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Realising the Transition towards the Circular Economy

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ReTraCE

Realising the **Tr**ansition towards the **C**ircular **E**conomy

D3.2

Review of critical factors, assumptions and constraints

in Circular Economy implementation

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Executive Summary

- The implementation of the Circular Economy is likely to encounter resistance from a variety of stakeholders that see their business threatened by the new paradigm. This resistance can materialise in technical, economic, social, organisational and even geopolitical constraints that can seriously hamper the development of the Circular Economy at any scale.

- Accurate identification and understanding of these critical factors, assumptions and constraints that can affect the implementation of Circular Economy practices is crucial.

- The aim of this report is to review the state-of-the-art literature on the Circular Economy to identify factors that are critical for, or can serve as constraints of, its implementation. These factors and constraints have been divided into constraints at micro-economic (firms), meso (supply chain level) and macro-economic (national and international) levels that can possibly hamper/enable Circular Economy.

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1 List of Abbreviations/Acronyms Used

3R – Reduce, Recycle and Reuse

CE – Circular Economy

CEAP Circular Economy Action Plan

EMF - Ellen Macarthur Foundation

EU European Union

GDP - Gross Domestic Product

OECD Organisation for Economic Co-operation and Development

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Introduction

As documented in ReTraCE deliverable D3.1, the idea of Circular Economy (CE) has emerged as a prominent concept in the political and corporate discourse around the world. In particular, countries like China and the European Union member states have developed policies to foster CE practices in a variety of sectors. In spite of the will to promote CE initiatives, there are several impediments which call for rigorous study and collaborative engagement of stakeholders to address. The practical implementation of CE requires the understanding of those critical factors, constraints and barriers that might hamper its efficient and effective development.

As discussed in D3.1, the implementation of CE is likely to encounter many resistances for a variety of stakeholders that see their businesses threatened by the new paradigm. This resistance can materialise in technical, economic, social, organisational and even geopolitical constraints that can seriously hamper the development of a global CE agenda. The existence of these constraints is particularly true if we consider the unequal class and geographical distribution of power and benefits across the globe that characterises globalisation. For example, over the past few decades, because of rapid industrialisation and urbanisation the demand for resources has grown exponentially. Such growth, however, is not equally distributed among world's nations. Industrialised countries in the Global North consume far more materials in comparison to countries in the Global South (Bastein et al. 2013; Wiedmann et al., 2015) leading to the phenomenon of unequal ecological exchange (Moran et al., 2013; Oppon et al., 2018) . This means that CE cannot be enforced with the same political and economic measures in different cultural and geographical contexts. This raises a number of issues such as casting doubt on the contemporary political setup of developed and developing countries, division of natural resources between the nations, and losers and winners of transition toward CE.

It is important to reduce extraction, processing and disposal of natural resources because of environmental issues including climate change. Avoiding these actions as much as possible is in line with tackling the environmental issues we are facing (Hart, 1995; McCarthy, Dellink, & Bibas, 2018). However, this also implies re-thinking the global North-South (productive vs. extractive economies) power relations. As a result, CE might force industrialised countries to abandon their positions of privilege that guarantee the easy and cheap access to natural resources in the global South. This could be an uneasy compromise for many countries in the global North and can represent a critical constraint to the implementation of CE at a global scale. Furthermore, natural resources are not divided equally between the nations all over the world. Therefore, any kind of fluctuations that affect the supply of natural resources extracted at the origin country, will result in the disruption of operations in the destination country, given that countries are inter-connected

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within global supply chains. The more a country relies on its own materials, (including recycled and recovered materials), the more resilient it gets when faced with global geopolitical shocks across the world (Wijkman & Skånberg, 2015; McCarthy et al., 2018). Moreover, several studies have argued about the co-benefits of the transition towards the CE. These include the potential to drive job creation, novel business models and economic growth [1]. However, this transformation is likely to disrupt many established technological regimes, especially in industries and sectors that benefit from linear models of production. Whilst sectors pertaining to secondary material production, repair and remanufacture can benefit from such a transition (Lacy & Rutqvist, 2016; McCarthy et al., 2018).

For the reasons outlined above, an accurate identification and understanding of the critical factors, assumptions and constraints that can affect the implementation of CE are crucial. The aim of this report is to review the technical, economic, social, political and organisational critical factors and constraints identified by the state of the art in the literature about CE.

2 Framework of Critical Factors Impacting the Development of the Circular Economy

Although multiple and contested, CE framings are usually techno-optimistic and often underpin an eco-modernist approach e.g. they do not fundamentally question the present global economic architecture based on capitalism. The eco-modernist nature of most CE literature, which highlights the ideals of CE, is problematic for a number of reasons that we can classify for the sake of simplicity into three main categories (Korhonen, Honkasalo, & Seppälä, 2018).

The first set of criticisms has a physical basis. If we assume an economic system totally based on solar energy – i.e. an abundant source of low entropy energy - a complete circularity of material flow, and thus an indefinite reutilisation of material resources, then such a system would be an 'energetic dogma' (Ayres, 2007), if such can be possible in theory. After all, this is how nature has functioned for millions of years. However, in the present industrial society this is virtually impossible in practice. Even considering unlimited availability of solar energy, the dissipation of minerals in distributed sinks all over the planet in high entropy state

[1] The compatibility of environmental sustainability with endless economic growth is highly controversial. This is particularly relevant for the debate about the viability of CE within a capitalist system that needs infinite economic growth to survive and reproduce itself (Genovese & Pansera, 2019). In this view, it is not very clear how the transformation of linear productive systems into circular would allow further expansion of economic activities. The opposite is much more probable to occur.

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(minuscule concentration) makes their recuperation extremely expensive and virtually impossible in practice (Kerschner, 2010). Similarly, the recuperation of tons of micro-plastic in the ocean even in the presence of revolutionary cleaning technology powered by solar energy is a highly improbable task. Moreover, perpetual recycling is another controversial notion. There exists the idea that the necessary material structures to harvest solar energy can be maintained over the long run just by the energy produced by themselves. However, the feasibility of this idea is yet to be demonstrated. In a nutshell, there is increasing evidence that questions the practical possibility of a total and perpetual recycling of all material resources in any type of economic system, regardless of the amount of energy related to recycling activities (Washida, 1998; Burkett, 2006; Rammelt & Crisp, 2014). It can therefore be argued that CE is bounded by the second law of thermodynamics (Korhonen et al., 2018). Another physical limitation is the vulnerability of CE to rebound effects e.g. the fact that it has been empirically observed that increased efficiency eventually leads to increased use of faster and greater use of natural resources (Polimeni et al., 2008; Korhonen et al., 2018). According to Zink and Geyer (2017), such effects can be either direct or indirect and are attributed to price and substitution effects respectively.

The second line of criticisms is based on the economic feasibility of CE in the present system of market capitalism, which is the dominant economic model in the European Union. In the 1980s, Schnaiberg (1980) famously introduced the 'treadmill of production theory' that hypothesised that class relations within Capitalism continually undermine any effort towards sustainability. Both capitalists and the workers reproduce the illusion that technology will make production greener, but this actually never happens. The system only functions if production continues to increase and waste is disposed of elsewhere. It is not hard to see that such a system is bound to collapse eventually. This would, at least in part, explain why, regardless of its evident environmental benefits, the economic viability of the CE paradigm is called into question by market dynamics and regulatory inefficiencies that can potentially lead to higher production costs (Genovese, Figueroa, & Koh, 2017). While environmental benefits may be obvious, in fact, the implementation of circular production systems and supply chains is often challenging in the current economic system, as market dynamics and the lack of incentives may lead to higher production costs. Some scholars have argued that in the European context, mainly dominated by free-market ideologies, companies are already capturing most of the economically attractive opportunities to recycle, remanufacture and reuse (de Man & Friege, 2016). Companies rely on the need to maintain the economic profitability of their activities and investments while market mechanisms (e.g. increase of prices of by-products provided by a company to another) may strongly discourage the adoption of CE strategies. This suggests that reaching higher levels of circularity may involve an economic cost that European economies cannot cope with, especially as companies are already struggling with high resource prices. Indeed, benefits from the recycling

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of materials tend to decrease until a cut-off point is reached where recycling could be economically too expensive to provide a net benefit. Recently, the ban on imported waste by Chinese public authorities that shows the unpreparedness of recycling networks and CE-related infrastructures in the European Union has made the situation known to the public. It shows the extent to which the EU has been relying on exports of waste rather than investing in CE-related infrastructures (Cole, 2017). Therefore, it is evident that the applicability of CE is problematic in free market and growth orientated economic systems characterised by free market policies.

Finally, the third argument is political and is related to the self-perpetuation of neoliberal capitalism itself. It has been observed that capitalism escapes regulation and tends to expand by removing state regulations or by moving to new unregulated virgin territories. In other words, capitalism survival depends on its capacity to expand through new ways of commodification and appropriation. If this is true, a transition towards an ideal CE paradigm, in which economic transactions are necessarily bounded by the circularity of the system, would seriously undermine a further expansion of capitalism (and economic growth itself). On the other hand, a technocratic and authoritative version of CE that denies the majority of people of resource access, could be totally compatible with 'capitalism without growth'. That is the elite maintain their privileges through impoverishment and exploitation of subaltern classes (Kallis, 2017). The transition toward CE could indeed lead to further concentration of capital in a way that larger and more technologically advanced firms benefit from the fact that many competitors would not be able to upgrade their means of the production as required by more stringent legislation, which practically force them to exit the market. Consequently, oligopolistic structures could emerge, and control entire value chains. In this sense, the idea of CE could open the door to unexpected dystopian futures.

The following sections analyse how these three main criticisms translate into critical barriers and constraints for an effective implementation of a CE. Following the conceptual analytical framework of ReTraCE, the constraints to the implementation of CE have been classified in 3 levels: micro-economic (Firm level), meso (Industry - Supply Chain level) and macro-economic (National and International) level. This classification is not meant to be strict as in many aspects - e.g. regulation or socio-economic aspects – these three levels hugely overlap each other.

2.1 Micro-Economic (Firm Level)

The transition towards a CE is likely to change the role of participants at both a microeconomic and macroeconomic level. At a microeconomic organisation-based level, new technologies and business models are expected to be adopted, such as leasing products as a service to consumers (van Loon, Delagarde, &

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Van Wassenhove, 2018). This transition however can be limited by several technological, financial and environmental factors.

2.1.1 Technical and economic limits to recycle

A first constraint that firms face at micro level are represented by the ***limitations inherent to the process of recycling***. Recycling is one of the fundamental 3R actions (Reduce, Recycle and Reuse) that should be embedded and underscored in any CE strategy (Sakai et al., 2011). There are several justifications for considering recycling as one of the most important actions in a CE strategy and its benefits are relatively well-established. To name a few, recycling will mitigate the harmful effects of disposing hazardous materials and it will help to recover useful resources such as paper and plastic from a product (Singh et al., 2014; Pringle, Barwood, & Rahimifard, 2016). One of the main technological issues of CE is the technological limitations for recycling materials. For instance, in plastic recycling, only 14 percent of plastic packaging is collected for recycling and as many as eight million tons of plastic ends up in the oceans (MacArthur, Waughray, & Stuchtey, 2016). There is no cost-efficient technology yet to allow us to collect all the plastics in the world. Recycling facilities are limited to recycling waste that its materials are easily separated because recycling processes and equipment are not advanced enough to take on waste material separation. Moreover, ***recycling may be a less profitable or efficient solution in comparison with reuse and reduction*** (Ghisellini, Cialani, & Ulgiati, 2016). The increasing complexity of products makes it challenging to recover and recycle different components of each product for the purpose of recycling (Pringle et al., 2016). Moreover, ***some waste materials cannot be recycled forever unlimitedly and there is a limit for the times they are getting recycled***; if not being completely unrecyclable such as some plastics that have ink or metals embedded in them (Prendeville, Sanders, Sherry, & Costa, 2014). Ordoñez and Rahe (2012) suggest that some issues pertaining to end-of-life uncertainties are much more easier to tackle if design of products shift toward capitalising on industrial waste streams. However, it runs counter to production optimisation principles, which promotes prevention of any waste production.

It is important to note that ***full recycling is a questionable notion***. To explain more, we should keep in mind that second law of thermodynamics states that the total entropy of an isolated system can never decrease over time, and is constant if and only if all processes are reversible (Adkins & Adkins, 1983). Georgescu-Roegen (1971) uses this idea and argues that full recycling is a myth because recycling will always require energy and will forever generate wastes of its own. Although his notion has drawn criticism and others have contested that earth herself is an open system which receives infinite flow of energy from sun that can be used to for full recycling (Converse, 1996; Ayres, 1999), it is true that with current technological gears it is very expensive to search, collect and recover all the wastes, if not impossible.

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Product quality is also a concern for using recycled materials. Usually the product made from recycled materials has lower quality in comparison with the one made from original resources (Singh & Ordoñez, 2016). Singh and Ordoñez (Singh & Ordoñez, 2016) pointed out that one of the main issues that needs to be tackled is the existing prejudice that products made of discarded materials have poor quality which has delivered a major blow to competitiveness of these products. They also proposed that this could be handled

Box 1. "Problem Shifting"

One barrier to transitioning towards a CE is the concept of 'problem shifting', where attempting to solve a problem in one area causes a more severe problem or a completely new problem elsewhere (Stilgoe, Owen, & Macnaghten, 2013). The concept can apply to the microeconomic firm-based level in a context where a firm attempt to prolong product durability and hence product lifetime to reduce waste. However, doing so would have a detrimental impact on the processes and mechanisms that rely on low-quality waste for the purposes of recycling by starving them of source materials (Korhonen et al., 2018). From a macroeconomic perspective, the concept of 'problem-shifting' equally applies at the national or regional policy making level. Policies could be implemented to, for example, eliminate landfill. However, this may only lead to more waste being incinerated, leading to an increase in carbon emissions. Alternatively, it may just lead to waste being exported overseas. For instance, in 2015 and 2016, the EU exported up to 300,000 tons of waste each month to China and Hong Kong (EEA, 2019). Sometimes the exporting of waste is done illegally, as in the case of e-waste from the UK being sent to developing countries such as Nigeria, Tanzania and Pakistan (Basel Action Network, 2019), which is shown to have negative impacts on the environment and health of the destination countries (European Comission, 2020b). See also section 2.3.4 on Cost Shifting.

by designers to make them attractive or by policymakers to incentivise the material recovery process, which will lead to lower product cost and prices.

There is another issue regarding both recycle and reuse. That is the difficulty of predicting the condition or situation of a product when it comes to its end-of-life stage. It is because a product can be handled very differently during use and end-of-life phases (Singh & Ordoñez, 2016). In addition, some waste streams are following a seasonal pattern and the amount of waste that can be collected differs over time and depends on the location where waste is collected (Singh & Ordoñez, 2016). It is worth mentioning that waste streams do not form a standard situation which can be trusted and considered reliable to the degree that supports recycling processes as a reasonable and stable input (Cucchiella, D'Adamo, & Gastaldi, 2017).

The environmental benefits from the CE are assumed through a reduced use of raw materials and energy inputs, and decreased waste generation and emissions outputs (physical throughput), operationalised by

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material longevity, efficiency and recycling supported by renewables-based energy. However, even complete (100%) recycling may have negative sustainability outcomes due to the laws of thermodynamics. In practice, the production process produces "waste heat", which is always dissipated as energy. As such, it is practically impossible to capture and reuse all the dissipated energy and thus energy is constantly needed as input. Consequently, the ideal vision of eco-effective circular economy should recycle all the materials and be fully sustained with renewable energy. However, approximately two thirds of the used energy is produced from non-renewable sources (Korhonen et al., 2018). Although powering the circular economy with renewable energy would theoretically eliminate greenhouse gases emissions, the increased production of renewable energy may displace negative socio-ecological impacts from resource extraction (batteries production) elsewhere (Sovacool et al., 2020), as well as pose changes in land use that put further pressure on biodiversity and ecosystem services (biofuels, biomaterials) (de Jesus & Mendonça, 2018).

Moreover, matter is also dissipated by dissolution, friction and wear (Walter, 2019). This dissipation can be both in quantity (physical material losses, by-products) and quality (mixing, downgrading) (Cullen, 2017). Even though the CE focuses on creating long lasting products, these can consume more useful energy and release more entropy in their longer lifetime than those designed from "natural" materials, likely with shorter life (Alan Murray, Skene, & Haynes, 2017). For example, the micro-plastic waste from products (such as in cosmetics, paints, detergents, tyres and textiles), which can pollute the environment and pose possible health risks to humans, is difficult to be captured and reused in the production process. Some propose increased capture of micro-plastics through wastewater treatment (Calleja, 2019); however, this process would require additional energy and while plastic is ubiquitous, this technology is not available everywhere, thus designing out plastic from products could be a more "sustainable" solution. However in the current economic logic this might not always a viable pursuit for companies (Elmore, 2015). Hence, a massive input of energy may be needed to sustain a circular economy in practice (Walter, 2019). On the other hand, some materials in the process of recycling create yet more waste and side-products (Skene, 2018), or downgrade and cannot be reused for the same purpose perpetually (Cullen, 2017), as nothing lasts forever in an entropic universe (Alan Murray et al., 2017) (Table 1).

Table 1 - Limits to achieving desired environmental outcomes through recycling

Circular economy principles	Limits to achieving desired environmental outcomes
Longer product lifespan	Longer-lasting products containing toxic materials are not necessarily socio-ecologically superior to products with a shorter lifespan designed with "natural" non-hazardous materials.

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Circular economy principles	Limits to achieving desired environmental outcomes
Product design	Not all materials should be recycled from a socio-ecological perspective, some need to be designed out of products, however, this might hurt economic profits therefore companies in the current market-based neoliberal economy would opt instead for recycling.
Product recycling	Some materials in the process of recycling can create more waste and harmful side-products, which defeat the environmental purpose for recycling harmful side-products. The quality of materials downgrade throughout series of recycling thus the recycled materials cannot be reused for the same purpose perpetually as nothing lasts forever in an entropic universe.
Product recovery	Materials dissipate by dissolution, friction and wear and its recapture may in some cases be impossible.
Renewable energy	The recycling or recovery of some materials can be energy-intensive, which would necessitate increased production of renewable energy that can cause negative socio-ecological impacts from resource extraction and land use.

2.1.2 Technical and economic limitation of design/redesign

Another important constraint is represented by product design. Market dynamics have experienced drastic changes in recent years which have led to production of complicated and diversified products to meet consumers' expectations and preserve their market share (Kang & Hong, 2012). On one hand, complex product designs have become a major challenge for manufacturers to implement robust recycling and remanufacturing processes. On the other hand, a trend of decreasing products lifespans has been identified which makes the situation of resource depletion worse. In some product categories, shorter product lifespan benefits manufacturers and they intentionally aim for decreasing product lifespan in design stage. In others, technological breakthroughs or changes in regulations might force manufacturers to change their products to keep up with the competition and meet customers' demands which will lead to shorter product lifespan, e.g. mobile phones in electronics industry (Bartels, Ermel, Sandborn, & Pecht, 2012).

In order to tackle this issue, design and re-design has drawn intensive attention as one of the most important phases of transition toward CE because it can contribute positively to increase product lifespan and make durable products (Govindan & Hasanagic, 2018). Design stage is the starting point to prevent pollution and conserve energy and resources in production of a product (Ying & Li-jun, 2012). However, transformation in research and development carries a costly tag and it does not come cheap (Ghisellini et al., 2016). Hence, it is essential to collect rigorous data that is required for design and re-design of products and processes in order to justify the investment. To name a few, an investigation to identify the type and amount of wastes, the potential for exploitation, the geographical location of producers, intermediaries such as laboratories which could be involved in the transformation of wastes, and finally, the potential customers will be necessary (Mirabella, Castellani, & Sala, 2014).

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In general, there are three strategies available for designers that are in line with the CE agenda: ***material efficiency, product life extension and product recycling*** (Hatcher, Ijomah, & Windmill, 2011). Material efficiency is the practice of designing products with less material. It is the most practiced approach among design projects since it brings down costs. The main problem of design and re-design projects is that they are usually costly and time-consuming. Usually manufacturers only accept to incur the costs related to re-design projects only if they are strongly justified with acceptable threshold of decrease in costs. That aside, in order to (re-)design products that fit within a CE, the main challenge for designers is to determine and justify when to apply which design strategy to optimize a product lifespan from sustainability viewpoint without endangering product's economic viability. Different product categories require different product lifespan extension and recycling/remanufacturing strategies. This requires massive research resources to rigorously conduct studies about many products which can certainly turn into an overwhelmingly difficult challenge. It can turn out to be a difficult task because products and markets change dynamically, thus monitoring product lifespan and innovations in resource and production efficiency should be a continuous process.

2.1.3 Economics constraints at organisational level

A transition to CE at the firm level can be also hampered by a number of economic factors such as uncertainty about future markets acceptability of CE business models, competitions of conventional firms, availability of non-virgin materials and resources.

First, ***uncertainty about the viability of CE business model*** can discourage firms to embrace the transition. The implications of the transition towards reuse, remanufacturing and recycling remain largely unknown (Robèrt, Broman, & Basile, 2013), presenting another constraint for firms wishing to transition towards a CE. Without information of what a transition would entail, many firms would be hesitant to act. The success of a transition towards a CE, which is an inter-generational initiative, can also be hindered by sub-optimal decisions made blindly or with little clear information, subsequently blocking or impeding optimal development paths (Korhonen et al., 2018). For instance, a manufacturing firm may invest in a certain technology that converts one of its by-products into a resource that can be sold to another firm. However, if better information was available, it could have invested into another technology that converts its by-products into another resource much more efficiently. The investment into the sub-optimal technology locks the firm into less efficient by-product production.

Second, the ***uncertainty about the competitiveness of CE business model*** can represent a serious constraint to their adoption, especially by SMEs. Five types of new CE models have been identified (Accenture, 2014). Circular Supplies, which involves the replacement of single use materials with fully

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recyclable material. Resource Recovery, which enables the usable materials to be salvaged from waste or by-products. Product Life Extension, which enables products to be in use for a longer period. Sharing Platforms, which allows the utilisation of products to be increased by improving access or ownership of the product. And finally, Product as a Service, which enables consumers to lease products instead of owning them. There is evidence of these business models being used by early adopters, however a challenge they face is it can be difficult for firms to overcome the competitive advantage held by conventional firms, simply because conventional firms were the first to market (Norton, Costanza, & Bishop, 1998; Fellner et al., 2017; Korhonen et al., 2018). In the textile industry, linear jeans manufacturers benefit from years of marketing, brand exposure and brand loyalty. In contrast, circular jeans manufacturers, perhaps offering jeans as a service for lease payments, may find it difficult to develop the same brand exposure and consumer loyalty quickly, especially with a modest budget. The transition towards the CE is further constrained by the lack of investment in research and development activities by conventional, linear, established firms into the CE concept (Markianidou, 2015; Mazzanti, Ghisetti, & Gilli, 2016; Spaini, 2017). Some early adopters are in the process of adapting their business models such as Ikea (2019), who are giving consumers the option to extend the life of their furniture by providing experts who can modify and repair products. However, significant steps towards adoption of CE principles is not yet widely seen by other conventional firms.

Finally, the ***availability of non-virgin resources and the volatility of their price*** can be an insurmountable obstacle for small and large firms. Firms that do transition towards a CE may face several challenges relating to the supply of non-virgin resources. There may be concerns over its quantity, quality (Koszewska, 2018) and uncertainty, particularly given the complexities inherent to global value chains. This is especially a concern in the textile and clothing industry, where use of non-virgin resources is particularly complicated by the existence of a wide variety of fibres and materials. Furthermore, virgin raw materials are often cheaper than secondary raw materials (Y. Geng & Doberstein, 2008; Iraldo & Bruschi, 2015). In a free market, there is, therefore, little financial incentive for firms to adopt CE systems.

2.2 Meso-Level (Industry - Supply Chain Level)

The meso-level refers to the level of interaction among firms and organisations. This level usually coincides with the analytical level of the supply chains. It is strongly argued that the more effective a supply chain management system works, the higher organisational performance reaches, regardless of the application. CE strategies are considered to be able to positively contribute to supply chain innovation (Govindan & Hasanagic, 2018). Therefore, they can majorly affect supply chain management systems. However, there are many barriers with different origins that hinder the adaptation of a circular economy in supply chains. It is

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worth noting that these barriers seem to be linked together in a sense that one cannot be solved independently.

The very first barrier relates to CE definition and understanding. CE strategies and objectives, targets and milestones, and the plan and ***program to implement the CE concept at the supply chain level are not clearly defined by the regulators and policymakers***. Pan et al. (2015) discussed this issue and its relevance to the energy sector. They emphasised that policy mechanisms are the most powerful tools to tackle several barriers at once but policymakers are yet to take the first step because the fundamental requirements of transition toward the CE at supply chain level are vaguely defined. This ambiguity consequently has a knock-on effect. Without proper objectives and targets, no one can come up with a standard system to measure the performance or circularity indicators in a supply chain (Su, Heshmati, Geng, & Yu, 2013). In addition to lack of objective and targets, existing laws and regulations in some systems, including waste management supply chains (even in China, which is the pioneer of CE implementation at the national level), are not in accordance with CE concepts (Li & Yu, 2011). Even those laws and regulations that are in line with CE concepts are neither strong nor effectively in place. There exist no tool to analyse and measure the effectiveness of these regulations (Yong Geng & Doberstein, 2008; Li & Yu, 2011; Su et al., 2013). Moreover, economic incentives are not supporting the companies to replace their well-established and trusted linear systems with circular ones that seemingly require considerable upfront capital and resources, especially in research and development, to implement (Su et al., 2013; Sauvé, Bernard, & Sloan, 2016).

A second set of barriers are concerned with ***implementation of CE at shop floor level of production lines which require high short-term costs with low short-term financial revenues*** (Shahbazi, Salloum, Kurdve, & Wiktorsson, 2017). Also, production costs in circular systems seem to be higher, especially for those that are meant to replace petroleum-based products (Palm, Nilsson, & Åhman, 2016). This aside, material and product prices, and the way they are determined, do not help further a CE perspective. In particular, the costs associated with the environmental goods and services that are consumed and degraded during production and manufacturing are not usually reflected in the price faced by the end consumer (Lieder & Rashid, 2016). As a result, recycled materials are often more expensive than virgin materials. Moreover, this has implications for consumer items given that consumers are often more focused on price rather than the lifecycle of a product (Lieder & Rashid, 2016). In light of this, there is clearly a role for the discipline of non-market valuation in estimating: a) shadow values for the environmental goods and services that are lost in current linear systems (and thus which can be considered costs), and b) the values gained (or costs saved) by circular systems that do not employ virgin materials. These values/costs go unaccounted for because markets do not exist for many environmental goods and services, and thus, societal preferences and

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resource scarcity goes uncommunicated. Indeed, by properly incorporating environmental impacts into product pricing, this would enable the welfare effects of trade-offs between competing linear and circular systems to be properly examined. Moreover, this perspective would allow us to address questions, such as which additional CE interventions become viable when externalised costs and benefits are taken into account, and which material streams and recycling options provide the greatest societal benefit.

A third set of barriers focus on ***knowledge and skill limitations which make it more difficult for supply chains to better implement CE strategies***. Companies constantly undermine the value of refurbished materials and they try to keep the idea of investing in recovering technologies at bay to avoid incurring costs (Govindan, Madan Shankar, & Kannan, 2016). Interestingly, not only lack of decent technical knowledge and skilled people to implement 3R principles hinder implementation of CE strategies, but also there are limited cases in which enterprises tried to invest rather a small amount of capital to address this issue (Wei, Cheng, Sundin, & Tang, 2015). On one hand companies blame lack of consumer acceptance of remanufactured products as the main reason for not putting in energy and money for investing in their technological gear and train experts to tackle remanufacturing and recycling challenges (Sharma, Garg, & Sharma, 2016). On the other hand, there are no clear guidelines and standards for authorities, companies and consumers to understand what their responsibility is when it comes to completing the circularity cycle. Consumers are unwilling to return used products because of being unaware of their possible impact which inherently adds up to volatility in supply and availability of used products (Sharma et al., 2016).

Finally, ***management issues towards CE is one of the most important yet prevailing problems at the heart of supply chains***. A study by Liu and Bai (2014) in China, which is considered to be the pioneer of CE initiatives implementation, show that around 70% of firms under study failed to carry out cleaner production auditing and a staggering 93% of those firms did not have any managerial department to supervise CE activities. Development of CE is highly dependent on long-term investments and managerial commitments while managers hired by firms have a relatively short term in office, especially in private firms. It is true that managers are obliged to stick to CE priorities on paper; however, in reality CE priorities are hardly supported by the firm's top management since the other rather short-term priorities such as gaining market share or expanding production consume the majority of capital and resources. Therefore, managers do rarely pursue CE agenda which is not internally incentivised (Liu & Bai, 2014).

2.3 Macro-Economic (National and International Level)

From a macroeconomic level, international institutions, national and regional governments are expected to design and implement a package of policies that encourages society to adopt more circular practices. At both national and international levels, several challenges lie ahead.

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2.3.1 Limits to modelling transition to Circular Economy

One of the most critical issues related to the technical feasibility of CE at macro-level is related to the overoptimistic assumptions that underpin the models of the transition toward circularity.

One of the ***main assumptions refers to future improvements in efficiency including the rate of material productivity growth*** (McCarthy et al., 2018). Material productivity is an integral part of CE and is expected to play a major role in creating business opportunities and decreasing environmental pressures. It is estimated that an increase in material productivity by 30 percent by 2030 could boost GDP by nearly 1 percent and bring about 2 million additional jobs in Europe (EC, 2014). Also, efficiency and productivity of material use have to significantly improve to avoid risk of supply shortage in near future, let alone having increased cost of materials (Coulomb et al., 2015).

A second strong assumption is an ***over reliance on the viability of substitution***. Substitution rates are related to material supply and production technologies which are subjected to change in transition toward CE. Substitution rates fall into three main categories: 1) substitution of materials and other production inputs such as capital and labour; 2) substitution between different types of materials (e.g. between timber and cement in construction sector); 3) substitution of primary materials (extracted from natural resources) and secondary materials (extracted from waste). Despite the undeniable importance of these categories of substitution rates in CE modelling, the substitution between primary and secondary materials plays a more pivotal role and is more relevant to CE practices. It is worth mentioning that actual substitution between primary and secondary materials is differing considerably in different applications for different uses of a certain material. More research is required to better identify the degree of substitution between primary and secondary materials, at least for critical materials which have a variety of applications (McCarthy et al., 2018).

Finally, there is a number of ***overoptimistic assumptions about changes in the structure of economy, production and consumption patterns that presume that consumers would naturally move towards more sustainable behaviours and practices***. For instance, the emergence of sharing economy has already made a huge impact on the way consumers behave (Hamari, Sjöklint, & Ukkonen, 2016), altering product and service delivery and affecting material flows. Despite the fact that the notion of sharing economy was introduced not earlier than twenty years ago, it makes some economic models seem obsolete (Benkler, 2004). Therefore, it is important to carefully study economic trends and make rational assumptions about the future structure of economy before developing innovative business and economic models which are compatible with CE goals and appealing for policymakers and investors.

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The three set of assumptions exposed above have not been rigorously validated and more research is need to under what socio-economic conditions they can be taken for granted.

2.3.2 Limits to Decouple: Rebound Effects

The assumption that CE would deliver improvements in efficiency is undermined by the Rebound Effect, also known as Jevon's Paradox. The CE policy aims at achieving supply security while embedding environmental concerns into the competitiveness strategy of the EU. These outcomes are planned to be achieved through reducing resource use by increasing efficiency while allowing continuous economic growth. The resource supply side is complex as it is interlinked with international trade of materials. Increasing resource efficiency is based on the premises 'waste as a resource' and maintaining products and materials longer in the productive cycle. This premise focuses on resource as an efficiency issue, not an issue of reducing the absolute input. Moreover, the policy concentrates on the output side of resource flows (i.e. emissions, waste) as the input side is more problematic to be tackled as it is connected to the global trade relations. As a result, the transformative potential of the circular economy, as a policy to enable an economy within the carrying capacity of ecosystems, faces many barriers on both sides for its realisation (de Jesus & Mendonça, 2018).

The CE logic of decoupling resource use from economic growth aligns with the ecological modernisation thinking, in which the sole use of proper science and technology, such as increased resource efficiency, is deemed sufficient to enable actors deliver the intended outcomes, such as increased financial gains and decreased environmental impacts. In this reasoning, the circular economy is envisioned as an "alternative growth" as opposed to an "alternative to growth" discourse, such as degrowth and steady state economics. These alternatives to growth discourses challenge the "Western" patterns of consumption and production and subordinate economic growth goals to socio-ecological sustainability. These socio-ecological concerns remain obscured and unaddressed in the current mainstream circular economy reasoning (Lazarevic & Valve, 2017).

Furthermore, measuring decoupling on a state level may result in reduced energy and material intensity of the economy, because resources and emissions embedded in many globally traded goods are not accounted for (Lazarevic & Valve, 2017). On the other hand, this "relative" dematerialisation (increased resource productivity) may naturally lead to rebound effects in the current economic logic (Martínez-Alier, 2011). The efficient resource use in the production processes could enable cost reduction which opens up the possibility for increasing economic output that would counteract the initial resource savings (Daly, 2014, p. 4). Moreover, once production efficiency increases, the prices of end-products can decrease. In turn, this may cause increased consumption (Korhonen et al., 2018). Therefore, even a resource efficient circular

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economy could become environmentally unsustainable, if it exceeds the physical scale of the economy, nevertheless in an optimal manner (Daly, 2014).

Box 2. Path-dependency and Technological Lock-in

Another important challenge that might seriously threat the feasibility of CE is the phenomenon of technological lock-in. A lock-in occurs when a specific technological trajectory (or regime) becomes dominant and its replacement, even with a more efficient and effective technological regime, become extremely difficult to implement[1] (e.g. fossil fuel industry, the automobile industry etc.) (Dolfsma & Leydesdorff, 2009). The reasons behind technological lock-in are multiple and complex and root in the socio-economic factors that shape a specific evolution of a technological trajectories, including power relations and access to resources. Lock-in can hamper the evolution and adoption of new and better technologies like those that can make a transition toward CE possible, because such large conventional technological systems, can sometimes be locked-in for more than 25 years because of their huge capital cost. For example, eco-designed innovation with positive net sustainability outcomes must compete with conventional recycling systems or incinerators that downcycle the products (Korhonen et al., 2018). The large investment costs of incinerators are enabled through long-term contracts with municipalities. The municipalities guarantee a certain volume of waste that justifies the economics of the incinerators through energy production. This may present a further barrier to protrusion of more "net sustainable" circular practices, as the established waste management practices could raise the costs to switching to higher quality recycling (de Jesus & Mendonça, 2018). One of the causes of lock-in is also the impossibility of many companies to keep the pace of technological evolution. At manufacturers' level, production costs in new circular systems apparently are higher in comparison with current systems that are already in place (Palm et al., 2016). Many companies use old technology and equipment because of the fact that they are not in a robust financial position to replace them with the advanced ones on their own. Usually, an existing technology and equipment often have significant 'sunk costs' from earlier investments which results in reluctance by companies to invest in new technology (Arthur, 1994). Policymakers are required to step in and help to tackle this issue by using proper instruments such as providing financial support mechanisms.

On the other hand, increasing efficiency and reducing waste could be in the interest of a single company unit. Nonetheless, if the circular economy is viewed from an interconnected business network perspective, it can be argued that maximising waste flows is in the interest of the economic logic of the businesses (Genovese & Pansera, 2019). This would lead to a paradox where the circular rhetoric aims to reduce and circulate waste flows, while the economic logic aims to increase its outputs, which would require increase in inputs. The interconnected concerns of rebound effects, globalised interconnected economy, rising affluence and thus ecological footprint in developing countries, fixation on economic growth renders resource efficiency as a principle incapable of delivering a truly transformational circular economy.

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2.3.3 Barriers to institutional uptake of Circular Economy

Many of challenges at both microeconomic and macroeconomic level exposed above have led to a slow transition towards the CE over the past few decades. Most of the countries that have officially embraced the CE paradigm, including the EU and China, still remain essentially Linear Economies. For example only 12% of materials used by EU industry come from recycling (Eurostat, 2019) and the extraction of virgin materials has tripled between 1970 and 2017 (International Resource Panel, 2019). 12 years ago, in recognition of the need to transition to an economy that is more circular, targets were set for recycling materials by 2020 to encourage incremental changes (European Comission, 2008). However, 50% of EU member states look likely to fail this target (European Comission, 2018).

A lack of data and the uncertainty about the financial viability of CE can definably contribute to hamper an uptake of the transition at macro-level. Unclear information may also compromise the long-term success of the CE even at a macroeconomic level, due to optimal development paths being impeded (Korhonen et al., 2018). For instance, a hypothetical situation might be that a government adopts a policy that seemingly encourages a transition towards a CE, but the policy fails to change consumer behaviour, leading to a breakdown of trust and developing scepticism of future CE policies, even if those future CE policies would succeed. The lack of statistics and tracking of CE initiatives may also be a barrier at a macroeconomic level. While western governments publish statistics on recycling, the same is not true for reuse, remanufacturing or refurbishment (Korhonen et al., 2018), making it difficult for policy makers to design and implement appropriate instruments.

More radical changes are being encouraged, with the recent introduction of the European Green Deal, and the Circular Economy Action Plan 2.0, which envisages, among several things, that sustainable products become the norm within the EU, and that consumers are empowered with accessible information about a product's sustainability (European Comission, 2020a). In addition, the 2018 version of the Circular Economy Action Plan set common EU targets for recycling municipal waste (65% by 2035) and decreasing landfill waste by 2035 to a maximum of 10% of municipal waste (European Comission, 2015). Whether EU member states will satisfy the more radical targets remains to be seen.

The critical factors in the literature that can determine the implementation of the CE by institutional settings are mainly two; the presence of a policy broker that promotes a specific formulation of CE to institutional settings, and the extent to which the CE can present itself as a solution to existing identified policy problems.

The first factor, the presence of a policy broker, is a key element to explain the implementation of the CE within certain institutional settings. In the case of the EU, a critical factor that was decisive to start the

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debate of the CEAP was the presence of a leading proponent that was actively promoting among the policy spheres the adoption of the CE, the Ellen Macarthur Foundation (EMF), who collaborated with McKinsey to produce reports for the European Institutions to advocate for the adoption of a CE for the EU (Murray et al., 2017).

The second factor, the extent to which the CE is presented as a solution to existing identified policy problems, was a crucial driver for its adoption among EU spheres. The EMF promoted a narrative where the CE is a solution not only to an important environmental crisis, but to the problems of the competitiveness of the European industry (Lazarevic & Valve, 2017). More specifically, the EMF pointed out the need for the European economy to create a solution to the resource scarcity for an European industry that largely depends on material imports and is vulnerable to unpredictable resource prices and supply disruptions (Lazarevic & Valve, 2017). For the European Commission and the European Parliament, the mainstream narrative of a CE generated a set of expectations of creating an economic win-win situation that is expected to provide an opportunity to support the growth of the EU's GDP, create new opportunities for the industry, employment growth, and a significant reduction in pollution (European Commission, 2019; Lazarevic & Valve, 2017). For some analysts, this perspective lacks reflexivity and fails to address many of the constraints illustrated above (Ghisellini et al., 2016; Korhonen et al., 2018; Genovese & Pansera, 2019).

2.3.4 Cost Shifting

Another important constraint for the implementation of an effective global transition towards CE is ***the mechanism that characterised the last 3 decades of globalisation***. Most production depends on global value chains through international trade and as such it is exposed to different regulations and standards. The domestic requirements for eco-design (phase-out hazardous substances from products) and eco-labelling schemes (requirements to secure information on chemical and material composition of products) of products, could be undermined by imported goods that do not necessarily comply with the same standards. Thus, the domestic downstream waste recovery processes would have to also manage products that do not comply with the environmental standards of the domestic country (Yamaguchi, 2018). Moreover, the global geographic dispersion of production increases the proportion of maritime or air freight shipping. This dispersion is associated with a fragmentation of specialised tasks across countries where "dirty" and "clean" tasks are redistributed between countries which creates environmental benefits for some countries and environmental costs for others (World Bank, 2019).

The ***production of circular products and services may seem to have zero environmental impacts due to cost shifting, where the environmental impacts occur at another point in the supply chain*** (Korhonen et al., 2018). These externalities could also take the form of shifting the cost to future

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generations, impoverished communities, to other species and other countries (Martínez-Alier, 2011), due to the fragmentation of specialised tasks of the global geographic dispersion of production. In the current globalised economy, trade of waste and scrap increases production efficiency in emerging economies as it enables supply of input material at low prices. However, bilateral trade in waste is found to increase if there is divergence in environmental policy stringency between the trading partners. Because of this, in some cases, the pollution is shifted to countries with laxer environmental standards (pollution havens) and underdeveloped waste management systems or "circular production" capacity. Moreover, there could be a structural incentive towards illegal trade in hazardous waste. Informal recycling activities can lead to severe environmental and health concerns, which pose a serious question to whether an increase in waste trade would actually be good for the environment (Yamaguchi, 2018).

To produce net positive sustainability outcomes with this strategy, ***the adoption of circular economy approaches would have to be applied widely and consistently, reflecting the complex international nature of supply chains*** (Cullen, 2017). In practice, a true circular economy is incompatible with global value chains. In order to achieve its envisaged socio-environmental benefits it must undergo a systemic transformation that should involve the principle of proximity between producers, resources and consumers through short distribution networks and by re-embedding production systems into local economies. Thus, rethinking the globalised chains of production and consumption is of paramount importance for the effectiveness of the circular economy concept, as smaller scale, local solutions can have better socio-environmental outcomes than large scale global solutions (Murray et al., 2017).

The global shift in manufacturing from the countries of the Global North to Asia has further facilitated the profitable waste trade. Once the shipping containers of new products are imported in the Global North, the economic sense facilitates a return of waste loaded containers from West to East or North to South. This occurs as economically convenient cheap labour costs and less stringent environmental regulations allow for further rounds of materials separation, segregation, and sorting of waste to secondary resources for recycling. The recovery of secondary materials in emerging countries can have negative socio-ecological impacts due to less stringent regulations, which stimulates investment interests from foreign investors in a world of liberalised trade (World Bank, 2019). In these contexts, informal waste workers can be exposed to physical and chemical hazards and infectious wastes in the process of recovery of secondary materials (Ferronato & Torretta, 2019). Another example concerns shipbreaking workers who work with heavy equipment in enclosed spaces and are exposed to excessive noise or chemicals (Zakaria, Ali, & Hossain, 2012). Also, processing of electronic waste in unregulated environments poses a number of health risks to workers. Of added concern is the exposure of children to these activities through use of child labour (Perkins et al., 2014). As such, it is important to know the origin of secondary materials in the circular economy to

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ensure human and environmental health in the recovery practices (Holland, 2020). However, many companies in the EU lobby for maintaining the deregulation agenda, despite the calls for the introduction of legal requirements regarding the traceability of materials and products (Lazarevic & Valve, 2017).

Nevertheless, traceability alone is insufficient to tackle the elimination of systemic injustices and development of alternative livelihood strategies for at risk workers who have come to rely or depend on the very activities that are harming them. As a solution to this systemic problem, ecological modernisation approaches have proposed introduction of modern waste management infrastructures in the developing countries. However, research on the privatisation of waste management in the South has shown that this may be another form of appropriation and control of secondary resource flows by multinationals from the Global North. Furthermore, this logic has been questioned as a new form of EU mercantilism, in which the EU's version of waste management is superior to the secondary resource recovery of workers in developing countries. This modernisation of waste management has been documented to negatively affect the livelihoods of traditional somewhat informal recycling labour in developing countries (Hartmann, 2018). As such, a contradiction has arisen between regulated waste management, which favours capital-intensive arrangements, and poverty-reduction programs, which see circular economy activities as livelihoods and survival strategies for people with lower incomes (Gregson & Crang, 2015).

A true implementation of the circular economy based on localised circular production implies re-thinking the global North-South (productive vs. extractive economies) power relations. As a result, CE might force industrialised countries to abandon their positions of privilege that guarantee the easy and cheap access to natural resources in the global South. Moreover, the global North should assist these countries to move away from dependence on resource exports, facilitate diversification of the local economy and redistribute wealth between the global North and South to settle its historical ecological debt. As such, alternative livelihood strategies for at risk workers could be formed, the global toxic waste relations eliminated, and local circular economies developed. This could be a problematic compromise for many countries in the North and can represent a critical constraint to the implementation of CE at a global scale. However, there is little confidence that with the current rates of consumption, Europe could become self-sufficient at the level of resources (Lazarevic & Valve, 2017), therefore it is likely to continue to rely on other countries for cheap resources and products in the current socio-economic system.

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Box 3. Social Constraints to Circular Economy

Social constraints to circularity are often neglected but the CE literature[1]. These can be generally classified in: issues about equity, or how the CE impacts across different social classes (Wirtenberg, 2014; Murray et al., 2017; Millar, McLaughlin, & Börger, 2019), and cultural factors, or how the CE may be affected by pre-existing cultural factors (de Jesus & Mendonça, 2018; Galvão, de Nadae, Clemente, Chinen, & de Carvalho, 2018). As Murray et al. (2017) point out, the CE literature is "virtually silent on the social dimension" as there is no clear understanding on how does the CE contribute towards promoting social equality, apart from supporting the creation of jobs. Although some authors assume that a potential creation of jobs and economic growth would be a social benefit (Mitchell & James, 2015), this idea has been criticised as growth and employment are not drivers of social equity (Murray et al., 2017; Millar et al., 2019). Secondly, as De Jesus and Mendonça (2018) point out, cultural factors will influence consumers to accept or not circular businesses. Some trends as public sensitivity towards sustainability, shifting customer preferences and attitudes (for instance, as switching ownership to services models), and business perception or reputation, are critical in a transition towards a circular paradigm. Also, the lack of societal pressure for a sustainable offer, or the lack of knowledge and awareness on the environmental problems can act as a constraint to the implementation of a CE (de Jesus & Mendonça, 2018; Galvão et al., 2018). This research, however, is still limited to only the behaviour of consumers and their willingness to accept circular products, and there is still a research gap on other important cultural factors, such as the different reactions that the idea of the CE may have in different cultural landscapes.

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3 Conclusions

Over the past decade, 'Circular Economy' (CE) has caught the attention and so been driven by many stakeholder groups including political institutions, industry and corporate businesses, research and academia as well as non-governmental organisations and the wider society as a mechanism that can replace the traditional linear models of production. The implementation of CE and its agenda are likely to draw criticisms and challenges from the different stakeholder groups due to their varying expectation and demands. The effective implementation of CE therefore calls for comprehensive study in order to understand its barriers and limitations from different aspects. This report has provided a review of the state-of-the-art literature on CE to identify factors that are critical for, or can serve as constraints of, its implementation. To enable circular transitions, this report highlights a number of factors that needs to be taken into account:

Micro Level (Firm Level)

The transitions to circularity at the level of a single productive unit is likely to encounter a number of technical, environmental and financial limitations:

- There are serious technological limitations associated with recycling including efficient waste collection and material separation. The notion of full recycling is a controversial one and with current technologies available, it is very expensive to collect and recover all the wastes, if not impossible. Product quality of products made from recycled materials is often (not always) is lower in comparison with those that are made from original resources. Finally, the recycling or recovery of some materials can be energy-intensive.
- Waste streams are not always reliable enough to support recycling processes as an input for mass production in general. Competition from conventional firms can easily reduce the incentives to initiate a transition towards circularity. For new CE firms, overcoming the competitive advantage held by non-CE firms can be a challenge, as non-CE firms were the first to appear in the market and have an established customer base. Finally, the uncertainty about the financial implications of transitioning towards a CE could represent a serious disincentive to SMEs.
- Managerial culture in firms and companies is yet to incorporate CE mind-set.

Meso – Supply Chain Level

- Strategy and objectives, targets and milestones, and the plan and programme to implement the CE concept at the supply chain level are not clearly defined by regulators and policymakers.

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- The implementation of CE at shop floor level of production lines requires high short-term costs with low short-term financial revenues.
- Knowledge along with technical and managerial skill limitations make more difficult for supply chains to better implement CE strategies.

Macro level (regional, national and international level)

The transition to circularity presents several constraints also at macro level i.e. relation among firms, regional, national and international institutions and governance:

- An important constraint is represented by the lack of data and tracking which pose a challenge for policymakers to monitor measures and make refinements.
- Increased waste trade might be worse for the environment, as a true circular economy is incompatible with global value chains. Maximising waste flows is in the interest of the economic logic of the businesses and contradicts the aim of reducing waste production. This paradox can undermine the implementation of effective policy at macro level.
- The presence of a policy broker that promotes 'decaf' ideas of a CE in policy spheres can undermine the effectiveness of such policies. Lack of clear objectives, targets, and plans for CE implementation by regulators and policymakers at supply chain level is a serious problem.
- Rebounding effects can minimise the effects of CE applied at macro level. Increased resource productivity may naturally lead to rebound effects in the current economic logic that could counteract the initial resource savings. In modelling the transition towards the CE, careful study is required for estimation of material productivity growth and materials substitution rates.
- A true implementation of the circular economy based on localised circular production implies re-thinking the North-South (productive vs. extractive economies) power relations. The recovery of secondary materials in developing countries can have negative socio-ecological impacts.

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