden and global tensions grow, since businesses and nations aim to secure access to increasingly scarce resources. The other side of the coin concerns the enormous amount of waste that societies have to deal with.

These system dynamics and effects have first been extensively analysed and described in the notorious publication '*The Limits to Growth'* by the Club of Rome (Meadows et al., 1972), which is to be read as a major wake-up call. An iconic follow-up was the so-called Brundtland report (*Our Common Future*) by the World Commission on Environment and Development (1987), addressing the global problems of non-sustainable production and consumption patterns and their global social and environmental consequences. This report stressed the need for a major shift towards more sustainable development, balancing people, planet and profit. In the decades following, the Brundtland report has increasingly framed major debates on socio-economic developments. Notions such as 'cradle-to-cradle', 'responsible entrepreneurship', 'closed loop', 'multiple value creation' and recently 'blue economy' (Pauli, 2017), were coined as further elaborations of Brundtland's call for sustainability. This process has, mainly since the beginning of this century, been accelerated by a wealth of studies on global warming associated with the use of fossil energy.

In response to these developments, the concept of a circular economy has been advocated as a sustainable alternative to the linear ‘take, make, dispose’ economy. The main principle embraced in circularity is to significantly reduce the production and consumption of raw materials in combination with a strategy to recover and reuse resources from waste. “A circular economy aims for the creation of economic value (the economic value of materials or products increases), the creation of social value (minimization of social value destruction throughout the entire system, such as the prevention on unhealthy working conditions in the extraction of raw materials and reuse) as well as value creation in terms of the environment (resilience of natural resources)” (Van Buren et al., 2016, p. 3). Cramer (2014) describes nine gradations / options for circularity, often referred to as the nine R’s:

1. Refuse: preventing the use of raw materials;
2. Reduce: reducing the use of raw materials;
3. Reuse: product reuse (second-hand, sharing of products);
4. Repair: maintenance and repair;
5. Refurbish: refurbishing a product;
6. Remanufacture: creating new products from (parts of) old products;
7. Repurpose: product reuse for a different purpose;
8. Recycle: processing and reuse of materials;
9. Recover energy: incineration of residual flows.

In today’s societal practices, important steps have been taken to introduce processes of reuse, repair and recycling, adding significant feedback loops to the linear production-consumption model. These loops are often approached as separate optimization steps. The concept of circularity however, goes substantially further. First, it focuses on designing products in such a way that they can be easily repaired, disassembled for renewed use of components, or enable an easy recuperation of raw materials. And secondly, related to the first issue, it focuses on splitting up product ownership and product use (e.g., Tukker, 2004), from both in the hands of the buyer - in the traditional system - to a system of permanent producer ownership of the product, while usage is provided as a service to the market. In this way, crucial materials remain in the hands of the producer.

The major characteristics of the three production-consumption models discussed in this section are summarized in Figure 1.

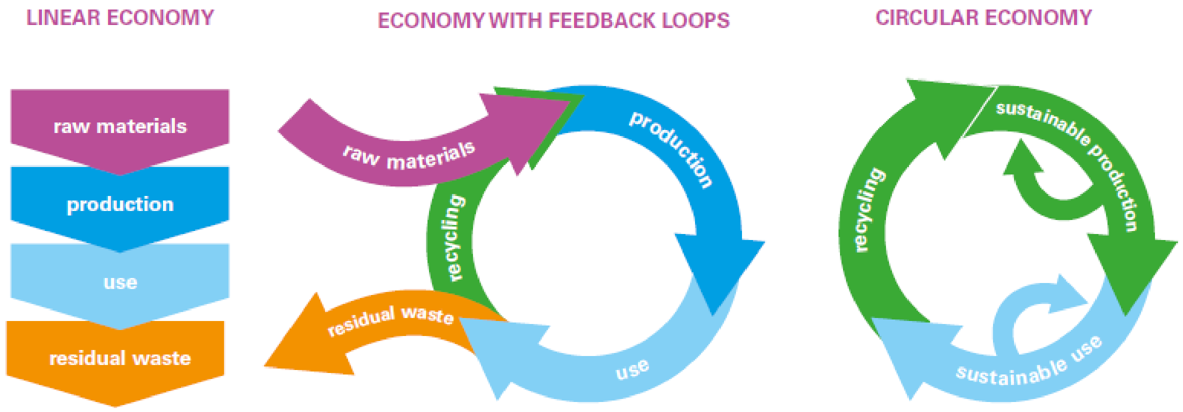

Figure 1: Characterizing linear economy, economy with feedback loops, and circular economy (RLi, 2015)

Van Buren et al. (2016) summarize the potential, and in some cases already proven, advantages of the circular economy approach in terms of three major categories. The first type of advantage is that the production processes in this setup require significantly less newly produced or mined raw materials. Consequently, these processes become less sensitive to the growing scarcity of many raw materials and suffer less from uncertainty due to the instable and strategic geopolitics of supplying countries, aimed at gaining more influence on consuming countries. This tends to outweigh the increase in uncertainty related to adequately organizing the reverse supply chain process. Secondly, the circular economy has the potential to generate innovations and new employment opportunities in the so called eco-industry, based on the development and application of eco-technology, as well as the potential to geographically shift back outsourced activities to national economies, in processes labelled as ‘local mining’, ‘near sourcing’ or ‘reshoring’. In the past decade, the eco-industry more than doubled in size, in Europe. The third advantage evidently concerns the reduction of environmental damage due to less extraction of raw materials, less fossil energy use and significantly smaller waste disposal problems.

Pursuing a circular economy requires major societal changes, however. The European Commission launched a Circular Economy Package in 2015 (European Commission, 2015) labelled ‘closing the loop’. The Dutch government recently published a broad policy package (Ministry of Infrastructure and Environment & Ministry of Economics, 2016) and e.g. the German government launched ProgRess, the German Resource Efficiency Programme, in 2012 (German Environment Agency, 2012), and now works on ProgRess II. Other countries are active at the national policy level as well. These policy frameworks call upon transitions in institutions, technology, societal behaviour and economic business models. They all underline the urgent need for change and describe potential benefits, but also recognize the complexity of the required transitions. The next section elaborates on these major transitions.

3. The transition challenge

Changing a linearly organized system into a circular organized system requires major systemic transitions. Such transitions imply a structural change of the system regarding various fundamental characteristics. Such transition-oriented developments generally do not occur spontaneously, although in certain cases system-external changes might stimulate systemic change, e.g., the introduction of new regulations (e.g., on food safety) or intensive societal debates (e.g., on the reduction of fossil fuel use). In many cases, however, these systemic changes must be triggered by deliberate decisions and actions from powerful stakeholders within the system. Systems' transitions are thus dependent upon the impact of purposeful change processes organized by the involved stakeholders. The change process focuses on changing the factors and processes that determine the basic structure, complexity and performance of the system. These factors involve:

- The type of system: Forward versus reverse supply chains;
- the type of innovation: Product design versus new services;
- the number of partners involved: Few versus many partners;
- the technology applied: Off-the-shelve or experimental technology;
- the relationship between actors: Contract-based or collaborative relationships, and small initiatives versus powerful players;
- the nature of the market: Local versus global markets and industries;
- the institutional conditions for the market: Regulation within one state versus international trading. And;
- the level of knowledge and understanding: Basic and/or at the surface versus in-depth and/or at the forefront understanding.

Since all the changes regarding these factors are not (nor need to be) realized with the same speed and with the same level of success, a variety of different stages in the transition of the system can be observed. These stages vary between, at one extreme, classical linearly organized production-consumption chains, and at the other extreme, a fully functional, circularly organized system. Hence, it is clear that such transition processes are complex regarding the changes in the system's structure, are dynamic regarding the changes in the system's behaviour and are uncertain regarding the changes in the system's performance.

In much of the literature on such transition management processes (see e.g., Rotmans et al., 2001; De Bruijn et al., 2003; Kemp et al., 2007) it is argued, and partly empirically illustrated, that the success of such a deliberately pursued transition strategy is strongly dependent upon the degree to which the process is organized and managed. The literature emphasizes issues such as:

- Involved stakeholders should have a shared view on the basic features of the present system and develop a shared vision on strategic aims to be realized when introducing or reinforcing measures for improving circularity;

- there must be a sufficient level of agreement on the necessary conditions for a successful process, such as: the data / facts that underlie the understanding of the present system state and the expectations regarding the impact of intended interventions, the basic uncertainties herein, the willingness of the stakeholders to take certain shared and individual risks and the minimum level of support from policy makers;

- involved partners must share their views on how to deal with risks, such as: doing additional research (and also: how), choose and implement no-regret measures, committing powerful players who can act as game changer, and/or guarantee the support of policy makers;

- they need to establish an agreement on the way of collaboration (code of conduct), describing what is expected in terms of sharing information, the rules for new stakeholders entering the collaborative network as well as individual exit rules, the way of communication within the collaborative network and to the outside world, the way actions and responsibilities are monitored and valued;

- the process requires a system of monitoring and evaluation of progress: which targets must be reached and when, and what are the criteria for determining whether the development was a success or a failure? And;

- a shared view on scaling up in case of success and scaling down and possibly termination in case of stagnation or failure of the initiative, reckoning with individual interests of the participating parties.

Clearly, the more complex the system and the higher the transition ambition, the greater the dynamics will be in the transition process, and the more perturbing factors will be included. Consequently, it then becomes more difficult to organize the transition as a controlled process. Van Buren et al. (2016) mention a series of barriers for change and perturbing factors that have a significant impact on transition processes towards a circular economy. These factors have been summarized into four categories: economic, institutional, social and knowledge-related.

The category of *economic factors* is directly linked to the critical necessity for involved companies to work within an economically sound business model. A realistic and robust expectation of sufficient economic earnings, as compared to the companies' costs, is essential for commitment and involvement. Given the innovative nature of circular value systems, new business models are needed to meet the entrepreneurial expectations. The presently dominant business models too strongly focus on optimizing economic value for the individual company and insufficiently take into account value creation in multiple dimensions, and joint business with other partners in production – consumption chains. Attention for new circular business models is growing. E.g., Jonker (2013) describes a series of small scale circular business models for what he calls the 'weconomy'. Such models, to a more or lesser degree, share the following principles: (a) focus on sharing, swapping, leasing and second life, (b) focus on horizontal collaboration, creating more than merely economic value, (c) accepting transactions based on exchanging service, time, credits or local money, and (d) often focused on crowdfunding. However, as mentioned previously, these models are so far small-scale and sometimes nothing more than theoretical designs. Barriers to further developing and implementing such models in practice are, according to Van Buren et al. (2016), among others: (a) vested interests of companies and branding organizations that cause path-dependent behaviour and resistance to change, (b) uneven distribution of costs and benefits across the chain, (c) lack of investment power and powerful game changers causing wait-and-see behaviour of involved parties, (d) deficient pricing of present products and services due to limiting the pricing of products and services to production costs and the neglect of life-cycle costing, and (e) as a result, insufficient economic triggers for companies or consumers to change their behaviour.

The category of *institutional factors* encompasses a broad range of structural rules that strongly influence the market play and the nature of the dynamics in various markets. These rules can be of a legal, cultural or social nature. Hence, they can differ between states and (global) regions. Examples are European limitations to the possibilities for cross-border trading of waste, differences in taxation regimes in different states or differences in competition policies (e.g., under European legislation intensive cooperation between companies is often prohibited). Furthermore, it is generally known that the dominant concept of a liberal and open economy is under pressure and that more centrally organized economies and measures of protectionism increasingly influence global and regional economic activities. In addition, differences in cultural and social institutions between global regions triggered by ethnic, religious or geo-political motives, increasingly influence the willingness to collaborate between companies and organizations in these regions. The concept of 'level playing field' seems increasingly difficult to realize, whereas no widely-accepted set of alternative rules is available yet.

The third category of *social factors* summarizes barriers and disturbing mechanisms related to the general acceptance of circular products and services. First, this is related to a lack of awareness and sense of urgency among consumers as well as producers. Transparency of chains and knowledge of the economic, social and environmental performance of these chains is generally limited, especially concerning international chains. For example, the basic notion that waste is not necessarily a product with a negative value, but could also be considered and treated as a resource for new production, is not common knowledge. Another example concerns the recognition of the strong relationship between the level of meat consumption and the production of greenhouse gasses. Secondly, values such as property and ownership are important within our societies. Splitting up ownership and use and replacing ownership by service ('what you have is only temporally yours'), requires a reframing of values. Moreover, the idea that new is best, while second-hand and recycled products and materials are basically inferior, is deeply rooted in many (Western) societies. Thirdly, much research provides evidence that consumer behaviour strongly depends upon social norms, perceptions, habits and traditions. These factors can be influenced by marketing narratives (e.g., regarding the functional quality of a new device, or the advantages of new sustainable products and services) as well as the public discourse (e.g., on environmental protection measures, or the need for a fundamental energy transition). However, consumers experience many influences from a large variety of views and interests, and this makes the direction of the summarized influences on values and believes hardly predictable.

Finally, the category of *knowledge-related factors* is described by Van Buren et al. (2016) as the barriers to reaching a higher level of professionalism. Think in this context of the systematic development and open access provision of a body of knowledge and methods that really helps to identify opportunities for improving circularity, for exploring the basic uncertainties and risks, and for elaborating collaborative arrangements between the involved stakeholders. This body of knowledge and methods is by nature multidisciplinary, but truly multidisciplinary research and the cross-disciplinary exchange of knowledge is scarce in practice as well as in science. Moreover, in-depth (scientific) research and (hands-on) practice are often viewed as two different worlds, with insufficient interaction and cross-fertilization. The consequence is that production-consumption chains in practice are not always receptive for innovations, whereas dissemination of newly generated knowledge often remains limited to the world of scientific researchers.

Above, we described the contours of a transition from a linear to a circular economy and emphasized various requirements and difficulties to arrange the complex transition processes. In the next section, these generic notions will be illustrated in the apparel industry, where several attempts are made and initiatives taken to introduce circularity in production-consumption chains.

4. Shifting from linearity to circularity: the illustrative case of the apparel industry

a. The apparel production and consumption system

The term apparel industry is actually a simple label for what is in reality a more comprehensive and complex system. In fact, this production system consists of four interwoven industries, namely the ‘primary fibre industry’, the ‘textile industry’, the ‘clothing industry’ and the ‘recovery and waste industry’. The primary fibre industry concentrates on the production of synthetic and natural fibres. The textile industry performs supply chain activities such as spinning and dyeing, and weaving, knitting and finishing respectively. The clothing industry focuses on clothing design and fabrication, marketing, distribution and retailing. The recovery and waste industry concentrates on supply chain activities such as collection and sorting of end-of-use or end-of-life apparel, recycling, retailing via re-use firms or exportation for re-use, and incineration. From a complex systems perspective, the recovery industry in terms of recycling and re-use can be referred to as a set of major feedback loops. The consumption system refers to consumption patterns or the use phase of apparel. See Figure 2 for a systems view of the apparel industry.

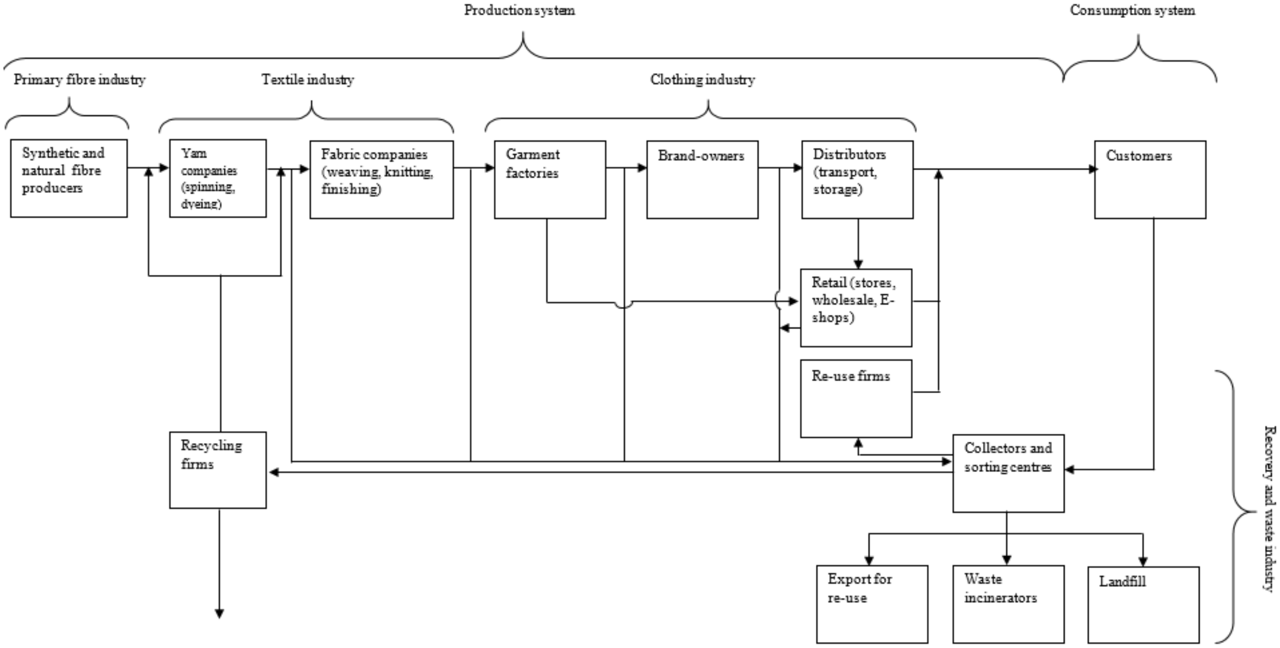

Figure 2: Current linear apparel value system with feedback loops

Based on the subdivision of the system, three global analyses will be performed hereafter. Firstly, the current situation of the system is analysed. This implies a descriptive analysis of numerical and non-numerical data about the various forward and reverse supply chain activities across multiple spatial scales, and their social, economic and/or environmental impact. We basically use the triple bottom line criteria framework, proposed by Jia et al. (2015), which consists of criteria such as toxic chemical usage, water consumption, energy usage, arable land usage and resource usage (the environmental aspect), competition, profitability and employment (the economic aspect); and child labour, wages and health (the social aspect). Secondly, (medium and long-term) external developments affecting the linear clothing system are analysed. Thirdly, value adding circular (supply chain) concepts and regulatory measures and their possible social, environmental and economic impacts are explored. To limit ourselves, for the recovery and waste industry, as well as for distribution and retail practices, we will focus on data for The Netherlands.

b. Analysing the current state

Primary fibre industry

People: The majority of fibres are produced in Asian countries. For the production of cotton, farmers use fifteen types of pesticides (Mukherjee, 2015); almost seven percent of the global amount of pesticides is used for cotton production (OrganicCotton, 2017). Research shows that the use of pesticides for cotton production causes human health problems such as chronic diseases and worker's poisonings, affect fertility and may as well have carcinogenic, allergic and neurological effects (Gardetti & Torres, 2013; Khan et al., 2015; Khan, 2010).

Planet: For the production of cotton, large surface areas and amounts of water are utilized, whereas a substantial amount of CO_2 emissions is produced, respectively 2.5 percent of the world's arable land (Jansen, 2014), 2.6 percent of global water use (Rissanen, 2008), and 0.8 percent of global CO_2 emissions (Karaosman, 2016). This makes the land used for fibre production, and in particular cotton production, vulnerable to soil degradation, depletion and the loss of biodiversity (Gardetti & Torres, 2013). For instance, in order to maintain and expand the production of cotton, entire rivers have been diverted into huge irrigation channels in Central Asia. This has led to the gradual drying-up of the Aral Lake, one of the largest inland waters in the world (OrganicCotton, 2017). In addition, it is estimated that 60 percent of irrigation water in Central and Southern Asia is lost because of cotton production (PAN UK, 2006). Then, the current average energy consumption of conventional cotton is around 130 MJ/kg, while the average energy consumption of (man-made) polyester is 175 MJ/kg (Muthu, 2014). The majority of energy consumption for fibre production is non-renewable, stemming from gas, oil and coal with high CO_2 emissions (Muthu, 2014).

Profit: In 2016, the global production of fibre is estimated at 99 million tons, of which 62.7 percent are oil-based synthetic fibres such as polyester, 24.3 percent is cotton, 6.6 percent are wood-pulp-based cellulose fibres such as viscose, 5.3 percent other natural fibres, and 1.1 percent is wool (Lenzing, 2016). Cotton production provides an income for more than 250 million people worldwide, which is around seven percent of all labour in developing countries (WWF, 2014). At the same time, the balance between supply and demand of the cotton market has become highly uncertain due to: (a) pest attacks, (b) lack of alternative fibres developed by developing countries, (c) an increasing competition from synthetic fibre 'polyester' and (d) high cotton inventories (80 percent of annual consumption) resulting in lower production and a fluctuating cotton price (OECD/FAO, 2016; Bhosale, 2016). For example, the current price (February 2017) for cotton is EURO 80 cents/lb, and experienced fluctuations in 2016 from March 59 cents/lb to 73 cents/lb in July back to 69 cents/lb in September (IndexMundi, 2017). In the period 2014-2016 world cotton inventories have reached over 80 percent of annual consumption. Prices of oil-based synthetic fibres on the other hand have structurally dropped over the last few years. The lower prices of these fibres, driven by substantially lower oil prices, have placed huge competitive pressures on world cotton markets in recent years (OECD/FAO, 2016). The market price of wood-pulp-based cellulose fibres such as viscose, on the other hand, significantly recovered in 2015, rising by an annual average of about 5 percent (Friedman, 2016).

Textile and clothing industries

People: In the textile and clothing industries, child labour is common. It has been indicated that 168 million children (almost 11 percent of the total child population) are child labourers and mainly employed by factories manufacturing textile and clothing (Moulds, 2015). Financially, this leads to low purchasing prices downstream the supply chain, yet keeps children from education and development (D'Ambrogio, 2014). Furthermore, in Asia, there is a gap between the wages clothing workers earn at the factory, and the minimum living wages necessary for a worker to meet their needs (Lu, 2016). For instance, in China the minimum living wage is €522 per month, while the factory average wage is €186. In Bangladesh, the minimum living wage is €340, while the factory average wage is €60 (Demkes, 2017). Because of this gap, poverty results in lower welfare for factory workers (Maas et al., 2016).

Planet and Profit: In 2015, the textile and clothing industries in the European Union (EU-28) generated a turnover of 169 billion €, with total investments of 4 billion €, and employed 1.7 million workers (Euratex, 2016a). Over the period 2014-2015, a turnover growth of 0.5 percent and an employment growth of 0.6 percent were observed in the textile industry (Euratex, 2016b). In the clothing industry, during that period a turnover growth of 1.5 percent and an employment growth of 0.3 percent were observed (Euratex, 2016b). Focusing on the Dutch clothing industry, there is fierce price-related competition between retailers, and decreased sales, because of recent financial and economic crises, leading to lower margins (Modint, 2016). However, sales are expected to rise again, given the recent recovery of the economy. These figures illustrate that important socio-economic interests are at stake in this production-consumption system. At the same time, the system seems to become subject to debate regarding environmental aspects. For example, in the textile industry 30 percent of costs are derived from electricity, while the energy used for yarning and spinning is mostly non-renewable at this moment (Muthu, 2014). Rising global non-renewable energy prices will cause higher costs downstream (Euratex, 2014), strengthening attempts to compensate this by reducing other costs, e.g., by implementing more industrial and automated production systems, which in turn jeopardizes local employment.

Recovery and waste industry

People and Profit: It appears difficult to find global figures for this industry. Therefore, we limit ourselves to the Dutch situation. In 2017, there are 2,225 collectors and second-hand stores within the Netherlands of which 22 percent are stores specialised in second-hand clothing (CBS, 2017). This number represents an increase of four percent in comparison to 2015 (CBS, 2015). The second-hand clothing stores employ 1,465 people, which is an increase of 0.3 percent compared to 2015 (CBS, 2017). 64.8 percent of the employees are people with what is called ‘a distance to the labour market’, which means that they generally have some handicaps and as a result, their entry into the labour market is restricted, making them more than average dependent upon social care (BKN, 2016). The average turnover of Dutch second hand stores (members of the second-hand association) increased by 11 percent from 90 M€ in 2014 to 100 M€ in 2015 (Kleinjan, 2017). The assumption is that this is due to economic recovery and the increasing quality of products (Kleinjan, 2017). At the same time, the Dutch clothing industry deals with a high level of obsolete inventory. For instance, in 2015, 6.5 percent of textile and clothing remains unsold, and hence remain ’stuck’ in the forward supply chain. Of this category, 1.4 percent remains at the production stage, 1.1 percent at the wholesale stage, and 4.2 percent at the retail stage (Wijnia, 2016). Of this 6.5 percent, 35.2 percent is perceived as ‘end-of-use’ material, collected by commercial firms and exported for re-use in Eastern Europe, Asia and Africa, while another 35.6 percent is collected by charities and exported for re-use to the same destinations. 17.6 percent is kept in stock, while 5.9 percent is sold in outlet stores, 3 percent recycled, and 2.7 percent incinerated. In total, this accounts for 314 M€ turnover loss in 2015 for the Dutch retail market (Wijnia, 2016). When it comes to the reverse supply chain, 210 Kt ‘end-of-use-cycle’ and ‘end-of life-cycle’ textile and clothing are annually collected separately within the Netherlands, whereas 145 kilotons are not collected separately (Ffact, 2012). In other words, annually 80 M€ ends up in the garbage can (TAUW, 2011), in particular due to operational uncertainties, such as the timing, quantity and quality of returned clothes as well as capricious consumer behaviour (Guide et al., 2009).

Consumption (sub-)system

People: Current consumer behaviour patterns towards apparel and the use of apparel are based on social pressure to compare themselves with others through the accumulation and display of possessions, the continuous replacing of apparel with ‘updated’ versions, the cultural obligation to experience everything and buy things accordingly, and constant consumption as part of a continuous process of identity formation (Fletcher, 2008; Wicker, 2016). This situation does not stimulate receptiveness for information and actions stimulating sustainably use of apparel in order to maintain its quality and to reduce environmental impacts.

Planet: Research shows that 8 percent of Dutch CO_2 emissions are (in)directly caused by the use of clothes and shoes (Jansen, 2014). One could argue that this is mainly caused by the laundry practices of consumers (Dombek-Keith & Loker, 2011; Sherburne, 2009). Aggregation of this finer-scale study into global studies teaches us that the actual volume of water required to wash clothing equals to about ten percent of the global water footprint (WRAP, 2012). Furthermore, it accounts for over 850 Mt of CO_2 per year, which is equivalent to three percent of global CO2 generation, i.e., 51 kg CO_2 per-person per year (Carbon Trust, 2011b). Various authors suggest that for frequently washed garments, the effects of reducing water and energy use during washing, drying and ironing processes are larger than the possible effects of modifying production methods (Dombek-Keith and Loker, 2011; Sherburne, 2009).

Profit: In the Netherlands, average spending on apparel per household in 2016 was five percent of spendable income, which is on average €1,700 annually (CBS, 2016a; CBS, 2016b). In the last five years, the average dropped by 1.5 percent, mainly due to the financial and economic crises (CBS, 2016a; CBS, 2016b). When it comes to consumer behaviour, within the Netherlands, there is ambiguous consumer behaviour: although consumers have a positive attitude towards environmental protection, they rarely translate this attitude into sustainable fashion consumption (Niinimaki, 2010; Chan & Wong, 2012). Consumers are interested in purchasing sustainable garments, yet they are (on average) not willing to make personal sacrifices, such as paying a higher price.

c. External developments affecting the apparel system in the medium and long term

Global resource scarcity

Global resource scarcity is increasingly affecting both the forward and the reverse apparel supply chains. Resource scarcity is further increased by (a) population growth, (b) disequilibrium between production and consumption, and (c) economic levelling of nations around the world (Bell et al., 2013). The current world population of 7.3 billion is expected to reach 8.5 billion by 2030 and 9.7

billion by 2050. Population growth will mainly take place in Africa, South and Southeast Asia, and Latin America (UN DESA, 2015). Meanwhile, the balance between production and consumption of resources is changing. In 2016 all resources (e.g., cotton, refined oil) the earth can generate on average per year were actually consumed within the first eight months (Kraaijvanger, 2016). Growth of the population in general and of the middle-class population in particular generate a (fast) growing need for apparel in emerging countries such as China, Russia and India. Karaosman (2016) expects that this will lead to an increase in competition for apparel production in the near future. By the mid-2020s, these countries will have turned into key forces shaping global apparel supply chains (OECD/FAO, 2016). Hence, without significant system changes, the growing population and middle-class in emerging countries and the associated consumption of resources like cotton and refined oil may lead in the medium and longer term to a further unbalance between production and consumption.

Climate change

The estimate is that global CO_2 emissions from cotton may reach 300 Mt in 2020, which is about 2.7 percent above the current level, if the business-as-usual scenario is pursued with no reduction in emissions (Carbon Trust, 2011a). The way the climate will change in coming years will be critical in shaping the future apparel supply chain system. This system is particularly sensitive to climate change because of its reliance on high-quality raw materials stemming from natural and agricultural systems that are geographically limited (Crowley et al., 2015). Climate-related hazards such as changes in the intensity and frequency of extreme weather events like hurricanes, droughts, floods and changes in precipitation patterns will affect the availability of water, while the vulnerability and exposure of natural systems will lead to a loss and degradation of biodiversity and ecosystem services such as water filtration, soil replenishment and crop pollination, as well as related social consequences such as loss of livelihood.

Geopolitical developments

In the past decade, geopolitical tensions have intensified, due to developments like (e.g. Quaedvlieg, 2016) (a) fast growing New Economies (e.g., China, India) and their need for access to basic resources, (b) stagnating traditional economies (e.g., Europe, USA) causing growing nationalism and protectionism, (c) increasing tensions between East and West having effect on e.g., energy supply and dependency, (d) regional conflicts causing large-scale migration of populations and intensifying cultural clashes, (e) effects of global warming causing natural disasters and (f) the easy access to new production and service technologies replacing traditional hand-based labour and causing large scale unemployment at the bottom of labour markets. The global system is rapidly changing into a multipolar system. Opinions about the likeliness of a stable and steady development of the global economy become increasingly diverse. Production systems that are based on consuming natural and production resources in different global areas, are vulnerable to these developments. They tend to cause more rapidly fluctuating prices of scarce resources, more dependency on geopolitical stability, and more hesitation with respect to the necessary investments (e.g., in more sustainable production and distribution methods). This trend increasingly conflicts with the need for more product differentiation and quality, fast responses to changing market needs, sails reliability and stable selling prices. Recently, Burberry announced to reinvest in 1000 new jobs in the UK, and Nike in 10.000 new jobs in the US. Smaller brands in the US and Europe seem to follow. These small examples of reshoring illustrate a robust trend.

Technological developments

In the coming decade, technological developments such as 3D-printing, new types of sustainable fibres such as ‘’Miscanthus Giganteus’’, continuing automation, the Internet, smartphones and recovery technologies will (have the potential to) influence the current apparel system. The concept of mass producing apparel half way around the world and then shipping them is inherently (economically and environmentally) inefficient. Alternatively, 3D-printing technology could disrupt manufacturing and the global apparel supply chain, meaning that products are produced on demand for local delivery, and thus many transport and logistics needs will disappear. However, at the same time, it is assumed that 3D-printing technology and continuing automation will threaten 85 percent of employment in developing countries in the upcoming decade (Citi, 2016). Then, ‘’Miscanthus Giganteus’’ is a species of grass with a highly efficient photosynthesis. This newly developed fibre is suitable for various applications, and may potentially be used to substitute raw materials (e.g., cotton) in the textile industry (Knowles, 2015). In addition, global access to internet via smartphones and the growth in e-commerce and social media has ensured that everyone can see how everyone lives. As a result, worldwide expectations and international competition keep on growing, and the lead-time of, in particular, fashion apparel keeps on decreasing. This allows overconsumption and low-pricing policies, resulting in an increasing amount of waste and low-quality end-of-life fabrics (Pookulangara & Shephard, 2013). Furthermore, apparel recycling while maintaining quality is still very difficult. For instance, the decline in quality of apparel and the ‘chopping-up’ process tend to further lower the cotton’s quality. The ‘chopping-up’ process shortens the staple length of fibres, while the staple length influences the strength and softness of cotton threads. At the same time, recycling technologies of textiles and clothing are still lagging behind, although they could lead to major environmental gains. For instance, Zamani (2014) states that when applying an integrated textile recycling system, 10 tons CO_2-eq and 169 GJ could be saved per ton of textile waste. However, the number strongly depends on the yield of the processes in such an integrated system. It implies combining different technologies (e.g., mechanical recycling, chemical recycling) for the treatment of one ton of textile waste.

d. Value adding concepts and regulatory measures for a circular clothing system

Based on the current situation of the apparel system, which is still primarily based on extensive resource use, i.e., a ‘take-make-dispose system’ with often single feedback loops in terms of ‘re-use’ and ‘recycling’, as well as the external developments affecting the production system of the apparel industry in the future, it is important to integrate value adding concepts with the aim of maximizing value creation over the entire lifecycle of apparel with dynamic recovery of value from different types of return over time (Guide & Van Wassenhove, 2009). Value adding concepts from the forward and reverse supply chain system that may leverage value creation can be classified into ‘product design characteristics’, product-service concepts’, ‘integrated supply chain processes’, ‘partnerships and collaboration’, ‘organizational characteristics’ and ‘IT solutions’ (Koppius et al., 2014; Schenkel et al., 2015). Furthermore, regulation plays an important role.

Product design characteristics

There are various design measures needed to increase circular system performance in terms of economic and environmental value. These are contained in a variety of design principles such as ‘design for re-use’ (Atasu et al., 2010), ‘design for disassembly’ (Kumar & Putnam, 2008), ‘design for recycling’ (Kriwet et al., 1995), ‘eco design’ (Laosirihongthong et al., 2013), et cetera. For instance, various firms within the textile industry are searching for ways to switch towards recycled cotton to reduce the sourcing of primary cotton. Herewith up to 20,000 litres of water per kilo of cotton can be saved (Luz, 2007), which contributes to lowering the impact of the estimated 40 percent shortfall in water supply by 2030. In addition, research in carbon, water and waste impacts of UK clothing shows that switching of cotton fabric into 50:50 poly-cotton-blend fabric could also reduce the water footprint by three percent, the waste footprint by 1.7 percent and CO2 emissions by 0.4 percent (Idle, 2017). In addition, product design concepts, such as modularity of design for disassembly, increase the re-use rate of materials by simplifying low-level separation of valuable components, thereby creating economic and environmental value.

Product-service concepts

In response to more difficult access to resources and climate change, it is important to increasingly retain ownership of apparel and, where possible, act as service provider, hence, selling the use of products, not their one-way consumption. This shift has direct implications for the development of efficient and effective tack back systems and the proliferation of product- and business model design practices that generate more durable apparel, facilitate disassembly and refurbishment and, where appropriate, consider product/service shifts. This shift also leads to resource efficiency and would reduce carbon, water and waste footprints. For instance, when the life time of clothing can be extended by nine months via a product-service concept, carbon, water and waste footprints would already be reduced by up to 30 percent each and resource costs would be reduced by about 20 percent (WRAP, 2012). Note that these are figures from the British context. However, important to notice is that for consumers, having control over products such as clothes is one of the most valued attributes: ‘’Product-service concepts are often less accessible, or have less intangible value, than the competing product, in part because product-service concepts usually do not allow consumers as much behavioural freedom or even leave them with the impression that the product-service provider could prescribe how they should behave’’ (Tukker, 2015: 76).

Integrated supply chain processes

In a circular system, the forward and reverse supply chains are integrated, constituting a system with three to integrate sub-processes to either maximize profitability or minimize costs (Guide & Van Wassenhove, 2009). It concerns (a) the Front-End process, (b) the Engine process, and (c) the Back-End process. The Front-End process is based on the activities ‘product acquisition’ and ‘reverse logistics’ of clothing. Product acquisition can be described as the acquisition of used (discarded) products that serve as the input to a reuse system (Guide & Van Wassenhove, 2002). Issues concerning product acquisition are the design of facilities for collecting ‘end-of-use’ or ‘end-of-life’ apparel (centralized or decentralized), planning product management, and policies to control inventory (De Brito et al., 2005; Guide & Van Wassenhove, 2002). The success of product acquisition is strongly influenced by the uncertain timing, quality and quantity of returns, as well as the reusability and demand for recovered products (Atasu et al., 2008; Koppius et al., 2014). Reverse logistics involves the transportation, storage and transhipment of clothing. Transportation refers to obtaining the product returns and transports to the location where the related Engine activities will take place. Storage and transhipment of product returns are often additional activities to prevent high inventory costs for manufacturers (Guide & Van Wassenhove, 2002).

The Engine sub-process is based on the operational activities for valuing (i.e. taxation) and recovery of apparel. Taxation concerns the first inspection and sorting of products returns. In some cases, taxation requires high asset investments (Toffel, 2004). For instance, a specialized machine is designed only to recognize and sort particular colours, where the machine’s value would depreciate if applied to any other selection criteria, e.g. on material level such as cotton, bio-cotton, polyester. In the current apparel system, the most common option of product recovery is direct re-use, while parts harvesting, recycling, refurbishment (i.e., repair) and remanufacturing are marginally used. Although ‘recycling’ is becoming more and more topical, many apparel today consists of mixed materials, which makes it more difficult to recycle.

The Back-End sub-process involves the remarketing of recovered products/materials in terms of market selection and sales (Atasu et al., 2008; Guide & Van Wassenhove, 2009). There are a number of sales channels available for recovered apparel. For instance, regarding recycled apparel, a manufacturer may choose to use the same channel that is being utilized for apparel not made of recycled fibres. Or in the case of refurbished apparel the manufacturer can create two different markets, i.e. the original market for new products and another market for the refurbished apparel (Prahinski & Kocabasoglu, 2006), also to minimize eventual market cannibalization effects (Atasu et al., 2010).

Partnerships and collaboration

Partnerships and collaboration facilitate the re-integration of recovered apparel and materials into the original forward supply chain. There are various forms of partnerships and collaboration; traditionally a distinction is made between vertical and horizontal coordination. The majority of research agree that vertical coordination is beneficial to forward and reverse supply chain management (e.g., Aitken & Harrison, 2013), yet few studies specifically analyse the advantages of horizontal or other forms of collaboration such as inter-firm networks (Mihi Ramírez, 2012), or third-party service providers (Sheu & Gao, 2014).

IT solutions

IT solutions, such as real-time information coordination (Lee & Lam, 2012), are very often already implemented in the forward supply chain in order to improve customer service levels or reduce inventory. IT solutions such as 'radio frequency identification' (RFID) add value by enabling information collection in the integrated forward and reverse supply chain (e.g., Lambert et al., 2011; Huscroft et al., 2013). For instance, in the Netherlands a circular content management system is built, which enables customers to gain information about the materials that have been used for the production of their clothes, about who manufactured the clothes, and about the environmental impact of the production (Mentink & Houben, 2014). Furthermore, ''smart clothing'' which enables digital components and electronics to be embedded in them, can be socially and ecologically beneficial. For instance, the integration of electronic sensing skin into clothes presents structural health monitoring benefits of ageing infrastructure in improving public safety (Chen et al., 2016).

Organizational or governance characteristics

The five above mentioned concepts or approaches (product design, product-service, supply chain processes, partnerships and collaboration, IT solutions) are interrelated (Schenkel et al., 2015), constituting a complex system that differs significantly in structure and operations from the traditional linearly organized apparel industry. The transformation process towards the development and management of value adding circular clothing systems is assumed to benefit from innovative leadership approaches (Defee et al., 2009), responsibility sharing (Jacobs & Subramanian, 2012), cross-functional integration and organizational alignment (Mollenkopf et al., 2011). For instance, Defee et al. (2009), argue that a circular system orientation is facilitated when the supply chain leader performs a transformational leadership style, a style that aims to raise the consciousness of stakeholders regarding possibilities in the future by encouraging them to rise above their own interests for the purpose of the network, and focus on strategic development rather than merely focusing on immediate needs (Bass & Avolio, 1994).

Legislation

Legislation can either promote or limit innovation towards a circular apparel system. From a Dutch perspective, the government has indicated the desire to eliminate restrictive legislation on the one hand, and to develop legal frameworks on the other hand, that stimulate innovation, enforce dynamics and support investments for a circular economy. Therefore, the government is planning to, among others, (a) stimulate circular business models, (b) provide space in regulations for experimentation, (c) expanding producer responsibility, (d) stimulate circular product design, et cetera (Ministry of Infrastructure and Environment and Ministry of Economics, 2016). One of the Dutch legal frameworks for stimulating and supporting the circular economy for clothing and textile is the ‘National Waste Management Plan 3’ (LAP). In this plan, textile is one of the seven priority material flows and had a guiding objective to achieve a 20 percent reduction in environmental impact over the entire supply chain by 2015. However, unfortunately this objective has not been achieved. In response, the new LAP (i.e., LAP3) intends to pay more attention to how to achieve this objective. This is relevant since reality seems to move in the opposite direction. The general objective of 75 percent waste separation in 2020, enables municipalities to compensate textile collection with other priority waste fractions such as plastics, metals, wood, construction waste, paper & cardboard and electronics. At first sight, one might argue that is not a problem, yet like mentioned earlier, within the Netherlands, six percent of our CO_2 emissions is caused by clothing. Hence, the separate collection of ‘end-of-use’ and ‘end-of-life’ clothing and textile should be properly stimulated and not become subject of a trade-off with other waste categories. Other regulatory measures that could be implemented in response to global resource scarcity are for instance ensuring that domestic markets are supplied first (as with rice exports in Indonesia (Reuters, 2008)), or ensuring exclusivity of supply. For instance, China invested six billion dollars in infrastructure in Congo in return for natural resources (Reuters, 2009). However, measures such as these may strengthen protectionism and increase geopolitical tensions. The analysis of the potential for value added approaches in the apparel industry is summarized in Figure 3.

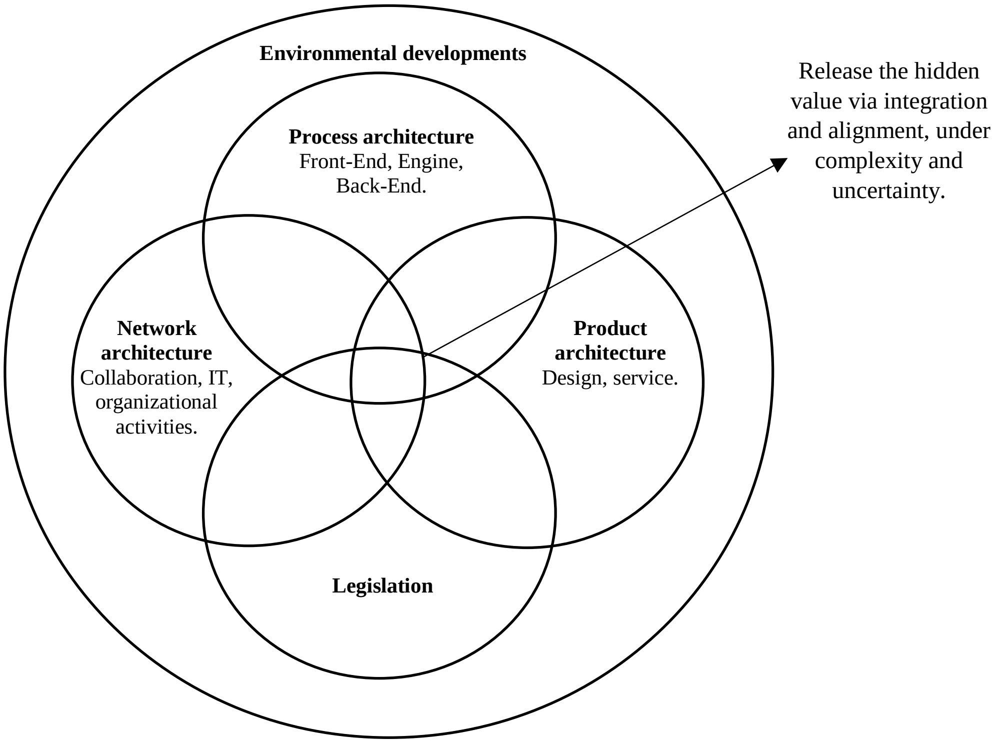

Figure 3. Value adding characteristics for circular value chain system management

5. Conclusion and discussion

The analysis in this chapter was triggered by an increasing sense of urgency for transitioning from linearly organized economic systems towards circularly organized economic systems. Therefore, the basic notions underlying circularity are described and the potential benefits are explored from a sustainability perspective. Furthermore, the complexity of the transition process has been elaborated and illustrated with the case of the apparel industry.

Based on these analyses, it becomes clear that indeed the linear economy is reaching its limits, or in the case of the clothing industry in certain aspects has already passed the limits. The concept of circularity has clear theoretical, economic, social and environmental benefits. However, an appealing concept alone is not sufficient to bring about large-scale changes. Supported by the analysis of the clothing industry practice, it must be recognized that transformation towards a circular economy is a normatively justifiable as well as practically messy challenge: the discrepancy between the actual and the desired state of the system is enormous.

Public and private decision makers, taking up this challenge and trying to influence the structure and performance of the system, must learn to cope with serious uncertainties due to the complexity of the system and its dynamics: they decide on events and situations where impact and probability of occurrence of various effects are both unknown (Marchau, 2014). Marchau summarizes these in terms of (a) uncertainties related to different demographic, socio-economic, geopolitical and technological scenarios, (b) uncertainties about the non-linear interactions and feedback effects between key elements within the system, occurring time delays as well as accelerations, determining the partly unpredictable behaviour of stakeholders and the impacts of interventions, and (c) uncertainties about the valuation of outcomes by different stakeholders. These types of uncertainty are very recognizable with regard to the presented exploration of the apparel industry. Marchau adds to this classification of uncertainties so called ‘deep uncertainties’, occurring when analysts and decision makers do not know or do not agree upon what model and probability distributions should be used to describe the system or how to evaluate the desirability of alternative outcomes (see also Kwakkel et al., 2016). With respect to interventions for circularity, such evaluations largely depend upon the weights attached to the triple bottom line (economic, social, environmental) impacts of alternative circular supply chain activities.

So far, limited multi-disciplinary, system-encompassing, research has been conducted in this domain, and consequently our awareness and knowledge are limited on what combinations of actions should be implemented, and when, to optimize the multiple value creation process. The illustrative analysis of the situation and developments in the clothing industry showed however, that serious options exist for sustainable improvements. Moreover, the sense of urgency for change is arguably high. Multiple value creation, i.e., value creation in multiple domains, by implementing more circularity-enhancing measures and concepts is within reach when all stakeholders take their responsibility and work together for a successful integration and alignment of transition initiatives in the industry.

It was mentioned that knowledge-related factors, among other things, can impede this collaboration. Dissemination of new knowledge is often hindered by the separation between (scientific) research and (hands-on) practice into two different worlds, with little interaction and cross-fertilization. Dissemination of newly generated knowledge consequently often remains limited to the world of scientific researchers. In the Netherlands, this problem has been recognized and has stimulated various initiatives to bridge these two worlds, such as creating knowledge networks regarding the circular economy, subsidies from the National Science Foundation for initiating collaboration between companies in research aimed at circular innovation and business models, and the organization of local ‘living labs’ for circular initiatives.

For academic researchers, such as the authors of this paper, these collaborations provide opportunities to intensify the study of the apparel or any other industry, dynamic, non-linear and re-enforcing interactions within these industries, to explore the possibilities and potential impact of circularity-based interventions. Participative intervention methods, such as serious gaming and participative group model building (see e.g., Vennix, 1996; Sterman, 2000; Rouwette, 2003), in combination with organizing small scale transition processes may provide an interesting approach for stimulating and facilitating real-world changes considering complexity and deep uncertainty.

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Chapter 4

INTERNATIONAL POLICY TRENDS AND PRACTICES TOWARD CIRCULAR ECONOMY DEVELOPMENT

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Abstract

Despite its various socio-economic and environmental benefits, the transition towards a circular economy will require an ambitious and consistent policy framework. This chapters aims to illustrate policy trends and practices toward circular economy development in Europe and beyond. It distinguishes between waste management and waste prevention policies and highlights that there is no need of innovative ideas and instruments – the key challenge will be a coordinated approach across different policy arenas and governance levels.

Keywords: circular economy; policy instruments; waste prevention; waste management; policy mixes

1. Introduction

In the past, the creation of waste relating to production and consumption was accepted as a necessary evil. Today, that apparent common sense is increasingly being challenged: circular economy, zero waste, closed-cycle, resource efficiency, waste avoidance, reuse, recycling – all these terms can be attributed to the ideal of achieving a world largely without waste, and instead with a responsible attitude to resources, materials, products and the environment. However, it will require a comprehensive holistic concept to actually ensure that approaches like avoidance, reuse and recycling are taken into account in every stage of the product life cycle and at the level of materials and energy – with environmental product design applied from the very outset to permit recycling at the end of the product life cycle. That is the circular economy. The transformation to the circular economy is associated with high expectations in terms of both ecological and economic benefits. Studies increasingly emphasise these benefits on four levels: resource utilisation, the environment, the economy, and social benefits including the creation of new jobs.

Nevertheless, it becomes increasingly clear that the circular economy will require a clear regulatory framework. The discussion about possible economic savings and market potential sometimes threatens to obscure the fact that many actors also profit very well from the existing linear system. Also taking into account the recent low price levels for primary resources, the transformation to the circular economy will certainly not come about automatically, and even the frequently-invoked new business models will only be able to fulfil their role as drivers of the circular economy if they are given the appropriate framework. Against this background this chapters aims to illustrate international policy trends and practices toward circular economy development. Section 2 analyses the European policy discourse on circular economy focussing on waste management, in addition section 3 highlights the need for waste prevention policy instruments. Section 4 finally undertakes the attempt to outline necessary next steps for supporting the transition towards a circular economy.

2. Circular Economy Policies

Looking at the potential positive benefits of a circular economy the obvious question must be what kind of policy framework would enable and support such a radical transformation from a linear towards a circular system. This question is especially high on the agenda of the European Commission. In 2015, the Commission published its Circular Economy Action Plan that set the ambitious target to treat any waste as a resource until the year 2020 and to turn the European economy into a circular economy (European Commission, 2015: 1). In order to achieve these goals, the action plan comprises various legislative proposals and measures in the areas of production (product design and production processes), consumption and waste management, as well as concrete targets for creating an ambitious long-term roadmap for waste management and recycling in Europe. As illustrated in Figure 1 the action plan can be divided into two key elements: a communication how to integrate circular thinking into different stages of the life cycle and a much more concrete proposal for changed regulations on waste treatments: Although circular economy of course goes beyond waste management, also the European Commission acknowledges that waste infrastructures are a crucial element for reducing linear patterns of production and consumption.

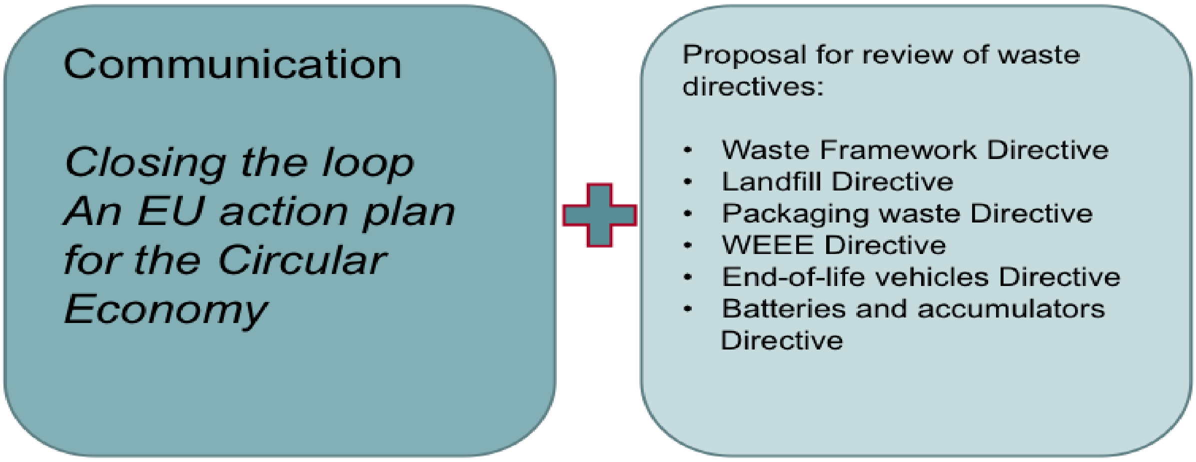

Figure 1. The key elements of the European Commission´s CE Action Plan

2.1. *Review of Waste Directives*

2.1.1 Objectives

The key objective of the legislative proposal for changed waste regulations is to set incentives for the waste sector to consider waste no longer primarily as a threat but as a potential source of future secondary resources. Against this background, the review includes the following key aspects:

- Alignment of definitions and reporting methods;
- Increase targets for municipal waste;
- Increase targets for packaging waste;
- Limitation of the landfilling of municipal waste;
- New measures to promote prevention, including for food waste, and re-use;
- Minimum conditions for Extended Producer Responsibility;
- Early Warning System for monitoring compliance with the targets;
- Simplification of reporting obligations.

The recent public discussion mainly focusses on the issue of concrete waste treatment targets. These objectives include:

- a recycling rate of 65 percent for household waste by 2030;
- a recycling rate of 75 percent for packaging by 2030;
- obligatory reduction of landfill disposal to a maximum of 10 percent of all waste by 2030;
- a ban on landfill disposal of separately collected waste (e.g. paper, glass packaging);

2.1.2 **Future waste targets as key driver of the circular economy**

The Commission believes that these targets will lead all EU member states to successively adopt proven methods and make the required investments (European Commission, 2015: 3). The following figures aim to illustrate the current status quo in the member states about the now envisaged targets for 2025/ 2030.

Municipal solid waste

Municipal solid waste (MSW) is still the priority waste stream of the European regulatory framework. The following figure indicates the countries’ progress towards the 2020, 2025 and 2030 targets in the years 2004

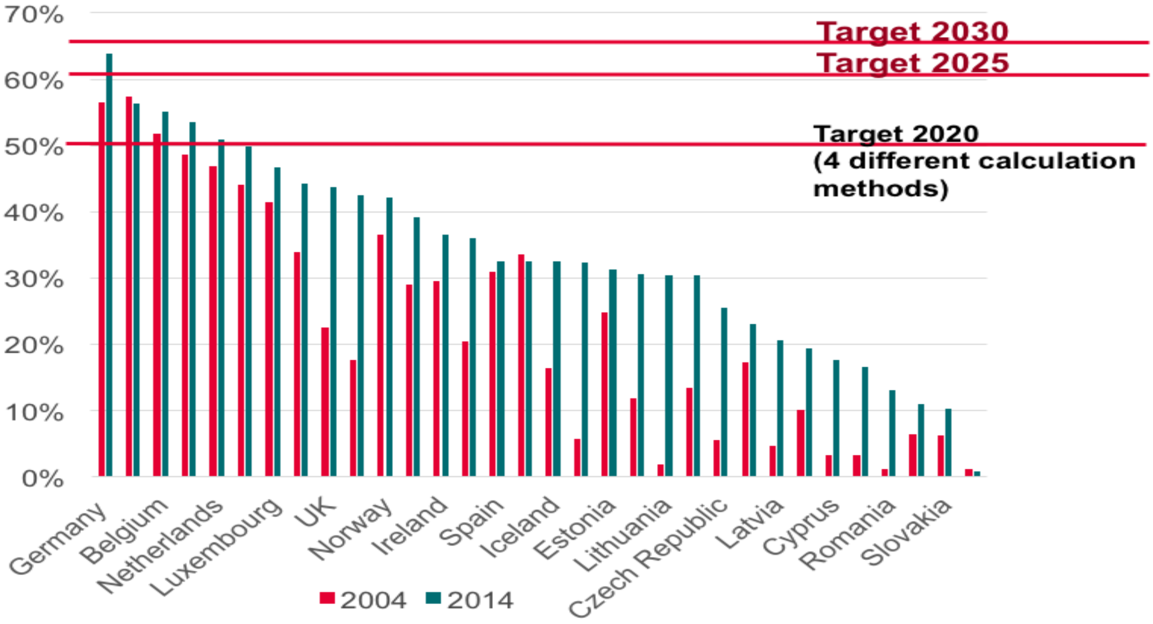

Figure 2. Waste Framework Directive – New targets for Municipal Solid Waste .Source: EEA, 2016

and 2014. Germany has already in 2014 reached the 2025 target. Whereas Belgium, the Netherlands and Luxembourg have already reached the minimum target for 2020, most countries are still below 50 %. There has been derogation for Estonia, Greece, Croatia, Latvia, Malta, Romania, and Slovakia of 5 more years to reach the target, as they show particularly bad results. It´s important to notice that as mentioned above the Commission would like to streamline the calculation method for the recycling rates and different methods will be tested.

Packaging waste and landfill targets

Despite limited volumes, packaging waste causes a significant share of environmental burdens, e.g. regarding marine littering. Therefore, it has been a key priority of EU waste legislation from the beginning. For packaging waste, as can be seen in the following figure, almost half of the countries have reached the 2025 target in 2013. Belgium even has achieved approx. 80 %, which is already above the 2030 goal. Only Lithuania, Greece, Latvia, Liechtenstein, Hungary, Malta and Poland are still below the 2008 target line. Looking at landfill targets for MSW, only 9 countries fall below the 10 % goal of 2030 in 2014. All other countries show significantly higher shares of MSW being landfilled. Also, there has been derogation for Estonia, Greece, Croatia, Latvia, Malta, Romania, and Slovakia of 5 more years to reach the target.

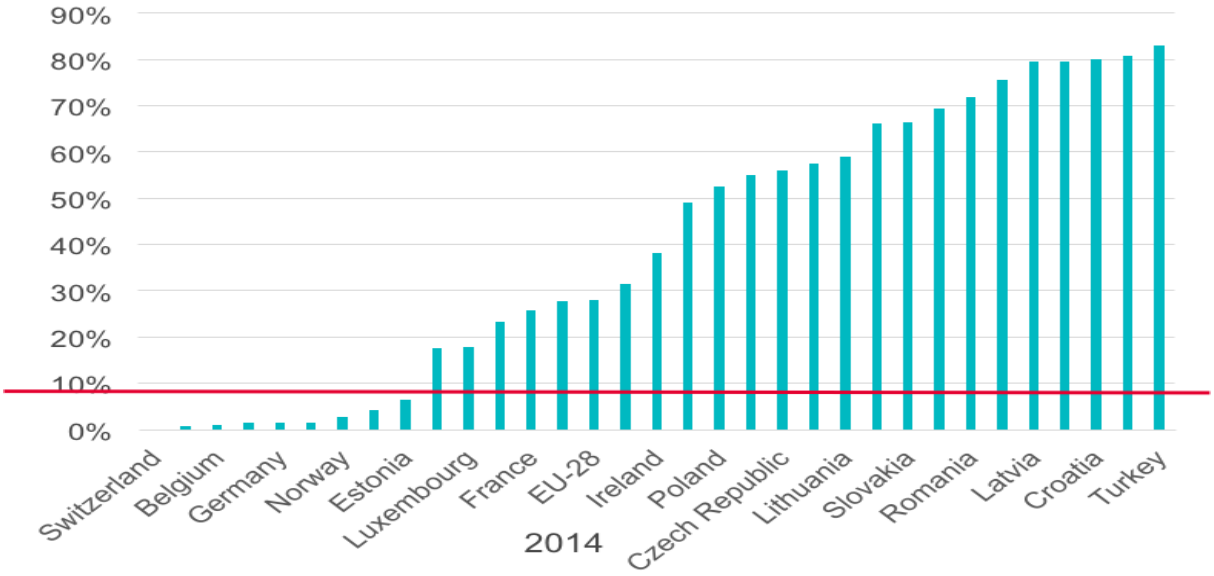

Figure 3. MSW landfill target, Source: EEA 2016

2.2 Policy Instruments to Support the Circular Economy

The Action Plan comprises a variety of measures to strengthen the implementation of the circular economy in the EU member states. As a policy innovation, the circular economy links waste management with production, consumption, and general policy frameworks.

2.2.1 *Production oriented policy instruments*

Support for Eco-design of products

Within the production phase, the Action Plan encourages an eco-design that promotes the reparability, durability and recyclability of products. A sustainable design may enable recyclers to disassemble products in order to recover valuable materials and components. However, current market signals appear insufficient to fulfil the Commission’s targets in particular because the interests of producers, users and recyclers are not aligned. It is therefore essential to provide incentives for improved product design while preserving the single market and competition and enabling innovation.

Looking at the required legal framework, the Commission’s Eco-design Directive consistently provides EU-wide rules in order to improve the environmental performance of products. This is achieved by setting minimum mandatory requirements so far mainly regarding the energy efficiency of these products, which helps to prevent the creation of trade barriers, to improve the product’s quality and to enhance environmental protection. It is implemented through product-specific regulations directly applied in all EU countries. Moreover, the Directive is complemented by harmonised European standards, indicating that a product fulfils the Directive’s requirements.

Only then the product gets the CE marking and can be put on the EU market. To guarantee this, the respective national market surveillance authorities verify the products.

Against this background, the European Commission has launched its Eco-design Working Plan 2016 – 2019: The Commission will continue to develop mandatory product design and marking requirements to make it easier and safer to dismantle, reuse and recycle especially electronic displays (e.g. computer monitors, televisions and electronic display integrated in other products). The Working Plan also aims to broadly integrate resource efficiency aspects into the evaluation criteria for products that so far are dominated by energy efficiency aspects. In the future, Eco-design will be stronger directed towards its contribution to the circular economy by systematically including issues such as durability and recyclability. This might also influence export-oriented sectors but at the same time offers opportunities for front-runners in the field of circular design.

Addressing planned obsolescence

A barrier to the circular economy is the planned obsolescence that occurs when a product is designed with the intention of it breaking, failing, or becoming unfashionable after a determined period of time. The Commission will initiate an independent testing programme to detect planned obsolescence practices and establish ways to address them. Although no specific EU regulation mentions planned obsolescence, the subject is tied to other EU legislation on eco-design, waste, the use of natural resources, consumer information and the recent Circular Economy Action Plan. Additionally, various ways to curb the practice of planned obsolescence have been proposed, promoting a shift towards enhanced product durability and sustainability. On the level of individual Member States, France has recently adopted a law defining planned obsolescence and making it a punishable offence.

Extended Producer Responsibility

Furthermore, the Action Plan demands an Extended Producer Responsibility (EPR). The EPR calls for an environmental policy approach in which the producer’s responsibility for a product is extended to the post-consumer stage of a product’s life cycle. Accordingly, producers are responsible for collecting or taking back used goods to sort and treat them for recycling. Incentives for producers to design easier recyclable products will further support the implementation of the EPR. Additionally, the industry will financially provide for collection and recycling. Having a national system to address the circular economy Action Plan will decrease pressure from municipalities. In the European Union, EPR is already mandatory in the context of WEEE, Batteries and End-of-Life Vehicles. The Packaging Directive indirectly includes the EPR principle by ensuring that the necessary collection and recycling systems are set up in the Member States. Furthermore, waste streams like tyres, waste oil, paper and card commonly show producer responsibility organisations. Already the 2005 Thematic Strategy on the Prevention and Recycling of Waste highlights EPR as a potential tool to increase recycling where the market does not otherwise financially set incentives for collection and recycling. This is complemented by the 2011

Roadmap to a Resource Efficient Europe, encouraging the adoption of EPR schemes. Hereby, the entire product lifecycle is covered via new business models, guidance on take-back and a better support for repair services. The European Parliament has therefore called on the Commission to further examine options for setting up a EU-wide EPR scheme to improve the overall resource efficiency in the EU.

Fostering industrial symbioses

In response to the global increase in waste accumulation, certain actors have begun to use resource scarcity and waste generation as solutions rather than problems. This refers specifically to industrial side streams, which also considered as wastes, e.g. distillate stillage, black liquor or crude tall oil from pulp industries. Industrial symbiosis describes the association between two or more companies or facilities in which the waste materials or by-products of one become the raw materials for the other. If firms turn their conventional partnership into part of a circular network, an initial step for an industrial symbiosis might be identified. Previously unexplored potential to add value, gain competitive advantage and achieve sustainable development goals may be tapped by through close and complex cooperation practices between industrial entities. The European Resource Efficiency Platform (EREP) has been established as a high-level group that advises the European Commission on how to turn political will into action on the ground. In June 2013, the Group credited industrial symbiosis networks for reducing carbon, preserving resources and improving the competitiveness of European companies, especially SMEs. The EREP subsequently called for the wide-scale implementation of industrial symbiosis networks across Europe - which is how EUR-ISA came about. Membership of EUR-ISA is open to any organisation that has proven expertise in establishing and implementing a facilitated industrial symbiosis network at local, regional or national level. EUR-ISA provides a framework for bringing leaders from industry, professional associations, policy makers, and NGOs together, enhancing the cooperation between organisations and combining activities.

Support for SMEs

The Commission has supported SMEs in their transition to the circular economy through the continued implementation of the Green Action Plan for SMEs. EU funds have also supported thousands of SMEs in the past decades, boosting resource efficiency, energy efficiency, and innovation in manufacturing and production. This support to SMEs continues from the cohesion policy funds in the 2014-2020 period. Especially the Executive Agency for Small and Medium-sized Enterprises manages programmes on behalf of the European Commission and turns EU policies into action. It manages significant parts of large-scale projects, such as COSME, LIFE, Horizon 2020 and EMFF. Therefore, they help to create a more competitive and resource-efficient European economy based on knowledge and innovation. Within the Horizon 2020 SME Instrument, projects like “Boosting the potential of small businesses in the areas of climate action, environment, resource efficiency and raw materials” recognise SMES as being able to become the engine of the green economy and facilitate the transition to a resource efficient, climate-smart circular economy. Especially SME often lack the time and resources to actually consider untapped economic opportunities from more circular business models and even limited consultancy support can help to pick low-hanging fruits in terms of economically viable investments with short amortisation periods.

2.2.2 *Consumption oriented policy instruments*

The European Commission´s Action Plan does not only address the production phase but also aims to influence consumer behaviour especially by providing reliable information to households so that they can benefit from the cost saving potentials of a circular economy.

Strengthening reuse and remanufacturing

As one of the key objectives the Action Plan addresses owners and society to promote reuse. The role of re-use and preparation for re-use in a circular economy has been significantly strengthened by the five-step waste hierarchy that now clearly states that reusing or remanufacturing of products should be preferably over all kinds of recycling. Reusing allows maximal practical benefits from products and generates minimum amount of waste. Thus the reuse of products or specific components will particularly efficiently help to reduce the demand for raw materials and especially maintain the physical assets and economic value of raw materials already contained in products. Both environmental and social benefits come along with reuse. 1/3 of goods collected at waste recycling centres are still reusable and could be sold second-hand instead of being recycled or landfilled. If only 1% of municipal waste in Europe was prepared for reuse, 200,000 local jobs could be created. Reintegrating one unemployed person through working at a social enterprise would benefit the government and society by a net return of 12.000 Euros (RREUSE, 2016). Just recently the interest in re-use has increased significantly – together with approaches to overcome "linear product systems of produce-use-throw away" – and new business models such as product-service systems based on leasing, renting or sharing (Vezzoli et al., 2014) have been developed and tested by innovative entrepreneurs. Nevertheless, there are significant barriers, especially a lack of common quality standards. The Commission aims to encourage reuse in different ways:

- Establish quality standards for reused and remanufactured products
- Support local and regional reuse networks in order to support the professionalization of the sector and to create economies of scale
- Enable the access of reuse organizations to relevant waste streams for they get mixed up
- Reuse may also be further strengthened by general policy frameworks, such as the Green Public Procurement programme.

Especially taking into account the labour intensity of reuse this issue could be of especially high interest.

Green Public Procurement

A key approach of the Action Plan is to see Europe's public authorities as major consumers: By using their purchasing power to choose environmentally friendly goods, services and works, they can make an important contribution to sustainable consumption and production and especially support circularity in domestic industry sectors. The European commission refers to this approach as Green Public Procurement (GPP) or green purchasing (European Commission, 2017[1]). Although GPP is a voluntary instrument, it has a key role to play in the EU's efforts to become a more resource-efficient and circular economy. It can help stimulate a critical mass of demand for more sustainable goods and services which otherwise would be difficult to get onto the market. GPP is therefore a strong stimulus for eco-innovation that creates business opportunities for the circular economy. To be effective, GPP requires the inclusion of clear and verifiable environmental criteria for products and services in the public procurement process. The European Commission and many European countries have developed guidance in this area, in the form of national GPP criteria and especially a European Green Public Procurement Guideline. This guideline sets criteria for office buildings, roads, and computers and monitors that are relevant to the circular economy. Requirements, for instance, aim at the durability and upgrade options, and can be adopted by public authorities on a voluntary basis.

2.2.3 *Policy instruments in the field of financing the circular economy*

In addition to policy instruments that directly target activities in the spheres of production or consumption; also, the overall policy framework will be of crucial importance for the transition towards a circular economy. The European Commission specifically addresses financing opportunities as a key framework condition.

Importance of innovative circular business models

Innovative business models based on closed cycles and resource efficiency are one of the most powerful drivers of the circular economy. Where successfully established, such business models will have a direct and lasting impact on the economic system and at the same time advance the adaptation of the necessary framework. Here very different approaches exist (see EEA, 2015). The various service-orientated concepts of “using instead of owning”, for example, seek to create economic incentives for long-lived product design with optimised return systems, and also to intensify customer relations. From the customer perspective, they often produce significantly greater transparency concerning the overall life cycle costs of products and thus enable more rational purchase decisions (Tukker and Tischner, 2006). Two examples of such approaches have already become classics: Xerox, as a supplier of copying services rather than photocopiers (where the service model already contributes almost 50 percent of company profits; Xerox, 2015) and the jet engine division of Rolls-Royce, whose power-by-the-hour contracts already include servicing and repairs. Other approaches focus more strongly on collective use through sharing or leasing. Here the business models generally involve the provision of online platforms for customer-to-customer exchange, whether private or commercial (B2B or C2C).

New financing models also play a crucial role. Whereas contracting is long-established in the field of energy efficiency, for example, similar models for circular economy concepts are frequently

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[1] http://ec.europa.eu/environment/gpp/index_en.htm

still in the early stages of development. The associated uncertainties and teething problems frequently make it difficult for innovative start-ups to gain the necessary access to capital markets. One fundamental problem affecting the aforementioned service-orientated concepts such as Xerox (and also Mud Jeans, for example) is that ownership remains with the manufacturer even in the use phase, and cash-flow is considerably delayed in comparison to linear business models. Such concepts could be supported by the new green bond market, although it is itself still in an early stage of development (EEA, 2014). Such circular economy business models could profit especially from ecological tax reforms, where the burden of taxation is shifted from work (earnings) onto resource consumption and environmental impact. This would particularly boost the position of reuse and remanufacturing – as labour-intensive sectors of the circular economy – vis-à-vis linear concepts for single-use products (EEA, 2014). A deeper understanding of such possible financial incentives and market-based instruments, along with their effects on the circular economy, will be one of the necessary preconditions for the successful implementation of new business models. One of the most successful examples in this field is the British National Industrial Symbiosis Programme (NISP), representing a network of more than 15,000 industrial enterprises to identify profitable transactions between businesses to optimise the use of resources including energy, water, waste and supplies. NISP has already enabled 47 million tonnes of industrial waste to be diverted away from landfill. It has also generated £1 billion and secured 10,000 jobs (ISL, 2015). As its example underlines, the promotion of new business models must be clearly tailored to national and regional contexts and circumstances. In Germany, developing programmes and funding formats tailored to regional innovation potential will be principally a matter for the federal states.

Investment strategies

The European Commission´s Circular Economy Action Plan explicitly aims to shift public investments away from investments in end-of-pipe waste infrastructures into such innovative business models: "Shifting the focus of waste management funds from waste incineration to closing material loops will financially push the implementation of the circular economy." (European Commission, 2015). Especially the European Investment Bank (EIB) will be a key partner in this process: Circular economy projects reduce resource use and are eligible for EIB financing on account of their environmental and climate benefits. Projects that include innovative features in products, production processes or business models are considered eligible owing to their contribution to innovation, which is another EIB priority. Overall, the EIB has co-financed circular economy projects worth around EUR 15bn in the last 10 years, but the circular economy lending needs and potential are clearly much larger. While in the past the EIB has mainly focused on municipal waste management projects, there is now both a need and potential to expand the lending to projects targeting commercial and industrial waste streams, in particular for the recycling and recovery of such waste. The associated market risk is different than for municipal waste, but can be managed under the European Fund for Strategic Investments (EFSI) and other risk mitigating instruments. EFSI is an initiative launched jointly by the EIB Group – European Investment Bank and European Investment Fund – and the European Commission to help bridge the current investment gap in the EU by mobilising private financing for strategic investments. EFSI consists of a EUR 16bn guarantee from the EU budget, complemented by an allocation of EUR 5bn of the EIB's own capital.

Figure 4. The waste management hierarchy according to the EU Waste Framework Directive, Source: European Commission, 2015

3. Waste Prevention Policies

Of specific interest for the transition towards is a circular economy is the question how effective incentives can be set for an avoidance of resource wastage. Waste prevention has been defined as top of the waste hierarchy mainly because of its environmental benefits: Avoiding the generation of waste throughout the value chain in most cases requires significantly less natural resources than preparation for reuse or recycling. These processes might allow keeping raw materials in the loop but they again require energy and other inputs, as well as leading to material losses due to down-cycling or leakages (Cox et al., 2010). But also for economic reasons waste prevention is the top priority because it offers significant cost-saving potentials. Companies that reduce the waste-intensity of their processes save money in terms of lower waste fees but also due to lower material purchasing or storage costs. From a societal point of view waste prevention offers opportunities to reduce necessary investments in waste treatment infrastructures like landfills or waste incineration plants._Waste prevention encompasses activities that reduce both the quantity and the hazardous character of wastes on a life-cycle basis. The following figure illustrates the waste hierarchy with its five steps. The last revision in 2006 introduced preparation for reuse as a specific step between recycling and prevention.

For the EU Member States the Waste Framework Directive requires the implementation of the waste hierarchy as a guiding principle in their waste legislation. As a consequence, it establishes waste prevention as a top priority in the legislative framework, also the establishment of specific waste prevention programmes is mandatory according to the Waste Frame Work Directive Article 29 that states ‘member states shall establish, in accordance with Articles 1 and 4, waste prevention programmes not later than 12 December 2013. The programmes provided for in paragraph 1 shall set out the waste prevention objectives. Member States shall describe the existing prevention measures and evaluate the usefulness of the examples of measures indicated in Annex IV or other appropriate measures’. Based on their specific waste prevention programmes or plans countries have developed an impressive variety of specific waste prevention measures that aim to avoid the generation of waste throughout the life cycle. The goal of this chapter is not to give a comprehensive overview about all past, on-going and planned measures but to highlight good practice examples in order to identify policy options for waste prevention. Given the complexity and variety of measures one challenge is to structure the measures in a meaningful way. The EU Waste Framework Directive has in its Annex IV developed a list of exemplary waste prevention measures that most countries have taken as a reporting structure (Box 3.1).

Box 3.1 Reporting structure of waste prevention measures according to the EU Waste Framework Directive- WASTE PREVENTION MEASURES ACCORDING TO THE LIFE-CYCLE APPROACH. **Annex IV of the Waste Framework Directive categorises the examples of waste prevention measures into 16 measures that are addressed in three areas:**

A. Framework conditions related to the generation of waste:

- supporting efficient use of resources
- promotion of research and development
- development of indicators.

B. Design, production and distribution phase:

- promotion of eco-design
- provision of information on waste prevention techniques
- organizing training to include waste prevention in permits
- prevention of waste production at installations
- use of awareness campaigns and other support to businesses
- helping businesses to establish their own waste prevention programmes
- promotion of environmental management systems.

C. Consumption and use phase:

- introducing economic instruments (subsidies, charges) to prevent waste
- provision of information for consumers
- promotion of eco-labels
- agreements with industry
- integration of environmental criteria into calls for tenders and contracts
- promotion of reuse and repair.

3.1 *Production Phase*

Waste prevention in the production phase refers to a broad range of policy measures with a significant potential to reduce the amount of waste that is generated and the related environmental impacts. Waste prevention in this phase inter alia includes the efficient extraction of raw materials as well as production processes that minimise the waste of resources. The production phase also covers the smart distribution and logistics that highly influence the share of products wasted before they even reach private households. And it includes all aspects of waste-light product design (e.g. reparability, upgrade options etc.) that be a key aspect for waste prevention. Waste prevention programmes all around the globe show a variety of different policy measures in this field including economic, regulatory and information-based measures. The following presents selected good practice examples, many of which are implemented in similar ways in other countries.

Economic Instruments

Economic or market-based instruments aim to set financial incentives that support waste prevention efforts. This includes disposal fees for industry or municipalities as well as subsidies for less waste-intensive production patterns. All these instruments aim to internalise the external costs of waste generation in the production costs. Box 3.2 presents an example from New Zealand which uses a waste disposal levy, similar to the practices in many other countries. Another increasingly important field for market-based approaches is support for new circular business models, such as those are based on sharing or leasing and help to reduce waste generation.

Box 3.2 Production phase, economic instruments - Case study: New Zealand

The waste disposal levy for all waste sent to landfill was mandatory introduced under the Waste Minimisation Act 2008 (Ministry of the Environment, 2013a). Disposal facility operators must pay $10 per tonne (excluding GST) of waste they dispose of at their facility. Disposal facility operators (as defined by the Waste Minimisation Act 2008) may pass this cost on to the waste producer, e.g. businesses. The objective of the levy is to encourage waste minimisation by increasing the cost of waste disposal, creating funding opportunities for waste minimisation initiatives as well as providing an economic incentive to polluters to change their behaviour. The revenue from the levy is distributed to territorial authorities, is put into the Waste Minimisation Fund and used to recover administrative costs associated with the waste disposal levy.

The waste disposal levy payments to territorial authorities' accounts for half of the revenue collected and is calculated on the basis of the population. Territorial authorities are obligated to spend the money on promoting and implementing waste minimisation in accordance with their waste management and minimisation plan (WMMP). To help territorial authorities in their spending decisions the Ministry of the Environment published Waste Levy Spending Guidelines for territorial authorities (Ministry of the Environment, 2013b). Councils report regularly on their spending of the waste disposal levy revenue, e.g. communication and education or research. Levy revenue used to recover administrative costs associated with the waste disposal levy include initial one off costs (e.g. developing guidance for councils, IT systems to manage levy collection) and on-going administrative costs (e.g. collection of the levy from disposal facility operators, monitoring that territorial authorities are using the funds for the intended purposes).

The remaining levy revenue goes to the Waste Minimisation Fund. Approximately $10-12 million is collected through the levy per year (Ministry of the Environment, 2013c). The Fund funds projects that promote or implement waste minimisation.

Regulatory Instruments

Regulatory instruments based on laws or technical requirements have been the dominant approach for waste management in most countries. With regard to waste prevention the share of such strict and binding instruments in the production phase is significantly lower and often focussed on qualitative waste prevention by regulating the use of hazardous substances. Also, most countries now use a pollutant release and transfer registers to raise awareness and encourage improved environmental performance as an incentive for waste prevention. Box 3.3 provides an example of how such a register is used in Israel.

Box 3.3 Production phase, regulatory instruments - Case study: Israel

ISRAEL: POLLUTANT RELEASE AND TRANSFER REGISTER (PRTR)

Israel's Protection of the Environment (Releases and Transfers to the Environment – Reporting and Registration Obligations) Law came into force in April 2012 and introduced the Pollutant Release and Transfer Register. The PRTR was officially launched in 2013. The law requires facilities with significant impact on the environment, which encompass hundreds of facilities, to report on their emissions and transfers of waste. The main objectives of the law are to increase the transparency of environmental information in Israel and to encourage facilities to reduce emissions and transfers of pollutants and waste into the environment. The mandatory program is aimed to encourage different sectors of the economy to improve their environmental performance, adopt cleaner production techniques, reduce pollution and waste and increase efficiency.

Data on 114 pollutants released to air, water, sea and soil or transferred offsite for treatment and disposal of waste and wastewater, is published on the website of the Environmental Protection Ministry (http://www.sviva.gov.il/PRTRIsrael/Pages/default.aspx) and accessibly for the public. The data is submitted based on reports by more than 400 factories in Israel. The main industries are active in the fields energy, production and processing of metals, minerals, chemicals, waste and wastewater management, intensive agriculture as well as food and beverages (Israel Ministry of environmental protection, 2015). In 2013, 497 reports were submitted (Israel Ministry of environmental protection, 2014).

Similar registries exist in several other countries, e.g. the European Pollutant Emission Register (EPER) and can be seen as a starting point for concrete waste prevention measures mainly focusing on hazardous waste.

Information-based instruments

Based on the information provided by the countries for this report but also other reviews of waste prevention measures there is a clear focus on information-based waste prevention measures targeted at the production phase that aim to highlight potential cost saving opportunities for the industry as well as the marketing effects of greener products or processes (see EEA, 2014). An example for Sweden is provided in box 3.4, but similar measures are being developed in many countries, focusing on specific sectors (e.g., construction and demolition, packaging), types of enterprises (usually SMEs), particular life-cycle phases (e.g., product design, production), or aiming at promoting synergies between sectors (e.g., industrial symbiosis).

Box 3.4 Case Study: Sweden

SWEDEN: DIALOGUE WITH THE TEXTILE INDUSTRY, 2011-2014

The dialogue between the Swedish Chemicals Agency and industry professionals was part of the national action plan for a toxic-free everyday environment, on-going 2011-2014 (KEMI, 2015). The dialogue was about the risks of hazardous substances in articles. Important objectives of the dialogue were to increase the company's awareness and knowledge about the risks of hazardous substances in articles as well as reducing chemical risks by voluntarily phase out hazardous chemicals beyond what the law requires.

The dialogue provided the opportunity to exchange knowledge between different companies, but also between companies, researchers, government agencies and industry associations. The participants contribute to the creation of proposal for new policies for textiles on EU-level, support a “Call for Action” sent to the commission to push for sharper policies on chemicals in textiles in REACH and established a research project where participators create a knowledge platform on chemicals and textiles. Overall the dialogues have led to an increased knowledge on use and content of hazardous substances in textiles compared to 2014.

Other instruments

Voluntary agreements on waste prevention have raised increasing attention over the last years; especially if they combine easy to monitor indicators and targets with sufficient flexibility for the producers how to reduce waste generation or toxicity of waste. The Australian Packaging Covenant (Australian Department of the Environment, 2011) can be seen as a good practice example of a voluntary agreement.

The analysis of on-going and planned activities in the countries shows some common characteristics:

- There is a clear focus on **information-oriented measures** that in most cases aim to highlight cost saving potentials based on existing good practice examples. Many of these measures seem to be based on an underlying assumption that there is a large potential of win-win waste prevention opportunities that enterprises are currently not exploiting due to transaction costs of information gathering or evaluation. These measures are in many cases related to voluntary agreements by industrial sectors. Some countries, such as Spain, also focus on chain-approaches that aim at waste prevention potentials that are located at the interface of different steps in the value chain. These measures are often related to voluntary agreements by industrial sectors that often include quantitative targets.
- **Regulatory approaches** often focus on product regulation especially with regard to hazardous substances. In some countries this is closely linked to health issues as an important enabler of qualitative waste prevention. At the same time countries seem to struggle to select relevant products, given the complexity and dynamics of product innovation. Another challenge that such approaches present lies in the significant level of cross-departmental and/or cross-jurisdictional coordination that is required.

- **Economic instruments** for waste prevention seem to be used to a lesser extent on the production side. Disposal fees that often also refer to the consumption side set some incentives for waste prevention, but the main effects relate to improved sorting and pre-treatment of waste. Another subcategory is **market-creating instruments that** emphasize the reduction of transaction costs e.g. by defining common quality standards etc.

3.2 *Consumption Phase*

Countries also reported a variety of policy measures aimed at the consumption phase. They are essentially used to encourage private households to reduce the amount of waste that they generate because of their consumption patterns. In the following a few good practice examples are presented.

Economic Instruments

Some types of economic instruments for waste prevention on the consumption side are applied in most of countries. This is especially the case of waste fees for residual waste or other waste streams from households (e.g. “pay-as-you-throw” and deposit/refund schemes). In most cases these fees set incentives to generate less waste, but they are mainly focussing on better collection and sorting. The OECD Greening Household Behaviour states that waste generation tends to be between 20% and 30% lower with unit pricing by volume or weight (OECD, 2014, p. 221). Nevertheless, flat fees are still the most common billing scheme in most countries that thus miss out significant waste prevention potentials.

Also, different forms of subsidies or economic incentives related to public procurement can be seen in several countries. Boxes 3.5 and 3.6 present an example of a public procurement related measure in Finland and of subsidies for reuse in Brussels, Belgium. The potential impact of green public procurement on the market is potentially large, given that the public-sector accounts for 10-25% of spending in many countries (European Commission, 2016).

Similarly, an increasing number of countries are now introducing measures to reduce the use of single carrier plastic bags. The European Commission has revised the Packaging Directive that now obligates all EU member states Member States to either adopt measures ensuring that the annual consumption level does not exceed 90 lightweight plastic carrier bags per person by 31 December 2019 and 40 lightweight plastic carrier bags per person by 31 December 2025 or the adoption of instruments ensuring that, by 31 December 2018, lightweight plastic carrier bags are not provided free of charge at the point of sale of goods or products, unless equally effective instruments are implemented (European Commission, 2015b). Already in 2002 Ireland introduced a plastic bag levy at the rate of 15 cent per bag. Its primary purpose is to reduce the consumption of disposable plastic bags by influencing consumer behaviour. All levies are remitted into the Environment Fund. It had an immediate effect on consumer behaviour with a decrease in plastic bag usage from an estimated 328 bags per capita to 21 bags per capita. This has fallen further to an estimated 14 bags per capita in 2014. In Germany, the national retail association HDE initiated a voluntary agreement not give away plastic bags for free. In the United States California passed a law prohibiting their use in September 2014 and it was implemented on July 1, 2015.

Box 3.5 Consumption phase, economic instruments – Case study: Finland

FINLAND: SUSTAINABLE PUBLIC PROCUREMENT

Finland is inter alia focussing on public procurement as an economic instrument to support waste prevention. In order to support Finish municipalities with legal and practical issues a help-desk has been set up that is managed by Motiva – an in-house unit of the government agency (the company's entire share stock is in Finnish state ownership) (Motiva, 2015) – and facilitates sustainable public procurement decisions by answering questions, disseminating information and providing consultancy in the planning of procurement (see Figure 5).

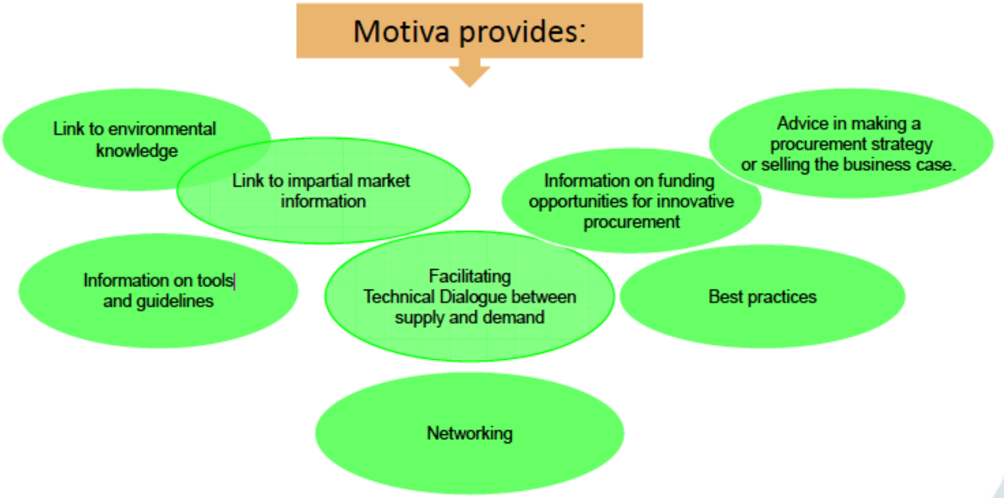

Figure 5. Motiva services, Source: Motiva, 2012

The overall objective of the service is to provide an opportunity for a purchasing entity to find the technologically and environmentally most advantageous solution more easily. The first phase of the service ran from 2008 to 2011; the on-going phase started in 2012 (Motiva, 2012). The service is free and intended for all public procures in public entities and municipalities, but can also provide project-based consultancy or for instance arrange supply side dialogues (Bergmann et al., 2012).

Box 3.6 Consumption phase, economic instruments - Case Study: Belgium

BELGIUM: SUBSIDIES TO SOCIAL ECONOMY ACTING IN THE REUSE SECTOR

Since the 90's, the Brussels region financially supports social economy associations acting in the reuse and recycling sector. The subsidy (since 2005) is provided to social economy actors according to the quantities of collected discarded products and products reused. The objectives of the subsidies are to support waste prevention by reuse and preparation for reuse, limit consumption of new goods, provide job and training to people socially marginalised as well as access to goods to people with low level of income (regions4recycling, 2014).

Overall, four categories of goods are subsidised - textile, bulky waste, waste electrical and electronic equipment (WEEE) and printer related consumable goods. Some categories are subsidised based on the quantity of collected material (WEEE and bulky waste) and all categories are subsidised based on the quantity of reused product. In 2014, following subsidies were granted (regions4recycling, 2014):

- 62€/tonne of reused textile
- 60€/tonne of reused bulky items and EEE items
- 3€/laser toner and
- 1€/ink jet toner.

Information-based instruments

The following presents just a small part of the variety of information-based instruments reported by the countries. Provision of information for specific waste streams, measures or groups of stakeholders count for a large share of activities in most of the countries.

Awareness Raising Campaigns	(a) Can be seen as the key instrument for waste prevention, aiming at specific target groups, waste streams or prevention approaches. Food waste prevention has been in the focus of many of these activities (see for example a good practice example from Spain in box 3.7). (b) The Greening Household Behaviour Report found that so far there is only limited awareness that food waste generation has negative environmental consequences (with Sweden, France and Korea as exceptions with high levels of awareness) (OECD, 2014, p. 196). (c) The need for awareness raising campaigns is also supported by the fact that households in almost all countries clearly underestimate the share of food that is thrown away (ibid, p. 197).
Eco-Labelling	(a) Several countries are applying eco-labelling for waste prevention. (b) Eco-labels are used for a variety of different product groups such as lamps, textiles or repaired products. (c) A recent OECD report shows a rapid increase of environmental labelling and information schemes, with their number more than doubling between 2000 and 2012.[2] In some cases labelling schemes have proven to be very successful as a guiding instrument for consumers. However, there are also concerns (1) that the multiplication of labelling schemes could lead to consumers and procurers finding it harder to distinguish good from bad labels; (2) that they could modify market access; that firms may bear excess costs in certifying with many different labels; (3) and that competition may drive down the stringency of standards as different labelling schemes bid for market share.

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[2] OECD (forthcoming 2016), Synthesis report on environmental labels and information schemes, Paris

Especially awareness raising campaigns can be seen as the key instrument for waste prevention, aiming at specific target groups, waste streams or prevention approaches. Food waste prevention has been in the focus of many of these activities (see for example a good practice example from Spain in box 3.7). The OECD Greening Household Behaviour Report found that so far there is only limited awareness that food waste generation has negative environmental consequences (with Sweden, France and Korea as exceptions with high levels of awareness) (OECD, 2014, p. 196). The need for awareness raising campaigns is also supported by the fact that households in almost all countries clearly underestimate the share of food that is thrown away (ibid, p. 197).

Another relevant instrument is eco-labelling with several countries applying this for waste prevention. Eco-labels are used for a variety of different product groups such as lamps, textiles or repaired products. A recent OECD report shows a rapid increase of environmental labelling and information schemes, with their number more than doubling between 2000 and 2012. In some cases, labelling schemes like the "Blauer Engel" (blue angel) in Germany have proven to be very successful as a guiding instrument for consumers, especially with regard to qualitative prevention by setting incentives to produce products with less hazardous substances. However, there are also concerns that the multiplication of labelling schemes could lead to consumers and procurers finding it harder to distinguish good from bad labels; that they could modify market access; that firms may bear excess costs in certifying with many different labels; and that competition may drive down the stringency of standards as different labelling schemes bid for market share. Despite different approaches or priorities in the countries covered by this survey, the analysis allows to draw the following conclusions:

- The majority of programmes show a clear focus on information-based measures that appeal to either environmental consciousness or cost saving potentials by waste prevention. Especially in countries with high quality waste infrastructures consumers are often very aware of their responsibilities to sort waste properly but in general waste is seen as a "solved problem" and it is sometimes difficult to communicate the necessity for waste prevention. Against this background many food waste prevention campaigns successfully managed to link waste prevention to social aspects of fairness and poverty.
- As outlined above many economic instruments focus on improving collection and sorting with clear positive benefits for material recovery but less so for waste prevention. The level of costs for waste disposal and waste fees for private households are in most cases considered to be too low in order to set sufficient incentives for waste prevention.
- Especially for the consumption side many countries have developed integrated approaches that include a set of different measures. Similar to voluntary agreements in the production phase these often follow a chain approach that aims to bring together different stakeholders, from the consumption as well as from the production side.
- Interestingly only very few (1%) countries reported the use of regulatory instruments for waste prevention in the consumption phase. Obviously, it is much more common to

regulate waste treatment by laws or technical standards but as waste prevention is very closely linked to consumption patterns it is very difficult and politically sensitive to intervene in this field with strict and binding instruments. Against this background there is a clear focus on allowing "informed choices" by informative instruments.

4. Conclusions

Facing the comprehensive approach of the circular economy concept aiming at radical innovations alongside the whole value chain, also the number of policy instruments shows an impressive variety – obviously the key challenge is not a lack of generic ideas but the need for a coordinated approach that brings all these different aspects together. As highlighted in this chapter especially the policy arenas on waste management and waste prevention could significantly benefit from a more coherent policy mix for the circular economy. Based on the analysis of these circular economy policies, four main conclusions can be drawn:

(A) The circular economy is more than improved waste management

One of the central conclusions is that the circular economy debate often still concentrates too strongly on the topic of waste management. There continues to be an excessive focus on measures that only take effect at the end of a product's life cycle, such as optimised separation of recyclable materials from residual waste or reclamation of metals from incinerator ash. In fact, technical optimisation measures can also expand the economic and ecological potential – although in comparison to the possibilities of a real circular economy these appear rather marginal. From the perspective of many citizens – and also political decision-makers – this made waste into a problem that had been technically "solved". One central challenge will consist in communicating that circular economy means much more than better waste separation and technically optimised waste management.

(B) The circular economy must bring new actors on board

Technical innovations will also play a central role in the circular economy. This is especially necessary in relation to the design of products, which need to be long-lived, repairable, and 100 percent recyclable. Yet the technical aspects of the circular economy are probably in fact the easier part of the challenge of switching an entire economic system from linear to circular. Especially in comparison to waste management, a whole new realm of cooperation and coordination will be required in order to make this model viable right along the entire value chain. Resource producers, product designers, merchants, consumers and not least waste management actors will have to work together on optimised solutions, rather than continuing to concentrate solely on "their" elements of the chain (optimised resource extraction, process optimisation, improved recycling rates etc.). For example, repairable products can only be sensibly developed if users also possess the necessary skills. This simple example suffices to underline why the European Commission for example speaks of the necessity for fundamental systemic innovations in connection with the circular economy. On top of this comes the challenge of connecting actors at very different levels: from globally operating corporations through European and national legislation down to the neighbourhood, where for example shared use can be arranged for power drills (which otherwise go unused 99 percent of the time).

(C) Waste prevention targets and efficiency assessment

The analysis has shown a surprising variety of policies related to waste prevention. Nevertheless, clearer and more coherent policy frameworks will be needed in the future, especially with regard to binding targets. EU Member states may define specific quantitative targets under Article 29 (3) of the Waste Framework Directive (but are not required to). In fact, only twenty of the twenty-seven programmes published by 2015 contained quantitative targets for waste avoidance.

Certain targets relate to total waste, others to specific sectors or waste types (EEA, 2015). Spain, Scotland and Wales have set quantitative targets for the total amount of waste; Italy has reduction targets tied to GDP. So, most of the programmes are seeking absolute decoupling, which is regarded as a challenge because the volume of waste is historically linked to economic growth. Latvia has not set a reduction target, but instead defined an upper limit of 400 kilograms of household waste per head by 2020. The Netherlands has set a maximum limit for total waste production of 68 megatons in 2015 and 73 megatons in 2021 (the figure for 2006 was 60 megatons). The Brussels region, the Netherlands and Sweden have set targets for food waste. Wales has set targets for waste reduction in certain sectors of the economy. The Swedish programme includes a general target intended to contribute to reducing dangerous substances in materials and products (EEA, 2015).

Most countries recognise the need to assess waste prevention policies. Using waste prevention indicators governments try to assess the success of their programmes and to identify the need for additional waste prevention policies. Most evaluation approaches and indicators focus on the process of waste prevention and only few monitor concrete outcomes of specific measures. Analysis of avoided waste generation or prevented environmental impacts would require a variety of assumptions with regard to waste generation baselines.

Approaches for the selection and operationalization of waste prevention indicators differ significantly making cross country comparisons difficult if not impossible. Only a few countries mention specific criteria or the procedure for the establishment of indicators.

With regard to the concrete assessment of environmental or economic benefits generated by waste prevention measures or programmes there seems to be a clear need for further support to the countries. With only three out of twenty-four countries indicating an intention to assess the economic efficiency of waste prevention, there is a need to develop methodologies to assist countries in this regard. Especially approaches and methods that would enable to prioritise activities and to identify measures with high levels of environmental effectiveness and economic efficiency could be helpful. Also, specific tools that would allow for an ex-ante assessments of economic benefits related to specific waste prevention measures could helpful.

Based on the available information there is also room to improve the consistency of indicators, targets and monitoring schemes. In several countries, there seems to be a gap between these categories, e.g. quantitative targets are not really covered by the indicators mentioned in the programme. Also, many countries are not explicit about the way they are planning to monitor and assess their programmes.

(D) The circular economy requires a new mix of instruments

Shaping the framework that could support a circular economy will require new policy instruments that extend far beyond existing waste legislation. As outlined above, such instruments should operate in particular where the cycles intersect: product design to enable recycling; business models that minimise waste, etc.

The big challenge will be to integrate these instruments in a new policy mix:

1. in which the individual elements are complementary and ideally mutually reinforcing. On account of the often unclear objectives for the future of the circular economy, relevant policy in Germany still often appears inconsistent and too many existing arrangements are still designed for a classical linear system – for example for the disposal of construction and demolition waste that could be used as a resource elsewhere.
2. that brings together in a sensible framework responsibility that are distributed over a wide range of political levels and ministries. This also includes the question of the responsibility of local authorities and private-sector waste operators, which needs to be considered more strongly from the perspective of a long-term circular economy and less in terms of short-term market share.

Only a policy mix of that type can in the long term create the necessary stable and credible framework within which businesses will invest in innovative circular-capable production processes and consumers will be able to enjoy the advantages of such a sustainable economic model.

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Chapter 5

RESOURCE EFFICIENCY AND CIRCULARITY IN ENGINEERING HIGHER EDUCATION

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Abstract

Changing engineering student's knowledge, skills and attitudes about resource efficiency, regenerative design and circularity in the built environment is a serious challenge. The development of engineering students' capabilities to design within a circular economy paradigm in higher education can foster sustainable behavior and contribute to the global sustainable development global agenda. This chapter presents the experience of introducing the concept of regenerative design within a project oriented design studio for undergraduates. The regenerative design objective and principles are used a method to develop engineer's capabilities to design within a circular economy paradigm. The aim of the study is to evaluate the adoption of circular economy principles and their influence on the decision making and final outcomes. A state of the art provides an over view on the similar approaches to incorporate sustainability into university courses and curricula with a focus out case study to make a step forward. The chapter describes a thorough evaluation of the course and report the outcomes in the form of projects evaluation and students' feedback, interviews and surveys, to assess the students' knowledge uptake, learned skills and design capabilities. Students completed a knowledge, skills, and attitudes questionnaire before the curriculum, after the final learning experience, and one year later. This chapter provides insights into the effectiveness of introducing circularity in an engineering course. Based on the lessons learned from our case study we provide a discussion on the main challenges such as complexity, decision making uncertainty and interdisciplinary, institutional reforms in engineering higher education. Finally, the chapter presents a range of tangible and realistic recommendations to better incorporate resource efficiency and circularity in engineering higher education.

Keywords: sustainable development, regenerative design, project-based approach, students, interdisciplinary, lessons learned

1. Introduction

The radical changes necessary for our planet require a vision that is rooted within an ecological paradigm. The tendency of urban sprawl and resource intensive built environment during the last decennia is contradicting with the need for positive impact development and the principles of sustainability. The urban sprawl is not only consuming large areas of resources and soil but is associated with negative environmental impacts, social and cultural disparities beside the overall decreasing incremental environmental cost.

Today’s problems require more complex, dynamic and sustainable solutions. Resource efficiency and circular economy are new paradigms that will influence both the ease of acceptance by and the direction in which circularity and regenerative design will change our society. Leaders and policymakers face requirements to simultaneously meet multiple needs and manage complex problems. In this context, Universities are expected to prepare students to work on the topic of resource efficiency and circularity and get engaged to address this new paradigm from a professional and academic interdisciplinary approach. According to Nandan and London (2013), social change initiatives are best approached from an interdisciplinary approach that is more holistic. In literature, there are several studies that identified the skills and competencies required to address complex problems including critical thinking, collaboration, communication, leadership, motivation, analytical thinking, group work and adaptive competence.

Moreover, interdisciplinary teams are found in the professional work and operate among heterogeneous groups of professionals and not in academia. Interdisciplinary work includes a different set of values, codes of conduct, and ways of learning. On the other side, traditional engineering higher education is based on deep specialization and reductionist approaches within tightly bounded disciplinary silos (ABET 2017). The specialization creates social and cognitive boundaries reducing collaboration and innovation (Nandan and London 2013). Therefore, graduates do not learn and develop skills required for being socialized into interdisciplinary work, which is essential for addressing resource efficiency and circular economy.

To counteract these silos and face these challenges the architectural design studio of the third -year architectural engineering students at Liege University in Belgium, is playing a central role for challenging its students to generate building that are resource efficient and circular. Within the Faculty of Engineering (Applied Sciences) the students are challenged to apply the principles of regenerative design for a collective housing project. The key question of the studio is: How can architects construct buildings with positive impact on the environment while addressing habitat, materials, energy, water and biodiversity.

In this context, the chapter intends to assess the students’ learning experience using qualitative and quantitative evaluation methods. In order to clarify the discussion on how to introduce resource efficiency and circular economy into engineering curriculum and in order to provide suggestions for implementation, this study aims to:

- Contribute to conceptualizing ‘resource efficiency and circular economy’ in academic education

- Suggest a range of actions that could contribute to the integration of circularity and sustainability in academic education

The importance of this study is significantly highlighted in the studio's ability to achieve an informed decision-making process regarding regenerative design and circularly in the built environment. Secondary, the study provided a reflection on the assessment of learning outcomes, expected knowledge, skills, attitudes, competencies and habits that student acquired during the studio's learning process. With its focus on the design experience and knowledge uptake this article will be of interest to engineers, architects, educators and researchers concerned with engineering education of sustainable development (EESD). The chapter determines the needs for interdisciplinary approaches, pedagogical and educational engagement to ascertain and quantify the effort needed to understand and apply the circular economy principles in future curricula.

This chapter is organized into five sections. The first section identifies the research topic. The second describes similar studios and courses that have been presented in literature aiming to describe the state of the art. The third section identifies the research methods and studio evaluation metrics and setting. The analysis of the results and the self-reported survey and questionnaires findings are presented in Section 4. The final section discusses the research finding and study limitations along with implications for future teaching and education.

2. Resource efficiency and circularity in engineering higher education

Resource efficiency and circularity in engineering higher education is a growing field of research and practice. This section describes the resource efficiency and circularity and sets a frame of definition to make it easier for the reader to understand and recognize those terms. Setting definitions qualifies to develop sub concepts and translate them into a common understanding. Also we will explore and review scientific literature and examine the approaches that introduced sustainability in the engineering curricula.

2.1. ***Definitions***

Resource efficiency and regenerative design forms an essential basis for circularity in the built environment. The increasing population growth and ecological destruction requires increasing the ecological carrying capacity beyond pre-industrial conditions. Regenerative design seeks positive impact development that incorporates maximizing the viability of harnessing renewable resources and become independent from depleting and polluting resources. In order, to achieve positive building footprint we must move from the cradle to grave paradigm that aims to reduce, avoid, minimize or prevent the use of fossil energy to a regenerative paradigm that aims to increase, support, and optimize the use of renewable (Lyle, 1996a). As shown in Figure 1, the previous efficiency strategies have been operating within a carbon negative or neutral approach that will never reach a positive and beneficial building footprint. Even the existing net balance approach assumes a fundamental dependence on fossil fuels. Therefore, we define the positive impact of the built environment from a renewable self-efficiency paradigm.

Figure 1. Paradigm shift towards a beneficial, circular and positive impact footprint of the built environment.

Regenerative design in the built environment seeks the highest efficiency in the management of combined resources and maximum generation of renewable resources. It seeks positive development to increase the carrying capacity to reverse ecological footprint. The building’s resource management emphasizes the viability of harnessing renewable resources and allows energy exchange and micro generation within urban boundaries (Attia & De Herde, 2011). Over the past years, regenerative positive development paradigm has been garnering increasing influence on the evolution of architecture. The progress is dramatic: plus energy plus, earth buildings, healthy buildings, positive impact buildings. This new way of thinking entails the integration of natural and human living systems to create and sustain greater health for both accompanied technological progress (Attia 2016a and 2017a).

2.2. ***Past research***

There is an extensive body of literature examining the effects of introducing sustainability in the engineering curricula on the students’ knowledge and skills and final learning outcomes. Higher education institutions have always been actors of change and innovation in the society (Huge et al., 2016, Kohtala C. 2015, Peer et al., 2013). The research on sustainability in academia has found a solid ground in publications, campuses and curricula all over the world (Lidgren et al., 2006). Higher education institution act as models in the society and have a critical role in creating a future that is sustainable.

In this context, we reviewed the key references drawn from a wide range of relevant journal and conferences. The international conference on Engineering Education in Sustainable Development (EESD) proceedings include several examples of integrating sustainable principles, resource efficiency and circularity as a framework for a redesign of engineering education and of engineering education institutions. Also, the International Journal of Sustainability in Higher Education, the Journal of Cleaner Production, the Journal of Perspectives: Policy and Practice in Higher Education and the Journal of Architectural Education provide a series of valuable publications related to introducing sustainability into engineering curricula. Also, we looked in the local Belgian context by reviewing the outcomes of the Doctoral Seminar on Sustainability Research in the Built Environment (DS2BE 2017). Three screening criteria were used to reduce the initial pool of 60 conference and journal articles to a focused set of representative studies: (a) review articles; (b) empirical studies (c) studies with an educational assessment or intervention with learner outcomes measured quantitatively or quantitatively; and (c) research that focus on architectural and engineering curricula due to the specific nature of our architectural engineering students.

Under the review articles we grouped the manuscripts under two groups. The first group is focused on integrating sustainability into engineering curriculum and second group is focused on integrating sustainability into architectural engineering curriculum. The first group of manuscripts include the study of Davidson et al. (2014) that discussed some efforts taken place in the United States, namely the activities of the Centre for Sustainable Engineering operated by a consortium of universities. The paper describes an initiative to develop a community oriented platform to serve as a repository for educational materials. Similarly, McPherson et al. (2015) compared engineering programs in Canada and review and analyzed the sustainability integration in curricula but with a focus on sustainable energy. The undergraduate programs reviewed by the authors were classified as conventional engineering programs with a sustainability add-on courses and did not embed sustainability fully in the curricula. Likewise, the study of Vargas, L. et al. (2015) reported embedding sustainability in the curriculum of engineering school but only for the University of Chile.

The second group of manuscripts has an architectural focus including the work of Álvarez et al., (2016) who compared the presence of sustainability in architectural education is Asia with a focus on professional degree curricula. The study provided an overview of 20 selected influential schools in 11 countries according to contents, intensity and teaching modalities. Sustainability design studios received a special attention by the study and were examined against the three sustainability areas of ecology, society and economy. The study provided qualitative and compared the curricula without describing their sustainability thematic content in detail. Similar to this study is the study of Olweny (2013) who investigated the presence of environmental sustainable design and energy efficiency in architecture education in East Africa and the work of Trebilcock (2011) in Chile. His study highlighted the basic integration of sustainability with at least one course in the studies curricula and the need for more integration efforts. Moreover, Wright (2003) provided a brief review on introducing sustainability into the architecture curriculum in the United States. The paper is out-dated and focused on the integration of sustainability in architectural programs. However, the publication of Iulo et al., (2013) provided an interesting overview of six architecture programs in the United States considered to be leaders in sustainability education. The study findings highlighted consistent approaches to promote sustainability core values to undergraduate architectural education by supporting courses fulfil needs for sustainable education and encourage students’ choice and specialization to sustainable design.

The most important manuscripts in this group are the COTE and EDUCATE reports. The Committee on the Environment (COTE), which serves as the community and voice on behalf of AIA architects regarding sustainable design works, together with the Association for the Advancement of Sustainability in Higher Education (AASHE) provides a more recent assessment of the state of ecological literacy and the teaching of sustainable design in architecture education as part of a proposal for a large-scale, long-term effort, led by the AIA COTE, to inject ecological literacy and sustainability principles into architecture education in the United States. The COTE mapped the strengths and gaps in teaching methodologies and identified top ten measures of a definition of sustainable design that are developed as a framework for different types of courses and studios. COTE reported that at many architecture schools, the mentor model is still firmly in place; students are “filled up” by the knowledge of a professor. The report (AIA 2007) indicate the use of other teaching modalities involving multidisciplinary, participatory, iterative, designing for place, designing across time and involving students to become more involved in framing the questions, shaping courses, and interacting with practitioners and in the community. Also a similar project took place in Europe in 2009, where Altamonte (2009) investigated environmental design in University Curricula and Architectural training in Europe. The European review identified mainly the status quo of integrating unsustainability across most European member states and encouraged the holistic approach to architecture education.

3. Methods

After reviewing the scientific literature regarding circularity and sustainability in engineering curricula and the built environment, the research was conducted through five phases as shown below:

1. Curriculum design
2. Assessment of students’ knowledge, skills, and attitudes
3. Assessment of students’ self-reported behaviors
4. Jury Evaluation
5. Curriculum Evaluation

The study methodology is partially inspired by the work of Madigosky et al., (2006) who investigated the changing knowledge, skills and attitudes of medical students regarding patient safety and medical fallibility. The sections below describe the different methods used to create and assess a case study with 50 students.

3.1. ***Curriculum design***

The first three-year Bachelor curriculum of architectural engineers of the Faculty of Applied Sciences of Liege University are built around project-based learning cases but also include basic science lectures and an introduction to engineering courses. The Bachelor Program curriculum focuses on developing students’ architectural design skills, increasing their understanding of architecture and construction and introducing technical issues. The program is divided into 6 blocks over three years and covers architectural design methodology I-III, sustainable building construction technology I-III, History of Architecture, Graphical Composition, Architectural Studio I-III, Chemistry I-II, Calculus, Algebra, Physics I-II, English, History of Urban Planning, Computer programing, Fluid Mechanics, Building Materials, Solid Mechanics, Geology, Heat transfer, Structural Design, Project management, Structural Engineering, Metallic Structures, Statistics and probability, Thermodynamics and heat engines, Geotechnics and infrastructure (Architectural Engineering 2016).

We identified opportunity for introducing regenerative design and principles of circular economy in the Architectural Studio III. The Architectural Studio III was chosen because of the maturation of the students and the need to develop and crystalize the fundamental knowledge and skills through an integrated project. The existing curriculum was based on introducing a design project of middle sized housing in the third year and we found that it could be linked with a new content. The studio's curricular goals and learning objectives focus on analyzing issues specific for the transformation of a European post-industrial city from a perspective of circularity. The studio focused on developing third year students' knowledge, skills, and attitudes relevant to regenerative design and circularity of the built environment. Several references guided our development of the studio curriculum. A body of literature informed students about the (Lyle, J. 1996, Rifkin, J. 2008, McDonough, et al. 2010, McDonough, W. et al. 2013, Mulhall et al., 2010 and Attia et al., 2013a). We implemented and taught the curriculum, which was approximately 4 ECTS equivalent to 120 hours in the fall of 2014, 2015 and 2016. The curriculum was taught by the author and teaching assistant, with the assistance of volunteer jury members and guests for the site visits, debate, jury and small discussion groups.

The studio content addressed seven main themes listed and described in Table 1 (Attia 2015 and 2016b). The activities in this design studio were a synergy between sustainability and regenerative design theory and their integration in an architectural design project. This approach allowed us to address issues of conceptual coherence, spatial and expressive design while exploring simultaneously the possibilities for sustainability as an essential element for the design; which will become an important and essential task in the field of architecture (Guy et al. 2001). The studio focused in particular on studying the interaction between questions of density, mixed functions, quality of life in buildings, while in the meantime integrating the principles of bioclimatic architecture. This included the development of construction details in accordance with a basic understanding of sustainable buildings concerning energy, water and materials. The project design case was based on a study of solutions adapted on the development of a collective housing of mixed density. They are successively developed in a throughout the different scales from the urban form, the clustering of buildings, the building itself and its envelope and materials.

Table 1. Regenerative Design and Circularity in the built environment curricular content and educational modality by theme, Liege University, Faculty of Applied Sciences, 2014-2016.

Theme	Content	Educational Modality
Theory and Principles	Sustainable architecture and regenerative design	Lectures
	Bioclimatic design and Passive House Standard	Lectures
	Human well-being and quality of life	Lectures
	Construction systems and materials	Lectures
	Energy conservation and production	Lectures
	Water Management + Biodiversity and air quality	Lectures
Philosophy	Cradle to cradle: Remaking the way we make things	Reading
Case Studies	Wijk van Morgen (Heerlen), Park 2020 (Amsterdam)	Site Visit
Reasoning	1. How far to go with technology? Low-Tech vs. High-Tech	Debate
	2. Prefabrication or self-construction?	+
	3. To certify or not to certify sustainable buildings?	Role Playing
Application	Concept development follow up (weekly)	Table Critiques
Assessment	Evaluating the design and project dynamics	Pre-Jury
	Provide individual Feedback	Panel Discussion
	Support and motivation for creation and design development	
Evaluation	Evaluating the design and project dynamics	Jury
	Provide individual Feedback	Panel Discussion

Four key concepts and principles should be addressed in any design according to the studio guidelines (Attia 2016b and 2017b) and should be implemented on the system level, element level and product level for each building (see Figure 2).

1. Design for Circularity
2. Design for Disassembly and Recovery
3. Design for Quality and Health
4. Design for Value Chain Collaboration

Figure 2. Circularity and regenerative design key concepts and principles for the built environment

In the same time, students had to address the requirements mentioned below. Students had to come up with architectural objects and spatial solutions that embed the project design principles of circularity and regenerative design. Integrating the architectural and building elements in the project layout and mass requires architectural intelligence and technical rigor. Every student has to select the most important elements that can create a beneficial impact for their project and size them. The challenge lies in the engineering sizing of every elements and spatial architectural integration. The design principles listed below are based on the literature review conducted earlier in relation to resource efficiency, circularity and regenerative buildings (Attia 2011, 2016a and 2017):

Energy Saving (Resource Efficiency): Energy efficiency and bioclimatic design plays an important role in this project. The compliance with the Belgian Passive House Standard requirement is essential to guarantee the minimum energy consumption and maximum thermal comfort (Feist et al. 2007). A building that complies with the Passive House Standard should not exceed 15kWh/m^2 annually for heating needs and should have an airtight envelope that does not exceed 0.6 air change per hour under an air pressure of 50 Pascal. Overheating should not exceed 25 °C for 5 % of the building operation hours. To guarantee the high efficiency of the proposed designs each student had to verify that walls have a conductivity between $U \leq 0.1$-0.15 W/(m²K) and conductivity of $U \leq 0.1$ W/(m²K) roofs and external horizontal surfaces. Based on the insulation material the sizing of the envelope thickness should be done and reflected in the project drawings. Special attention to facades and windows design is important. Passive solar gains should be maximized for south facades. A rule of thumb of Passive House Standard recommends the orientation of large window area to the south while not exceeding 30% of all wall areas. Shading solutions should be provided to avoid overheating. For the North, East and West façade it is recommended to not exceed 20 % window to wall ratio or provide a double skin while addressing solar protection. The value of windows conductivity should fall ≤ 0.85 W/(m²K) and solar factor or solar heat gain coefficient should be $g > 0.5$. For this project, a double flow mechanical ventilation system is required. Supply and return air ducts must be integrated in the building shaft. Technical service room(s) should be integrated in plans and sections including the heat recovery unit, heat exchanger, heating equipment's and fuel storage. It is encouraged to use free cooling earth cooling tubes. Building thermal nodes should be designed to comply with the Passive House Standard requirements (Feist et al. 2007).

Energy Production: A regenerative building must produce more energy that it consumes. Every student should estimate the energy consumption of the collective apartments. At least, more than 30% of the total annual consumed energy must be generated onsite. The choice of the renewable technologies (photovoltaics, solar thermal collectors, geothermal pipes or other systems), their sizing and spatial integration in the project must be achieved by every student. The area of photovoltaic panels, their orientation and positioning must be considered and represented in the project drawings, schemes and models. The integration of the panels architecturally in the building roofs and facades or technically with the HVAC system should be considered based on rules of thumbs and basic calculation. The installation of solar water collectors for domestic hot water can be based on local approved rules of thumbs. For example, a 4-person household will require a 4-square meter of solar thermal panels. Thus, every student should achieve a positive energy balance and validate his choices and estimations for his/her project.

Water Usage: A regenerative building should allow the separation of different water streams and benefit locally from rain water. An optimal beneficial positive impact building would be off-grid and treat its sewage on site using helofytenfilters (a type of reed field or water filtering bioswale). A helofytenfilter would clean sewage water and grey water, will resist heat stress and provide a green landscape that can increase biodiversity. It is not obligatory to include a helofytenfilter system in this project, but every student must explore the beneficial water elements. Also, every student must integrate a rainwater cistern that can store water at least two months water independence. The sizing and spatial integration of the in the project must be achieved by every student. The separation of different water loops for potable water, rainwater, greywater and black water must be reflected architecturally in the building roofs or underground schemes and technically in the building raisers and greenery systems using rules of thumbs and basic calculations.

Air Cleaning and Heat Island Effect Reduction: Air cleaning can mainly be achieved through green areas. Using green walls, green roofs or rooftop garden can provide a lung that can produce clean air for humans and the city. Clean air increase biodiversity and productivity of buildings users. Natural ventilation and air circulation should be coupled to air cleaning. Integrating such elements in the project design is essential and requires careful detailing and technical validation for issues such as roots invasion, artificial irrigation, weight and impact on carrying structure, water storage and overflow issues, erosion, solar access and orientation, plant selection and diversity and insulation.

Healthy Humans: Humans are in the center of regenerative design. Providing high quality indoor and outdoor spaces for individual and collective usage can bring live hood and satisfaction to users. The design of naturally lit and ventilated atriums, common spaces, gardens, staircases stimulates people’s encounter and activity. Introducing vegetation indoors provides a pleasant living environment and provides a good indoor environmental quality (humidity, oxygen, and acoustic). Each project should adapt these elements and integrate them to provide a high quality architectural experience.

Sustainable and Regenerative Materials Selection: The use of regenerative materials whether from the technical or biological sphere should be achieved without losing their quality. In this project Cradle to Cradle (C2C) certified materials or other eco certified products. Special consideration should be taken for fire safety, acoustic insulation, embodied energy beside the thermal, structural and mechanical performance of materials. Biosphere materials such as clay, wood, straw, hemp is encouraged as well as techno sphere materials such as concrete, aluminium and steel. As long as those material products are C2C certified that avoid the use of toxic substances or include an environmental product declaration it will be easy to know the environmental effect of each material. Techno sphere materials should come in a second priority for essential building elements such as foundations, windows, mechanical installations or for structural safety including lateral resistance or fire safety.

Biodiversity and Sustainable Urbanisation: Enhancing sustainable urbanisation through biodiversity and nature-based solutions can improve the environment; make cities healthier, and enhancing human well-being. Introducing green areas within and around a project site and consciously enforced the ecosystem resilience and enable plants and species to deliver vital ecosystem services can enable robust ecosystem in the built environment. Biodiversity plays a key role in climate change adaptation and outdoor air quality improvement beside other risk reduction solutions in the area of storm water management. The growing awareness of the value of nature and the importance of introducing it in the city through green areas, trees, green roofs and water drainage solutions make it important for designers to connect their projects to the urban green network and provide spaces for celebrating biodiversity. We learn from literature that biophilia, which is the innately emotional affiliation of human beings to other living organisms, can improve the health of humans and therefore, we look to integrate nature based solutions in the built environment (Keller et al. 1995). Nature based solutions include water sensitive urban design, green streets, urban food, urban forest, integrated water cycle management, living green walls, and green roofs and should be manifested through landscape design.

3.2. ***Assessment of students' knowledge, skills, and attitudes***

We developed a 30-item questionnaire to evaluate the impact of sustainability of the curriculum on architectural students' knowledge, skills, and attitudes. Item development was informed by our literature review. The questionnaire included items modified from existing questionnaires assessing i) the knowledge concerning regenerative design, ii) the decision-making attitude and behavior (reactions to design uncertainties), the jury evaluation, as well as items based on our curricular learning objectives. We selected items for the questionnaire based on the like hood that they would demonstrate change after students participated in our studio. Five multiple-choice items assessed students' knowledge, five items measured their comfort with skills (using a five-point ordinal scale where 1 = very uncomfortable and 5 = very comfortable), and 30 items measures attitudes (using a five-point ordinal scale of agreement with statement where 1 = strongly disagree and 5 = strongly agree).

Based on our experience from a previous research (Attia 2013b) we pilot tested the questionnaire for comprehensibility with second-year architectural engineering students and for applicability with one Master student with prior involvement with regenerative design. We deleted two attitude items from the analysis because the item wording in French was inconsistent across questionnaire administrations. For each student, we calculated a composite knowledge score as the number of correct knowledge items out of correct knowledge items out of five. For the composite knowledge score and the remaining 28 items, we calculated a 95% confidence interval for paired differences to assess changes between students' pre-test and post-test as well as their pre-test and one-year post-test. We also analyzed the paired differences between the post-test; however, because these data did not change our conclusions, the results are no included here.

3.3. *Assessment of students' self-reported behaviors*

On the one-year post-test, we also asked students to report their behaviors since completing the curriculum. Students responded 'yes' or 'no' to items about whether they used what they learned in the curriculum, design errors, and disclosure and reporting experiences. We calculated the percentage of students responding 'yes' to each item.

3.4. *Jury Evaluation*

Three project juries, in 2014, 2015 and 2016, were held by experts and invited speakers to the studio and were attended by the entire class. The evaluation was based on assessing each student's project global vision and detailed project solutions. The goal of the jury was not to propose a project that meets actual practice and market conditions but to generate a series of concepts as an exercise to exchange creative and innovative ideas and learn about different energy efficiency and circularity solutions for buildings. For each jury a panel of international and national experts was assembled representing the Cradle to Cradle experts at TU-Delft or Brussels University in additions to the technical director of the Passive House Platform in Belgium (Wallonia) and local resources and materials experts.

3.5. *Curriculum Evaluation*

We developed studio evaluations to measure students' reactions to the curriculum. Student used five-point ordinal scale to rate how well the curriculum met learning objectives, its usefulness in their medical education, its future benefit to their architectural career, and if it should be continued. We also invited students to describe the most important thing they gained from the curriculum and to offer suggestions for improvement.

4. Case Study Results

To assess students' knowledge, skills, and attitudes, 50 students answered the questionnaires before and after the studio. Our analysis of paired comparisons of pre-test to post-test was based on these responses. No students indicated that they had had prior experiences with regenerative design or circularity in the built environment. These results can be divided into three categories: students' responses with improvement, those without change, and those with change in an undesired direction.

4.1. *Responses with improvement*

Table 2 presents the pre-test means, mean paired differences, and confidence intervals for items with improvement both immediately after students participated in the curriculum (pre-test to post-test). Students' responses to one attitude item addressing the inevitability of regenerative paradigm, another about the effectiveness of this approach to create a positive impact versus the efficiency paradigm, and a third reflecting perceptions about competence and design errors improved immediately after attending the studio. These improvements were sustained after the studio. Four skills items also improved immediately after students took the curriculum: supporting a peer involved in a design error, analyzing root causes of an error, accurately estimating the energy loads and production, and disclosing an disclosing an error to a faculty or teaching assistant. Although not improving immediately, students' responses to one attitude item about architects routinely sharing information about errors and their causes improved at one year. Students' responses to an additional attitude item on the effectiveness of design errors, as well as the composite knowledge score, improved immediately following the curriculum, but these changes were not sustained at one year.

Table 2. Questionnaire items with Improvement from a Study of the Effects of a Regenerative Design Architectural Studio Curriculum on Third-Year Architectural Engineering Students' Knowledge, Skills, Attitudes, Liege University, Faculty of Applied Sciences, 2014-2016.

Item	Mean Change (95% CI)		
	Pre-Test mean response	Post-Test mean response	Post-Test after Two-Years
Attitude Questions*			
Making errors in design is inevitable	68.75	31.25	21.5
After an error occurs, an effective design strategy is to work harder to be more careful	62.5	65	61
Competent architects do not design errors that lead to quality decrease	6.25	25.5	22.1
Architects routinely share information about design errors and what caused them	12.5	56.2	53
Design assessment types (weekly meeting with professor, debate, jury) do little to reduce future errors	16.25	3.0	4
Skills Questions**			
Supporting and advising peer who must decide how to respond to a design error	18.5	72	66
Analyzing a design to find the cause of a error	50	48	45
Defend the design successfully in a design assessment	31	56	33
Disclosing a design error to a professor	81.25	12.50	8.5
Knowledge Items			
Knowledge uptake score	37.5	74.5	61

* Scale: 1 strongly disagree, 2 = disagree 3 = neutral, 4 = agree, 5 = strongly agree

** Scale: 1 very uncomfortable, 2 = uncomfortable, 3 = neutral, 4 = comfortable, 5 very comfortable

4.2. ***Responses without change***

Table 3 presents the pre-test means, mean paired differences, and confidence intervals for students' responses that did not change in either of the two comparison intervals. These items – six attitudinal and one skill – reflect that architectural students already believed that a gap exists between regenerative design and actual design practice, that architects and engineers can affect the sources of design errors, and that it takes more than just architects to determine the causes of an engineering error. However, students do not believe architects routinely discuss design errors, and they do not feel strongly that regenerative design and circularity of the built environment is a high priority at our Faculty. The mean student responses were neutral with regard to whether or not architects should tolerate uncertainty of design decision making process regarding regenerative design and in their comfort with errors disclosure to faculty.

Table 3. Questionnaire items without Change, from a Study of the Effects of a Regenerative Design Architectural Studio Curriculum on Third-Year Architectural Engineering Students' Knowledge, Skills, Attitudes, Liege University, Faculty of Applied Sciences, 2014-2016.

Item	Mean Change (95% CI)		
	Pre-Test mean response	Pre-Test to Post-Test	Pre-Test to Two-Year Post-Test
Attitude Questions*			
There is a gap between what we know about regenerative design and we design regularly in other studios	3.92	-0.15	-0.27
Most design errors are due to things that architects can't do anything about	2.57	-0.11	-0.16
Only architects can determine the causes of a design error	1.34	-0.09	-0.11
Architects routinely share information about design errors	2.86	-0.21	-0.23
In my design and learning experience so far, professors communicate to me that regenerative design is a high priority	1.95	-0.13	-0.09
Architects should not tolerate uncertainty in regenerative design	2.31	-0.08	-0.16
Skills Questions**			
Disclosing a design mistake to a professor	2.75	0.38	0.31

* Scale: 1 strongly disagree, 2 = disagree 3 = neutral, 4 = agree, 5 = strongly agree

** Scale: 1 very uncomfortable, 2 = uncomfortable, 3 = neutral, 4 = comfortable, 5 very comfortable

4.3. *Responses with change in an undesired direction*

Table 4 presents the pre-test means, mean paired differences, and confidence intervals for items where students' responses changed, but in an undesired direction. Immediately after the curriculum and at one year, students agreed less that there was value in spending professional time improving design and disagree less that the culture of architectural design makes it easy to deal constructively with design errors. At one year, students agreed less that spending time in architectural school learning how to improve regenerative design was an appropriate use of time, were less likely to be open about design errors they witnessed, and were more likely to believe, that no design errors did not require disclosure.

4.4. *Assessment of self-reported behaviors*

A substantial proportion of students completing the questionnaire at one year answered 'Yes' to whether they had certain behaviors in the year following curriculum completion. 28 (77%) students reported having used what they learned in the curriculum and 32 (88%) reported observing a design mistake. Of these 32 students, 8 (32%) had disclosed a design mistake to fellow student, and 16 (50%) had disclosed a design mistake to a faculty member.

4.5. *Jury Evaluation*

Three project juries, in 2014, 2015 and 2016, were held by experts and invited speakers to the studio and were attended by the entire class. The evaluation was based on assessing each student's project global vision and detailed project solutions. Since the studio is adopting a student centred education through a project-based approach, the jury had to assess the possibilities of multiple solutions for the building design problem. The jury revealed the importance to define design projects that are stronger linked to the real world with real stakeholders. The jury evaluation is not the only evaluation here because the learning level of the students varies significantly and not all students are aware about sustainability science including regenerative design and circularity in the built environment. Therefore, the studio instructors provide also an additional evaluating on the effort made by students, and how they receive the teaching feedback and support and motivation to evolve and improve their design all over the whole project design process.

4.6. ***Curriculum Evaluation***

At the completion of the curriculum, 31 (86%) of students agreed that the studio content improved their ability to meet the learning objectives either well or very well. Eighty-five percent, on average, agreed strongly that the curriculum and learning modalities were useful in their architectural education. Ninety-two percent, on average, agreed or strongly agreed that the curriculum would be of benefit to their future career, and on average 78% recommended that the curriculum be continued for future architectural school classes. Topic mentioned as the most important thing students gained from the curriculum were an understanding that everyone makes design errors, how to address those errors at the root cause, and the mistake reporting and disclosure are important. Suggested improvements included changes in the timing of the curriculum, shorter sessions, less lecture and more personal follow up sessions, and feedback more guidance on communication issues.

Table 4. Questionnaire items with Change in an Undesired Direction, from a Study of the Effects of a Regenerative Design Architectural Studio Curriculum on Third-Year Architectural Engineering Students' Knowledge, Skills, Attitudes, Liege University, Faculty of Applied Sciences, 2014-2016.

Item	Mean Change (95% CI)		
	Pre-Test mean response	Pre-Test to Post-Test	Pre-Test to Two-Year Post-Test
Attitude Questions*			
Students should routinely spend part of their study time to improve their design.	4.21	-0.29	-0.25
The culture of architectural studios makes it easy for students to deal constructively with design errors	1.68	0.25	0.36
Learning how to integrate regenerative design in the project is an appropriate use of time in architectural school	3.21	-0.11	-0.18
If I saw a design mistake, I would keep it to myself	1.82	0.12	0.19
If there is no harm from a design mistake, there is no need to address the mistake.	1.85	0.23	0.31

* Scale: 1 strongly disagree, 2 = disagree 3 = neutral, 4 = agree, 5 = strongly agree

5. Discussion

Higher education institutions have a responsibility to lead societal changes and promote innovations. The call or resource efficiency and circularity y became essential that academic faculty members, researchers and students can create a sustainable future. A multitude of international declarations have been produced in an effort to stimulate the transition and change to face the ecological and economic crisis. After performing our case study at Liege University, we present in this section the results of our study. All members of the engineering academic world, including architectural engineers, should be able to recognize the importance of applying the regenerative design, resource efficiency and circularity concepts in concept in their curricula.

Students should be able to systematically apply those concepts and principles in a project oriented format with a thorough understanding of student's problem solving and creativity skills. Our results demonstrate regenerative design and circularity in the built environment curriculum was well received and led to some changes in third-year architectural engineering students 'knowledge, skills, and attitudes. However, not all of these changes were for the better, nor were all of the positive changes sustained after the design studio or supported by students' self-reported behaviors on the long term.

We believe there are several sets of factors that contributed to these results. The first is the curriculum itself, including the course content, instructors' effectiveness, educational modalities, timing and integration topics within the overall curriculum, planned redundancy, and evaluation methods. The second comes from other formal or informal learning experiences within the pre-architectural and architecture study years, including hidden curriculum. The third set of factors includes the study design, questionnaires, and evaluation tools used. We discuss each of these three areas below.

5.1. ***Curriculum characteristics***

Our analysis identified aspects of the curriculum that worked well for our third-year architectural engineering students. We believe that presenting the studio content at Bloom's (1956) taxonomy of higher order thinking skills (understand, apply, analyze, evaluate, create) and the interactive nature of the learning modalities contributed to the improved responses after students participated in the curriculum and after two years. For example, the most improvement was seen in items addressed by interactive sessions, such as the debate and the weekly follow up corrections, where students applied knowledge and practiced skills. Conversely, students' improved mastering of content delivered solely by lecture, such as design principles and guidelines reported in the body of literature, but this knowledge was not sustained at two years. These results and the curriculum evaluation suggest that application-focused learning and case-based interactive or narrative sessions may achieve more lasting impact of students' knowledge, skills, and attitudes, as well as improved student satisfaction with the curriculum. In addition, when we covered topics multiple times using several educational modalities during the curriculum, as in the inevitability of design errors, students' learning was sustained.

On the other hand, several topics let to no change in students' knowledge, skills, and attitudes. For many of these topics, students were already familiar with the concepts that were taught, such as the quality gap between ideal regenerative design philosophy and actual application limitations and it takes more than architects to determine the causes of design errors. Students' prior experiences and baseline knowledge may eliminate the need to cover this material in a curriculum. Alternatively, this lack of change in students' responses might indicate that curricular timing and integration should be improved for these topics. For example, the curriculum did not convince students that regenerative design and circularity in the built environment is a priority at Liege University. This may be due to a lack of clear messages and planned redundancy with the curriculum about our institutional focus on circularity, sustainable development and regenerative design. Based on these results, when we presented the curriculum to the next class of third-year architectural engineering student in 2015 and 2016, we decreased the amount of time spent on introductory material, substituted a required reading for a background lecture, and focused more on the interactive, application-based aspects of the curriculum, including the time allotted for students to apply the project requirements in the project design.

5.2. ***Other learning experiences***

Calling to mind the effects of the informal and hidden curricula, our study shows that students' responses to the two items describing secrecy about architectural design errors weakened after one year of architectural practice. Additionally, responses to two items on the value of learning about improving design quality during the study period and working to improve design quality as part of their professional life.

Surprisingly, students appreciated the site visits that took place during the studio more than the theory courses. Students visited a series of projects over the three consecutive studio study years 2014-2016. The illustrated project in Figure 3, represent building with exemplary sustainable performance. Each of those building was documented through walkthrough visits, interviews with architects and table critique. Students reported the value of learning from those values and appreciated the concrete representation of the circularity into physical buildings.

Figure 3. a) Passive House Standard Collective Housing, Marcinelle, Belgium, b) Wijk Van Morgen, regenerative building, Heerlen, The Netherlands, c) Business Park 2020, Cradle to Cradle

Certified, Amsterdam, The Netherlands, and d) Strowijk Project or Straw Bale Social Housing Project, Nijmegen, the Netherlands.

5.3. *Study design, questionnaire, and evaluation tools*

Limitations in our study design, questionnaire, and evaluation methods also may have blunted the effects of our curriculum on student's learning. A stronger study design would have included a control group of Liege University students or students from similar institutions. However, we thought strongly that all Liege University students should be exposed to this content and thus integrated it into the core curriculum. As this was a novel curriculum and likely to be adapted further, we did not seek to implement it at another institution during this phase of the study. Although the response rate was adequate at each time period, our core analysis focused only on those students who completed the questionnaire at all three administrations. The survey instrument was new and therefore limited by its lack of formal validation and reliability testing. Some attitude items were confusing in that they required the students to respond in a way that reflected both what we taught (i.e., in general architects do not report errors routinely) and what we demonstrated to contrary. Ultimately, our study is limited by reliance on students' self-reporting their comfort with skills and behaviors, rather than our using observational methods to determine their actual performance or measuring patient-related outcomes with respect to regenerative design and circularity on the built environment. In addition, students completed the curricular evaluation after the last session, thereby requiring them to recall sessions presented several weeks.

5.4. *Lessons Learned to integrate Circularity in Engineering Higher Education*

The paradigm of resource efficiency and circularity and the key design concepts and principles of regenerative design were used as a strategy to guide the decision making of architectural engineers during a full semester project oriented design studio in 2014, 2015 and 2016.

- Complexity and wicked nature of problems
- Uncertainty of circularity science
- Inter and trans disciplinarily
- Institutional reform

The complexity of regenerative design forced students to manage available knowledge and generate knowledge adapted to their project context and multiple objective criteria of sustainability. The debate on the topic of circularity and regenerative design during the studio pushed the students to take a standpoint to defend their understanding and conviction. All students succeeded to integrate renewable energy systems in their design, conserve energy, use healthy and regenerative materials, collect and mange water and create healthy and positive impact buildings with daylight and high air quality. The complexity of applying the paradigm of resource efficiency and circularity and its principals in engineering and architectural practice requires rethinking how to educate engineers. Regenerative design and circularity lie across many disciplines and interacts with various scale levels (Huges et al., 2016). In the same time, the science for circularity is still unstructured and not mature. Students needed to define the building material elements with limited available resources (e.g. case studies, products). There was a difficulty to apply and examine the regenerative design principles in practice. Therefore, there is still working to do to share and amplify practices, principles, and breakthroughs to tackle the wicked nature of design problems.

Also, resource efficiency and circularity involve a large choice of technical and social parameters and is embedded in sustainability science as well as ethical aspects. Even expert knowledge provided through the studio learning material or invited speakers is incomplete, fragmented plural and uncertain. Despite the site visits, student complained from the complexity and lack of agreement on materials sustainability and the deep uncertainties related to life cycle assessment. Also, discussions on social life cycle assessment and social concerns took place during the debate and to take care of social considerations closely for societal stakeholders and work with them (Ryu et al., 2006). Uncertainty of decision making associated the whole design process and students could not find always answers to their questions on how to build with a positive impact. Identifying circular materials, their origin and positive impact in relation to the construction system and the ability to disassemble the building is an uncertain process in the architectural engineering and construction industry. There are no building circularity indicators that guide the decision-making process so far. Moreover, the debate generated very interesting questions related to materials volumes. Since a building is a combination of elements. Volume will dominate the circularity result as a normalization factor and will lead to select less materials volumes. However, the characteristics of high performance buildings indicate to highly insulated building with high amounts of insulation materials volumes. The conflict between using more materials for energy conservation and fewer materials for resource consumption reduction is a concrete example on the delicate intellectual uncertainty associated with resource efficiency, circularity and regenerative design.

On the level of academia, engineering educations is trapped in silos and we need to deconstruct those silos. Faculty and students need to have the courage to move out of their comfort zones (Attia 2016c). In the same time, educators need to create safe spaces for interdisciplinary learning and send to students the message that what they do outside their discipline is valuable to the community and outside the campus. Faculty needs to be convinced too on the importance of transdisciplinary. Interdisciplinary is essential and critical we should move with engineering education towards transdisciplinary following the medical education. This requires effort, time and an infrastructure to prepare educators and allow them to work with educators from different disciplines. This is the only way to prepare students for a wide spectrum of skills (Murray et al., 2007).

Another key challenge that emerged from our case study was the importance of considering social challenges besides technical challenges, the studio addressed resource efficiency and circularity from a technical approach. The multidisciplinary facets of circularity require academia to reform engineering education and bring professional together to solve societal problems in an interdisciplinary approach. We are looking to prepare T-shaped professionals who can address the circularity problems as specialists in their own disciplinary area but also have an overview on the overall circularity and positive development agenda. We need to raise the awareness on the ecological crisis we are living in and that the engineering field is responsible socially and ethically to address those problems. We need an integrative learning environment that allows engineering educators to find way to allow for greater interdisciplinary in the curriculum to allow comprehensive and interactive problem-solving approaches (Brody et al., 2006). The outcomes of the case study are in line with the previously published work of Siller et al. 2016 and Trulsson et al., 2016.

Finally, we believe that there is an opportunity to achieve resource efficiency and circularity within a strategy of institutional change and rethinking the role of engineering higher education within the societal and environmental context. Therefore, re-educating engineers should address complexity of interdisciplinary and uncertainties related to regenerative design and circularity.

6. Conclusions

We designed an innovative regenerative design and circularity in the built environment curriculum for third-year students at the at the University of Liege and studied the effects of the curriculum on architectural students' knowledge, skills, and attitudes after their participation in the curriculum and at one year, gathered data on student-reported behaviors regarding use of the curriculum and exposure to and disclosure or errors, and measured students' evaluation of the curriculum.

Our results show that the circularity paradigm can affect the knowledge, comfort with skills, and attitudes of undergraduates engineering students to develop sustainable ideas, solutions and projects. Within several different domains, students demonstrated improvement that was sustained two years later. However, some improvement was not sustained, and some changes were not consistent with the learning objectives. Student-reported behaviors at the two-year timeframe demonstrated that although students recognize architectural design errors, the number of students who disclose errors to faculty members is far than those disclosing errors to their peers. In addition, the regenerative design and circularity in the built environment curriculum was well received by students. Students perceived it to be useful, beneficial for their careers, and recommended it for future architecture engineering students. However, resource efficiency and circularity should be achieved within a strategy of institutional change and rethinking the role of engineering higher education within the societal and environmental context. Re-educating engineers should address complexity interdisciplinarity and uncertainties related to regenerative design and circularity.

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Chapter 6

Circular Economy: A Holistic Resource-light Business Model

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Abstract

A holistic resource-light business model supporting the development of circular economy for energy and material conservation is discussed. In the paper is emphasised that policy development on international, national and regional/local levels in both public and private sectors must take place in parallel with market driven initiatives, utilising digitalisation, low-cost renewable energy and engagement from the private and public sectors. Market driven initiatives can be facilitated with an active use of taxation to support renewable uses and increase the costs for non-renewable uses of materials. It is clear that many projects and companies already are up and running based in a circular economy business model emphasising sharing of resources and more than ten different examples of these are presented in the paper. But many more needs to be implemented in order to save the fossil resources for the future needs and some ideas on how good examples should be spread is discussed in the paper.

1. Introduction

The present consumption level of Earth´s population is heavily relying on virgin materials and resources. Several international reports have year after year provided information on how the consumption level of humans requires more and more materials (UNEP, 2017). If for instance everybody living on earth would consume as a Swedish consumer does, the material supply from 4.2 planets would be required to meet the demands, which is an increase in 0.5 planets in from 2014 (WWF, 2016). Yet the number of planets available for humans to abstract material from is of course only one. With increasingly growing awareness of these facts, an intensive discussion on how to support the development of a resource-light business model and to facilitate the introduction of a truly circular economy for all has been emerging for several years.

The concept of the circular economy was first introduced in the 1970s and recent circular economy initiatives from international and national actors reflect quite faithfully most of the initial concepts which have since then been defended by numerous organisations such as the OECD, the Stockholm Environment Institute, the Ellen MacArthur Foundation or the World Wildlife Fund. It is clear that a circular economy must distinguish between technical and biological cycles of materials as described in Figure 1. It must also be restorative and regenerative to utilise products, components and materials at all times at the highest value. A circular economy involves the more effective use of natural resources, which also enables reduced costs. Studies of the potential for a circular economy in Europe indicate possible gains for Europe's citizens that are comparable to the gains calculated when the plans for the European Single Market were formulated in the 1980s. The European Commission has for instance adopted a so called Circular Economy Package with the aim to stimulate the transition of the EU-countries towards a circular economy with the ambition to boost global competitiveness, foster sustainable economic growth and generate new jobs. But how is a circular economy achieved?

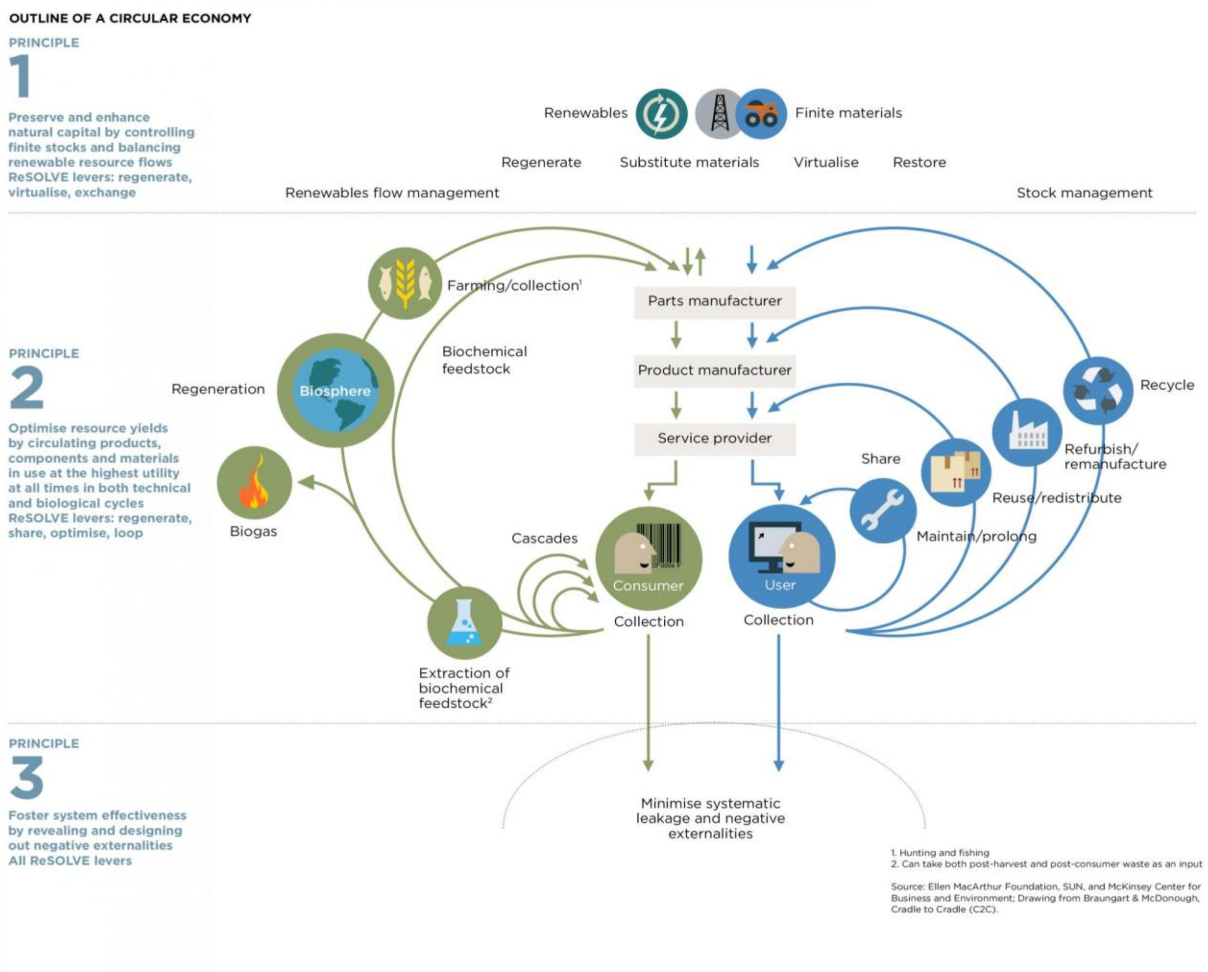

Figure 1. The combination of the biological and technical cycle of materials. Source: Ellen MacArthur Foundation, 2017

Technological developments contribute to strong and growing opportunities for the circular economy in the 21st century. This is mainly due to two technological revolutions in recent times. The first is digitalisation, which affects the entire development of society and provides entirely new opportunities to measure, monitor and control materials in individual products or material cycles in society. Many services can be rendered material-free or virtual, as has been done in the case of music, books or meetings. Digital platforms for the rental of homes or premises or for sharing vehicles enable underexploited assets in the economy to be utilised (Airbnb, BlaBlaCar, Uber).

The other revolution concerns the fact that renewable energy, mainly renewable electricity production, is becoming competitive without subsidies in more and more markets around the world. In September, 2016, it was reported that the Abu Dhabi Water & Electricity Authority had received a record-low bid of 2.42 US cents a kilowatt-hour for power from a planned 350 MW facility in the Persian Gulf sheikhdom. This price is by far less than what any fossil fuelled power plant can match. The bid was offered by Jinko Solar Holding Co. of China and Japan's Marubeni Corp (Bloomberg, 2016). Thus, the circular economy can also be driven by circular, renewable energy.

While many resource-efficiency initiatives relate to production, questions regarding consumption are also being addressed. Studies are being carried out on the 'rebound effect' – the idea that the introduction of technology and policy instruments intended to improve environmental efficiency might have the unintended side effect of increasing consumption. Home insulation, for example, to make a home more thermally efficient and cheaper to heat, might result in householders leaving the heating on for longer or at a higher temperature, cancelling out the efficiency gains. The existence and significance of the rebound effect and how to address it is hotly debated, so more information is needed.

More efficient use of resources and pollution control can be major drivers of economic growth, as is shown by Europe's eco-industry. The sector has grown by around 8% per annum in recent years, and its annual turnover of €319 billion accounts for about 2.5% of Europe's GDP. Much recent growth has been concentrated in resource management involving new technologies such as solar and wind energy. The environmental protection market is a worldwide opportunity for European firms: the global market for eco-industries, currently worth around €1 000 billion per annum, is expected to triple by 2030. The EU holds roughly one-third of the world market and is a net exporter, with many European producers benefiting from 'first-mover advantage'. Strong export markets include China and other developing countries pursuing environmentally sound growth. The world market is growing by around 5% per annum.

2. Reduce the amount of waste generated

The production of waste must be avoided. In a circular economy, virtually no waste should be produced; instead the product should be recycled, possibly after upgrading, cleaning or modernisation of the original set-up. When recycling not is possible anymore, the different components in the product should be dismantled to be reused in new products and processes. Should this not be possible to achieve, the material of the components should be utilised for other purposes when it has done its service in the original component.

The fact is at present that material is consumed in a linear way in all countries. In the EU, for instance, approximately 43.6% of all the waste treated in EU-28 in 2014 was subject to disposal operations other than waste incineration, i.e. landfilling or corresponding techniques. Since 2 145 million tonnes of waste were treated in 2014 in the EU-28, it means that 935 million tonnes of waste was landfilled in EU-28 countries in 2014 (Eurostat, 2017). In these figures municipal, commercial and industrial waste are included. The statistics looks better when only municipal waste is considered, yet this is only a share of the total waste amount generated to meet the market needs for consumption. For countries with mining activities, like Finland and Sweden, substantial amounts of slag and tailings are produced from the mines. These materials are normally deposited in large piles. The residuals are oxidised and exposed to air and water that mobilise metals and anionic compounds, particularly sulphate, which is transported from the tailings downstream in the environment.

Water and air is central in the circular economy. In the waste statistics, the use of water and air is normally not included, but any economic, political, scientific, social or technological solution or policy aimed at the creation of a sustainable urban environment must include both water and waste. Both clean air and pure water are necessary commodities for all production. Therefore, the concept of virtual water present in different products consumed can be used to give a clear and relevant description of how much water is needed for sustaining the production of the goods (see for instance Mekonnen et al, 2015). Much can be said on virtual water and one example is that the global water footprint related to agricultural production is about 8 400 billion cubic meters per year. The import-export of food and agricultural products between states saves 4% of the global water resources, or about 370 billion cubic meters per year. With better management of virtual water economics, substantial savings can be made (Mekonnen and Hoekstra, 2011).

Uberization and 3C: internet platforms for circular economy

With the help of internet platforms, some global actors and many hundreds of local actors have emerged the last 10 years utilising shared economy. The maybe most known example is the San Francisco based Uber Corporation which connects drivers with clients (passengers) who want to get a ride in a car from one place to another thereby competing with standard taxi services in cities. The company was founded in 2009 and the launch of the first booking platform was made in 2010. Uber is according to its webpage present in 584 states, provinces or cities in all regions of the world from New Zeeland to Canada, from South Africa to Northern Europe, from Asia to Latin America (Uber, 2017). In France, a similar company named BlablaCar started its booking platform activities in 2007. BlablaCar offers shared transportation in cars from one city to another, for instance from Paris to Brussels, and says on its webpage it has 40 million members who offers shared travelling in 21 countries in the world (BlablaCar, 2017). A third internationally active platform is Airbnb, which claims to offer more than 3 000 000 different accommodations in more than 65 000 towns and cities in 191 countries. Airbnb was founded in 2008 (Airbnb, 2017).

From this sharing economy background, the term Uberization has been suggested for the cooperation between consumers and providers using cooperation / sharing platforms (David et al, 2016). In the car context, consumers and providers are individual actors proposing and requesting use of a service. In the transportation case, the user-consumer-traveller tries to find a vehicle with driver that could take him/her to their destination. The platform is used to find a vehicle, which is located not far from the consumer's geographical location and available to make this trip. Uberization can be practiced for several markets to enhance a higher utilisation of resources already made technically available, yet where no safe and reliable exchange system has been offered to the clients or providers previously. To share an economic resource, the sharing parties need to trust each over. Trust is fundamental to human collaboration and collaborative economy. In smaller networks built up by neighbours or members of the same society, the trust and social responsibility is inherent. Utilising technology and new digital trust tools also previously unknown persons can be trusted. Platforms such as BlaBlaCar are empowering individuals to create trusted online profiles made from verified information, declarative content, and ratings from previous experiences. Taken together, this information allows peers who have never met before to make an informed decision, trust each other instantly, and start collaborating. When all this information is aggregated and made visible to others, it becomes part of an individual's "trust capital" and peers can instantly download it. Using digital trust tools, the historical performance of persons, also strangers, can be traced from their trust track records. Business models for these global shared economies are typically based on a fee which the seller (Uber or BlablaCar car driver, Airbnb landlord) pays to the platform provider. The fee can be fixed or be a fraction of the income from the transaction.

Another path forward is to offer the services for free in collaboration and cooperation between either identified or anonymous actors who work locally or at a distance by sharing data and information which are made available to the actors in a workflow in different data operations (read only, creation, edition, etc.). This collaboration can be either short-term oriented solve a given problem or, more commonly, long-term oriented such as design, development or long-life support with a relatively stable set of actors. One example is the internet encyclopaedia Wikipedia, where the number of articles in English is about 5.4 million, which would require more than 2000 print volumes of the size of Encyclopaedia Britannica. Assuming that each article needs 10 minutes to write and that a person works 40 hours per week and 48 weeks per year, the amount of work put in the English Wikipedia corresponds to more than 58 man-years. The total number of articles in Wikipedia in all languages is 41 million, representing more than 440 man-years of work using the same assumptions as for the English Wikipedia.

Communication is needed to exchange freely between different actors in relation with expected activities and collaboration has as its goal to manage access and work on shared data. Coordination is used to manage the activities. Abbreviating Communication-collaboration-coordination, this work organisation is called 3C (David et al, 2016). In several of the 3C systems, people gain from sharing of information and data and accept therefore that the service is free of charge. Sometimes, the service will be made available after paying a license fee or similar. In many of these cases, the business model here is that the service can be offered for free, since the public gain is much higher than the cost for each private. Each work effort is rewarded hundredfold.

Business model policies can enhance the development of a shared economy

Good business models allow the manager of a company to offer solutions to the market with profit. Most conventional business models suggest increased sales volumes to offer increased profit. To foster business models for increased circular economy, policy instruments cannot only be based on prohibition and punishment, which reduce the purchasing power of consumers and weakens the competitiveness of industries. On powerful positive stimulus is to use public procurements for developing local and regional material cycles. The Swedish government estimates the public procurements to reach €70 billion annually (SOU, 2017). If half of that be dedicated to circular economy solutions, the profitability could increase for market actors in these sectors. SITRA, a Finnish Innovation Fund funded by returns from an endowment granted by the Finnish Parliament, reports several *policy actions* toward establishing a circular economy, a number of *key projects* in focus areas which are flagship projects for the development of a circular economy and a large number of *pilots* which should be developed in a first phase to prove the versatility and usefulness of circular economy solutions (SITRA, 2016).

For sustainable food systems as an example, SITRA (2016) suggest a market for organic recycled nutrients to be created. This market should promote the use of recycled fertilisers via blending obligations in the same was as has been practised for renewable fuel in fossil fuels, both petrol and diesel. To minimise food waste, obstacles for food reuse and resale should be eliminated without risking safety and efficiency. The implementation should be done with the support from market based solutions and actors, but also in collaboration with voluntaries. An energy tax refund which supports the use and expansion of biogas, and increases the cost of using fossil gas could be applied to enhance replacement of fossil resources in agriculture. Other key areas identified for the Finnish economy are loops in the forests of Finland where more products from the forests than just wood are developed to maximise the overall value in the forest industry; technical loops which promote the use of secondary raw materials as much as possible; transport and logistics which accelerates the development of service- based transport systems instead of private car use; and common actions with measures such as an elimination of regulation barriers or clearer policies for education and research that enables a circular economy.

Clear circular economy policies require regulations

In Sweden, the public inquiry for circular economy was presented in 2017 (SOU, 2017). The Government’s overarching aim of appointing the Inquiry was to achieve a more resource-efficient and circular economy. In the report, the concept of a dynamic circular economy is described and what is needed to steer the Swedish markets in that direction. The reports is clearly inspired by thinking and policies from Finland, but uses also what has been developed and implemented in Japan, the Netherlands, Denmark, Scotland, China and Canada. The need for a circular economy policy is stated and a broad national cooperation on it is suggested as an effective strategy for both sustainability and Swedish competitiveness. The main task of the Inquiry has been to analyse and propose policy instruments to promote increased utilization and re-use of products in order to prevent waste. Policy instruments must provide incentives to producers and consumers alike to promote trade in used products and stimulate their repair and upgrade. Focus has been on products intended for the consumer market.

The Swedish government is suggested to raise the transition to a circular economy to strategic level in close collaboration between central government, the business sector, regions, municipalities, the research sector and civil society. The collaboration should aim to strengthen both Swedish competitiveness and global sustainability and be designed as a part of industrial policy and Sweden’s implementation of the UN’s 2030 Agenda. This calls for broadly supported and ambitious objectives, visible leadership from the highest level and a common framework for ongoing and future initiatives. To initiate the work and drive the collaboration, a time-limited delegation for the circular economy should be appointed that is directly responsible to the Ministry of Enterprise and Innovation containing high-level representation from the world of politics and business, as well as others actors. The forms of concrete collaboration should be developed jointly. The delegation’s remit should include:

- initiating and running the process needed to launch a broad and active national cooperation, including proposals for objectives, priorities and action plans,
- being the contact point for all key stakeholders: government, industry, academia, regional and local level and civil society.
- maintaining an overview of, and facilitating effective collaboration between, all initiatives related to circular economy. In particular, the delegation can strengthen the link between innovation and policy development.
- providing a knowledge center for Sweden and being responsible for international intelligence,
- contributing to the discussion of an appropriate strategic management by objectives for Sweden's sustainability efforts and how the continued work on circular economy should be organised after the delegation has completed its work.

Based on the need to prevent waste but also to enhance a separation of biological and technical flows (see Figure 1), product design is identified as a central area for promoting more circular business models. Since Sweden is a small part of a global economy and also part of the European Single Market, many concrete regulatory changes cannot be decided nationally, but should be initiated together with the other member-states in the EU and sometimes even on an international arena.

The most important obstacle to increase utilisation and re-use of products is identified as the price relations between new and re-used products. Many times, it is more expensive to have a product repaired than to buy an identical, new one. Even renting products and finding help to sell second-hand products can be expensive. Demand may be limited due to consumers’ preference for new things and models. Time is a third obstacle counter-acting the consumers’ interest for repairing, renting or trading in second-hand products. The pay-back can be regarded as little since attention and time from the consumer is required to pursue re-use. The markets for second-hand goods and repair services are also held back by rules adapted to waste, and circular design has so far had modest impact on the manufacture of new products.

Cost reductions for re-use will facilitate circular economy

To facilitate increased repairing and reduce the price gap between new and re-used products, the inquiry suggests that a tax deduction for repairs should be implemented. In Sweden, a previously introduced system of tax deductions for household work (abbreviated RUT in Swedish) and for building repairs and maintenance (ROT in Swedish) have been in place for several years. These tax deduction systems are suggested to be mimicked for consumer products. The Swedish government is suggested to encourage households to repair, rent and sell on consumer products through a “hyber” deduction (probably a pun based in Uber, but explained as hyra-begagnat-reparation, i.e. rent-second hand-repair). Under the proposal, households would receive a tax reduction (as with the ROT and RUT deductions) when they repair or rent consumer products or buy services to sell second-hand products. A tax reduction amount to 50 per cent of the labour cost of these services is suggested, thereby reducing the tax wedge for households that buy “hyber” services. To combat abuse of the tax reduction, the government is suggested to give greater possibilities to the Swedish Tax Agency for checking that the services carried out really are those intended for the tax reduction. The “hyber” deduction is estimated to result in some 10 000 new jobs in Sweden, with positive effects for the labour market, integration and the environment. The estimated cost for the “hyber” deduction is approximately €0-180 million per year depending on what proportion of new jobs that goes to people that is currently unemployed.

Waste must not be wasted

Municipal solid waste management is the legal responsibility for the 290 municipalities in Sweden. The total amount of MSW in Sweden was 4.7 million tonnes in 2015, an increase with 4% since 2014 (Avfall Sverige, 2016). The MSW generation has increased more than the population for many years, which is the general case for most countries in the world. The role of the municipality in preventing waste should be made clearer to create a higher level of ambition and lead to more strategic work on waste prevention. The municipal waste plan should contain information about waste prevention in the municipality’s own activities and about how the municipality is working to reducing the levels of household waste. The government is suggested by the inquiry to give each municipality the obligation to inform inhabitants about how they can take measures to prevent waste and to take measures themselves to make it easier for households to reduce their waste by enabling the collection of recyclable products. The municipalities are also suggested to be given the possibility of financing certain measures to prevent household waste with the help of refuse collection fees. The total costs for the municipalities are expected to amount to between €7.5- €15 million per year which for instance could be financed through an increase in the refuse collection fee.

The public sector can lead by example

The public sector itself can affect the circular economy. The Swedish National Agency for Public Procurement can develop measures and criteria for circular procurement. The municipalities' obligation to prevent waste in their own activities can become clearer by making the rules that govern municipalities' waste plans more precise. Also, government agencies should be given an obligation to prevent waste in their activities, within the framework of their environmental management system. The proposals are expected to result in increased costs with €20 million annually for more employees in the municipalities but on the other hand generate savings of approximately €200 million due to reduced costs for the government agencies and municipalities' when less waste must be handled. Another great saving in climate emissions can also be expected when less material is used. The inquiry estimates a total reduction of 45 000 tonnes of carbon dioxide equivalent per year for the municipalities and governmental agencies.

Products should last longer

To facilitate more sustainable and robust product design, the Swedish government is encouraged to move the burden of proof in consumer law by extending the period in which the seller has to prove that no defect existed at the time of delivery, from the current six months to two years. Not until two years have passed, therefore, should the burden move to the consumer to show that the flaw was present at the time of delivery. The Government should also work to strengthen confidence and legal rights in the trade of second-hand products and the sharing of products. Straight-forward measures include:

- reviewing the Swedish Consumer Agency's remit concerning trade between private individuals;
- investigating the need for certification systems or codes of conduct for second-hand trade, particularly in the area of second-hand electronic goods, and, if such a need exists, developing these systems or codes of conduct;
- instructing relevant agencies to produce guidance documents describing when re-use should generally be avoided for environmental or security reasons; and
- instructing relevant supervisory authorities to together look into how the EU's product safety regulations should be interpreted with regard to trade in second-hand products.

Environmental taxes can be used more actively

Costs are important and one direct to increase the cost of new materials and reduce the cost of re-used material is to impose environmental taxes. On a general level, there has long been broad political support in Sweden for increasing the contribution of environmental taxes and fees in favour of reducing taxes on labour. In practice, the biggest environmental tax payers are industry. To protect Swedish enterprises, environmental taxes are not practiced. It is now estimated that Sweden has one of the lowest proportions of environmentally related taxes among EU Member States. In 2016, the environmental taxes amounted to 6% of the total tax incomes the Swedish state had (ESV, 2017) and 1.7% of the gross domestic product (SCB, 2017). The total government revenue from environmental taxes in the EU-28 in 2015 amounted to EUR 359.3 billion; this figure represents 2.4 % of the EU-28 gross domestic product (GDP) and 6.3 % of the total government revenues from compulsory levies (Eurostat, 2017). If Sweden had the same level of environmental taxes as the average in EU-28, another EUR 3.1 billion would be generated for the state. A route towards more comprehensive tax shifting that could provide scope for significant labour tax reductions and thus increased service content in consumption is suggested for the Swedish government.

Car pools – less parking, more transport

Using data on the number of car trips and their average time, then survey results about the time we spend driving, and finally extrapolates from reports on the distance and speeds cars travel, it is possible to confirm that cars are parked 95% of the time on average (Fortune, 2016). The number of passengers in a car is seldom more than 1 (the driver). The total transport capacity of the cars is thus not utilised particularly efficient. One straight-forward measure is to increase access to car pools. One suggestion is to define statutory criteria for what is to be considered a publicly available car pool vehicle that can then be used as a basis for central government or local promotion measures. Car pools should be given the opportunity to apply to the Swedish Transport Agency for vehicles meeting the criteria to be registered as publicly available car pool vehicles in the Vehicle and Driving Licence Registry. In addition, the municipalities should be given the opportunity to reserve street space as car pool parking space, through local traffic regulations. The effects of this proposal are expected to be a reduced need for new production of cars, a reduced need for parking space and lower emissions from car journeys. From a technical side, the corrosion pace is also reduced when the car is running which increases its life-time.

Water in the circular economy

Water is central for society and nature and used very inefficient in most countries of the world.

The linear philosophy is very clear for water use, with a separation of fresh drinking water and polluted wastewater. Globally, the water challenges, such as water scarcity, water quality, and aging centralized infrastructure with inadequate funding mechanisms have resulted in negative impacts to economic development and business growth along with gender and income inequality.

The circular economy paradigm requires that the value of water and associated wastes are addressed which will, in turn, drive innovation in public policy, financing, business models and technology. Using data from the EU, the water use from public water supply in EU in 2011 ranged from 146.2 m³ per inhabitant in Ireland to a low of 26.4 m³ per inhabitant in Belgium (Eurostat, 2017). Water is used also in industry and agriculture and the total water use is much higher than the public water in all countries. Many regions face problems associated with water scarcity; this is the case particularly in parts of southern Europe, where it is likely that efficiency gains in agricultural water use (as well as other uses) will need to be achieved in order to prevent seasonal water shortages. Regions associated with low rainfall, high population density, or intensive agricultural or industrial activity may also face sustainability issues in the coming years, which could be exacerbated by climate change impacts on water availability and water management practices.

Different attempts have been made in several countries to implement more of resource-light business models to stimulate and support the development of circular economy in the water sector. The most obvious is to reuse the water in urban areas. Without a legal support for water reuse for all purposes and a clear guideline of the quality of the reuse products obtained from used water, the consumer will remain very reluctant to integrate water into their understanding of the concept of circular economy. To initiate this, a legislative proposal may be needed on minimum requirements for the reuse of wastewater. This has been implemented for drinking water in Windhoek and Singapore (NeWater) and for different water reuse solutions without potable water supply in many countries. One example is the policy for water reuse in China, see table 1. To encourage the use and operation, the relevant incentives policies have been made at both the government and the local level. ‘The notice on the value-added tax (VAT) policy of comprehensive utilization of resources and other product’ (Finance and Taxation [2008] No.156) by the Ministry of Finance and State Administration of Taxation and ‘The identification and management methods on the comprehensive utilization of resources encouraged by the state’ ([2006] No.1864) by the National Development and Reform Commission, Ministry of Finance and State Administration of Taxation, stipulate a free VAT policy on the sale of reclaimed water; the Beijing government sets the policy that the user of reclaimed water is exempt from the water resources fee and the sewage treatment fee; the Tianjin government formulates that there is a lower price and free water resources fee and city utility surcharges for reclaimed water users (Wu et al., 2010, Liu and Persson, 2013).

Table 1. National Reclaimed Water Quality Standards

Classification	Purpose	Reclaimed Water Quality Standards
Industry uses	Cooling water, Washing water, Boiler water, Process and Products water	“The reuse of urban recycling water - Water quality standard for industrial uses ” (GB/T 19923-2005)
Urban miscellaneous water	Landscaping, Flushing water, Street sweeping, Vehicle washing, Construction, Fire-fighting	“The reuse of urban recycling water - Water quality standard for urban miscellaneous water consumption” (GB/T 18920-2002)
Scenic environment use	Entertainment landscape environment water Aesthetic landscape environment water Wetlands environmental water	“The reuse of urban recycling water - Water quality standard for scenic environment use” (GB/T 18921-2002)
Agriculture, forestry, husbandry and fishery	Agriculture irrigation, Forestation, Farm and pasture, Aquaculture	“The reuse of urban recycling water — Quality of farmland irrigation water” (GB 20922-2007) “Water Quality Standards for Fisheries”(GB 11607-89)
Water resources supplement	Groundwater recharge (surface and injection recharge)	“The reuse of urban recycling water - Water quality standard for groundwater recharge” (GB/T 19772-2005)

Source: The series standards for the reuse of urban recycling water. (China's State Administration of Quality Supervision, Inspection and Quarantine, China National Management Committee for Standardization, 2002-2007) , GB: National standards

Within the EU, Cyprus and Malta where the water is very scarce, more than 90% and 60% of their wastewater is reused, respectively. In Greece, Italy and Spain between 5 and 12% of their effluents are reused. Some test-sites and demonstration plants are running also in other member states. The reuse is mainly focused on irrigation, water for industrial uses and aquifer recharge. At present in EU-28, about 1 billion cubic metres of treated urban wastewater is reused annually, which accounts for approximately 2.4% of the treated urban wastewater effluents. The potential for up to 25% reuse is high. Pricing is a general issue where water rates in many locations do not represent the true value of water and the incentives to conserve and reuse are low. Minimum requirements for reuse of water applied for agricultural irrigation and groundwater recharge has a potential to boost water reuse in all countries where regions and districts face water shortage.

Considering the benefits of the above mentioned practice, reusing local water supplies should be an integral part of a circular economy since it increases water supply resilience, offers solutions to recover water, energy, nutrients and heat from waste streams, releases water quality pressure on receiving streams and not least provides a platform for innovative technologies increasing companies' competiveness in the global marketplace (EU Water reuse, 2017). The Commission published an Inception Impact Assessment on the initiative "Minimum quality requirements for reused water in the EU (new EU legislation)" where in total 14 positive important impacts in the economy, society, environment, administration, impacts for SMEs, innovation and competiveness, public administration and third parties are listed. There is an estimate from the Commission that water reuse at the EU level as a legislative proposal set for mid-2017. A step forward is the inclusion of water reuse in the Circular Economy Package with forthcoming initiatives on reuse in integrated water planning and management, and minimum quality requirements for water reuse in irrigation and aquifer recharge. The issue of water pricing has been raised stressing the complex issue of setting the right price on water. Discussions also highlight the need for integrated management working across all levels in order to align economic, environmental, and health standards. The importance of establishing EU quality standards of reused wastewater has been identified as means to gain social acceptance among citizens for water and material reuse.

3. How a holistic resource-light business model for circular economy can be developed

It is clear that material use in production and consumption globally is high and non-sustainable. With increasing wealth, the consumption increases. Several international, EU and national initiatives have been made to formulate policies towards more circular economy and as can be seen from different examples, some solutions develop even without any policies, just due to market needs. The global examples of Uber or Airbnb can be used to illustrate this. Market driven solutions are more or less successful and grow more or less fast, but the big change towards a full circular economy in society will most probably not be accomplished only with their help. An obvious flaw in all purely market driven solutions is that those who cannot afford to take part of the markets will not enjoy the benefits of them. Different combinations of circular economy policies for targeted areas of material use can be one way forward. Five golden rules for maximising economic growth while mitigating pressure on the resource base are suggested as:

- Save: take existing opportunities for resource savings wherever possible – some EU economies are 16 times more efficient than others;
- Recycle: increase the recycling of materials and the reuse of elements in products (mobile phones are a recent example);
- Substitute: replace primary resource inputs with alternatives that offer greater efficiency and which have lower environmental impacts throughout their life cycle (by phasing out mercury, for example);
- Reduce: dematerialise how we meet people's needs, through new business models or goods and services with lower resource inputs. Examples include reducing the weight of vehicles, or downloading music and entertainment legally from the internet rather than buying a solid object like a DVD.

- Value: policy-makers need to find ways of bringing the proper value of natural resources into consideration in decisions, enabling the improved management of our natural resource base. Learning to value – and to put a price on – ecosystem services and natural resources will ease the pressure on the environment.

With the aid from Finland, the policy actions toward establishing a circular economy should be nurtured by key projects in focus areas which are flagship projects for the development of a circular economy. It is not enough to talk, decide and write grand plans for implementation of circular economy policies. They need to be done in real life. The plan suggested by SITRA is handy since it both addresses key projects and a large number of pilots which should be developed in a first phase to prove the versatility and usefulness of circular economy solutions. The pedagogical concept lead by doing is highly relevant for these solutions. Policy actions should be enforced by managers in public and private sectors. It is very clear from the given examples that policies can be useful in all sectors and at all levels.

But sometimes the policies can be inspired by national and international documents which clarify the usefulness and need for the change in pathways, should this not be inherently understood. To summon the efforts such as suggested in the Swedish Circular Economy inquiry, a delegation is suggested to be formed for outlining the process needed to launch a broad and active national cooperation, including proposals for objectives, priorities and action plans. Such a delegation should have a temporary mandate and act as the contact point for government, industry, academia, regional and local level of government and all other key stakeholders in civil society. It should facilitate effective cooperation between initiatives related to circular economy, not least liaise innovation and policy partners. It could offer knowledge of other countries and parties action within the circular economy field and assist in developing strategic management by objectives for a country's sustainability efforts and how the continued work on circular economy should be organised in the long run.

- *Cost reductions for re-use will facilitate circular economy*

Hyber deduction – which facilitates increased repairing and reduce the price gap between new and re-used products can be implemented with positive effects for the labour market, integration and the environment.

- *Waste must not be wasted*

Each municipality or the corresponding responsible party for solid waste management should be given the obligation to inform inhabitants about how they can take measures to prevent waste and to take measures themselves to make it easier for households to reduce their waste by enabling the collection of recyclable products.

- *The public sector can lead by example*

Measures and criteria for circular economy procurement should be applied as often as possible. Public sector actor' must prevent waste generation in their own activities.

- *Products should last longer*

The seller of products should take a bigger responsibility for offering products that have a longer technical duration time. The national Government should also work to strengthen confidence and legal rights in the trade of second-hand products and the sharing of products.

- Environmental taxes can be used more actively

Costs are important and one direct to increase the cost of new materials and reduce the cost of re-used material is to impose environmental taxes. Green taxes should be further developed to favour work and counteracts excess consumption.

- *Car pools – less parking, more transport*

To increase the usage of the total transport capacity of the cars in a society, car pools should be supported legally and practically. Clear statutory criteria for what is to be considered a publicly available car pool vehicle should be developed and car pool vehicles should be given favours in the traffic to make them the first hand choice for private transportation.

- *Water in the circular economy*

Water should be reused to prevent water shortages and facilitate material, nutritional and modern water management and the price of water should correspond to its actual value.

- *Uberization and 3C: internet platforms for circular economy*

Embrace the technical development and utilise technical support for more data management, more information sharing, and more availability of shared resources.

4. Conclusion

A well-known quote from the Chinese chairman Mao Zedong is “Let a thousand flowers bloom”. This should be the final summary of the paper. When implementing circular economy policies and business models, it is clear that there is no single silver bullet that solves everything. Instead, there is a need for many flowers, many different attempts and pilot tests, implementation of simple or advanced material recovery schemes and proofs of several good ideas on how to practice the solutions. Politically, it can be important to argue for the need to develop new solutions in a country, but the largest number of circular economy business solutions will be developed in other countries. Therefore, is an active market intelligence and active participation in international and regional meetings and projects also central to support a circular economy for all. Good ideas should be regarded as resources and be shared and recycled as much as suitable for the needs of the society. The solutions are only valuable when they are implemented. It’s time for the next spadesful.

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Chapter 7

The Role of Biomass Conversion Processes on Circular Economy

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Abstract

Circular economy and renewable sources has become increasingly important for sustainable development. As a renewable source, biomass has the potential to replace the fossil sources when wastes of biomass activities and disposed products are processed within a supply chain network. The sectoral integration network involves pre-treatment at each biomass site, regional conversion processes, and centralized upgrading plants. This network uses wastes from many biomass sectors and produces energy and multiple products. In this way, the risk of supply shortage is reduced, and the revenue of each sector increases. This network structure provides more evenly distributed population and development of rural areas as well. To enable these features, this network needs multi-feed-multi-product and flexible biomass conversion processes. The conversion processes are the heart of biomass supply chain network.

Keywords: biomass conversion, circular economy, sectoral integration, integrated biorefinery

1. Introduction

The current sustainability issues drive economy from linear model to circular economy. The linear model involves extracting raw materials from nature, producing the desired products and disposing after product lifetime. The wastes during the production stage are also treated and discharged to the nature. However, disposals cause large usage of area and release of toxic species. Moreover, extracting raw materials increasingly become more difficult: e.g. depletion of natural resources at sites. In contrast, circular economy involves the usage of production wastes for energy or as raw material some other production and the recovery of valuable components from the disposed products as well as regenerating the resources in case of biomass (Ellen Macarthur Foundation, 2015). This model reduces the emissions by using the waste streams, increases the resource yields through multiple value creation mechanisms and decreases the system risks due to market changes through diversity (Ellen Macarthur Foundation, 2015). Some examples of industrial applications include solid recovered fuels from disposals, heavy metals and minerals recovery from disposed products and waste streams, and energy or fertilizer from manure in livestock as well as integrated processes sharing infrastructure.

Circular economy can provide the resource management needed for sustainable development. The solutions against resource depletion are crucial, and the linear model is insufficient in this aspect. The inorganic components are to be recovered from the disposed products and waste streams, such as heavy metals, minerals and nutrients. The fossil based resources are depleting as well despite providing effective raw material for energy and organic compounds. In addition, the environmental issues associated with fossil sources has become critical, e.g. climate change. Therefore, biomass has increasingly become an important raw material to replace fossil based resources: as a renewable source, with no net carbon emission, less ash content and air pollution impact.

The biomass sources are involved in numerous sectors and can provide wide spectrum of products and energy. Some main sectors of biomass include agriculture, livestock, forestry, pulp and paper, textile and aquaculture. From the circular economy viewpoint, all these sectors generate waste and/or by-product useful as raw material for chemical or energy production in another sector, thus being interconnected. For instance, agriculture produces food and animal feed as products and lignocellulosic residue as waste. The residue can be processed to produce energy or chemicals. The animal feed is used in livestock sector which produces meat as product and manure as waste. The manure can be used as raw material of fertilizers or energy. Similarly, pulp and paper industry uses wood or agricultural residues and the by-product (black liquor) is utilized as the energy source. In addition, the recycled waste papers and textile products can also be raw material for paper, textile or energy production. Furthermore, the carbon dioxide generated during the energy production can be used in aquaculture for algae production and acidification operations. Algae can be used in various applications, such as for energy, fertilizer and pigments. To sum up, biomass as a renewable source provides opportunity for sustainable development and circular economy.

The objective of this chapter is to investigate the role of biomass conversion processes on the circular economy model. The chapter first introduces biomass conversion processes and integrated biorefinery. Then, the chapter covers biomass supply chain network as well as the impact of conversion processes in terms of circular economy.

2. Biomass Conversion and Integrated Biorefinery

The biomass components and the conversion processes determine the possible products of biorefinery facilities. All kind of biomass can be used for energy production through the combustion or decomposition of the organic content. Besides energy production, the various valuable chemicals can be produced from the organic components. For instance, the lignocellulosic biomass can provide phenol and phenol derivatives through lignin, sugars and alcohols through cellulose and hemicellulose as well as other organic compounds (such as carboxylic acids, furans and furfurals) through partial decomposition (Elliott, 2004). The manure has nutrients needed in fertilizers for agriculture, and the food waste can provide biogas. Algae has lipids, proteins and carbohydrates. Lipids are the raw material of transesterification producing biodiesel, and proteins and carbohydrates can be used to produce animal feed (Rafael et al., 2008; Elliott, 2004). Similarly, industrial organic waste streams can also be utilized for energy production or chemical production in accordance with the content. Furthermore, the interconnected biomass activities result in integrated biorefinery facilities.

2.1. ***Biomass Conversion Processes***

A biomass feedstock can be processed as whole or fractionated into components each of which are processed separately to produce various products. For instance, lignocellulosic biomass can be fractionated to lignin (phenolic fraction), cellulose (polymer of glucose sugar) and hemicellulose (polymer of various sugars) (Kim et al., 2016; Li et al., 2016). Then, each fraction is processed separately for various products. Alternatively, biomass as whole can go through a conversion process for biomaterial, chemicals, biofuel or combined heat and power (CHP) production.

Biomass conversion processes are classified as biological, thermal and hydrothermal processes. The biological processes involve the conversion achieved with enzymes or microorganisms, e.g., biogas production from food waste, sugar production through the hydrolysis of carbohydrates or cellulose and hemicellulose, and alcohol production through fermentation of sugars (Zheng et al., 2009; Ishola et al., 2013; Ishola et al., 2015). The thermal processes involve the conversion achieved by heat treatment and occurs at high temperature. For instance, combustion requires heat to be initiated and then produces much more heat than needed for initiation. This heat is used for steam generation, and steam provides electricity and district heat. Another main example is gasification: heat requiring process to decompose the biomass to syngas (mixture of gases including mainly hydrogen, methane, carbon monoxide and carbon dioxide) (Balat et al., 2009b). Other examples include pyrolysis producing crude bio-oil (Balat et al., 2009a), and torrefaction to remove water and some volatiles (Koppejan et al., 2012). The hydrothermal processes involve the conversion by heat treatment and using water as the reaction media. The main examples are hydrothermal liquefaction (HTL) producing crude bio-oil (Toor et al., 2011), supercritical water gasification (SCWG) producing syngas (Yakaboylu et al., 2015), and partial wet oxidation (PWO) (Muddassar et al., 2015a, 2015b). Figure 1 shows the simplified scheme of biomass processing. After the conversion process, further processing is usually applied in order to obtain the desired product for usage: chemical/physical operations to produce final products or to improve the properties of conversion products.

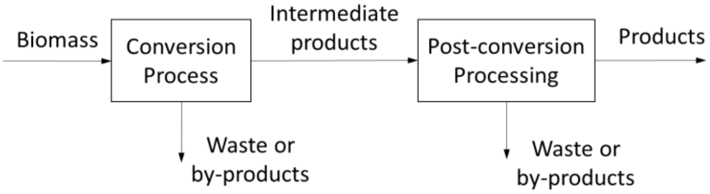


Figure 1. Biomass-to-product scheme

For instance, crude bio-oil is upgraded through hydrodeoxygenation (HDO) or zeolite upgrading to improve the fuel quality (Zhang et al., 2007). In addition, the waste and by-product streams could be used as raw material for CHP or other production to achieve circular economy model. Table 1 lists some applications on the basis of the scheme in Figure 1. As it can be seen, it is possible to have the same products through different processes or a biomass kind can be processed in more than one way resulting in different products. Moreover, each conversion process has advantages and disadvantages making it suitable for some biomass kinds and unsuitable for some other biomass kinds. Therefore, the biomass conversion process is to be selected in accordance with the application situation.

Table 1. Some examples of biomass conversion applications

Biomass	Conversion	Intermediate	Post-conversion	Products
All kind	Combustion	-	-	CHP as product Carbon dioxide as by-product
All kind	Gasification or SCWG	Syngas	Combustion in gas engine	CHP
All kind	Gasification or SCWG	Syngas	Separation and purification	Hydrogen
All kind	Pyrolysis or HTL	Crude bio-oil	HDO or zeolite upgrading	Bio-oil
Cellulose Hemicellulose Carbohydrates	Hydrolysis	Sugars	Fermentation	Alcohols
Wood or straw	Pulping	Pulp Black liquor	Papermaking Recovery boiler	Paper CHP
Food waste	Fermentation	Bio-gas	Combustion in gas engine	CHP

2.2. ***Selection and Design of a Biomass Conversion Process***

The selection and design of a conversion process plays important role in sustainability of biorefinery. Figure 2 shows the selection and design approach. The conversion process is selected in accordance with the feedstock properties and target products. Some relevant feedstock properties include the organic components, moisture and ash content, and heating value.

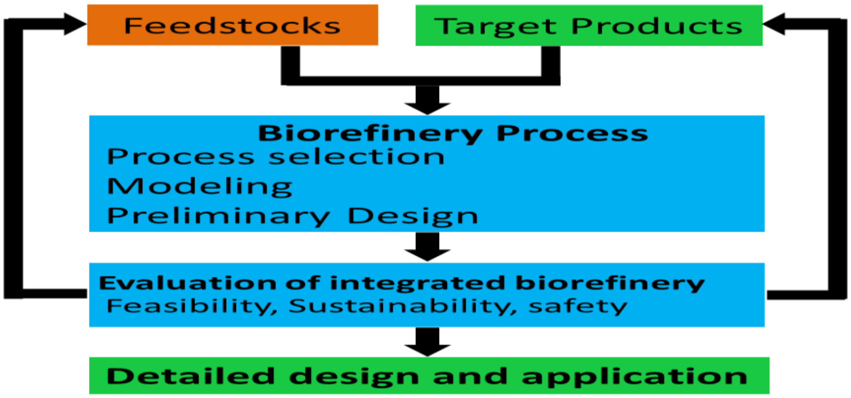


Figure 2. The selection and design approach to biomass conversion processes

The thermal processes are suitable for feedstock with low moisture content. Therefore, drying or evaporation is usually pre-treatment of those processes in case of biomass feedstock. Nevertheless, the extent of drying or evaporation can be optimized based on the overall efficiency. For instance, Brammer and Bridwater (2002) investigated the impact of drying on the overall efficiency and cost of electricity for gasification of wood with 50 % moisture: the optimum configuration was to reduce the moisture to 10 % and then to feed to gasifier, i.e. intensive drying before the gasifier. Another process is torrefaction followed by pelletization. This process is suitable for transporting the torrefied pellets to long distance, e.g. to a centralized power plant. Fast pyrolysis produces crude bio-oil that has to be upgraded before the usage in order to reduce the oxygenated compunds, viscocity and acidity, and to improve the thermal stability. On the other hand, thermal processes is not suitable for a feedstock with high moisture content. An exergy analysis on biofuels stated drying/evaporation step as the main source of exergy loss (Saidur et al., 2012). As an example, Naqvi et al. (2010) reviewed black liquor gasification with various options of CHP or chemical synthesis from syngas; however, the concluding statement was to investigate SCWG of black liquor instead. Despite some increase in economy performance compared to the recovery boiler treatment in pulp mills, gasification of black liquor has the same issues with the commercial treatment.

The hydrothermal processes use water as the reaction media, thus eliminating the energy-consuming drying and evaporation need. These processes benefits from the changes in water properties with pressure and temperature (Kruse and Dahmen, 2015). The polarity of water decreases with temperature, and water becomes non-polar at supercritical conditions (critical point of water: 22.1 MPa and 374 ºC). In other words, supercritical water becomes an effective solvent for organics whereas the salt solubility decreases to ppm levels. Viscocity and specific heat decrease with temperature as well. The hydrothermal processes produces the same products with thermal processes. Nevertheless, the hydrothermal processes provide higher yields and product quality as well as occuring at lower temperatures compared to the thermal processes. For instance, the bio-oil produced through HTL is in higer quality than that produced through pyrolysis, requiring less hydrogen during the upgrading process (Tekin et al., 2014). HTL occurs at 330-550 ºC whereas fast pyrolysis occurs at 580-980 ºC. Similarly, gasification occurs at 800-1100 ºC where SCWG occurs at 500-700 ºC. The hydrothermal processes require high pressure; nevertheless, this is a minor drawback regarding the improvements in yields and product quality. The hydrothermal processes have short residence time and are suitable in terms of adaptability and flexibility.

The biological processes can produce relatively more pure products selectively. The biological conversion involves four types of processes: simultaneous saccharification and fermentation (SSF), separate hydrolysis and fermentation (SHF), simultaneous saccharification and co-fermentation (SSCF), and consolidated bioprocessing (CBP) (Zheng et al., 2009). SHF has two separate units: first for sugar generation through hydrolysis and then for alcohol production through fermentation. This process is relatively simple; on the other hand, the residence time of the overall process and the investment costs increase in this configuration. SSF reduces the investment costs by implementing both hydrolysis and fermentation in the same unit. SSCF is enhanced version of SSF, in which both C6 and C5 sugars are fermented to produce alcohol. CBP is the recent development operating with an engineered yeast. All the breakdown of cellulose, hydrolysis, and fermentation occur in the same reactor: the yeast generates the relevant enzymes for all these phenomena. However, these processes have issues regarding the flexibility: very long residence time due to cell growth, difficult process control and product inhibition. Table 2 lists the conversion processes and remarks about those processes. After selecting the conversion process, the following steps are process design and evaluation of the designed process. In case of negative result of the evaluation, the next step is either to modify the designed process or to restart the selection process shown in Figure 2.

Table 2. The biomass conversion processes

Process	**Raw material**	**Product**	**Conditions**	**Remarks**
Trans-esterification	Vegetable oil Alcohol	Biodiesel	T: 50-70 °C	Glycerol is by-product Catalyst: NaOH
Fractionation of lignocellulose				
Kraft pulping	Wood	Pulp	T: 170-180 °C P: 11 atm t: 2-4 h	Black liquor is by-product pH around 13 by adding NaOH and Na_2S
Soda pulping	Straw	Pulp	T: 140-170 °C t: 2-4 h	Black liquor is by-product pH around 10 by adding NaOH and Na_2O
Biological processes				
Hydrolysis	Cellulose Hemicellulose Carbohydrates	Sugars	T: 120 °C t: 15-60 min	Acidic condition by adding H_2SO_4 solution
Fermentation	Sugars	Alcohols	T: 40-50 °C t: 36-48 h	
Fermentation	Food waste	Bio-gas	P: 1 atm T: 10-72 °C	Anaerobic bacterial digestion
Thermal processes				
Torrefaction & pelletization	Wood	Torrefied wood pellets	$P_{torr.}$: 1 atm $T_{torr.}$: 250-350 °C	Increasing energy density
Pyrolysis	Wood, Straw, Grass	Crude bio-oil	P: 1-3 atm T: 450-650 °C t: 0.5-2 s	Char and gas by-products
Gasification	Wood, Lignin, Straw	Syngas	P: 1-3 atm T: 850-1200 °C t: 1-3 min	Suitable for low-moisture feedstock or otherwise drying is required as pre-treatment
Hydrothermal processes				
PWO	Black liquor		P_{O2}: 0.5 MPa T: 180-270 °C t: 10-30 min	Suitable for high-moisture feedstock
HTL	Black liquor, manure, straw	Crude bio-oil	P: 4-25 MPa T: 250-370 °C t: 1-12 min	Suitable for high-moisture feedstock; Char and gas by-products
SCWG	Black liquor, manure, straw	Syngas	P: > 25 MPa T: 600-700 °C t: 1-2 min	Suitable for high-moisture feedstock; Reactor inlet with 5 % organic content maximum

In addition to being classified based on the conversion process, biomass processing is classified based on the feedstock source as 1st generation and 2nd generation (Rafael et al., 2008). The 1st generation refers to biomass conversion process using the edible biomass as the feedstock, such as corn crops, sugar cane, wheat, vegetable oils and animal fat. One example is the production of alcohol through fermentation when edible crops are the feedstock. Another example is biodiesel production from vegetable oils or animal fat through transesterification. This type of conversion provides the production of valuable products through simple processes. However, the 1st generation biomass processing competes with the food sector in land and water usage. The emission calculations of 1st generation biomass processing usually give very small decrease or even increase in carbon emission compared to fossil-based production when the previous stages of the biomass feedstock are taken into account, such as harvesting, machinery, fertilizers and distribution.

Moreover, the quality and quantity of agricultural crops vary from season to season, and spontaneous degradation can be an issue in case long-time storage. These issues of the 1st generation biomass processing drive biorefinery towards the 2nd generation, which refers to processing the non-edible biomass sources and waste/by-product streams. Some feedstock examples of the 2nd generation include wood, straw, sawdust, bark, manure, black liquor, grass and non-edible crops. The 2nd generation processes reduce the environmental impacts of biomass activities and provide additional revenue by converting waste streams into valuable products. Consequently, the 2nd generation biomass conversion has potential to play the key role for sustainable biorefinery. However, this requires advanced conversion processes: high operation costs and operational concerns of each alternative. The processes listed in Table 2 are the 2nd generation when non-edible sources or waste/by-product streams are used as the feedstock. Therefore, applying the 2nd generation biomass conversion implies integration of additional processes to existing facilities or collecting and processing the 2nd generation feedstock from various sectors together, i.e. integrated biorefinery.

2.3. ***Integrated Biorefinery***

The typical approaches of integrated biorefinery are co-processing with fossil-based sources and integrated process to an existing biomass industry. The major application co-processing involves blending wood pellets or torrefied wood pellets with coal as the feed of boilers in power plants. However, this approach can provide limited replacement of fossil fuel with biomass, around 10 % in energy content. High biomass ratio in the feed blend requires a secure biomass supply and costly modifications in the boiler units. The other approach is the integration of a process with an existing plant, using the waste/by-product of the plant to produce valuable products. This approach provides reduced risk of revenue by expanding the product spectrum besides reducing the environmental impact and increasing the revenue.

One industrial example of integration of a process is to recover lignin from black liquor in pulp mills (Tomani, 2010; Kouisni et al., 2012). The commercial treatment of black liquor involves evaporation followed by recovery boiler for CHP production and lime kiln for the recovery of pulping chemicals. The recent application integrates acidification by carbon dioxide to reduce pH to 9-10, namely LignoBoost process (Tomani, 2010). Lignin precipitates at this pH and is recovered as an additional product after filtering and washing. Partial wet oxidation prior to acidification was proposed as an improvement to LignoBoost process, namely LignoForce process as shown in Figure 3 (Kouisni et al., 2012).

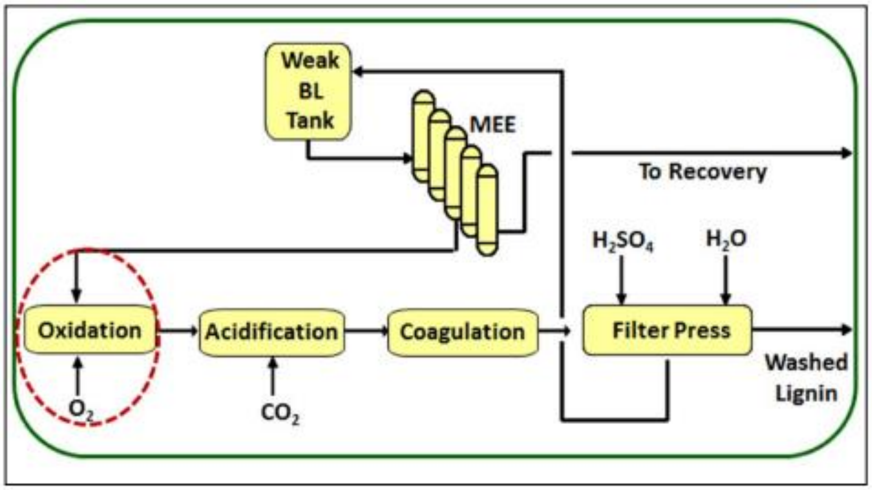


Figure 3. The scheme of LignoForce process (Kouisni et al., 2012)

In addition, the recent research on black liquor seeks an alternative treatment process. An effective alternative can increase the power efficiency for Kraft pulp mills using wood and provide solution for non-wood mills. The commercial recovery boiler is inapplicable for non-wood black liquor. This is because of high silica content causing very sharp increase in viscosity with concentration. Then, the evaporation is limited to concentrate black liquor to 50 % solid content: inlet with this moisture to recovery boiler reduces the efficiency and makes the commercial treatment unfeasible for non-wood mills. The most investigated alternative is gasification of black liquor followed by either synthesis or CHP production; however, high water content of black liquor rises the need of energy- consuming evaporation as well. The recently investigated alternative include PWO and SCWG. The main parameters of PWO are temperature, residence time and oxygen pressure. Muddassar et al. (2015a) investigated partial wet oxidation of various biomass including Kraft black liquor and wheat straw black liquor with the residence time of 30 minutes or more, at 160-270 ºC and various oxygen pressure of 0.4-2 MPa. Muddassar et al. (2015b) studied the impact of iron-based catalyst on partial wet oxidation of black liquor with the residence time of 30 minutes, at 170 and 230 ºC and oxygen pressure of 0.5 MPa. Those catalysts had only minor impact on the yields of carboxylic acids. On the other hand, Özdenkçi et al. (2014) stated that the downstream of partial wet oxidation is still dilute: recovering organic salts require intensive evaporation, and separation each organic acid with high purity could be costly. Therefore, Özdenkçi et al. (2017)

suggested that PWO can be an intermediate step of a broader biomass conversion process. SCWG of black liquor resulted in promising yields and hot gas efficiency. De Blasio et al. (2016) investigated SCWG of Kraft black liquor at 25 MPa, 500-700 ºC, in Inconel 625 and stainless steel 316 reactors. The operation in Inconel reactor at 600 ºC provided the highest hydrogen yield and the operation in Inconel reactor at 700 ºC provided the highest hot gas efficiency. However, it might be economically unfeasible to integrate an advanced process to an existing plant due to small capacity and high investment cost, despite the advantage of sharing the infrastructure. Currently, biomass conversion processes are not competitive with the fossil-based source conversion in terms of economic feasibility. For example, Zhu et al. (2014) stated that HTL of wood is not competitive with the petroleum-based gasoline. This situation directs the biomass conversion towards the utilization of waste as feedstock, processing multiple feed and producing multiple product, in order to improve the economic performance.

Various biomass sectors have waste or by-product that can be processed together. For instance, PWO can be applied to saw dust as well as to black liquor. For instance, Muddassar et al. (2014) investigated the production of carboxylic acids from softwood particles through cooking followed by partial wet oxidation as two sequential operation. As further study, Sipponen et al. (2016) investigated the production of various compounds (e.g., bio-oil, sugar monomers, lignin monomers, organic acids and furans) by partial wet oxidation of softwood particles in a single unit: reported the optimum conditions for each product type and proposed flexible operation in accordance with the demand. In addition, SCWG can also be applied to various biomass feedstock, e.g., to black liquor (De Blasio et al., 2016; Sricharoenchaikul, 2009; Cao et al, 2011), manure-wood mixture (Yong and Matsumura, 2012) and paper sludge (Rönnlund et al., 2011). SCWG Collecting wastes from various biomass activities would enable larger capacity conversion processes and reduce the environmental impacts of all those activities. This concept can potentially make the biorefinery sector competitive with petroleum refinery. On the other hand, this concept requires multi-feed-multi-product and flexible conversion processes. To address this issue, Özdenkçi et al. (2017) proposed a novel hydrothermal process as shown in Figure 4 to produce lignin and bio-oil or syngas flexibly. The process starts with PWO, then some portion goes to acidification to recover lignin, and finally the PWO downstream and the remaining liquid from lignin recovery go to the reactor. This process is in the progress of being patented: the provisional patent application has been made (Özdenkçi et al., 2016). Table 3 shows the conditions at each unit operation of the hydrothermal process shown in Figure 4. PWO can have shorter residence time since no chemical production is aimed. The purposes of PWO are self-sufficient heating and dissolving solid biomass. The reactor can perform either HTL to produce crude bio-oil or SCWG to produce syngas, depending on the adjusted temperature and pressure. Finally, the separation takes place in the drum in case of bio-oil production or as two-stage separation in case of syngas production. During SCWG operation, temperatures of high-pressure and low-pressure separators can be changed in accordance with the desired use of syngas and the solubility of the gases. Hydrogen production aims at maximum hydrogen production whereas CHP production aims at maximum combustible gases in H_2-rich gas outlet. Moreover, this concept would cause transportation costs as well. Therefore, the evaluation must cover the whole path including transportation of wastes and recycled products, conversion processes and transportation of products, i.e. supply chain network.

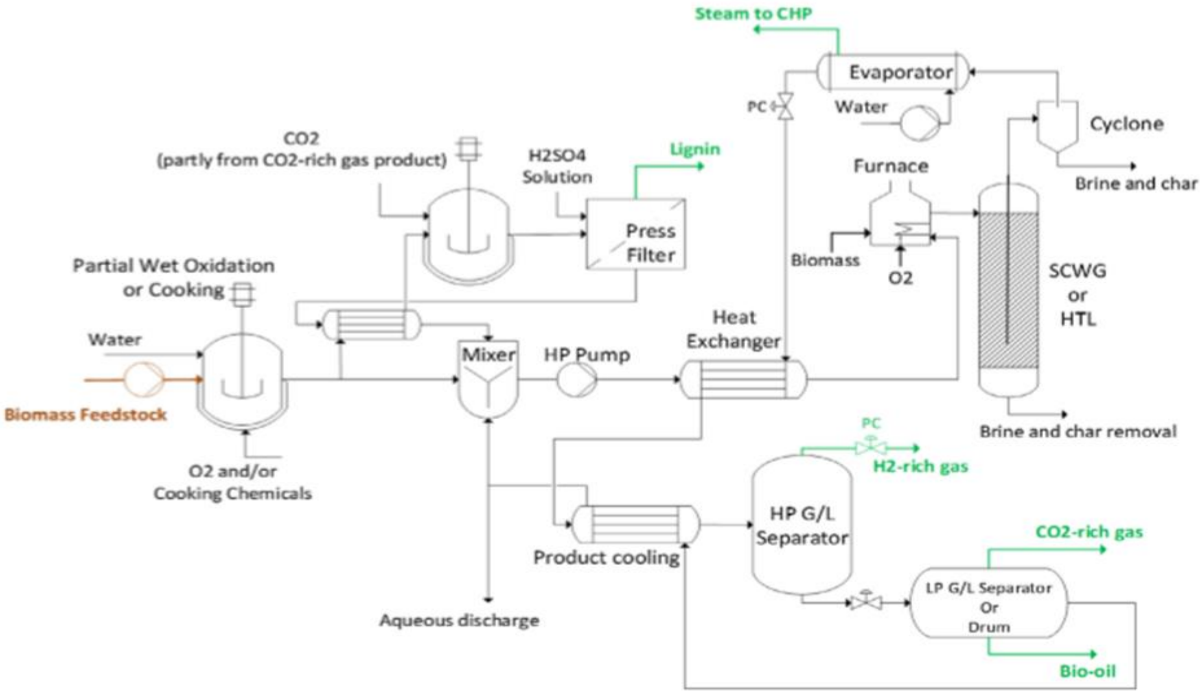
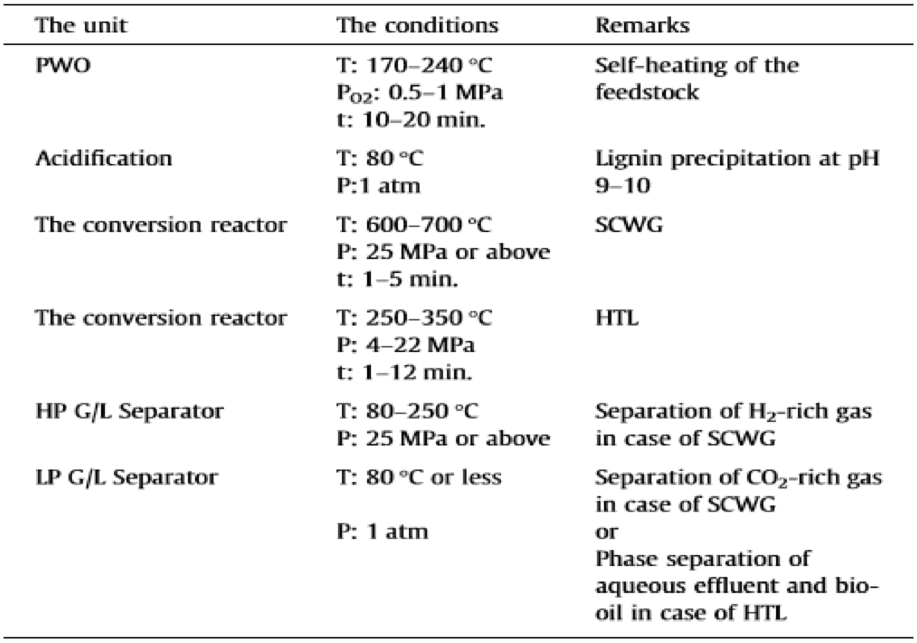


Figure 4. The multi-feed-multi-product and flexible hydrothermal process (Özdenkçi et al., 2017)

Table 3. Process conditions of the hydrothermal conversion shown in Figure 4 (Özdenkçi et al., 2017)



The unit	The conditions	Remarks
PWO	T: 170–240 °C P_{O2}: 0.5–1 MPa t: 10–20 min.	Self-heating of the feedstock
Acidification	T: 80 °C P:1 atm	Lignin precipitation at pH 9–10
The conversion reactor	T: 600–700 °C P: 25 MPa or above t: 1–5 min.	SCWG
The conversion reactor	T: 250–350 °C P: 4–22 MPa t: 1–12 min.	HTL
HP G/L Separator	T: 80–250 °C P: 25 MPa or above	Separation of H_2-rich gas in case of SCWG
LP G/L Separator	T: 80 °C or less P: 1 atm	Separation of CO_2-rich gas in case of SCWG or Phase separation of aqueous effluent and bio-oil in case of HTL

3. Biomass Supply Chain Network and Circular Economy

The main steps of biomass supply chain network include collection of feedstocks (i.e. wastes and by-products both from production plants and usage), pre-treatment and conversion processes, upgrading/purification processes and finally distribution of the products. Therefore, the design of a supply-chain network aims at the minimum cost of the whole chain.

The design of supply chain network determines the capacities and locations of conversion processes and upgrade/purification plants. The network modeling involves strategical decisions, input information, the objective function, and tactical and operational aspects of implementation (Yue et al., 2011). The strategical decisions involve the selection of biomass types and conversion technologies as well as modes of transportation. The input information includes the biomass activity site locations, the feedstock amounts from those sites, product yields, operation costs per unit product, fuel consumption and transportation costs per unit distance, and the demand site locations and the demand amounts in those sites. Then, the objective usually covers the economic aspect of the network, on the constraints of locations and amounts of available feedstock and product demand.

For instance, Marvin et al. (2012) used maximum net present value as the objective when designing a biomass-to-ethanol supply chain network. In addition, Kim et al. (2011) used maximum profit for a biomass-to-liquid fuels network, and Akgul et al. (2012a) used minimum cost as the single objective when designing bioethanol supply chain network. This is called single-objective optimization: one objective function with respect to the locations and capacities of the processing plants. The single-objective optimization models are easier to solve and require less computation than multi-objective models.

The multi-objective optimization involves the compromise between two contradicting objectives, e.g. minimizing the greenhouse gas emissions and maximizing the profit. For example, You and Wang (2011) used minimum greenhouse gas emissions and minimum annualized costs as the multiple-objective when modelling biomass-to-liquid fuels network. Another approach is to define emission constraints as well in the single-objective model. Akgul et al. (2012b) inserted emission limits as constraints and used minimum daily cost of the whole chain when designing the bioethanol supply chain network defined by Akgul et al. (2012a). Sharma et al. (2013a) provided a detailed review of the studies about supply chain network, covering the aspects of objective functions, model types, network structures, and biomass and product types. The other important aspect is uncertainty of the conditions, e.g. the impact of weather. This aspect is involved through stochastic models (Awudu and Zhang, 2012; Sharma et al., 2013b).

3.1. *Supply Chain Network Structures*

The structure of a supply chain network involves a compromise between the operation costs and the transportation costs. The high capacity in plants would decrease the operation cost per unit product but increase the transportation costs of feedstock and vice versa. Therefore, different sturctures occur in supply chain networks, namely distributed, centralized and distributed-centralized as shown in Figure 5.

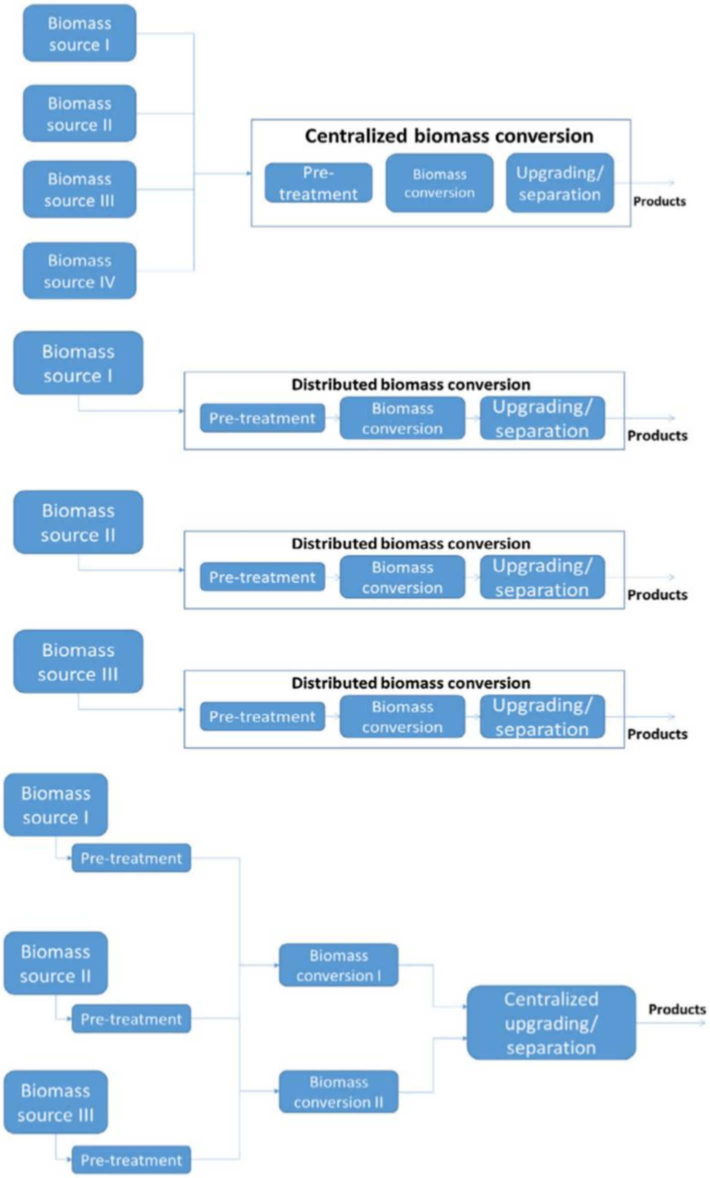


Figure 5. Centralized (top), distributed (middle) and distributed-centralized (bottom) supply chain network structures

The distributed structure locates the complete processing from pre-treatment to purification at each biomass activity site. This eliminates the transportation costs of feedstock; however, the operation costs would increase, and the processes are likely to be economically unfeasible. In contrast, the centralized structure involves a single processing from pre-treatment to purification in large capacity, to where the feedstock is transferred from all the biomass sites. This structure provides reduced operation costs but increase the transportation costs sharply. In this regard, Bowling et al. (2011) proposed the collection hubs for the transportation of feedstock from biomass activity sites to the centralized plant. However, despite the improvement, this type of network still results in very high transportation costs and spontaneous deterioration in case of long storage time. The transportation costs from hubs to the centralized plant can be reduced by processing the collected feedstock, i.e. the distributed-centralized structure. This structure addresses the issue of spontaneous deterioration as well.

The distributed-centralized structure is the balance between the other two structures: conversion processes receiving feedstock from few biomass activity sites and a centralized upgrade/purification process. The biomass conversion processes increase the energy density, thus reducing the costs of transportation to the centralized plant. For instance, Kim et al. (2011) compared centralized gasification followed by Fischer-Tropsch synthesis (the centralized structure) with distributed pyrolysis and centralized gasification followed by Fischer-Tropsch synthesis (the distributed-centralized structure). The optimum result was the distributed-centralized structure with respect to the profit. Furthermore, this structure was stated to be more robust against the variations in market demand and prices than the centralized structure (Kim et al., 2011). Similarly, You and Wang (2011) obtained the distributed-centralized structure as the optimum network when designing biomass-to-liquid biofuel supply chain. The distributed-centralized structure provides more distributed job opportunities and development in rural areas (Papendiek et al., 2012).

However, the studies on biomass supply chain network are limited to a single feedstock and/or product through a specified conversion process in the whole chain. For instance, ethanol was the only target product in the investigations by Akgul et al. (2012a, 2012b) and Marvin et al. (2012). Similarly, Kim et al. (2011) and You and Wang et al. (2011) targeted only liquid biofuel. Instead, biomass enables multiple products, and biomass supply chain needs improvement through involving more feedstock. These issues can be addressed by more enhanced supply chain network structure and biomass conversion processes.

3.2. *Sectoral Integration for Circular Economy*

A biomass supply chain network should have the features of adaptability and flexibility (Yue et al., 2014). The product demand and prices can change based on the situation in the industrial sectors. In addition, the biomass feedstock can vary seasonally in quantity and quality as well. The supply chain network should be able to adjust the production amounts of various products and adapt the feedstock variations. This requires multi-feed-multi-product and flexible conversion processes (Özdenkçi et al., 2017). For instance, the hydrothermal process in Figure 4 can adjust lignin production by controlling the stream going to lignin recovery section. In addition, the other product can be switched between syngas and bio-oil in accordance with the demands to CHP, liquid fuels and other products that can be produced from syngas. Furthermore, the temperatures in gas separation units can also be adjusted in accordance with the desired use of syngas: e.g. maximizing hydrogen content or miximizing the heating value in H_2-rich gas stream. Regarding the feedstock, this process can utilize both solid and liquid streams. The PWO unit operates as simultaneous dissolution and partial oxidation in case of solid feedstock. There can be other multi-feed-multi-product amd flexible processes involved in the network design as well.

The sectoral integration structure is the enhanced version of distributed-centralized network structure as proposed by Özdenkçi et al. (2017). Figure 6 shows the conceptual structure of the sectoral integration network. As additional features, the sectoral integration involves pre-treatment at the biomass sites and multi-feed-multi-product conversion processes. The pre-treatment at biomass sites prepares the waste or byproduct streams as suitable raw materials for the regional biomass conversion processes. The regional conversion processes can produce CHP for the region and products to be used locally or to be upgraded at the centralized facility. The optimization model can result in more than one centralized plant and/or a centralized plant integrated to one of the regional conversion processes. This type of configuration benefits from the shared infrastructure. For instance, the centralized HDO plant can be integrated with a regional conversion process producing hydrogen, and bio-oil from other regional processes can be transferred to this centralized plant. Figure 7 illustrates a network with this configuration: only illustrative figure, not a network design for a real case. As further integration, CO_2 produced in the regional conversion processes can be utilized in algae production, i.e. to be transported to another biomass activity site. Then, algae can be used in hydrothermal processes, such as the one in Figure 4. Alternative use of algae includes animal feed and food supplement, pharmaceutical and plant protection products through supercritical algal extracts (Michalak et al., 2015).

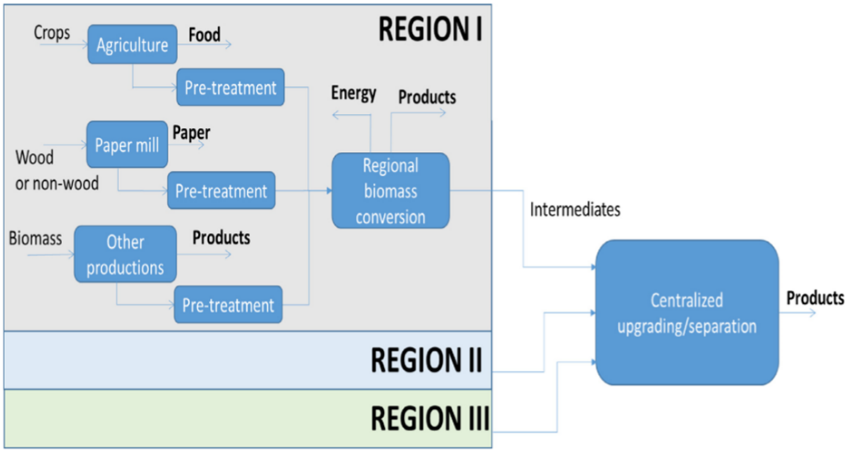


Figure 6. The sectoral integration structure

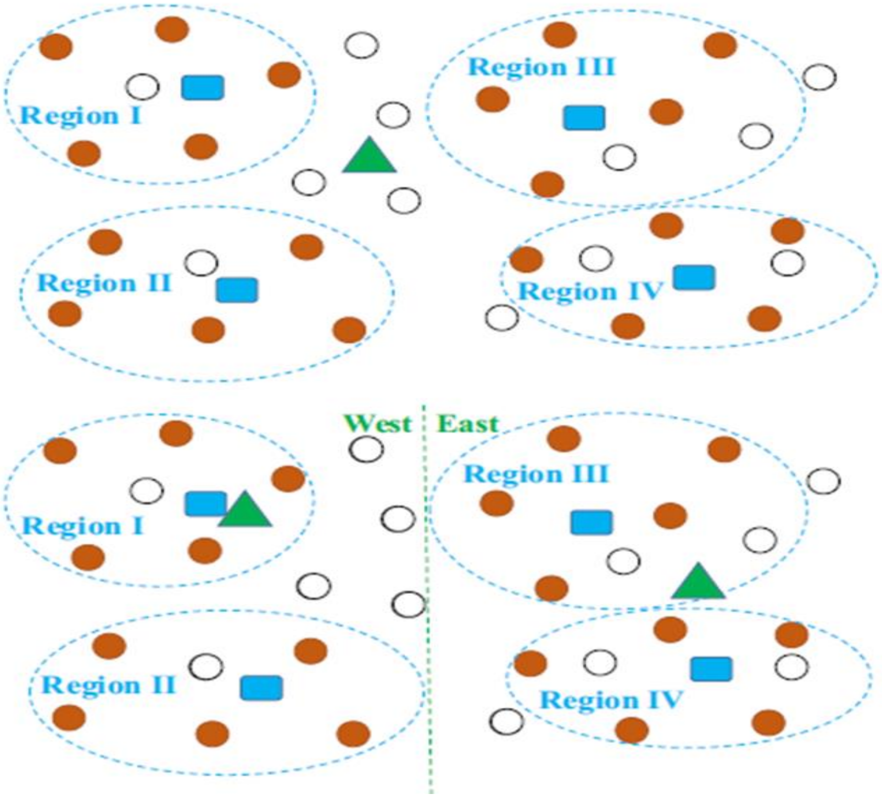


Figure 7. Illustrative example of plant locations through network design: brown filled circles for the biomass activity sites, blue rounded rectangles for the regional biomass conversion plants and green triangles for the centralized upgrading plants

The sectoral integration structure has several benefits:

- additional revenue and reduced financial risk via wider product spectrum
- secured feedstock supply for conversion processes from various sectors
- reducing the environmental impacts of all the involved sectors
- more evenly distributed job opportunities and development of rural areas
- more self-sufficiency to the countries with biomass activities

The sectoral integration has economic benefits distributed to the whole area of the network. The additional revenue is distributed to the rural areas as well as to the conversion processes. The wastes of biomass activities in rural areas become valuable raw materials for the regional conversion processes. The conversion processes have additional revenue as well via wider product spectrum. In addition, the risks are minimized through wide product spectrum and wide spectrum of feedstock supply. Even if the demand or price of one product reduce, the conversion process can switch partly or completely to other products and maintain the revenue. Similarly, no feedstock shortage occurs even if one biomass sector declines. The supply shortage may occur only if all the sectors declines simultaneously, which is very unlikely.

Furthermore, the sectoral integration has environmental and social benefits as well. The environmental impacts of all involved sectors reduce simultaneously since all the waste streams are utilized in the conversion processes. In addition, the job opportunities are distributed to the rural areas as well in the sectoral integration structure. This would result in more evenly population distribution and hence improved management of social services in terms of those services reaching everywhere and everybody. Furthermore, a country applying the sectoral integration can be self-sufficient energy need and have major production of other biomass-derived products (such as food, animal feed, textile and chemicals) simultaneously. These productions would be sourced from the renewable biomass sources, thus eliminating the import of raw materials for energy and reducing the import of other chemicals.

4. Future of the Biomass Conversion Processes and Circular Economy

Biomass conversion processes play a key role in a biomass supply chain network. The sectoral integration structure can be applicable in case of multi-feed-multi-product and flexible conversion processes. The biomass conversion process should be able to utilize different types of feedstock with high energy efficiency and product yields. For instance, the feedstock can be lignocellulosic or manure and liquid or solid. In addition, techno-economic performance of biomass conversion processes would influence the design of supply chain network. Conversion processes being efficient in small capacities would result in more distributed network design: more regions having smaller areas. In contrast, conversion processes being efficient in large capacities would result in less number of regions having larger areas.

Biomass conversion processes are selected based on the adaptability and flexibility features as well as the feedstock properties and desired products. The thermal processes usually require drying or evaporation as a pre-treatment process due to high moisture content in biomass. The biological processes might not be suitable for flexible operation to switch between the products due to long residence times. Nevertheless, the biological processes can be utilized in the distributed structure and small capacity, the product produced in the demand site by using the waste in the demand site. For instance, biogas production from food waste is potentially suitable for restaurants and residences in order to reduce the outsourced energy need. The hydrothermal processes are suitable for the sectoral integration structure: various types of feedstock processed flexibly. Drying and evaporation need is eliminated since water is used as the reaction media. In addition, a hydrothermal process gives higher yields and quality than the thermal process producing the same products. For instance, bio-oil produced by HTL is in higher quality than that produced by pyrolysis. On the other hand, SCWG operates with larger volumetric flow rates due to dilute streams. This affects the heat integration and the sizes of equipment as well, thus introducing investment and operation costs. Therefore, SCWG is more suitable for large capacity production, i.e. for wider regions, whereas HTL or hydrothermal processes can be used in moderate or small capacities as well depending on the feedstock and techno-economic performance.

Regarding circular economy, developing effective biomass conversion processes is the heart of biomass supply chain networks. The conversion processes should have the ability to process waste and byproducts from plants and biomass activities as well as the recycled, used products and wastes occurring during the usage. This would reduce the environmental impacts of all the involved sectors from harvesting to product end life. It is more beneficial to extract more value-added products from the biomass raw materials. For instance, wood gasification produces only syngas, which can be used for chemical synthesis or energy. However, harvesting wood is a costly operation and requires regeneration of the sources. Despite being renewable, biomass availability is also limited by the land, water and regeneration rate. Instead, pulping produces the raw material for paper and textiles, lignin recovery produces lignin raw material for mechanical applications and replacing fossil-based phenolic compounds in chemical industry, then the wastes/byproducts and the recycled products can be used in the hydrothermal process shown in Figure 4 to produce syngas or bio-oil. This type of production scheme enlarges the product spectrum and reduces the biomass regeneration need. There can be other conversion processes as well targeting the chemical production, to replace the fossil-based compounds used in the industrial applications.

The energy policy might change in case of effective biomass supply chain networks with proper conversion processes. The regional conversion processes can generate CHP for the grid of own region. This will shift the energy policy from large-capacity power plants to more distributed grid structure and save the losses due to energy distribution. In addition, there can be more renewable energy sources used immediately and reduce the energy need from a grid, e.g. solar power for individual buildings and agricultural fields, distributed wind turbines in the regions, and distributed biogas energy production from food waste.

5. Conclusion

The current sustainability issues drive the industries towards renewable sources and circular economy model. Waste and disposed products become valuable raw material, and wider spectrum of products is produced with less natural sources.

Biomass is the potential replacement of fossil sources. The 2nd generation biorefinery provides sustainable concepts from biomass to energy and chemicals. However, rather than integrating a process to an existing facility, the sectoral integration structure provides potentially sustainable supply chain network. The sectoral integration network reduces the risks and increases the revenues through feedstock from several biomass activity sites and wider product spectrum. Furthermore, the revenue and job opportunities is distributed from rural areas to the conversion processes and upgrading plants, thus providing more evenly distributed population balance. The implementation of the sectoral integration requires multi-feed-multi-product and flexible biomass conversion processes.

The biomass conversion processes are selected based on the feedstock properties and desired products as well as the features of flexibility and adaptability. The conversion process should have the ability to utilize different types of feedstock (e.g. lignocellulosic or manure, liquid or solid) and to switch between the products. Consequently, the supply chain network would have the ability to adapt the changes in quality and quantity of feedstock as well as the demand and price changes of products. A regional conversion process can produce some chemicals for demand sites and energy (heat and power) for its own region, thus replacing the non-renewable fossil-based processes. In addition, the sectoral integration network can be supported with more distributed energy production, e.g. biogas production from food waste, wind turbines and solar power.

The future aspect of biorefinery is to develop multi-feed-multi-product and flexible biomass conversion processes with efficient techno-economic performances. This will facilitate the implementation of sectoral integration network.

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Chapter 8

Circular economy and renewable energy through industrial applications

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Abstract
Presently, solar energy conversion is widely used to generate heat and produce electricity. A comparative study on the world energy consumption released by International Energy Agency (IEA) shows that in 2050, solar array installations will supply around 45% of energy demand in the world. It was found that solar thermal is getting remarkable popularity in industrial applications. Solar thermal is an alternative to generate electricity, process chemicals or even space heating. It can be used in food, non-metallic, textile, building, chemical or even business-related industries. On the other hand, solar electricity is wildly applied in telecommunication, agricultural, water desalination and building industry to operate lights, pumps, engines, fans, refrigerators and water heaters. It is very important to apply solar energy for a wide variety of applications and provide energy solutions by modifying the energy proportion, improving energy stability, increasing energy sustainability, conversion reduction and hence enhance the system efficiency. The present work aimed to study the solar energy systems utilization in industrial applications and considered the industrial applications which are more compatible to be integrated with solar energy systems. A circular economy is an attractive and viable alternative that businesses have already started exploring today. A 100% renewable energy system is the foundation of a circular economy which will help industrial sector to move forward.

Keywords: solar energy; solar thermal; industrial application, circular economy

1. Introduction

Energy use has become a crucial concern in the last decades because of rapid increase in energy demand. Moreover, environmental issues of conventional energy resources such as climate change and global warming are continuously forcing us for alternative sources of energy. According to the statistics released by World Health Organization (WHO), direct and indirect effects of climate change leads to the death of 160,000 people per year and the rate is estimated to be doubled by 2020. Climate change causes natural disasters such as floods, droughts, and remarkable changes in atmosphere temperature. Moreover, some diseases become epidemic among the societies mainly malaria, diarrhea, and the associated side effects such as malnutrition. One of the disasters was reported in 2003 is the heat wave which attacked European countries and caused death of 20 thousand people while remained $10 billion losses in agricultural sector (Muneer, et al., 2006).

Currently, conventional energy sources constitute almost 80% of global energy consumption. The urgent need to substitute the energy sources was postponed aligned with discovering nuclear energy in the middle of 20th century, which would stand out for ten to twenty times more than fossil fuels. However, there are some limitations associated with nuclear source of energy. For instance, nuclear fusion is exposed of uranium and thorium ores which are considered fossil fuels as well. In addition, nuclear plants are currently available only in large scale power generations. Therefore, for cooking, heating and small-scale applications renewable energy is still the best choice. It is the source of energy that mankind can continue their survival on the earth without depending on fossil fuels (source: www.life.illinois.edu/govindjee/photosynBook/Chapter4.pdf). Renewable energy sources like solar, wind, biomass, hydropower and tidal energy are promising CO_2 free alternatives (Schnitzer, et al., 2007; Bazen, et al., 2009). Despite the general awareness of advantages of renewable energy utilization, this source of energy contributed only about 1.5% of world industrial energy sector's consumption in 2006. The trend is estimated to rise up to 1.8% in 2030. Table 1 shows global industrial energy consumption patterns for various sources of energy for the years 2006 and 2030.

Table 1. Global industrial energy consumption pattern by fuel in 2006 and 2030 (Abdelaziz, 2011)

Sources of energy	2006 %)	2030 (%)
Liquids	34.6	28.6
Natural gas	24.1	25.6
Coal	24.8	24.3
Electricity	14.9	19.7
Renewable	1.5	1.8

The importance of energy in industrial development is very crucial since major fraction of energy is used in industrial processes. It has dominated more than 50% of total energy consumption worldwide. The delivered energy in industrial sector is utilized in 4 major sectors: construction, agriculture, mining and manufacturing. Industrial sector energy consumption, savings and emission analysis for electrical motors, compressed air, and boilers have been discussed in (Saidur, et al., 2010) and revealed that a major chunk of energy is used in this sector. Table 2 shows the industrial sector energy use for few selected countries around the world.

Table 2. The industrial sector energy use for few selected countries around the world.

Country	Industrial sector energy use (%)
China	70
Malaysia	48
Turkey	35
USA	33

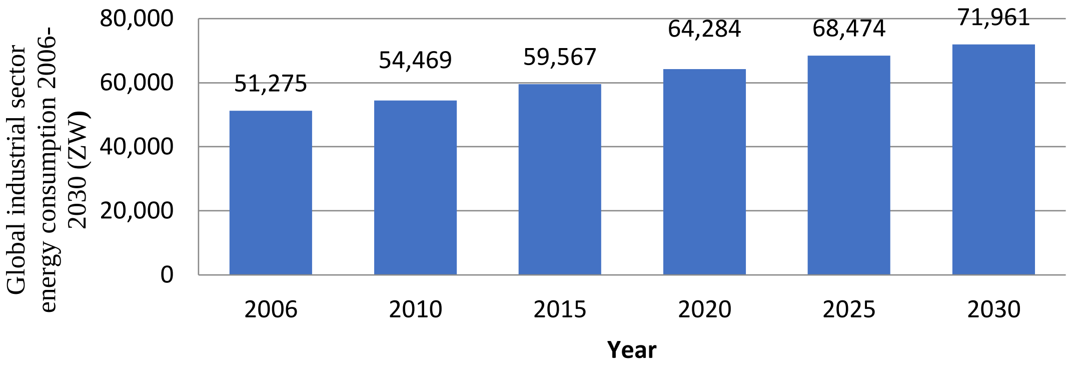

Figure 1. Global industrial sector energy consumption during 2006 - 2030 (IEO, 2009)

Due to rapid growth in conventional fuel prices and environmental constraints, enterprises are not attracted to use fossil fuels in industrial sector anymore. By applying renewable energy based systems in industries, the greenhouse emissions could be reduced significantly. Therefore, traditional energy supplies should be shifted to renewable sources of energy and new technologies must be developed and applied in industries.

In this regard, the remarkable strategy of circular economy is used to combine the basis of ecology and economics in a unique principle, methods, and indicators. The principle is generally known as the 3-Rs, which includes reduce, reuse, and recycle. Firstly, reduction is related to the production and consumption of the available resources and energy. Secondly, reuse to ensure completely usage of the used products. Finally, recycle to significantly translate the wastes into new resources. The circular economy highlights the need of considering material, capital, and labor circulations and their supply-demand relationship while exploring the economic growth. Meanwhile, to apply the 3-Rs principle several methods were proposed where Material Flow Management (MFM) is highly recommended to apply such principle. In addition to the related analysis tools such as MFA and Life Cycle Assessment (LCA). In the meantime, MFM is regarded as recent tool that is used for implementing sustainable resource and environmental management on a systematic basis. While, MFA, and LCA are considered as an analytical tool for MFM where it is related tools support the implementation of the circular economy and it is planning activators (Yong, 2007).

Among all the renewable energy sources, solar power attracted more attentions as a greatest promising option to be applied in industries. Solar energy is abundance, free and clean which doesn’t make any noise or any kind of pollution to the environment. So far, many attempts have been made to extract solar energy by means of solar collectors, sun trackers and giant mirrors in order to utilize it for industrial purposes. Solar energy applications in industry are divided into 2 main categories: the solar thermal and the photovoltaic. Some of the most common applications are hot water, steam, drying and dehydration processes, preheating, concentration, pasteurization, sterilization, washing, cleaning, chemical reactions, industrial space heating, food, plastic, building, textile industry and even business concerns. Table 3 shows the share of different sources of renewable energy for industrial applications (excluding hydroelectric and biomass) in term of annual production and global electrical demand for 2015.

Table 3. Renewable energy sources, annual production and electricity global demand in 2015 (Renewables, 2016)

Renewable source	Annual production (Gw)	% of Electricity global demand
Solar thermal	4.8	0.1
Photovoltaic	227	1.2
Geothermal	13.2	0.1
Wind	433	3.7
Total	678	5.1

Due to the global energy shortage and controlling harmful environmental impacts, application of solar energy has receiving much attention in the engineering sciences. In the literatures, there is no comprehensive review on the applications of solar energy in industrial facilities. It is expected that this review will be very useful for industrial energy users, policy makers, research and development organizations, and environmental organizations.

2. Integration of solar energy into industrial systems

A typical industrial energy system is composed of 4 main parts; power supply, production plant, energy recovery and cooling systems. Figure 2 shows a block diagram of a typical industrial energy system.

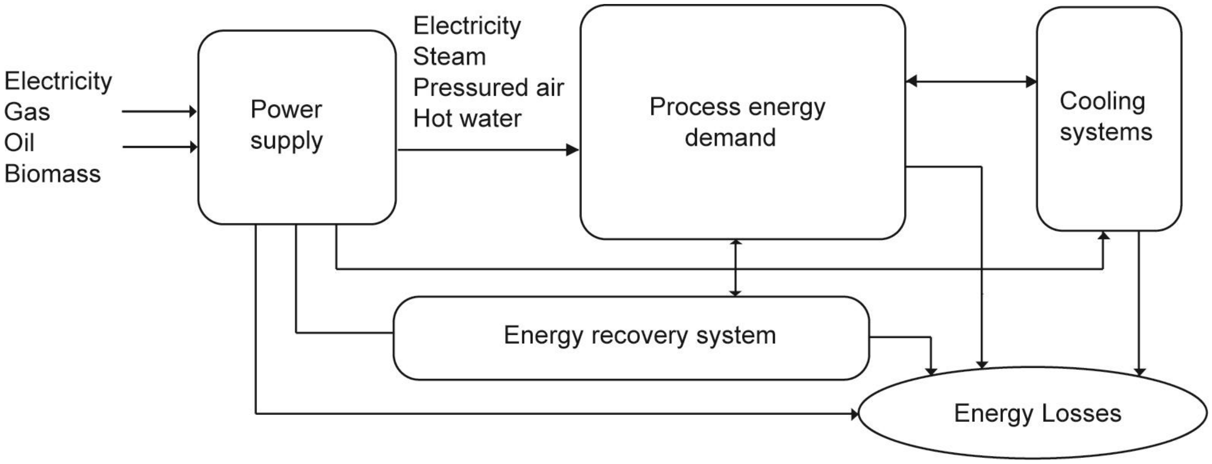

Figure 2. Block diagram of a typical industrial energy system (Schnitzer, et al., 2007)

The power supply provides the energy needed for the system to operate mainly from electrical energy, heat, gas, steam or coal. Production plant is the part of the system that executes proceedings of production. Energy is utilized in this part for running subsystems, pressure/vacuum/temperature solenoids, valves and switches. Solar energy systems can either be applied as the power supply sector or directly to a process. Table 4 has tabulated the solar energy applications and the technologies adopted in industrial processes.

Table 4. Solar energy applications, system technologies and type of systems commonly used in industry (Kalogirou, 2004)

Solar energy application	Solar system technology	Type of system
SWH	Thermo syphon systems Integrated collector storage Direct circulation Indirect water heating systems Air systems	Passive Passive Active Active Active
Space heating and cooling	Space heating and service hot water Air systems Water systems Heat pump systems Absorption systems Adsorption (desiccant) cooling Mechanical systems	Active Active Active Active Active Active Active
Solar refrigeration	Adsorption units Absorption units	Active Active
Industrial heat demand process	Industrial air and water systems Steam generation systems	Active Active
Solar desalination	Solar stills Multistage flash (MSF) Multiple effect boiling (MEB) Vapor compression (VC)	Passive Active Active Active
Solar thermal power systems	Parabolic trough collector systems Parabolic tower systems Parabolic dish systems Solar furnaces Solar chemistry systems	Active Active Active Active Active

3. Solar thermal energy

It can be stated that solar thermal is the conversion of solar irradiation into heat. Among renewable energy systems, solar thermal is considered as the most economical alternative. Typically, the systems use solar collectors and concentrators to gather solar radiation, store it and use for heating air or water in domestic, commercial or industrial plants. Figure 3 presents a schematic diagram of solar irradiation conversion to mechanical energy (Kalogirou, 2004).

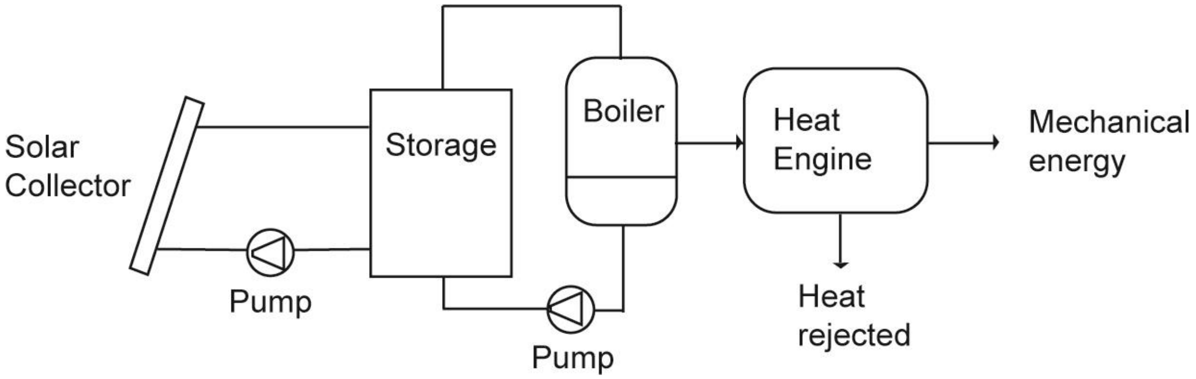

Figure 3. Schematic of a solar-thermal conversion system (Kalogirou, 2004)

The location, type of collector, working fluid to determine required storage volume, size of the system and storage volume to determine the heat exchanger size and the load are the factors that need to be considered for the specific applications (Kalogirou, 2003). However, it must be noted for some applications that solar energy is not available continuously for 24 hours. In such cases, addition supplementary measures should be provided to accumulate solar irradiation during sunny days, store it in an embedded phase transition and release it in a controlled manner in severe conditions. To increase the efficiency of solar thermal systems, solar collectors are applied to heat the air or water as the medium of heat transfer. However, each collector is dedicated for a specific application. For example, flat-plate collectors are properly designed to be used in low temperature applications, the concentrating and sun-tracking parabolic trough collectors (PTC) are suitable for high temperature applications in which the system can obtain temperature higher than 250^{o}C with high efficiency, two axes tracking collectors are applied in power generation, stationary (non-tracking) and one axis PTCs are mainly used in industrial heat processes. Among the collectors, movable collectors require higher maintenance cost compared to other collectors. Table 5 illustrates the three main categories and types of solar collectors currently used (Kalogirou, 2003). A concentration ration, defined as the aperture area divided by the receiver/ absorber area of the collector of each type is presented as well.

Table 5. Types of solar energy collectors (Kalogirou, 2003)

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (^{o}C)
Stationary	Flat plate collector (FPC)	Flat	1	30-80
	Evacuated tube collector (ETC)	Flat	1	50-200
	Compound parabolic collector (CPC)	Tubular	1-5	60-240
Single-axis tracking	Fresnel lens collector (FLC)	Tubular	10-40	60-250
	Parabolic trough collector (PTC)	Tubular	15-45	60-300
	Cylindrical trough collector (CTC)	Tubular	10-50	60-300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100-1000	100-500
	Heliostat field collector (HFC)	Point	100-1500	150-2000

Cost of the energy generated by solar thermal systems varies from 0.015 to 0.028 C£/kWh depending on initial investment and the type of solar collectors used (Kalogirou, 2003). Large scale solar thermal systems with large collector fields are more economical. They need less initial investment compared to several small plants; however, the collector cost is higher.

4. Thermal energy for industrial processes

Nearly all the industrial energy networks and systems are partially or fully dependent on burning fossil fuels to generate essential thermal energy. Distribution of energy consumption indicated that about 13% of thermal industrial applications require low temperatures thermal energy up to 100^{o}C, 27% up to 200^{o}C (Goyal and Tiwari, 1999) and the remaining applications need high temperature in steel, glass and ceramic industry (Schnitzer, et al. 2007). Table 6 shows few of potential industrial processes and the required temperatures for their operations.

Table 6. Heat demand industries and ranges of temperatures

Industry	Process	Temperature (^{o}C)
Dairy	Pressurization	60-80
	Sterilization	100–120
	Drying	120–180
	Concentrates	60–80
	Boiler feed water	60-90
Tinned food	Sterilization	110–120
	Pasteurization	60–80
	Cooking	60–90
	Bleaching	60–90
Textile	Bleaching, dyeing	60–90
	Drying, degreasing	100–130
	Dyeing	70–90
	Fixing	160–180
	Pressing	80–100
Paper	Cooking, drying	60–80
	Boiler feed water	60–90
	Bleaching	130–150
Chemical	Soaps	200–260
	Synthetic rubber	150–200
	Processing heat	120–180
	Pre-heating water	60–90
Meat	Washing, sterilization	60–90
	Cooking	90–100
Beverages	Washing, sterilization	60–80
	Pasteurization	60–70
Flours and by-products	Sterilization	60–80
Timber by-products	Thermo diffusion beams	80–100
	Drying	60–100
	Pre-heating water	60–90
	Preparation pulp	120–170
Bricks and blocks	Curing	60–140
Plastics	Preparation	120–140
	Distillation	140–150
	Separation	200–220
	Extension	140–160
	Drying	180–200
	Blending	120–140

Many industrial processes are involved in heat utilization with temperature between 80^{o}C and 240^{o}C (Kalogirou, 2003; Goyal, 1999). Industrial energy analysis shows that solar thermal energy has enormous applications in low (i.e. 20–200^{o}C), medium and medium-high (i.e. 80–240^{o}C) temperature levels (Kalogirou, 2003). Almost all industrial processes require heat in some parts of their processes. In southern European countries, almost 15% of the final energy demand in industrial sector is used for heating applications (Kongtragool and Wongwises, 2003). Most common applications for solar thermal energy used in industry are the SWHs, solar dryers, space heating and cooling systems and water desalination.

Solar as an input power is widely used for heat engines in many industrial applications. Stirling engines use any kind of external heat source for their operation. They are highly reliable, simple in design and construction, easy to operate and cost effective. Nevertheless, the efficiencies of such mechanical devices are quite low. Compared to external combustion engines, they perform more efficiently with less exhaust emissions. Using solar irradiation to generate heat for Stirling engines can reduce the cost and complexity of the system while increasing their efficiency. Mass production of solar powered Stirling engines would make them cost effective. Generating solar electricity using Stirling engines in the range of 1-100kW for industrial applications is the cheapest alternative (Kongtragool and Wongwises, 2003).

Using solar energy to generate thermal energy for industrial processes not only reduces dependency on fossil fuel resources but also minimizes greenhouse emissions such as CO_2, SO_2, NO_x (Schnitzer, et al. 2007). Nevertheless, there are some challenges for merging solar heat into a wide variety of industrial processes like periodic, dilute and variable nature of solar radiation (Schnitzer, et al. 2007). Solar thermal applications in industrial sectors are classified as: 1) Hot water or steam demand processes, 2) Drying and dehydration processes, 3) Preheating 4) Concentration, 5) Pasteurization, sterilization, 6) Washing, cleaning, 7) Chemical reactions, 8) Industrial space heating, 9) Textile, 10) Food, 11) Buildings, 12) Chemistry, 13) Plastic, and 14) Business establishments

4.1. **Solar water heating (SWH)**

Solar water heating industry constitutes most of solar thermal applications in both domestic and industrial sectors. They are considered as the most cost-effective alternatives among all the solar thermal technologies currently available. SWH systems are now in commercialized stage and very mature in many countries in the world. Since 1980, utilization of SWHs has been increased with 30% annual growth rate (Langniss, et al. 2004; Lie, et al., 2007).

SWHs are usually composed of solar collectors and a storage space. It works on the basis of the density inequality of hot and cold water or thermo syphon. In colder countries, integrated collector/storage SWHs is more common because of simple and compact structure. Batch solar collectors are more suitable for compensating sun radiation limitations in the evening and afternoon (Langniss, et al. 2004). A schematic of a flat plate solar water heating system is shown in Figure 4.

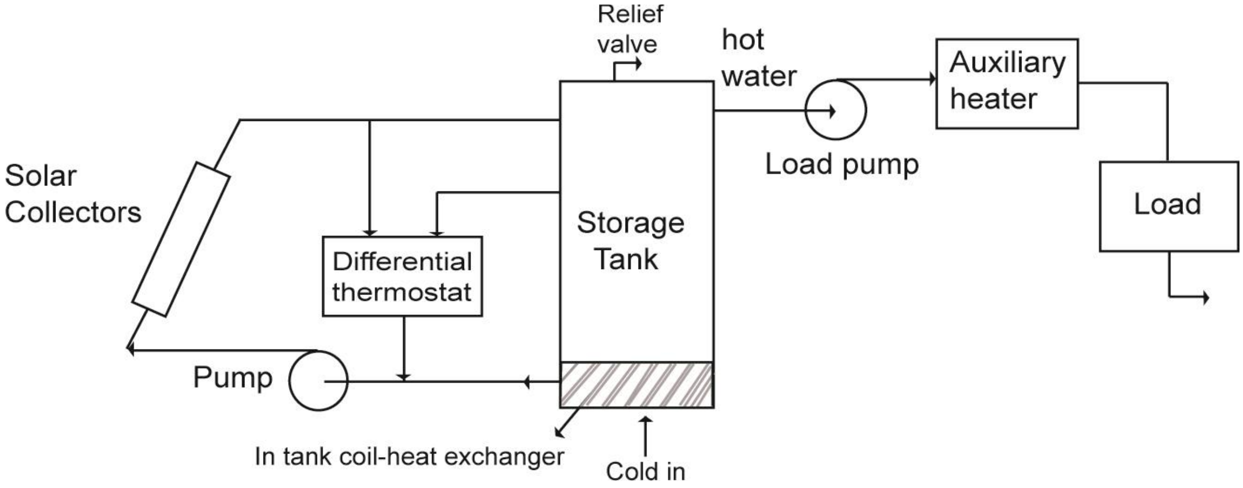

Figure 4. Block diagram of a SWH system (Kulkarni, et al., 2008)

Figure 4 is the block diagram of SWH systems commonly used in industrial applications in which the water never go back to the storage tank. It involves solar collectors, circulating pump, load pump, storage space or tank, differential thermostat and thermal relief-valve. The controller components are required to adjust temperature for the system operation. If the temperature of the tank goes above the pre-set value, the valves will release energy by mixing the hot water with main water supply system and obtain required temperature. An auxiliary heater is considered for the situations that temperature of the tank is not adequate. SWHs are generally divided into 2 main groups: the once-through systems and the recirculating water heaters. Once-through technologies are largely used in cleaning procedures of food industry. Therefore, the used water is not allowed to circulate again in the system due to contaminants available in the used water. The recirculating water heaters are exactly similar to domestic SWHs (Kalogirou, 2004).

Industrial heat demand applications usually use hot water (low-pressure steam) or pressurized steam corresponding to the heat required for the system operation. Water is usually the running fluid in thermal applications depending on its availability, thermal capacity, storage convenience and low cost. Nevertheless, cost of the storage system increases remarkably when higher pressure is required. For temperatures above 100^{o}C, the system is needed to be pressurized. For medium temperature (above 100^{o}C) applications, mineral oils are used. However, higher costs, tendency of cracking and oxidation are few issues involved in such systems (Kulkarni, 2008). SWHs are applied in medium temperature hot water applications are as follows:

- Water preheating to be used in cleaning, washing and dyeing

- Steam generating
- Direct integration to a conventional system

Figure 5 shows the integration of solar collectors to an industrial thermal powered system.

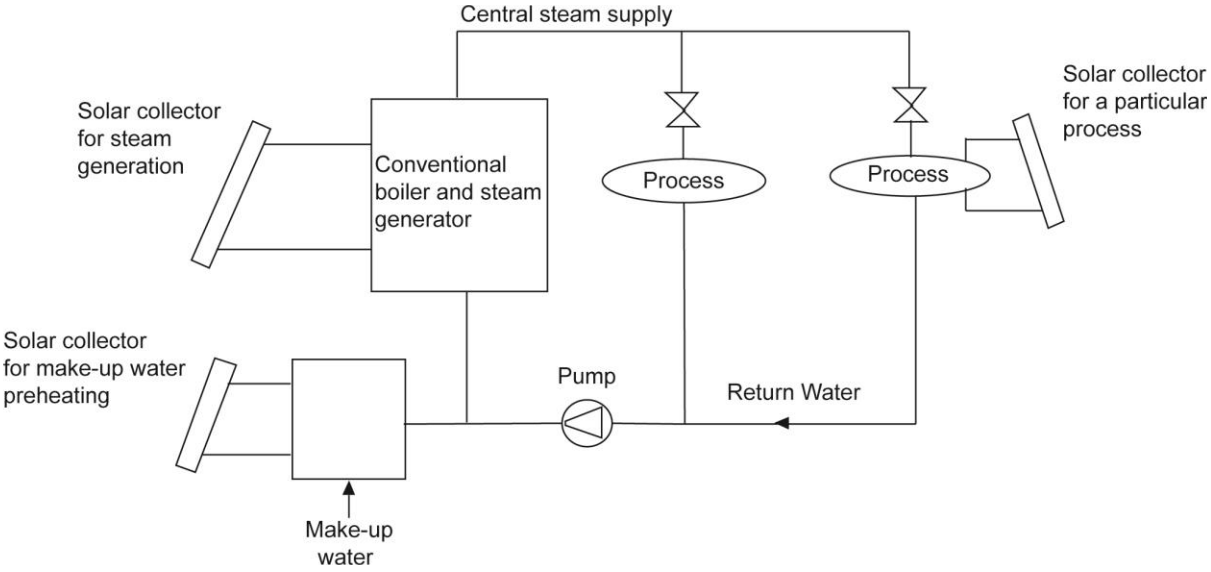

Figure 5.Integration of solar collectors to an industrial thermal powered system (Kalogirou,2003)

Processes which require water preheating have met higher efficiencies because of the nature of solar systems where the input temperature is slightly low. The main reason is that in such systems simple collectors capture the sunlight at the temperature required for the load.

Solar thermal is also used in textile industry for heating water at temperatures close to 100°C for bleaching, dyeing and washing purposes (Kalogirou, 2003). Currently, fossil fuels are used for fuel-run in textile industry. Therefore, SWHs can significantly contribute to reduce the ecological problems associated with textile industry. Built-in-storage water heaters are introduced in Pakistani textile industry to further improve the performance and stability of the systems (Muneer, et al., 2006).

Another emerging SWH’s market which is already widespread and reached developmental stage is building industry. Statistics shows that SWHs and space heating and cooling is going to be generalized and will achieve 20–30% of the full commercialization (Kulkarni, et a., 2008). Most of the developing countries are located in warm climate and hence hot water is not as important as in developed countries which are situated in colder climate. However, according to (Langniss, et al., 2004) nearly 10 million SWHs are presently installed in developing countries.

On the other hand, large scale SWHs has significant economic benefits. For example, in Nepal monthly electricity bill was reduced by 1200 Euro by installing SWHs in a school for 850 students.

Even after 20 years 75% of collectors are still operating properly. Another advantage of installing such project is to encourage domestic sector to use the new technology for kitchen, bath and swimming pool with temperature between 45°C and 50°C. Designers, engineers, architectures, service engineers and material providers may play critical roles in sustainable development for the large-scale production. Besides, various policies by governments and communities might have a great influence to encourage domestic and industrial sector to apply the new technology (Li, et al., 2007).

4.2. **Steam generation using solar systems**

Low temperature steam is extensively used in sterilization processes and desalination evaporator supplies. Parabolic trough collectors (PTCs) are high efficient collectors commonly used in high temperature applications to generate steam. PTCs use 3 concepts to generate steam (Kalogirou, et al., 1997); the steam-flash, the direct or in situ and the unfired-boiler. In the steam-flash method, pressurized hot water is flashed in a separate vessel to generate steam. In an in-situ method, there are 2 phase flows in the collector receiver to generate steam. In an unfired-boiler system, steam is generated via heat-exchange in an unfired boiler. In this concept, a heat medium fluid goes through the collector. Figure 6 is a schematic of a steam-flash system. The system pressurized the water to avoid boiling. The pressurized water goes through the solar collector and eventually flashed to a flash vessel. Water level in flash vessel is maintained at constant level through feed water supply.

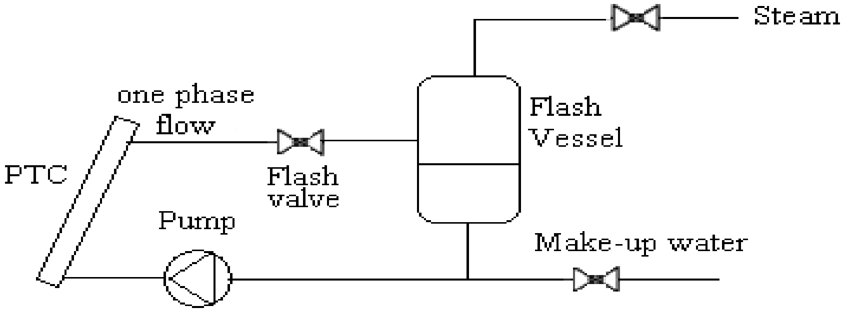

Figure 6. The steam-flash generation system (Kalogirou, et al., 2004)

Figure 7 shows the direct or in situ boiling concept. The only difference is that flash-valve is removed in this configuration. Make up water is directly heated to generate the steam in the receiver.

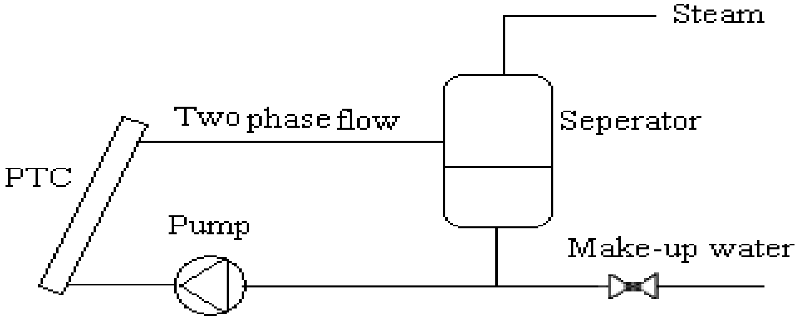

Figure 7. The insitu generation system

Figure 8 illustrates the unfired boiler system. This system is rather simple than before mentioned systems. The pressure is quite low and control scheme is straightforward.

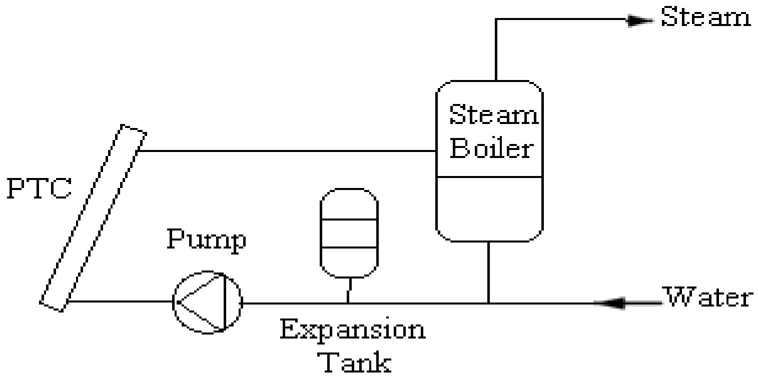

Figure 8. The unfired-boiler steam generation concept

Flash-steam and direct-steam systems require approximately the same initial cost. However, in situ systems suffer from stability problems and scaling of the receivers. To design an appropriate industrial application, the proper steam generation system with suitable decisive factors should be chosen.

4.3. **Solar drying and dehydration systems**

Solar drying and dehydration systems use solar irradiance either as the solely power supply to heat the air or as a supplementary energy source. Conventional drying systems burn fossil fuels for their performance whilst the solar dryers take advantage of sun irradiation for drying and dehydration processes in industries such as plants, fruits, coffee, wood, textiles, leather, green malt and sewage sludge (Schnitzer, et al., 2007). They are categorized into 2 main groups: high and low temperature dryers. Almost all high temperature dryers are currently heated by fossil fuels or electricity, but low temperature dryers can use either fossil fuels or solar energy. Low temperature solar thermal energy is ideal for use in preheating processes as well (Ekechukwu and Norton, 1999). On the other hand, solar dryers are also classified based on the method of air flow generation into 2 major groups: natural-circulation (passive) and forced-convection (active) solar dryers.

Generally, passive solar dryers use solar energy which is abundantly available in the environment. Therefore, this technique has been usually addressed as the only commercially available method in agriculture industry in developing countries. They are categorized into 2 main methods; open to sun and natural-circulation solar-energy crop drying method. Developing countries especially who are in tropical climate are widely taking advantage of open- to- sun passive drying systems. They dry the crops using 2 main approaches; in the field or in situ and by spreading it on the ground or any vertical or horizontal plate exposing to solar radiation. Open to sun passive dryers are very common since they have low initial and running cost and less maintenance required. However, open-to-sun drying method produces huge wastes and crop losses due to imperfect drying, fungus and insect infestation, birds and rodent encroachment. In addition, unpredictable changes in weather and climate changes such as rain and even cloudiness affect the efficiency of such systems.

Natural-circulation dryers are another type of passive solar dryers which are favorable options for rural and isolated areas. In this type of dryer, the heated air flow toward the drying crops based on buoyancy forces or using wind pressure or even a combination of both. They offer many advantages over open- to- sun drying systems:

- Require smaller area of land for similar quantities of crops
- High efficiency due to more protection against fungus, pets and rodents
- Shorter time is needed
- Protection against unpredictable rains
- Low capital and maintenance cost
- Commercially available

Active solar drying systems use solar energy in combination with electricity or fossil-fuels to generate power for pumps and engines to provide air circulation. In this type of solar dryer, solar energy is the only source to generate heat. This method is used in large-scale commercial drying applications. Such a system can reduce the energy consumption along with controlling the drying conditions. High temperature solar heaters are used for direct drying process. However, for medium and low temperature systems, the fossil-fuel fired dehydrator is applied to boost the air flow temperature to the necessary point. The latter system is called 'hybrid solar dryer'. It avoids the effects of fluctuating energy output from the solar collector at night or when the sun irradiation is low. Solar active dryers are widely used in high temperature drying processes where continuous air flow is required (Smith, 1977; Pattanayak, et al., 1978; Reddy, et al., 1979). Based on system component arrangements and the way system uses solar heat; both active and passive solar dryers could be classified into 3 main groups: integral type, distributed type and mixed mode dryers (Ekechukwu, 1989). Table 7 shows the working characteristics of integral and distributed methods of natural-circulation solar dryers.

Table 7. Working principles of integral and distributed methods in natural-circulation solar dryers (Ekechukwu, 1999)

Parameter	Type of system	
	Integral	Distributed
Principal modes of heat transfer to crop	Direct absorption of solar radiation and convection from heated surrounding air	Convection from pre-heated air in an air-heating solar-energy collector
Components	Glazed drying chamber and chimney	Air-heating solar-energy collector, ducting, drying chamber and chimney
Initial cost	Low	High
Construction, operation and maintenance	Simplicity in both construction and operation. Requires little maintenance	Requires high capital investment in materials, large running costs More operational difficulties of loading and occasional stirring of the crop
Efficiency	Low efficiency due to its simplicity and less controllability of drying operations	High efficiency since individual components can be designed to optimal performance

Industries which involve drying process usually use hot air or gas with a temperature range between 140^{o}C to 220^{o}C. Solar thermal systems can be integrated with conventional energy supplies in an appropriate way to meet the system requirements. Heat storage seems to be necessary when system is required to work in the periods of day when there is no irradiation (Kalogirou, 2004).

Solar dryers can extensively be used in food and agriculture industry to improve both quality and quantity of production while reducing the wastes and minimize environmental problems. In spite of using large scale solar dryers in commercial food industries, lack of information is the main barrier to further improve the technology in developing countries. This type of dryer has high initial investment and installation costs. Therefore, only large farms can afford the monetary burdens (Karekezi and Majoro, 2002: Sharma, et al., 2009). Table 8 shows the classification of solar energy drying and dryer systems.

Table 8. Classification of solar energy drying and dryer systems

System	Major groups	Sub-class types
Solar energy dryers	Active dryers	Distributed type
		Mixed mode
	Passive dryers	Integral type
“Natural” or Open to sun drying	Crops dried in-situ	-
	Post-harvest drying	Drying on ground mats or concrete floors
		Drying on trays

4.4. **Solar refrigeration and air-conditioning systems**

Increasing standards for living and working conditions, remarkable rate of urbanization, unpleasant outdoor pollutions and affordable price of air-conditioners have initiated increasing demand for air conditioning systems. The more request for air conditioning, the more need for electrical power. Hence, power stations meet their peak load demand in hot summer days leading to blown-out situations (Papadopoulos, 2003). Statistics indicate a huge rise in the number of air conditioning installations within European countries since last 20 years where the cooling capacity has been five-folded. Energy consumption of air conditioners was 6TJ and 40TJ in 1990 and 1996, respectively and it is rising to reach 160TJ in 2010 (Adnot, et al., 2002). Figure 9 is the block diagram of a typical solar cooling system with refrigerant storage.

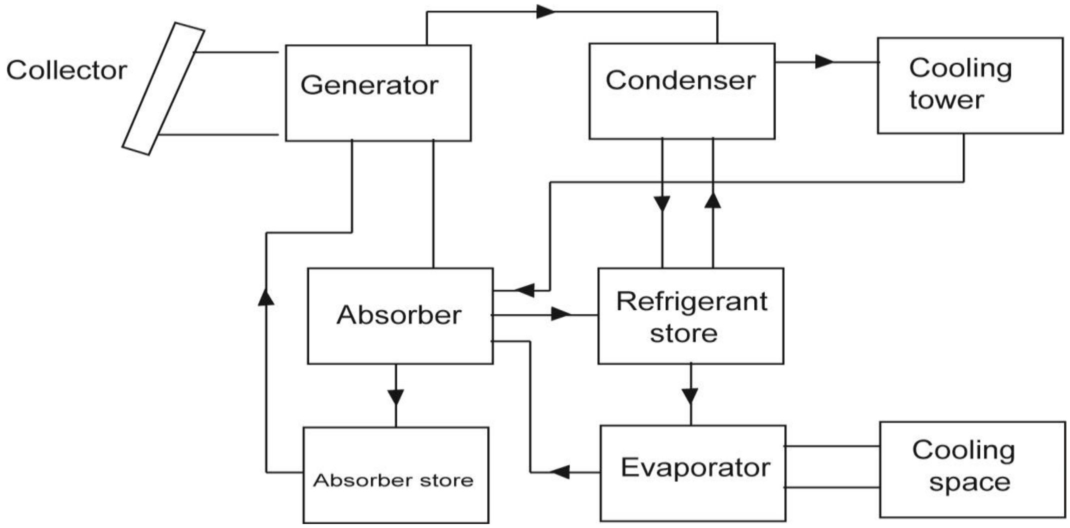

Figure 9. Block diagram of a typical solar cooling system with refrigerant storage (Sumathy, et al., 2003)

The peak demand in cooling loads is usually happening when the solar irradiation is high. Solar air conditioners are the type of solar energy application that fulfills this specific condition. They don’t require Freon refrigerants or any other harmful substances that depletes ozone layer. Furthermore, operating costs are 15% less than conventional air conditioning systems. By installing solar assisted cooling systems in southern European and Mediterranean region, about 40-50% of primary energy was saved (Balaras, et al., 2007). Figure 10 illustrates the working principles of an absorption air conditioning system.

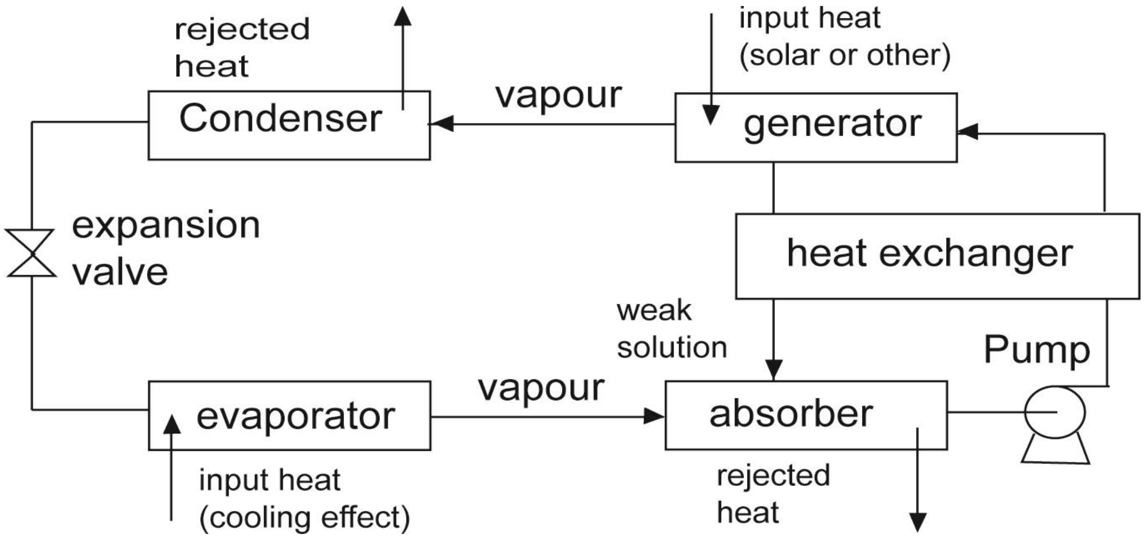

Figure 10. Working fundamentals of an absorption air conditioning system (Kalogirou, 2004)

Solar powered air conditioners are usually connected to the heat supply cooling devices. They require solar collectors, heat buffer storage, heat and cold distribution systems, heat supply cooling devices, cold storage and an auxiliary (backup) heater. The auxiliary heater is connected parallel to the collector or the collector/storage, or integrated as an auxiliary cooling device. It can even be combined to the system in both arrangements, simultaneously (Balaras, et al., 2007).

Indoor air conditioning seems to be a necessity in commercial and residential buildings such as hotels with growing market in building industry worldwide. Traditional methods to generate electricity can be replaced with solar energy in heat-driven cooling technologies. The most cost effective ventilation system in a building is a system which is capable to provide both heating and cooling requirements (Sumathy, et al. 2003).

Generally, there are two different solar powered air conditioning systems: closed (recirculating) and open cycle systems. The closed-cycle system uses heat-driven pump which is supplied by solar energy. It requires solar collectors for its performance which increases the initial investment required for the system. It rejects heat from condenser and supply desorbers. The operations are performed in two distinct pressure and three temperature levels.

- Low temperature for cooling in the evaporator;
- Intermediate temperature in the absorber and condenser;
- High temperature in the desorber

Closed-cycle systems are capable of being adopted with solar-powered installations with high temperature solar collectors. In addition, they can be applied in solar assisted air conditioning applications because of simplicity, wide range of heating temperatures and noiseless operation. Re-circulating air conditioning use a mixture of recycled air with ambient air in food crop industry and lumber.

In open cycle systems, solar energy is used to provide the appropriate temperature for heating the ambient or exhaust air and regenerate the sorbent. Open-cycle systems use dehumidifier to the process air before supplying to the conditioned space (Balaras, et al., 2007). In open cycle systems, ambient air is heated where recirculating of air is not practical. The examples in drying applications include supplying fresh air to hospitals and paint spraying. Nevertheless, open cycle applications are highly efficient where recirculating systems can improve the quality of the product because of adequate control on drying rate (Kalogirou, 2004).

Researches aimed toward environmental protection and improvements in components and performance of the solar powered air-conditioning systems. They reported that generator inlet temperature, collector choice and system arrangement are the factors need to be considered for design and operation of a system. Despite new revelation of heat-driven cooling technologies; numerous large-scale solar air conditioners exist in commercial stage in the market. They usually take advantage of sun collectors to satisfy capacities more than 40kW. Many attempts and efforts have been put to develop this technology and many projects have been introduced to demonstrate solar powered buildings air conditioning systems. Governments and communities have demonstrated some projects to fascinate attentions to new solar air conditioners. However, there are few problematic issues such as high initial cost, lack of information and experience for designing, operating and running maintenance of the systems (Balaras, et al., 2007). Figure 11 shows an example of solar air conditioning system installed on the rooftop of a building located in China.

Figure 11. Solar air conditioning system installed on the rooftop of a building (Li, et al., 2007)

4.5. Summary of solar thermal applications

Solar thermal systems are widely used in industrial processes. However, the integration of each system into an industrial process has its own advantages and disadvantages. Table 9 presents a summary of the types of solar thermal system and techno-economic features of each system.

Table 9. Summary of solar thermal systems for the integration to industrial processes (Schnitzer, et al. 2007)

System	Cash ratio	Storage	Process control	Heat demand	Heat transfer medium	Type of collector
Direct heat transfer	Low	No	Continues	Always much higher than solar fraction	Air	Air collectors
					Water, process medium	Depending on temperature level of the process
					Steam	PTC
Indirect heat transfer	Low	No	Continues	Always much higher than solar fraction	primary: water or water + glycol, thermo-oil secondary: air, water, steam, process medium	Depending on temperature level of the process
Indirect heat transfer with storage	High	Yes	At intervals continues	The same or Higher than solar fraction	primary: water or water + glycol, thermo-oil secondary: air, water, steam, process medium	Depending on temperature level of the process

Two major industries that have further potential to apply solar thermal energy are explained as below.

4.5.1. **Solar thermal in food industry**

Food industry has favorable conditions to use solar heat since treatment and storage processes of food products are highly durable. Authors (Benz, et al., 1999) conducted a study on non-concentrating solar collectors commonly used in food industry in Germany. The system analysis showed that efficiency of the system is comparable to SWHs and solar space heating systems. Solar thermal can be applied in milk, cooked meats (sausage and salami) and brewery industries at medium temperature for washing, cleaning, sterilizing, pasteurizing, drying, cooking, hydrolyzing, distillation, evaporation, extraction and polymerization.

In brewing industry, around 80% of overall final energy consumption is used in the form of thermal energy. This amount of energy is dedicated for three main processes: boiling the wort (25–50%), Washing the bottles (25–40%), and pasteurization. Solar thermal is used in malt factory for brewing processes as below:

- Low pressure steam generation at temperature 100-110^{o}C
- Wort refrigeration; using absorption cooling
- Malting process; for barley drying
- Stop germination of grains after germination
- Conservation with hot air at temperature 60– 80^{o}C
- Air cooling in the germination process
- Power supplying of washing machines for returned bottles
- The wither and kiln processes

Food preservation industries also use solar heat in scalding, sterilization (vegetables, meat and fish), cleaning, pre-cooking, can sealing, cooling and refrigeration. Dairy industries can also fully utilize solar energy for their various process operations. They usually operate for the whole week with no day off. Thus, solar systems can be considered very cost effective in this type of industry. Dairy industries mainly use thermal energy for pasteurization (60–85^{o}C), sterilization (130–150^{o}C) processes and even for drying milk to produce powder. Milk powder industries are needed high constant energy with a large running time up to 8000 h/year (Benz, et al., 1998). Milk and whey are scattered in the spray-dryers at temperature range 120^{o}C to 180^{o}C.

Authors (Nandi and De, 2007) introduced a case study for solar thermal applications in an energy intensive food industry in India. Sweat meat industry has both economical and traditional culture aspects of the country. The conventional systems are running with diesel fuels. Since they don’t need high temperature for their performance, solar energy is a good substitute to supply energy for the system. Sweat meat industry is currently in commercial stage. It was reported that about 20% of annual production cost is spent just for annual energy consumption. It is recommended to use parabolic concentrators in sweetmeats production plants to maintain the quality and taste of the products (A Report of Paschimbanga Mistanna Byabsayee Samity, 2001).

4.5.2. **Solar thermal in building industry**

Building industry and the industries associated with it have dominated as the second largest energy users of the world energy consumption. In China, 27.8% of total energy demand is dedicated to the building sector (Li, et al., 2007) while energy expenditure in residential and commercial buildings stands for about 40% of Europe's energy budget (European Union Energy, 2004).

Currently, solar energy is widely applied directly or indirectly in building industries. Using solar energy in building, industries can lead the communities to create immense environmental and economic benefits. Solar building industries are an inevitable move toward solar technology in the near future. Moreover, customary passive solar thermal systems are moving toward integration of solar material, substances and systems in buildings. Solar energy in building industries was limited in a few applications for several centuries. However, by developing solar technology, it is extensively used as SWHs, solar ventilation, air conditioning systems and photovoltaic power systems. Solar energy in building industries has three distinguished applications:

- Passive sunspace; the building collects and distributes sun radiation taking advantage of the building orientation, structure and materials.
- Active sunspace; the building applies solar heating system to generate heat or cool. The system is usually containing sun collectors, fans, pumps, radiators, solar air conditioners and absorption chillers.
- Photovoltaic applications; the building usually called ‘‘zero emission building’’ uses PV power system to generate electricity lightening, heating, ventilation and air cooling.

Solar heating system for building industries consists of both passive and active technologies which are generally embedded in building materials and substances. Building industry uses solar heat directly to provide building heat demand using SWHs, trombe wall and solar roof. Absorbed heat by the solar collectors can be accumulated in materials with excessive heat capacity such as a liquid, air, packed bed, phase-change and heat-of-fusion units in the floor and wall materials for the periods when there is no sun present in the sky.

Solar space heaters are more complicated and need larger panels to collect sufficient sun radiation compared to SWHs. Figure 12 shows a SWH system installed on a rooftop.

Figure 12. SWH system installed on a rooftop (Li. et al, 2007)

To make full utilization of solar sun in solar integrated buildings, the buildings usually should be south oriented. The glass windows and trombe walls collects the sunlight though the day and warm the buildings. In such buildings, appropriate ventilation seems to be necessary since the absorbed heat should be circulated in the building. Figure 13 is a solar energy heating building of a demonstration project which uses trombe wall technology for natural ventilation. Use of solar heating systems in buildings found to be cost effective with long lifetime.

Figure 13. Solar energy heating building with trombe wall (Li, et al. 2007)

5. Photovoltaic (PV) systems

A solar cell converts energy in the photons of sunlight into electricity by means of the photoelectric phenomenon found in certain types of semiconductor materials such as silicon and selenium. Efficiency of solar cells depends on temperature, insolation, spectral characteristics of sunlight and so on. Presently, efficiency of photovoltaic cells is about 12-19% at the most promising conditions. Table 10 presents PV technology goals have been accomplished between 2000 and 2015.

Table 10. PV technology goals have been accomplished between 2000 and 2015 (Fiorenza, et al., 2003; Chung, et al., 2015; Polman, et al., 2016)

Parameters	1995	2000	2005	2015
PV modules efficiency (%)	7–17	8-18	10-20	10-22
PV modules cost ($/Wp)	7-15	5-12	2-8	1.7-3
System life (years)	10-20	>20	>25	>25

Photovoltaic systems are generally categorized into 2 main groups: stand-alone and grid connected systems (Libo, et al., 2007; Park, et al., 2006). Stand-alone systems are the systems which are not connected to the grid and energy produced by the system is usually matched with the energy required by the load. They are usually supported by energy storage systems such as rechargeable batteries to provide electricity when there is no sunlight. Sometimes wind or hydro systems are supporting each other, where they are called ‘photovoltaic hybrid systems’. On the other hand, grid connected systems are the systems which are connected to the public grid. This kind of connection removes the dilemma by stand-alone systems. They demand energy from grid when there is not enough power generation on the panels and feed in the power to the grid when there is more than required power by the system. This trend is a concept called ‘net metering’.

It is expected that grid connected systems are growing in the developed countries while the priority is given for the stand-alone systems in developing and non-developed countries. Small PV power systems are wildly used in building industries where they can generate electricity for lights, water pumps, TVs, refrigerators and water heaters. There are also some villages called “solar village” that all the houses are operated by solar energy system. Other commonly applications for stand-alone systems are:

- Stand-alone systems on solar cars, vans and boats,
- Remote cabins and homes,
- Parking ticket machines,
- Traffic lights,
- Applications in gardening and landscaping;
- Solar pump systems and desalination.

Standalone systems seem to be necessary where there is no access to the public grid or where there is a huge cost of wiring and transferring electricity to the rural areas. The operation of standalone systems depends on the power extracted from the PV panels. Figure 14 shows various types of the PV systems.

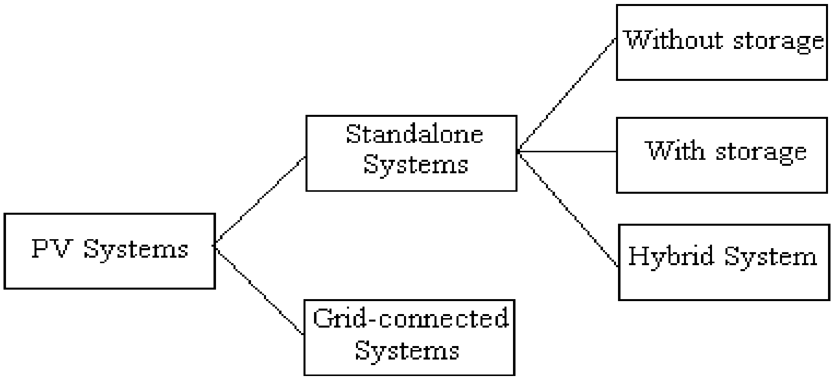

Figure 14. Types of PV systems (Libo, et al., 2007)

5.1. **Building-integration photovoltaic (BIPV) systems**

Building industries use solar energy not only for heating and cooling purposes in ventilation and air conditioning systems but also to generate electricity by photovoltaic cells. PV solar industries definitely can contribute to the world electricity demand. PV installation capacity in China was about 300 kW in 2005 and therefore total PV installation in the country was around 1MW. The current total global PV installed capacity is about 3GWp. High capital investment and low efficiency have limited the applications of PV systems in building industries. However, PV panels have experienced 86% reduction in the cost while increasing in PV module production rate. The price for solar energy was around \$25/W in 1970 which has dropped to around \$3.50/W in recent years (Brandford, 2008; Hoffmann, 2001). The PV cell productions in the world varied in 2015 between 56 GW and 61 GW while in 2016 it varied in range of 65-75 GW. Figure 15 shows the trend of PV module production between 2005 and 2016.

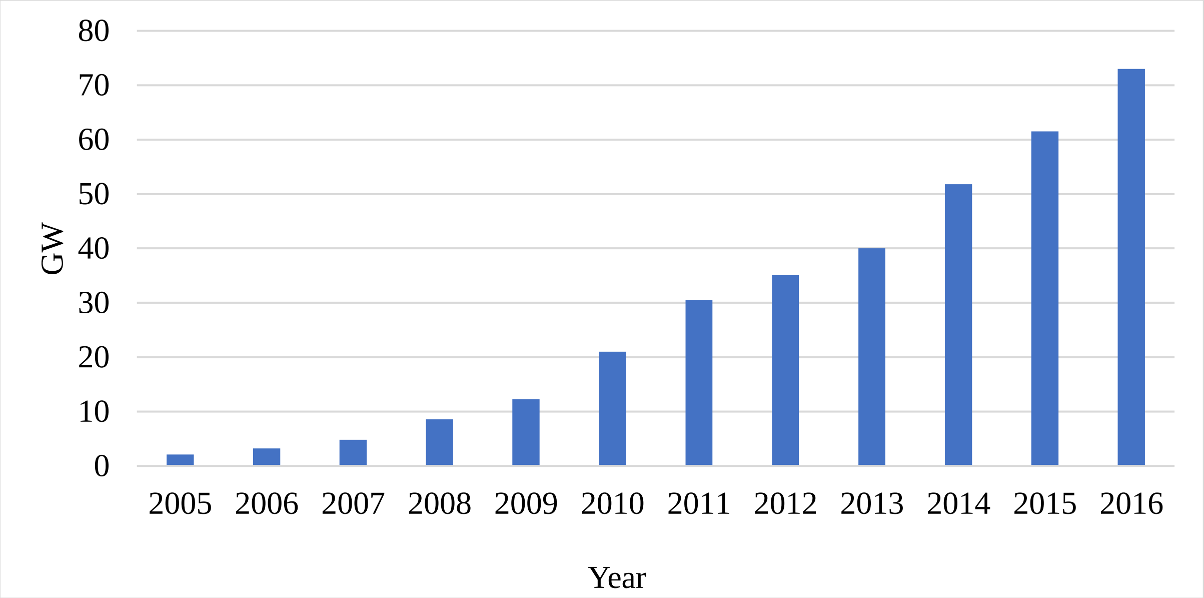

Figure 15. World PV cell/module production in GW (Arantegui and Waldau, 2017).

PV integrated buildings use photovoltaic cells replacing traditional building materials in the wall, rooftop, and balcony or even as semitransparent glass windows. Figure 16 shows a typical BIPV system with shading materials.

Figure 16. Illustration of BIPV with shading materials (Lewis and Crabtree, 2005)

The major issue to encourage the citizens for PV power installations is the financial incentives. Hence, intense research should be made to improve the efficiency and reduce cost of photovoltaic systems.

5.2. **Solar electricity for industrial applications**

It may be reported that the solar powered systems are reliable and cost-effective. They are largely applied in industrial processes in line with energy sustainability issues. Primary energy consumption released by Shell shows remarkable growth in PV solar electricity by 2030. Figure 17 shows the sustained growth of global energy consumption (Wittmann, et al., 2008; Hoffmann, 2006).

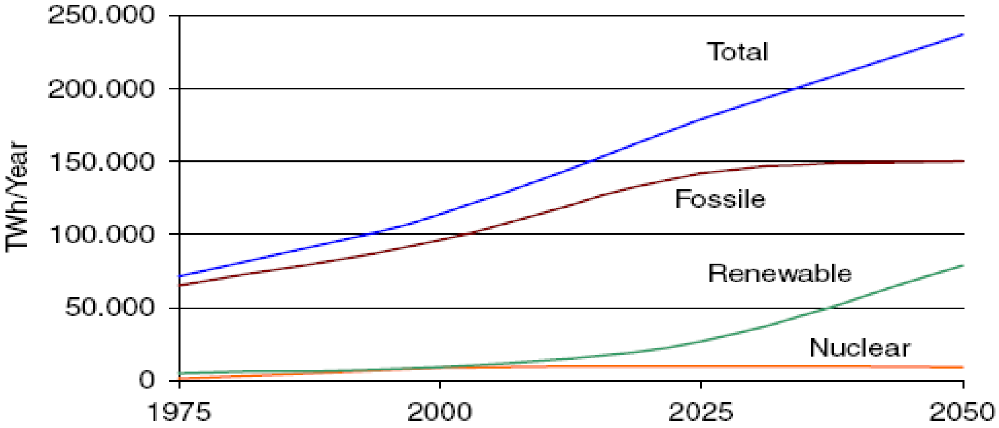

Figure 17. Global energy consumption (Hoffmann, 2006)

Solar electricity is used in many remote and isolated industrial applications such as traffic lights, telecommunication instruments and geographical-position systems (GPS) for the last 15 years. Most of remote installations are off grid or hybrid systems. Off grid systems are independent of public grid and provide electricity to the load solely generated from solar irradiation. The hybrid PV-diesel systems have additional storage batteries or diesel generator. Table 11 is a cost analysis for a 5kVA Diesel/battery system and a 1.8kWp PV/ 5kVA Diesel/battery system. It was found that hybrid PV-diesel systems are most cost effective.

Table 11. Probability increase by adding PV to a diesel- battery system (Hoffmann, 2006)

Electricity generation cost (€/kWh)	Standard lifetime of Diesel and battery	Reduced lifetime of battery to 1 year
Diesel (5kVA) @100% Battery	3.0 €/kWh	5.3 €/kWh
Diesel (5kVA) @25% Battery PV (1.8 kWp) (@5kWh/m^2 ×d)	2.2 €/kWh	3.1 €/kWh

Storage battery powered by solar energy is used in many telecommunication industries. Telecommunication systems need incessant power which assures continuous operation of the system even during cold or cloudy weather and hazy days when there is no sunlight. Hence need for energy storage with sufficient capacity seems to be necessary which poses some special operational demands in addition to the requirements of batteries operating in conventional ways (Gutzeit, 1986).

Another application of solar electricity in telecommunication industry is solar photovoltaic-powered dc mixing fans used to reduce peak temperature in un-insulated outdoor cabinets containing telephone equipment. Usually they use thermostatically controlled ac fans. However, operating cost, need for battery reserve and high starting current poses few limitations. The operating cost can be eliminated by solar powered dc fans. The storage batteries are not necessary since the operation of fans is in accordance with solar irradiation and lower starting currents leads the dc fans to longer lifetime (McKay, 1989). Use of solar energy in agricultural industries can reduce the farm production costs. Poultry industry can use solar photovoltaic systems to generate electricity for bird production running fans and lightings. Conventional poultry producers need huge electrical energy to run their chicken industry. However, solar panels can be installed on the roof spaces available in the poultry houses (Bazen and Brown, 2009).

5.3. **Solar powered water desalination industry**

World population growth rate especially in developing countries has brought many concerns such as poverty, pollution, health and environmental problems. Currently, one forth of habitants in the world is deprived of sufficient pure water (Fiorenza, et al., 2003). Table 12 shows the distribution of world population since 1950 and predictions up to 2050. As observed, the world population is more concentrated in developing countries. Therefore, water desalination technology is seeming more necessary in these regions.

Table 12. Distribution of world population since 1950 and predictions up to 2050 (millions) (Cleland, 2013)

Year	1950	2010	2050
Europe	547	738	719
Northern America	172	345	447
Asia	1403	4146	5142
Latin America	167	590	731
Oceania	13	36	55
North Africa	53	209	332
Sub-Saharan Africa	186	856	1960

Water desalination industry was initially developed to tackle water shortage and overcome the limitations of the available water resources. Where, it can provide a useful clean water from brackish or sea water as well. Meanwhile, conventional desalination methods which are known as supply-side techniques, cause a huge severe environmental impact and disturb natural ecosystems. In addition, they require high amount of energy to complete their operation process.

Solar energy can be used to desalinate sea water using small tubs embedded in the life boats so called "solar stills". Solar stills are suitable for domestic applications, particularly in rural and remote areas, small islands, and big ships with no access to the grid. In this situation, solar energy is economically and technically more competitive than conventional diesel engine powered reverse osmosis alternatives. This method is extremely simple but it needs high initial investment, massive surface, frequent maintenance and sensitivity to weather conditions. Hence its application on large scale production plants is very limited. However, currently most of the low to medium size plants are using this method.

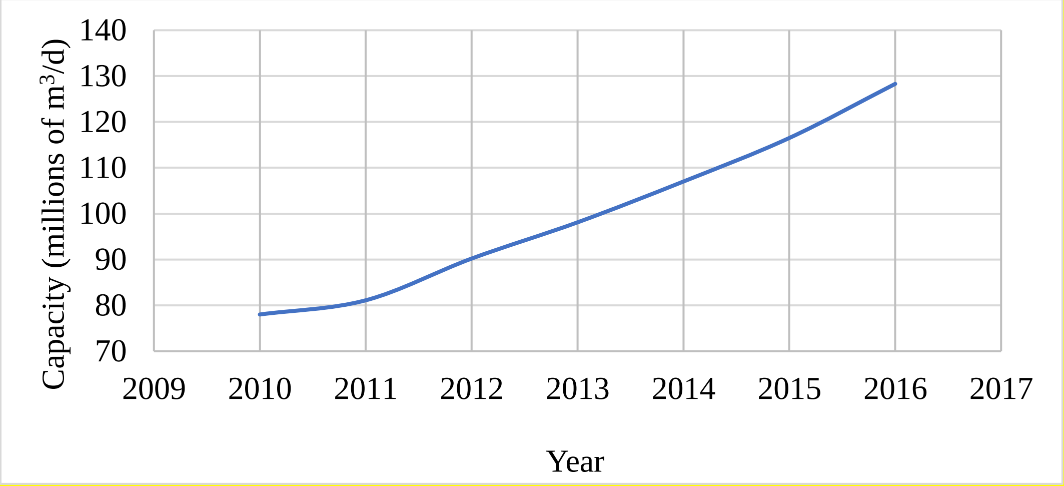

Figure 18. Global trend in desalination system installation capacity (Manju and Sagor, 2017)

Figure18 shows the total water desalination capacity installed worldwide between 2010 and 2016 according to a recent survey carried by Pike Research. Based on this figure, there was an increasing trend in installing desalination plants which will continue in the future where the capacity growth by 55 million m^3/d with a Compound Annual Growth Rate (CAGR) of 8.9%, during the period 2010-2015 (Manju and Sagor, 2017). Hence, an investment of $10billion is needed to desalinate 5million m^3/d water. Contribution of resources in desalination plants is nearly 65% and 35% for seawater and brackish water, respectively (Fiorenza, et al., 2003).

Common water desalination technologies used in industrial scale are 2 main categories: thermal process or phase-change technologies and membrane technologies or single-phase processes. Table 13 shows the different methods of the two main categories while thermo economic features of the desalination technologies are tabulated in Table 14.

Table 13. Desalination processes

Phase- change processes		Membrane processes
1.	Multistage flash (MSF)	1. Reverse Osmosis (RO)
2.	Multi effect evaporation (MEE)	RO without energy recovery
3.	Multi effect distillation (MED)	RO with energy recovery (ER-RO)
4.	Vapor compression (VC)	2. Electro dialysis (ED)
5.	Freezing	
6.	Humidification /dehumidification	
7.	Solar stills	
	Conventional stills	
	Special stills	
	Wick-type stills	
	Multiple-wick-type stills	

Table 14. Thermo economic features of the desalination technologies (Fiorenza, et al., 2003)

Technology	MSF	MEE	MVC	RO
Typical average capacity (m^3/d)	25,000	10,000	3000	6000
Maximum average capacity (m^3/d)	50,000	20,000	5000	10,000
Thermal energy consumption (kWh/m^3)	80	60	-	-
Electric energy consumption (kWh/m^3)	4	2	7	5
Equivalent electric energy consumption (kWh/m^3)	15	7	7	5
Cost of plant (S/(m^3/d))	1300	1200	1000	1000
Production cost (S/m^3)	1.1	0.8	0.7	0.7

Table 15 shows the possibility of solar thermal usage for MSF and MEE processes. However, solar PV systems can generate electricity for MVC and RO. In addition, they can be integrated to the hybrid RO and MSF systems.

Table 15. Solar energy potential for desalination technologies (Fiorenza, et al., 2003)

Solar energy	MSF	MEE	MVC	RO
Photovoltaic			✓	✓
Solar thermal	✓	✓		
Solar thermal (electric)	✓	✓	✓	✓

Figure 19 shows the market share for different water desalination technologies in 2015 (Ghaffour, et al., 2015). It is shown that the most common desalination combinations were RO, MED, and MSF technologies used to desalinate sea water.

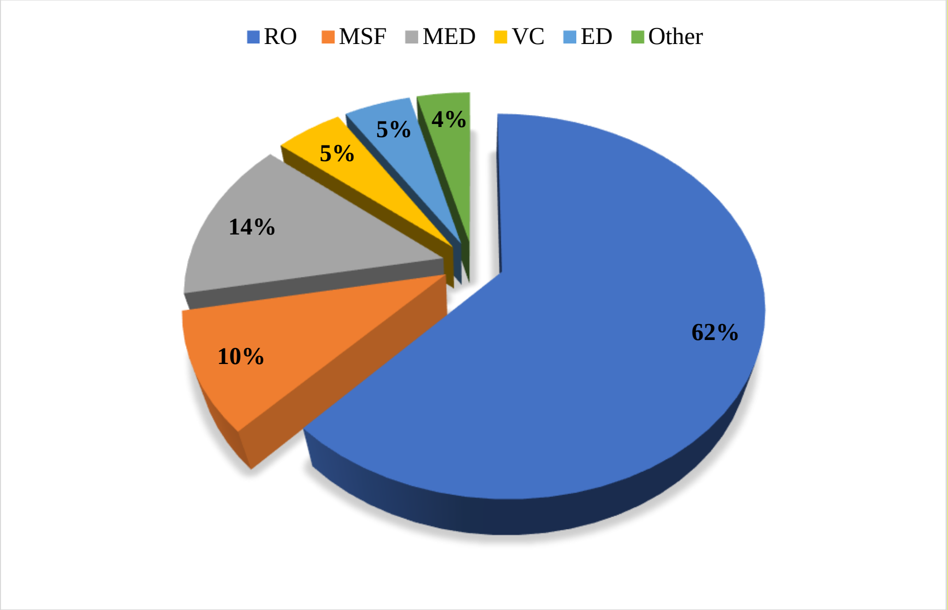

Figure 19. Sea water desalination technologies market share in 2015 (Ghaffour, et al., 2015)

Traditional isolated water desalination plants commonly use RO technology supplied by gas or diesel engines. Therefore, solar powered systems are more competitive. Reverse Osmosis and Electro Dialysis desalination systems [48, 49] are considered best options for intermittent nature of solar energy source. RO and MSF technologies in medium capacity desalination plants with capacity around 1000 m^3/d can be coupled with solar thermal and photovoltaic systems, respectively (Fiorenza, et al., 2003).

Solar power systems are reliable substitute to be used as an innovative power source for water desalination plants. It is the most effective and feasible approach for such systems. In addition, they are environmentally friendly and economically competitive compared to traditional methods. The economic outlook for these systems is more considerable when the system is operating in remote regions where there is no access to a public grid. In addition, initial investment, depreciation factor, economic incentives, cost of PV modules and oil price should also be considered (Voivontas, et al., 1999).

6. Conclusions

Applications, developments and forecasts of solar energy used in industries were presented in this chapter. It was discussed how the solar energy utilization can improve the quality and quantity of products while reducing the greenhouse gas emissions. It has been found that both solar thermal and PV systems are suitable for various industrial process applications and can contribute significantly to circular economy. However, the overall efficiency of the system depends on appropriate integration of systems and proper design of the solar collectors.

Solar energy systems can be considered either as the power supply or applied directly to a process. Large scale solar thermal systems with large collector fields are economically viable due to the usage of stationary collectors. In addition, they need less initial investment cost compared to small plants. Feasibility of integrating solar energy systems into conventional applications depend on industries' energy systems, heating and cooling demand analysis and advantages over existing technologies.

Solar PV systems are reliable substitutes to be considered as an innovative power source in building, processes industries and water desalination systems. The economic outlook for these systems is more viable when the system is operating in remote regions where there is no access to a public grid. In addition, other technical and economic variables such as wear and tear, initial and running costs, economic incentives, PV module diminishing price rate and oil price raises should not be neglected.

Designers, engineers, architectures, service engineers and material providers must consider solar energy installations as a sustainable energy development. Besides, policies by governments and communities may play a great role to encourage domestic and industrial sector to apply the new technologies.

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Chapter 9

Biofuels in the Framework of a Circular Economy

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Abstract

Increased urbanization all over the world increases energy consumption (mainly from fossil fuels) as well as waste generation. The depletion of the energy resources reserves is inevitable and when this occurs, biofuels could potentially be the ones to satisfy their demand. Despite of that, the biofuel industries along with certain economic models, are not necessarily green or sustainable. Biofuel industries generate waste such as water, food scraps, glycerine and methanol, just to mention a few, which force these industries to pay for final disposal services. This review will enlighten the biofuel industry throughout the transformation journey from investing in waste disposal services to discovering added value in waste by using a circular economy model.

Keywords: biofuels, waste, circular economy

1. Introduction

For many years, industries had applied linear economy models on processes that transform energy resources to create added value products and, at the same time, generate waste streams as an additional and unavoidable output. When societies seized that energy, resources are limited they decreased their use to generate less waste nevertheless, the population has continued growing and so has the demand for energy and materials. The current solution is therefore inadequate though it gives a longer resource lifetime (MacArthur, 2012).

The biofuel industry is not out of the industries' waste equation. It generates a handful of different types of waste such as wastewater, food scrap, glycerine and methanol among others. So, is waste an unavoidable output of every process then? The correct answer would be no. The definition of the term "waste" is a matter of how is looked at it. If industries stop categorizing by products as waste, and start categorising them as added value products and as inputs for other industries, then waste wouldn't be labelled as such and numerous benefits could be obtained from it. Using "waste" (or underestimated by products) could potentially contribute positively to industries by reducing disposal services costs and making profits of it if sold to other industrial sectors for which waste could be an input.

Planet Earth have finite energy resources, thus there is an urgent need to begin rethinking, innovating, transforming the way industries act and operate and, simultaneously, transforming the way in which citizens interact on this subject. This review aims to explain and deepen into the biofuels industry in the framework of a circular economy by explaining basic concepts, giving some examples and exposing the barriers that are to be faced when implementing this model.

2. Circular Economy

The model of a circular economy can be explained as the upgraded linear economy model. This means upgrading from an extraction-production-consumption-waste disposal model towards a model where all materials involved in the design phase of a product are recovered, recycled and upgraded in energy or materials. In other words, for the circular model the end of products' lifetime is considered to promote a maximum reuse of all its components as raw material (Jacquet, Haubruge, & Richel, 2015).

Within a circular economy model, the reuse of materials is regarded as a separate optimization step, consequence of the changes made during the design phase, production and use of a product. Below, Figure 1 shows the differences between these two economy models. Notice that the linear model (a) starts the process off with new raw materials and it ends it with residual waste streams that must be disposed by a third party. On the right-hand side of Figure 1 is the circular model (b.). In this one, the process works as a cycle and has no end. It is integrated by 3 parts: a sustainable production which indicates that process waste streams are being recycled within the same production process; a sustainable use which refers to the lifetime of the product; and finally, a recycling of the product's materials (van Buren, Demmers, van der Heijden, & Witlox, 2016).

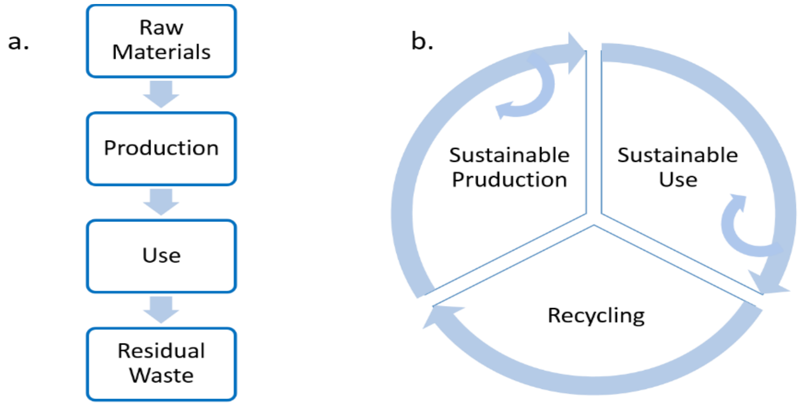

Figure 1. Linear (a) and circular (b) economy models **(van Buren, Demmers, van der Heijden, & Witlox, 2016)**.

As mentioned earlier in this review, the planet has finite resources, therefore a circular economy model could offer a potential alternative to overcome this limitation. Replacing a linear economy with a circular one has multiple advantages. For example, it could help by be reducing or, in fact, eliminating raw materials sourcing, waste disposal services and because of these two this model could also be reducing costs. Additionally, it creates sustainable value by minimizing the environmental impacts and creating new economic activities (van Buren, Demmers, van der Heijden, & Witlox, 2016). A circular economy goes beyond the concept of linearity. It demands the product's design to be in such manner that it can be easily taken apart and reused by prolonging its lifespan through maintenance and repair. Furthermore, it suggests the use of recyclables in products and recovering raw materials from waste flows. It offers less dependency on imports of raw materials for goods production, this being significant considering that dependency leads to vulnerability, thus reducing it by capitalizing on opportunities and earning capacity within the raw material-dependent regions can be a strategic choice that will stimulate businesses to recover them from recycled products. Moreover, this model offers a great potential to generate new employment opportunities due to the greater demands for reuse, repair, remanufacture and reclamation of raw materials. Finally, it helps in significantly reducing the environmental deterioration caused by the increasing world population which demands more and more natural resources (van Buren, Demmers, van der Heijden, & Witlox, 2016). It is important to mention that a circular economy model differs from the recycling economy model because the latter does not involve close loops regarding the raw materials (inputs) and waste generation (residuals).

The transition to circularity is not easy. It requires internal and external changes of industries. Internally, industries will need new business models, value chains, and product-service delivery models. They will require changes in the design, production, use and disposal processes as well as in the collection of products and materials for reuse. Similarly, it will demand changes in the energy, logistics and financial subsystems. Externally, it will require modifications in consumer behavior. Governmental policies and business practices (van Buren, Demmers, van der Heijden, & Witlox, 2016). This transition will require a considerable effort for the industries. It will demand the industries to do a deep research and verification of different technologies involved in their processes to fit together and create factory clusters to work in a closed loop. They need to have a strong understanding of all material and waste flows along with their respective value across their management and resource systems. Perhaps the greatest challenge to achieve circularity will probably be to learn how to integrate technologies and how to expand the horizons to integrate the biological systems and bioprocesses to make the circular economy loops even bigger (Venkata Mohan, y otros, 2016). This circular approach is still in its early development stages, with huge amount of studies being conducted at laboratory scale and few at pilot scale but at the end, this model is economically feasible and may offer a promising future.

This paper is organised as follows: section 2 presents the biofuels industry within the concept of a circular economy, section 3 lists examples of countries that are already deploying the circular economy model in the biofuel industry followed by the conclusion which provides the summary of the review and some future research suggestions.

3. Biofuels within a Circular Economy

It is known that despite the existence of biofuels, petroleum based products still account for 95% of fuel consumption by road transport. This represents 21% of the European greenhouse gas (GHG) emissions. But, although it has been proven that biofuels help in decreasing the GHG emissions, they remain having negative effects on water and soils (Millares, 2016). To avoid these negative effects, there have been legislations developed. For example, the European Union has set a remarkable target that every Member State must have at least 10% of its transport fuel coming from renewable energies by 2020 (Millares, 2016).

For the aforesaid requirement, there exist the first-generation biofuels like the agricultural bioethanol and biodiesel made from oilseed crops for example. Undoubtedly, these help by reducing some GHG emissions, but it should be taken into consideration that by nature, when the population grows, the need for more food and fuel grows simultaneously, thus creating a competition for land (land use dilemma). Unfortunately, biofuels production particularly requires larger amounts of feedstock than food crops, which means that enough land is needed to satisfy such demand. By 2013, the land use dilemma had pushed the European Union to no other option but to redesign their strategy of green energies. This time, the strategy was moving towards "advanced biofuels". The reason why they are called "advanced biofuels" is because they are made from waste, agricultural, forestry and algae residues (Millares, 2016). Nevertheless, this approach is not enough to satisfy the current planet's needs. What is currently required is not advance biofuels as a solely alternative but also to imperatively rethink the way biofuels are produced. Biofuels production can follow a circular economy model but first a profound understanding of current processes and exploiting the waste that it already exists within and outside the biofuel production factories is needed to become a circular economy model.

Within a circular economy model, biorefineries visualizes negative-valued waste as a potential renewable feedstock and these are emerging as a powerful alternative to replace petroleum based refineries. Opposite to traditional refineries, biorefineries see a great opportunity in using biomass of non-edible feedstock or biogenic waste as raw materials to produce biofuels (Venkata Mohan, y otros, 2016). For a better understanding of a biorefinery, there is an interesting definition which says: "a biorefinery is a sustainable processing of biomass into a spectrum of marketable products". This simple but meaningful definition implies that is not only using biomass (which can be a stream of waste) to produce biofuels but using it to generate/produce all the spectrum of byproducts in all the stages of the production processes which must not be considered as waste. The diagram below (Figure 2) clearly explains this definition (Jungmeier, y otros, 2016).

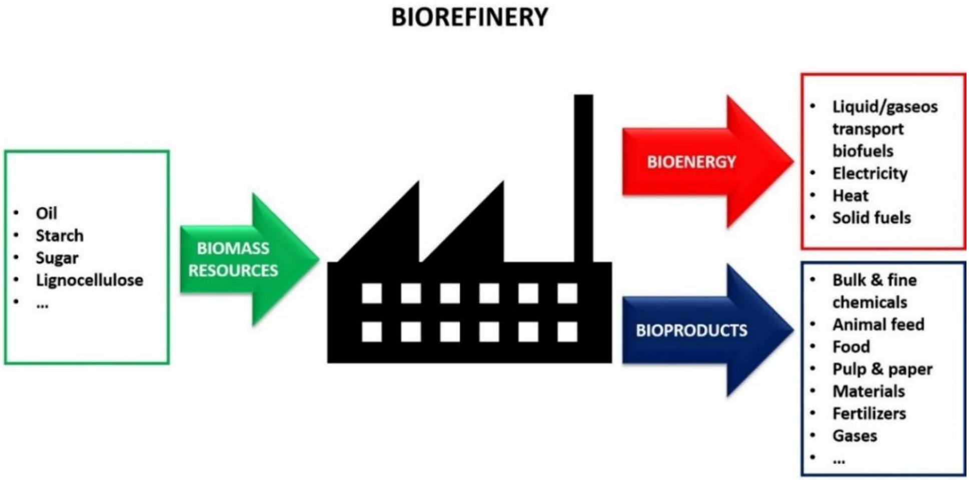

Figure 2. Biorefinery concept diagram by showing the inputs and outputs of the process (Jungmeier, y otros, 2016).

Biofuels can be produced from different available sources. They can be produced by simply using residues rich on starch and sugar. As a matter of fact, residues from the biofuel production process itself can be used to supply the process's energy requirements instead of using new raw materials every single time a production batch begins (Jacquet, Haubruge, & Richel, 2015). There are plenty of biomass residues from crop processing and forestry waste all over the world that can be useful to produce biofuels. Not to mention that there exists aquatic biomass which can be used to extract nutraceuticals first and for biofuels production later (Bashkar, y otros, 2016). There is an abundance of waste sources for biofuel production, what is needed is to see a potential opportunity on them. Let's illustrate this with an example. Grapes are not just attractive to eat and make wine but also for biofuel production as well.

Globally, per year, the wine production leaves around 13 million tons of grape residues that, sadly, are not being destined for any use but to be disposed at the cost of the winery industries. On this regard, researchers of the Bioresource Technology journal showed that up to 400 liters of bioethanol can be produced by the fermentation of 1 tons of grape residues which may include grape skin, stalks and seeds from the wine making process (The University of Adelaide, 2015). With this into consideration, now 3.5 million tons of urban waste are generated on a daily basis and by 2025 it is expected to be around 6 million tons per day of which approximately 50% corresponds to organic waste (see, Figure 3) (Hoornweg & Bhada-Tata, 2012). This should be and give enough motivation for industries to explore and use the wide variety of waste sources that can be of utility for many different purposes while at the same time it gives the Governments an opportunity area to reduce waste generation and one of many reasons to support and expand the implementation of the circular economy model.

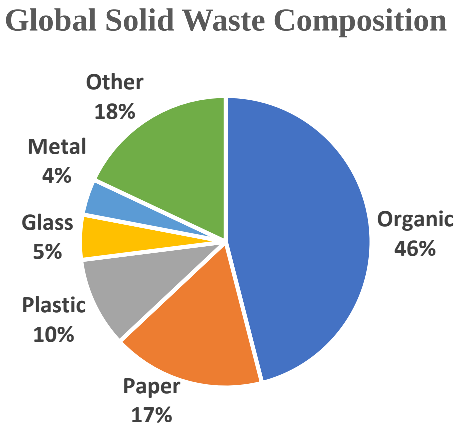

Figure 3. Global Solid Waste Composition (Hoornweg & Bhada-Tata, 2012).

4. Examples of Biofuel Industries within a Circular Economy

Bioethanol production has been controversial for many reasons; one of these is the competition of land for food production. To address this problem several studies have shown that bioethanol can be obtained from a variety of sources such as sugar or starch from waste streams and waste fractions of crops (Hirschnitz-Garbers & Gosens, 2015). Obtaining bioethanol from waste not only means stopping the land use competition but along with that, it means having important benefits associated with it such as the potential GHG emissions reduction compared to crop based ethanol and the increasing value of waste streams and revenue for industries that create this waste. Yes, waste can be used for biofuels production, but a circular economy does not end with that. This model is much more complex. After identifying waste sources for biofuel production, the next important step to follow would be the integration of processes from different factories and industries (one's process waste is the other's process input).

Several countries have been supported by their federal governments by developing policies that compel businesses to keep their waste out of the landfill, for example (McCabe, 2016). This is what gives these countries a respectable pace towards constructing circularity. Denmark, Japan, the Netherlands, Scotland and Sweden are the highlighted ones. On October 2014, the European Union adopted a zero-waste programme which establishes a framework for a circular economy. It's been said that this will boost recycling and will prevent the loss of valuable materials. At the same time this will drive to job creation, economic growth, new business models and it will help in reducing GHG emissions as it's been already mention above in this review.

Starting with Denmark, this country treats all waste as a resource either to be recycled or reused. To support this, they had announced a ban for new incinerating plants construction. The focus of the Danish Government is creating an industrial symbiosis that promotes resources cooperation within the industries. Japan as a country outside of the EU, has moved towards the circular economy by promoting the law of efficient utilization of resources which covers the entire lifespan of products. This law obligates the manufacturing industries to have disassembly plants with material recovery as an additional step of their processes. This turns product disposal into an asset as companies are now able to use these materials (Braw, 2014). Another great example relies on the Netherlands. Years before, the Netherlands was highly dependent on import products and raw materials. Around 68% of its raw materials were imported. Recently, a change has been triggered on which the Government is promoting a circular economy through a programme in collaboration with sustainable business associations. In this programme, the concept of circular economy is explained and disseminated around the country with the objective of providing training and start-up support.

Moreover, they have allocated budget for scientific research on the matter (van Buren, Demmers, van der Heijden, & Witlox, 2016), developed a criteria for end-of-waste in order to take advantage of the resources they already have and they have also set new targets aiming to reduce the waste-to incineration by 50% and a target of 75% waste-sorting and separation at the source (Braw, 2014).

Furthermore, the government is willing to make changes in their current waste regulation to facilitate the circular model adoption. For example, this country is recently using the glycerine that comes as a residue from biodiesel production as a byproduct rather than a waste and they are also allowing the use of phosphates recovered by other processes because phosphate is a scarce raw material in this country. A noteworthy programme the Netherlands has launched is that one that includes people. This programme consists in stimulating consumer behavior by having an agreement with the Dutch rail in order to promote waste separation. This does not mean that people do not separate waste at home, but it means that people should be encouraged to do it in public spaces as well (van Buren, Demmers, van der Heijden, & Witlox, 2016). To have this type of programmes is crucial for the reason that that this economy model transformation is not only technological but also social, thus people is a key participant.

In Latin America, Ecuador stands out of the rest by implementing circularity. Ecuador has developed some projects regarding bioenergy production. These projects consist in producing biogas for energy consumption through a mixture of municipal urban waste and livestock manure. The circular model design starts off with biogas combustion. This generates CO_2 which can be collected instead of being released to the atmosphere. After its collection, this gas can be used in the microalgae production process. In this production process, microalgae convert CO_2 into biomass and oxygen through photosynthesis. Next, biomass is processed through thermochemical liquefaction allowing the separation of lipids from proteins and carbohydrates to produce biodiesel through transesterification. The transesterification process produces glycerine that can be sold in the local market. The remaining proteins and carbohydrates from the liquefaction can be reused as animal feed and as effect of this, farmers are encouraged to collect the livestock manure for biogas production. This way the cycle is completed. These environmental friendly interactions with other productive sectors create job opportunities in the agricultural, food, chemical, healthcare, pharmaceutical and logistics sectors, diversifies energy sources, encourages rural development and food sovereignty and increases public profitability. (Vega-Quezada, Blanco, & Romero, 2016).

Moreover, Ecuador, there are other countries that are beginning to join to the circular economy model movement. Mexico, for example, being the second largest economy of Latin America is strongly investing in it. It is investing in renewable energy, water management and waste management technologies. In addition, Mexico has set a goal to produce 35% of its energy from renewable energy sources by 2024, 40% by 2035 and a minimum of 50% by 2050. Likewise, Mexico has been developing climate change laws that set obligations for industry and municipalities to report and mitigate their GHG emissions.

Starting on 2018, penalties will apply to those (municipal landfills, wastewater treatment plants, and industries) that are not complying with these laws and are known to generate emissions that do not develop and show mitigation efforts. Some of the projects to be developed are decentralized energy production, biogas projects at municipal and industrial wastewater treatment plants and at landfills as well and biomass projects using agricultural waste (mainly sugar cane, corn, sorghum and wheat) for power production. Other projects are bio-digesters to produce biogas from livestock manure and residues and waste-to-energy projects within energy intensive industries such as cement, steel, and petrochemical. The circular economy in Mexico is developing rapidly and this gives a significant business opportunity to foreign companies (Hatanpää, 2017).

England has also found great value on waste. In 2014 the Daily Mail Australia published an article which states that researchers from the University of Bath did a study in which they show that biofuel can be obtained from coffee beans waste. On average, a coffee shop generates around 10 kg of coffee beans waste and from this up to 2 liters of biofuel can be produced. Imagine if this amount of waste was multiplied for the total quantity of coffee shops that are around the world? Chris Chuck, one of the researchers, said that around 8 million tons of coffee are produced globally and that there is a 20% oil content per unit weight of coffee beans. This could be a valuable sustainable source for biofuels production. Regarding the method proposed for biofuel production, this is based on oil extraction from the coffee beans. The beans are soaked in organic solvent to extract oil and it goes through a transesterification process to transform it into biodiesel (Massey, 2014). A company with the name Bio-Bean took advantage of this and is turning coffee into fuel with the aim of powering London. Just 3 years after the start-up, 10% of the country’s coffee waste (50,000 tons) were transformed into energy which is sufficient to power 15 thousand homes. The Bio-Bean business consists in collecting the coffee waste of coffee shops with the support of a waste management company and then bringing it to the Bio-Bean factory to process it and produce power for supermarkets, offices, homes, airports, and factories. The interesting part of the project relies on the fact that the disposal costs for coffee shops are 70% less when they dispose it via Bio-Bean if compared to the traditional disposing method. This turns out to be attractive for the coffee shops owners. The company is currently using the pellets as fuel but there is a promising future by using the oil they separate from these beans in order to get biodiesel to power cars and jet engines. Arthur Kay, the owner of the company, saw an opportunity of business when he observed that coffee shops generated hundreds of thousands of wastes at a huge environmental and waste disposal costs. Kay also states that coffee is not the only waste stream that can be used as this review has been mentioning throughout this research. It also applies to the breweries industry which can offer valuable compounds that can also be beneficial to the environment (Ridley, 2016).

Analyzing the case of Australia, every year 4 million tons of food reaches the landfill being the largest unrecovered stream of waste in the country. This waste could be valuable to produce biofuels, nevertheless there are not any federal initiatives to do so. Taking this situation as a motivation drive, State and Municipal Governments are working together with the communities to develop projects to foster a circular economy and start using this waste. The reason why Australia is looking for a circular economy is because disposing waste into landfills can affect households, business and Governments, plus it requires energy, space and poses environmental risks. If this waste could be repurposed, then this would offer a sustainable growth and job creation. Examples of what they have been doing is to introduce policies that offers incentives for recycling and penalties for producing landfill (McCabe, 2016).

5. Barriers of Implementation of a Circular Economy

It is highly common to have barriers and resistances when it comes to introduce any specific change into a system. Why? Because ‘change’ means: new, rare, unfamiliar, unknown. In the case of circular economy there are institutional, economic, social and professional barriers. Implementing a circularity will have institutional barriers because societies have been following a linear economy for many years, meaning that the current structures and daily activities have been developed using this model as a scaffold, hence changing them would require a considerable effort. There are also economic barriers because adopting a circular model requires new business models and processes. To overcome this, companies need to be completely aware of other companies’ existence, interests and strategies but unfortunately, the current status on this is very deficient. Regarding the social barrier, earlier in this review it was mentioned that transforming into a circular model not only involves technology but also people. People will most likely resist to change and gaining the public’s acceptance is fundamental for the success of this model. Regarding this specific barrier, the Harvard Business Review published an article called “How to Deal with Resistance to Change” by Paul R. Lawrence.

Above mentioned article points out a few advices on how to overcome it. The first one is to involve all the stakeholders to participate in the change not only by making people aware of it but also by letting them interact with the pioneers of the change. The second one is to understand the cause of the resistance. Lawrence says that it is believed that knowing what to change is sufficient for many people who are at the head of the projects, but more careful attention is needed in understanding in depth and detailed the social arrangements that will be sustained or threatened by introducing this change or by the way it is introduced. A third advice is that the people in charge of triggering change should consider not to adopt the change idea as exclusively of them, but to be open for suggestions from the stakeholders. Another highlight is that the change justification should be put on terms that people can understand. When this justification is too complicated to explain, this means that there is a need to translate it to practical language so that the people can understand the reason why the change is being proposed.

Moreover, the article explains that there will always be resistance if it is believed that there will be resistance. To look at resistance in a different way is needed then. Resistance should be an indicator that something in the adopting-the-change process turned wrong instead (Lawrence, How to Deal With Resistance to Change, 1969). Finally, there are professional barriers. These can be the most complex and they exist since the circular economy concept is relatively new, demanding knowledge development, dissemination and innovation (van Buren, Demmers, van der Heijden, & Witlox, 2016).

Above mentioned barriers are the participation of governments in the transition to a circular economy. Single businesses may adopt the circular economy model, but they will face difficulties and barriers that only Governments can tackle. Interestingly, Governments can tackle most of the barriers by using several instruments. For example, they can introduce or improve law and regulations, take financial measures like offering subsidies, taking fiscal measures, utilizing procurement power and developing symbiotic partnership (De Groene Zaak, 2015). But as governments can be the key player to tackle barriers they can also turn into the biggest barrier if not convinced of the power of the circular economy model. Governments in the EU and Japan are already ahead in this circularity system, but many others are still lagging and are not yet convinced of the necessity of a circular economy. Governments need to explore this alternative since this model contributes to a sustainable economic growth, it has the potential to increase productivity, create jobs, reduce carbon emissions and help in the preservation of valuable raw materials (Zero Waste Scotland, 2017). Food waste, for example, should be a matter of concern for industries to reduce and for Governments to support as well. Globally, one third (equivalent to 1.3 billion tons) of the total food produced for human consumption is lost or wasted. This gives a tremendous opportunity area within the food and beverage industry to develop cascading biorefineries that captures the value of byproducts and waste streams by extracting several different products (Mintel, 2016).

Governments' participation is crucial. Let's take a recent report of Denmark as an example where some suggestion for further investigation were proposed to overcome the concern mentioned above. The suggestions were the following (Ellen MacArthur Foundation, 2015):

- Inclusion of biorefineries as part of the Government long term strategic plans
- Provision of capital to deploy commercial-scale versions of biorefinery technologies
- Creation of markets for biorefinery outputs

- Stimulation for advanced high-value biorefinery technologies development in the long term by setting up or founding cross-institutional R&D
- Measures complementation with a business service advice

6. Conclusion

This review started off by expressing the need of transformation from a economy model based on extraction-production-consumption-waste disposal (linear model) towards one that focuses on having sustainable processes, sustainable products use and product recycling (circular model). It gives an ilustration of biofuels into a circular economy and shows some examples of the countries that are standing out of the rest on this subject. Finally, it lists the barriers that could be faced when implementing this model.

As Nicholas Machiavelli once said: “whosoever desires constant success must change his conduct with the times”. That is exactly what is needed. When an idea of a project is conceived and later it becomes a reality, very often there are unententional gaps left. These gaps demand the ideas to be improved or even redesigned. This is the case of the linear economy model. It could have been just what was needed at the beginning, but as the time goes by, some imperfections or gaps are detected and this model just does not seams to fit the current planet needs anymore. Today, the world facing an increasing energy demand and a limited supply of resources. Fortunately, the circular economy model can offer an alternative solution by being a model that can close those gaps and adapt to the current needs of our planet. Moving towards this model might not be simple or easy being technologies integration and expanding horizons and loops the greatest challenge.

In addition to this, some research is required by the innovation and industrial sectors in understanding materials flow across waste management system and bringing technologies together in the right way, so that favorable economics and sustainable industrial structures can be possible to develop (Venkata Mohan, y otros, 2016). But even though it might not be easy to implement this model and despite that the approach is still new with most of the studies being carried out at laboratory scale, the advantages can be substantial. For example, cost and impact reduction can be achieved in the value chain by eliminating sourcing of raw materials, promoting economic growth by increasing job opportunities, allowing countries to be less dependent on raw materials and reducing environmental problems (van Buren, Demmers, van der Heijden, & Witlox, 2016)

The biofuels industry can work under a circular economy model. In fact, biorefineries visualizes negative-valued waste as a potential renewable feedstock and these are emerging as a powerful alternative to replace petroleum based refineries. Some waste that can be used for biofuel production are the ones coming from crop, forestry and aquatic processing. For biorefineries, biomass is not just a resource to fabricate a solely marketable product but a whole spectrum of it. The challenge for these industries within a circular economy would be the competition for biomass and other raw material resources, water and land usage, quality of products, GHG emissions and biodiversity impacts. Those challenges must be addressed to reach sustainability.

Arthur Key, the founder of Bio-bean said an interesting quote in one of the interviews he had for a newspaper. He said that waste is just a mentality and that it is whatever people want it to be. For this, he calls for a change in mind set regarding waste, meaning that people should stop seeing waste with a negative connotation and start seeing it as a potential resource instead.

Again, turning to a circular economy model might not be easy as mentioned above. In fact, many are concern of implementing this model because it is believed that environmental protection is an obstacle to economic growth but, according to what Janez Potocnik, a Slovenian politician and ex-European commissioner for environment, said that the environmental protection is absolutely the opposite. And, on top of that, this system is economically feasible and may have a promising future. Some suggestions for future research are the following:

- Design and characterization of processes for integration and interactions with different industry sectors
- Process materials and waste flow deep understanding
- Waste sources exploration for biofuel production (e.g. wineries' grape waste)
- Creative solutions to avoid competition for waste biomass and other resources (e.g. water and land) to achieve biorefineries sustainability
- Innovative ideas to persuade Governments of other countries to begin implementing the circular economy model
- Governments legislation solutions and development to promote circularity

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