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Analysis

Circular futures: What Will They Look Like?

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ABSTRACT

The circular economy is argued to hold great promise for achieving sustainability. Yet, there is a dearth of research about what a circular future may look like. To address this gap, this paper proposes different plausible scenarios for a circular future, using a 2 × 2 scenario matrix method developed through a thought experiment and a focus group. Key drivers of change in this matrix are the nature of technologies deployed – high-tech or low-tech innovations – and the configuration of the governance regime – centralized or decentralized. From this, our paper builds four scenario narratives for the future of a circular economy: "planned circularity", "bottom-up sufficiency", "circular modernism", and "peer-to-peer circularity". It delineates the core characteristics and the upsides and downsides of each scenario. It shows that a circular economy can be organized in very contrasting ways. By generating insights about alternative circular futures, these scenarios may provide a clearer directionality to policy-makers and businesses, helping them both anticipate and understand the consequences of a paradigm shift towards a circular economy and shape policies and strategies, especially in the context of so-called mission-oriented innovation policies. They may also provide a sound basis for quantitatively modelling the impacts of a circular economy.

1. Introduction

The concept of circular economy (CE), which finds its roots in environmental and ecological economics, industrial ecology as well as management and corporate sustainability literature (e.g. Boulding, 1966; McDonough and Braungart, 2002; Pearce and Turner, 1990), is today hyped by policy-makers, academics and businesses as a concept to enable sustainable development (Geissdoerfer et al., 2017). A CE can be defined as "an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr et al., 2017, pp. 224–225). Major systemic transformations such as a transition to a CE call for a long-term vision and challenge current mindsets (Dufva et al., 2016). Firms, governments and other organizations need to anticipate future developments in order to prepare for them and the many barriers to be overcome (Kirchherr et al., 2018). While it is relatively easy to accommodate short term linear changes, longer term shifts in socio-technical systems and the impacts of technological disruptions are more difficult to cope with (Uotila et al., 2005).

Yet, despite the hype around CE, there is very little discussion around what a circular future may look like. As noted by Geissdoerfer et al. (2017, p. 766), the "[Time dimension] is excluded from "most [CE] discussions". Only 1 of 114 CE definitions scrutinized in Kirchherr et al. (2017) discusses the time dimension and the impact of CE on future generations (Kirchherr et al., 2017, p. 228). Furthermore, as Weigend Rodríguez et al. (2019) argue, future studies[1] and the CE literature are poorly integrated. Some practitioner studies have been published on the alleged economic, environmental and social impacts of CE, but their conceptual underpinning is limited (as further discussed in the next section). While insights about the potential impacts of a CE are important to accelerate the transition towards CE, a better understanding of the conceptual underpinning of a CE is a sine qua non for rigorously assessing its impacts. Indeed, we posit that a CE can be conceptualized in very different ways and that it is essential to better examine the trade-offs between these conceptual models and their societal consequences. Furthermore, many current approaches to CE

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[1] Future studies are defined by Inayatullah (2012, p. 37) as the "systematic study of possible, probable and preferable futures including the worldviews and myths that underlie each future."

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adopt a micro perspective, focusing on a single firm or industry, and overlook the fundamental systemic changes needed to transition towards a CE.

To address these research gaps, this study aims to qualitatively conceptualize potential circular futures, providing a possible “true north”, particularly for policy-makers in their efforts to transition towards a more circular economy. Accordingly, the research question addressed is the following: *What would a circular future look like*? To do so, a thought experiment and a focus group are conducted to explore different plausible scenarios–scenarios “which ‘could happen’ (i.e. they are not excluded) according to our current knowledge (as opposed to future knowledge) of how things work” (Voros, 2003, p. 17)–for a circular future. These scenarios are not sector-specific, but are rather intended to outline the broad societal trends that may pervade multiple or all industrial sectors. The core upsides and downsides of each scenario and the potential trade-offs between them are described.

In terms of policy and business implications, these scenarios, by generating insights about alternative circular futures, may help policy-makers and businesses both anticipate and understand the consequences of a paradigm shift as well as support action in the present. They can provide a clearer directionality to shape policies and strategies for a transition towards CE. As such, they are particularly useful for the design of “mission-oriented innovation policies” (i.e. “systemic public policies that draw on frontier knowledge to attain specific goals”; Mazzucato, 2018; Wanzenböck et al., 2019) intended to accelerate the advent of a more circular economy.

The remainder of this article presents the methods adopted to address the above-mentioned research question (Section 2), the theoretical framing of this study (Section 3), the scenarios obtained (Section 4), their discussion (Section 5) and some concluding remarks (Section 6).

2. Methods

As a preliminary step to our scenario building analysis, we conducted a literature review on CE and futures. Keyword full-text searches up to 2020 were undertaken in Elsevier's Scopus, Thomson Reuters' Web of Science and Google Scholar, employing the following search query: “circular economy” AND (“scenarios” OR “impact” OR “foresight” OR “future” OR “vision” OR “prognosis”). This literature review provided us with an overview of what has already been written on the topic. We skimmed the results of these searches, specifically looking for relevant content on circular futures with a social science focus. We identified only nineteen studies that examine CE futures, among which nine are peer-reviewed and ten are not. These publications were carefully scrutinized, with a specific focus on the factors that may influence the future developments of a CE. These studies reflected the diversity of plausible circular futures, as described in Section 3.1., justifying the exploration of different scenarios.

We then used a scenario planning method based on thought experimentation. Scenario planning is a central approach in future studies (e.g. Börjeson et al., 2006; Vervoort et al., 2015) which has often been used to envision sustainable futures in various contexts, such as territorial planning (Folhes et al., 2015) and sustainable land use (Tress and Tress, 2003). Scenario planning was conducted via the 2 × 2 scenario matrix method, which is reportedly one of the most established methods in scenario planning (van Asselt et al., 2012; Bradfield et al., 2005; Curry and Schultz, 2009). The advantage of a 2 × 2 matrix over other methods (e.g. causal layered analysis, Manoa approach, scenario archetypes approach; Curry and Schultz, 2009) is that it produce a clear, memorable and easy to communicate structure allowing the comparison of scenarios with one another. The first step of this method involves identifying two contextual factors which are believed to be key underlying drivers of change. The most reported criteria for choosing these two factors over others are based on a ranking in terms of most uncertain and greatest potential impact over the time horizon considered. In addition, they need to be mutually independent. The intersection between these two axes define four clearly differentiated spaces, which are then developed into scenario narratives, reflecting the influence of other events and trends in addition to those represented on the two axes.

The axes in the 2 × 2 matrix can represent a continuum (“grid”) with more–less calibration in each axis, or they can represent instead incommensurate possibilities (“frames”) with an either/or calibration (Ramirez and Wilkinson, 2014). In the former case, the scenarios that the matrix maps can coexist, overlap and are not mutually exclusive of one another, while in the latter case, they are incompatible with one another. In the present case, the four scenarios that result from our analysis can be best thought as extreme cases of continuums. That is to say, they are not mutually exclusive and can co-exist to some extent, a topic which will be returned to in Section 5.1.

The method of thought experiment was employed to define the axes and develop the narratives of the scenarios, as it is particularly suited for examining hypothetical future scenarios. Indeed, the purpose of a thought experiment is to think through the potential consequences of a hypothesis or theory. As Yeates (2004, p. 150) puts it, a thought experiment is “a device with which one performs an intentional, structured process of intellectual deliberation in order to speculate, within a specifiable problem domain, about potential consequents (or antecedents) for a designated antecedent (or consequent)”. Thought experiments have been an important theoretical tool in analytic philosophy and natural sciences, such as physics and biology, but they are also currently experiencing a resurgence in social sciences, such as sociology (Hill, 2005) and economics (Aligica and Evans, 2009; Frappier et al., 2012).

The thought experiment followed a structured process for each scenario: first, to define the axes of the matrix, we set a list of factors likely to influence the pace and the direction of a transition towards a CE, based on the literature review (business models, technological innovations, spatial scale of economic activities, type of governance, etc.). We then ranked these factors in terms of uncertainty and potential impact. The two top high impact-high uncertainty factors chosen to define the axes are, on the one hand, the nature of innovations deployed in a CE and, on the other hand, the configuration of the governance regime of a CE (as further described in Section 3). Second, one author developed a narrative for each scenario defined by the crossing of the axes based on the other identified factors. These narratives were then critically assessed by the two other co-authors to check for unsound argument (Gendler, 2014). Finally, the scenarios were presented in a focus group session with twelve CE experts, including five policy-makers, five academics and two circular entrepreneurs to test the framework with a broader audience and collect additional feedbacks. Participants were asked about their thoughts and insights regarding the scenarios and their upsides and downsides, and also about the scenario they deemed most probable and the one they preferred most. These insights formed a basis for the discussion of the upsides and downsides of the scenarios in Section 4.5 as well as their probability and preferability in Section.

3. Theoretical framing

3.1. Circular futures

Among the studies on circular futures that we identified, ten are predominately focused on CE impacts (see Table 1), most commonly defined as triple bottom line impacts (i.e. economic, environmental and social impacts). The core message of these studies is generally the same: a transition to a CE will deliver more jobs, more economic value and reduced CO_2 emissions (Stegeman, 2015). Yet, estimates regarding impacts vary widely across studies. For instance, regarding environmental impacts, the Ellen MacArthur Foundation (2015) estimates that there will be a halving of CO2 emissions due to CE until 2030, while

Table 1
Overview of existing impact studies on the circular economy.

#	Study	Regional scope	Vision	Impact: Economic	Impact: Environmental	Impact: Social
1	Arushanyan et al. (2017)	Sweden	2030	N/A	Reduction of greenhouse gas emissions between 1610 and 6130 megatonnes of CO_2eq	N/A
2	Bastein et al. (2013)	The Netherlands	2020	Additional EUR 7.3 billion GDP annually	Annual CO2 reduction of 17,150 t	54,000 new jobs
3	Ellen MacArthur Foundation (2015)	European Union	2030	■ Additional EUR 1.8 trillion GDP ■ Additional EUR 3000 household income	Reduction of CO2 emissions by 48%	N/A
4	European Commission (2014)	European Union	2030	15–30% cumulative GDP increase	Reduction of CO2 emissions by 25%	2 million new jobs
5	European Commission (2015)	European Union	2030	Additional profit of EUR 600 billion for EU businesses	Reduction of CO2 emissions by 25%	580,000 new jobs
6	EPA (2014)	Luxembourg	2050	Additional EUR 1 billion GDP annually	Reduction of CO2 emissions between 96 and 146 billion tonnes	7000–15,000 new jobs
7	Morgan and Mitchell (2015)	United Kingdom	2030	N/A	N/A	200,000 new jobs
8	Stegeman (2015)	Netherlands	2030	Additional EUR 8.4 billion GDP annually	Reduction of CO2 emissions by 30%	83,000 new jobs
9	Wijkman and Skånberg (2015)	Finland, France, the Netherlands, Spain, Sweden	2030	1,5% GDP increase	Reduction of CO2 emissions by 66%	■ Finland: 75,000 new jobs ■ France: 50,0000 new jobs ■ The Netherlands: 200,000 new jobs ■ Spain: 400,000 new jobs ■ Sweden: 100,000 new jobs
10	Wrap (2015)	European Union	2030	N/A	N/A	1.2–3 million new jobs[a]

Source: constructed by authors.
[a] The study also includes estimates for every single Member State.

The European Commission (2014, 2015) believe there will be a 25% reduction. As regards social impacts, the European Commission (2014) argues that 2 million CE-related new jobs will be created in the EU by 2030, EC (2015) estimates that there will be 580,000, whereas Wrap (2015) believes that there will be 1.2–3 million new jobs.

A likely reason for these discrepancies between impacts is that these studies greatly diverge regarding their assumptions about what a circular future will look like. However, these assumptions are not explicitly stated in these studies. The "what" (i.e. the conceptual underpinning of a CE) remains underspecified, neglecting aspects such as the dominant circular loops, the dominant business models, the key technological innovations, the organization of decision-making processes and the spatial scale of economic activities. For instance, Wijkman and Skånberg (2015) assume that their focus countries will become 25% more material-efficient, substituting half of the virgin materials used with recycled materials, and doubling the product-life-time of long-lived consumer products. However, the report does not specify the CE core principles that are supposed to be at work to bring about these improvements.

Nine studies explicitly engage with the "what" of CE in future scenarios. Dobers and Wolff (1999) present scenarios for new industrial logics in recycling industries, automobile and household appliances, focusing on the concepts of eco-efficiency[2] and dematerialization, while Parajuly et al. (2019) sketch three scenarios for the future of e-waste. Kuzmina et al. (2019) outline future scenarios for fast-moving consumer goods in a CE, with special attention to value creation as well as the roles played by consumers and the IT within CE. Some studies explore CE "imaginaries" for different cities (Fratini et al., 2019) or for consumption practices (Welch et al., 2017). Other studies focus more on the perceptions of different scenarios by specific actors, such as government partners (Velenturf et al., 2018) or users (Atlason et al., 2017). In contrast to these studies, the present contribution does not focus on one or multiple specific sectors, spatial settings or types of actors, but rather highlights the meta-principles that may shape a CE across industries, since many characteristics are common to various sectors (e.g. technologies impacting different industries, such as ICT and 1D printing). Similar approaches are found in Stahel (2010), who describes the underlying mechanisms of what the author calls the "performance economy",[3] and in de Jesus et al. (2019), who engage in a foresight exercise to identify "eco-innovation pathways" to a CE. However, these authors do not contrast multiple scenarios and Stahel (2010) barely considers behavioral and institutional dimensions.

3.2. Technology and institutions as core drivers of change

Transitions towards a CE take place in socio-technical systems (STS), defined as clusters of "interrelated components connected in a network or infrastructure that includes physical, social and informational elements and that thus involves technology, science, regulation, user practices, markets, cultural meaning, infrastructure, production and supply networks" (Maréchal, 2010, p. 1105). This underscores that a transition towards CE "must be understood as a fundamental systemic change instead of a bit of twisting of the status quo to ensure its impact" (Kirchherr et al., 2017, p. 229). Yet, current approaches to CE often adopt a micro perspective, taking the view of a single company or a single sector. For instance, only around 40% of definitions analyzed by Kirchherr et al. (2017) conceptualize CE from a systems perspective.

Technologies and institutions[4] form the two core drivers of change

[2] Eco-efficiency refers to the "strategy of reducing the material content of goods without reducing their utility"; Opschoor et al., 1995).

[3] This concept entails a full shift to servicization, with revenue obtained from providing services rather than selling goods and a high emphasis on re-use and re-manufacturing strategies to maintain the quality of manufactured capital.

[4] Technologies are defined here as a tool, method, or design practice that

in STS, since the dynamic interplay of institutions and technologies over time are at the root of their evolution. As Fuenfschilling and Truffer (2014, p. 772) put it, “socio-technical regimes denote the paradigmatic core of a sector, which results from the co-evolution of institutions and technologies over time”. Indeed, as new technologies have their specific physical and social features, institutions generally need to be adapted, or even invented, to address specific problems or conflicts that arise (Nelson, 1994). Conversely, institutions may considerably influence the emergence and diffusion of new technologies by facilitating it or, instead, hindering or impeding it. Furthermore, technologies and institutions are both highly impactful and highly uncertain factors in the evolution of STS. Accordingly, we define the axes of in the 2 × 2 matrix scenarios along these two contextual factors: one relating to the nature of technologies deployed and one relating to the configuration of institutions. These factors are detailed further in the two next sections.

3.3. High-tech and low-tech innovations

There has long been a tension between more techno-pessimistic and more techno-optimistic views regarding the environmental and social impacts of technologies (Kerschner and Ehlers, 2016). In a techno-optimistic perspective, the primary societal goal is to maintain a growth-orientated consumer economy and attempt to decouple this form of life from environmental impact via technological innovation and market mechanisms. By contrast, technoskeptics usually emphasize the need to move away from resource-intensive, consumerist lifestyles and adapt to a resource descent pathway through the adoption of “low-tech” innovations.

In the innovation literature, low-tech innovations are those which do not need substantial R&D activities (Czarnitzki and Thorwarth, 2012). They are designed to be as simple as possible, can typically be fabricated with a minimum of capital investment and are characterized by the low knowledge transfer costs incurred to understand them. Low-tech can also simply refer to behavior change, as opposed to relying on technological solutions of any variety (e.g. putting on warm clothing rather than installing an novel energy efficient heating system).[5] By contrast, high-techs innovations offer more advanced and complex features, “on the cutting edge of technology developments” (Baruch, 1997). They are R&D intensive and years of scientific education and specific experience are needed to become familiar with them. Low-techs are typically less resource-intensive and more resilient than high-techs, due to their higher simplicity (Alexander and Yacoumis, 2018). As an example for reducing the resources used for clothes washing and drying, high-tech solutions can be highly efficient appliances which would optimize water and energy use. An obvious low-tech way to washing clothes is to wash by hand, while the use of a clothesline represents a low-tech alternative to drying clothes.

High- and low-tech solutions can be related to the different options of the waste treatment hierarchy (see Table 2). The strategy “Refuse” is typically associated with low-tech innovations and important behavioral changes, since it stresses the choice to buy less, or use less, which may apply to any consumption article aiming at prevention of waste creation. Reduce can be achieved through both low- and high-tech solutions: for instance, by the sharing of products (low-tech solution) or by some eco-efficient technological innovation (high-tech solution). Similarly, Reuse can involve low-tech solutions and behavioral or cognitive changes (e.g. buying second hand, consumer involvement in take-back management), but can be facilitated via high-tech innovations, such as digital platforms and blockchain-based asset-tracking systems. This also holds for Recycle and Recover. Generally, low-tech approaches to circular strategies entail larger behavioral changes.

3.4. Centralized and decentralized governance

The question whether a CE should be centrally or decentrally governed can be approached through the broader debate over the relative merits of democratic and authoritarian environmentalism (Hysing, 2013). On the one hand, proponents of authoritative, expert-guided environmental governing point to the length of participatory processes, the short-termism of the electoral system and the pressure of lobby groups, to argue in favor of a technocratic vision of political leadership by the experts, which is believed to produce optimal outcomes compared to more participatory approaches (Shearman and Smith, 2007). Authoritarian environmentalism entails two dimensions (Beeson, 2010): 1) a decrease in individual freedom that prevents self-interested individuals from engaging in unsustainable behavior and compels them into acting in the collective interest by, for example, producing fewer children (Wynes and Nicholas, 2017) and living more frugal lifestyles; 2) a policy process dominated by a relatively autonomous central state, affording little or no role for social actors or their representatives.

On the other hand, some authors argue in favor of decentralized environmental governance. Generally defined, political decentralization refers to “the expansion of local autonomy through the transfer of powers and responsibilities away from a national political and administrative body” (Carter, 2007, p. 42). Similarly, economic decentralization refers to an economic system in which economic decision-making is distributed among various economic agents rather than concentrated in a few central authorities, such as the state or large corporations. Decentralization, based on a higher involvement of small-scale, local communities in political and economic decision-making, is often seen as a way to deepen and strengthen democracy, as small-scale communities are able to practice direct participatory democracy (Hysing, 2013). In its most radical, eco-anarchist forms, the green polity would consist of a stateless society based on a confederal system of autonomous communities (Bookchin, 1989) or on “bioregions” defined by the natural boundaries of the land rather than the human administrative borders (Sale, 1980).

Similar to high-tech and low-tech approaches to circularity strategies, these strategies can be developed in a centralized or decentralized manner. Waste reduction, reuse and recycling operations can, for instance, be conducted in centralized facilities, under the entire responsibility of large producers and with minimal consumer involvement. By contrast, they can also be organized in a much more decentralized fashion, for example by relying more extensively on the participation of households and community organizations in waste recycling, reuse and reduction schemes (Slater and Aiken, 2015).

In accordance with this theoretical framing, the horizontal axis is about the technological dimension of the CE and denotes the degree of high-tech or low-tech innovations, while the vertical axis relates to institutions and governance and reflects the degree of decentralization or centralization of the governance of CE. The narratives of the scenarios focus on the following key characteristics: dominant technological innovations, dominant loops and business models, spatial scale of economic activities as well as core upsides and downsides. Technological innovations are scrutinized since, as mentioned above, technologies are one core driving change in STS. Dominant loops are approached through the waste treatment hierarchy presented in Table 2, while business models, which are perceived to be crucial in a transition towards CE (e.g. Bocken et al., 2016), are approached through the typologies proposed by Bakker et al. (2014) and Bocken et al. (2016). The question of spatial scale is considered, because it has

(*footnote continued*)
helps humans solve problems and achieve goals, while institutions refer to “the rules of the game”, including laws, rules, regulations and social norms.

[5] Close concepts are appropriate technology (Akubue, 2000; Schumacher, 1973) and convivial tools (Bradley, 2018; Illich, 1973; Vetter, 2018), which highlight the necessity to use locally adapted materials and technologies that can be built, maintained and repaired without foreign experts and that are not environmentally harmful.

Table 2
Waste hierarchy and potential circularity strategies.

Strategy	Definition	Low and high-tech solutions
Refuse	Refrain from buying	*Low-tech solution*: behavioral changes
Reduce	Increase efficiency of product design or manufacturing by preventing or minimizing the use of specific hazardous materials or any virgin materials, or allowing for more intensive product use through sharing of products	■ *High-tech solution*: biologically based plastics ■ *Low-tech solution*: pooling or sharing of products; package-free shops
Reuse	Bring products back into the economy after initial use, or extend the lifespan of products and their parts (through repair, second-hand markets etc.)	■ *High-tech solution*: digital exchange platforms and blockchain-based asset-tracking systems ■ *Low-tech solution*: buying second hand, consumer involvement in take-back management
Recycle	Process materials through, e.g., shredding or melting to obtain the same (upcycling) or lower (downcycling) quality	■ *High-tech solution*: chemical recycling, automated sorting ■ *Low-tech solution*: composting or manual dismantlement and extraction of valuable materials
Recover	Incinerate residual flows with recovery of embodied energy	■ *High-tech solution*: Hydrothermal Carbonisation, Dendro Liquid Energy ■ *Low-tech solution*: Anaerobic digestion

been underscored as an essential aspect in sustainability transitions (Coenen et al., 2012).

Finally, upsides and downsides are highlighted to better understand the trade-offs between scenarios. To do so, we consider the scenarios according to their environmental effectiveness, socio-political feasibility, economic efficiency and fit with democratic values. These criteria were chosen because they reflect the central factors in measuring sustainability: economic efficiency, environmental effectiveness and socio-political feasibility correspond to the economic, environmental and social dimensions of the triple bottom line. Fit with democratic values corresponds to the governance dimension of sustainability, which is part of the Environmental, Social and Governance (ESG) assessment criteria used to classify sustainability issues. Table 3 summarizes these elements and Fig. 1 represents the axes and the four identified scenarios.

Given the systemic nature of a transition towards CE highlighted above, going beyond technological advances alone to encompass institutional and behavioral dimensions is necessary from a policy perspective. For this reason, the concept of mission-oriented innovation policies (MIP) is particularly insightful. MIP are policies targeting complex, multi-dimensional and systemic societal problems to influence the directionality of innovation activities (Hekkert et al., 2020; Mazzucato, 2016; Wanzenböck et al., 2019), articulate them with the demand side (Boon and Edler, 2018) and break up path-dependencies in the existing system (Schot and Steinmueller, 2018). They also usually involve a larger diversity of stakeholders influencing and being influenced by the policy agendas, beyond well-established innovation systems built around incumbent firms (e.g. consumers, governments and local communities; Bauwens and Eyre, 2017; Kirchherr and Piscicelli, 2019). The scenarios presented here can be particularly helpful in devising MIP for a CE, since they provide clear visions for possible futures of a CE and depict the main transformations needed to materialize these visions, not only in terms of technological innovations, but also institutional and behavioral changes.

Table 3
Definition of the axes and core characteristics of scenarios.

Core dimensions	Definition
Definition of the axes	
High-tech innovations	Advanced and complex technologies characterized by high R&D intensity and high knowledge transfer costs
Low-tech innovations	Technologies designed to be as simple as possible, characterized by low R&D investment and low knowledge transfer costs
Centralized governance	Concentration of political and economic power and responsibilities into the hand of national governments and large corporations
Decentralized governance	Expansion of local political and economic autonomy through the transfer of powers and responsibilities away from large national political and administrative bodies and large corporations
Core characteristics of scenarios	
Dominant loops	Waste treatment strategies (Refuse, Reduce, etc.)
Dominant business models	• Classic long life model: primary revenue streams generated by the sales of high-quality product with a long lifespan • Hybrid model: primary revenue streams generated by the repeat sales of relatively cheap products with a short lifespan that only function together with a dedicated high-quality durable product • Gap exploiter model: primary revenue streams generated by providing repair services or sales of refurbished units • Access model: primary revenue streams generated by providing access to a product, while its ownership remains with the access provider • Performance model: primary revenue streams generated by providing the performance of a service. It is up to the provider to decide which equipment or products are deployed to perform this service • Sufficiency-based model: model that actively seeks to reduce end-user consumption through principles such as durability, upgradability, service, warrantees and reparability and a non-consumerist approach to marketing and sales (e.g. no sales commissions)
Dominant technological innovations	Main new technologies deployed
Spatial scale	Spatial scale at which economic and socio-political activities are organized
Core upsides and downsides	Main advantages and disadvantages of the scenarios assessed in terms of • Environmental effectiveness: degree to which a scenario is successful in producing desired environmental outcomes, with specific emphasis on the likelihood of rebound effect and the trade-offs between materials, energy and biodiversity • Socio-political feasibility: degree to which a scenario is politically and societally accepted or supported • Fit with democratic values: degree to which a scenario is in phase with democratic processes and values • Economic efficiency: degree to which a scenario allocates economic resources to produce the highest welfare while minimizing costs

Admittedly, many other socio-economic dimensions could have been chosen as economic and social assessment criteria: quality of life, strength of social ties, health, education, economic and physical safety, etc. However, these criteria are too specific for the purpose of our analysis. We suggest that the assessment of the scenarios along these criteria constitute an interesting avenue for further research.

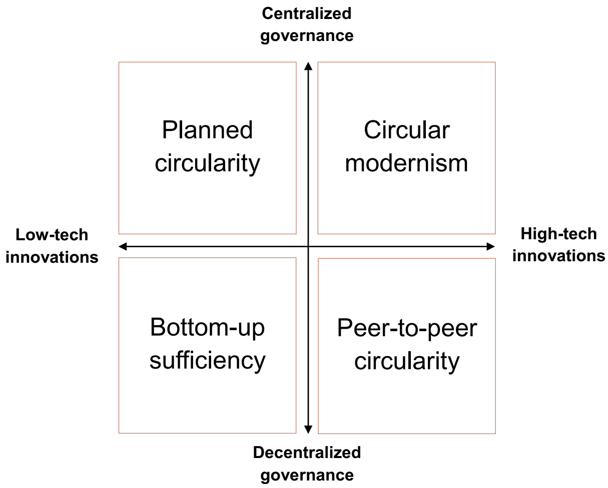

Fig. 1. Four scenarios for circular futures.
Source: constructed by authors.

4. The scenarios

4.1. Planned circularity

4.1.1. Overview

In this scenario, the transition towards a CE is centrally piloted by the government via strong coercive measures. It echoes the views of the advocates of "authoritarian environmentalism" who, in the early 1970s, reluctantly concluded that an ecological elite of scientific experts was required to take the reins and authoritatively guide society towards sustainability (Heilbroner, 1974; Ophuls, 1977). The government sets command-and-control regulations on production and consumption to force firms and consumers to engage in high R strategies, for example by introducing taxes on raw material consumption, emissions and waste or setting hard caps on these activities, by banning the use of environmentally hazardous substances, by legislating a "right to repair" and introducing laws against planned obsolescence, by establishing regulations to massively support access and performance models, by banning plastic packaging and single-use products or by establishing a full producer responsibility program. This scenario involves large changes in consumers' behaviors and lifestyles, but may not necessarily imply a change in the cognitive and emotional aspects of engagement with the new system, since in this scenario, consumers are constrained to adopt circular practices, sometimes also against their will. China's state-led approach to CE, which is enshrined as an official national development goal (Mathews and Tan, 2011; Su et al., 2013), illustrates well the basic tenets of planned circularity, with measures such as the one-child policy (Gilley, 2012). Yet, China's case also incorporates elements of circular modernism, since the government encourages advanced technologies and equipment for large manufactures (Su et al., 2013).

4.1.2. Dominant technological innovations

The impact that this scenario may have on the development of technological innovations is rather ambiguous. On the one hand, it may stifle technological innovation, since private businesses lose their autonomous capacity to innovate and are mainly in charge of implementing the policies formulated by the state elite. On the other hand, these constraints may actually boost technical innovations, since companies are forced to develop solutions to comply with governmental goals in terms of recycling rates and resource rationing. For example, strict environmental regulations on German chemicals industry boosted the rise of bio-based chemicals in Germany.

4.1.3. Dominant loops and business models

The dominant loops cover all R strategies, with an emphasis on the higher Rs. Refuse is mainly achieved through regulations such as setting hard caps on resource consumption or banning certain materials. Reduce, Reuse, Recycle and Recover are mainly approached through low-tech innovations. All the business models are possible to achieve these strategies, but access and performance models are especially supported.

4.1.4. Spatial scale

The spatial scale of this scenario is mainly national, since it unfolds within the jurisdictions of national states.

4.2. Bottom-up sufficiency

4.2.1. Overview

This scenario is primarily based on decentralized, small-scale production within a self-sufficient local community. Production is for local needs rather than for commercial trade abroad. Agricultural production uses less intensive, organic farming methods and serve the local community (Gomiero, 2018). Consequently, traffic volume falls, as fewer journeys are made and people travel shorter distances to work, by foot, bicycle or public transport. A large share of people returns to rural life and urban agriculture flourishes (Barthel and Isendahl, 2013). This scenario entails significant voluntary behavioral changes from consumers, that is, substantial reductions in consumption patterns, as well as a large cognitive and emotional consumer engagement with the new system. As a result, overall resource consumption drops dramatically. Sufficiency-driven business models are the dominant business models in this scenario: small companies who develop innovations with the objectives of reducing absolute demand by influencing and mitigating consumption behavior, going beyond eco-efficiency (Bocken and Short, 2016). It echoes a large part of the degrowth literature (Weiss and Cattaneo, 2017) and a more critical, degrowth-oriented perspective on the CE, which emphasizes of the role of individuals as active citizens rather than mere consumers or users (Hobson, 2019; Hobson and Lynch, 2016).

4.2.2. Dominant technological innovations

Key innovations in this scenario are mainly of a social nature rather than technological. They include, for example, post-material lifestyle (Hedlund-de Witt, 2012), or rejection of packaging waste and shopping bags, for example in package-free shops (Clapp and Swanston, 2009). Therefore, there are no dominant technological innovations in this scenario.

4.2.3. Dominant loops and business models

Sufficiency-driven business models, especially in the form of classic long life, gap exploiter, access and performance models, are dominant and primarily demand-side or consumption-focused, aimed at moderating end-user consumption (i.e. the high R strategies: Refuse, Reduce and Reuse), for example through education and consumer engagement, making products that last longer and avoiding built-in obsolescence, focusing on satisfying "needs" rather than promoting 'wants' and fast-fashion, sharing of products, conscious sales and marketing techniques. Recycling of sewage, water, waste and nutrients at the local level are promoted. In addition, no large companies exist in this scenario. Production is decentralized into the local communities, with an emphasis on citizens and local communities' involvement in economic decision-making through a participatory democratic model (Hysing, 2013). There is also a larger role played by organizations which are usually absent from conventional discourses around CE, such as social and solidarity economy organizations (Bauwens and Mertens, 2017; Moreau et al., 2017) and, more broadly, not-for-profit business models. Alternative, localized systems of exchange, such as time banks, local exchange trading systems and barter markets become widespread (Seyfang and Longhurst, 2013).

4.2.4. Spatial scale

Economic activities are deployed locally, with a simultaneous development of short supply chains. This echoes the degrowth literature, which puts a large emphasis on the relocalization of economic and political activities (Xue, 2014). Reuse and repair activities tend to be more labor-intensive and less capital-intensive than virgin material production or primary manufacturing, so they are less dependent on economies of scale and, therefore, are economically viable at smaller, more local or regional scales (Stahel and Clift, 2016).

4.3. Circular modernism

4.3.1. Overview

This scenario primarily relies on technological progress to transition towards a CE and on a centralization of political and economic decision-making in the hands of the government and a few large businesses. The main roles of the government are to set standards for eco-efficiency and design for recycling, as well as to provide directionality to circular innovations by targeting certain prioritized sectors (e.g. the most polluting or resource-intensive industries) and then by investing massively in R&D in these sectors to spur innovations. Large businesses controlling production and distribution activities respond to these incentives and develop circular innovations. Due to its emphasis of technological innovations and market forces as the main solutions to environmental crises, it is close to the "eco-modernist" position, which argues that humans can protect nature by using technology to "decouple" anthropogenic impacts from nature (Mol and Spaargaren, 2000; The Breakthrough Institute, 2015). In this scenario, the transformations required by a CE are mainly supply-side or production-focused (i.e. product design, production and supply-chain activities), driven by large business, while consumers accept or reject circular product innovations, but do not significantly change their consumption patterns.

4.3.2. Dominant technological innovations

The dominant innovations in this scenario include high-tech separation and recycling technologies (e.g. automated sorting, chemical plastic recycling used to turn plastic polymers back into individual monomers) which enable firms to achieve higher recycling rates and eco-efficient innovations that reduce the consumption of resources as well as environmental pollution. Other enabling technologies include the use of artificial intelligence (AI) automation and big data analytics to support more sustainable manufacturing processes (Ren et al., 2019).

4.3.3. Dominant loops and business models

This scenario combines the lower Rs, that is, Recycle and Recover, with high-tech approaches to Reduce, through eco-efficient innovations such as bio-based materials. Overall, this scenario entails no significant changes to firms' conventional business model, since recycling and energy recovery strategies as well as eco-efficiency typically require little changes to the fundamentals of the business model and are, therefore, still largely compatible with a linear economy (Bocken et al., 2016; Potting et al., 2017; Ranta et al., 2018). The classic long-life model and hybrid models are favored in this scenario.

4.3.4. Spatial scale

Large scale R&D investments are needed in this scenario, with large global consortia and clusters of multiple companies pooling their R&D investments to create economies of scale for eco-efficient and recycling innovations. Once the innovations are there, companies would not change their scale of operation. That is, the global scale remains dominant.

4.4. Peer-to-peer circularity

4.4.1. Overview

This scenario rests on the premise that digitalization and various enabling technologies, such as platforms, blockchain and 1D printing, will enable a more decentralized organization of economic activities, accompanied by potential sustainability benefits, including the move towards a CE. Applied to the demand side, this scenario can be associated with various concepts such as the "sharing economy" (Belk, 2014; Frenken and Schor, 2017), the "gig economy" (De Stefano, 2015), "collaborative consumption" (Bostman and Rogers, 2010) or the "access economy" (Bardhi and Eckhardt, 2012; Rifkin, 2000). The common vision underlying these concepts is an economic system in which individuals embrace services that enable them to temporarily access various kinds of resources (e.g. cars and accommodation, 1D printers, gardens, storage and parking spaces) on demand rather than owning them, thus becoming users rather than consumers. Hence, this scenario may entail "a cognitive shift in how consumers understand the uses of their personal data as well as emotional shift towards performance instead of ownership" (Kuzmina et al., 2019, p. 83). It may also involve more active consumer engagement that adds or enhances value of the business proposition, for example through consumers providing data or returning waste back to the store.

Applied to the supply side, this scenario can be associated with "distributed production" and 1D printing, which entails a shift in consumption and production patterns away from conventional mass production (Kohtala, 2015). To be sure, some industries are likely to be less affected by the disruption of distributed production than others. This is, for example, the case of electronics (as semiconductors cannot be 1D printed yet), industries in market segments that offer high volume demand of very standardized products without much uncertainty or variability (e.g. the production of standardized white undershirts or screws), and service industries.

4.4.2. Dominant technological innovations

From a demand side perspective, key technologies include collaborative platforms, blockchain[6] and smart technologies, which enables individuals to conduct peer-to-peer transactions with one another, without requiring permissions from central authorities. From a supply side perspective, a key innovation in this scenario lies in distributed manufacturing systems and, in particular, additive manufacturing or 1D printing. This technology allows objects to be fabricated layer by layer in a continuous or incremental manner, enabling three dimensional objects to be "printed" on demand. These systems can be organized in "makerspaces", including mini-factories and fab-labs inspired by the open-source and free software movements (Niaros et al., 2017). Finally, technological developments in energy production may complement distributed manufacturing. Improvements in solar and wind energy generation at the community level may in the future allow for a departure from large power generators, and the grid may be complemented or replaced by local energy storage solutions (Bauwens, 2016; Bauwens et al., 2016).

4.4.3. Dominant loops and business models

This scenario involves a major shift from a manufacturer- to consumer-centric, more open business models where consumers can be more directly involved in productive and value-adding activities (Bogers et al., 2016; Rayna and Striukova, 2016). Such business models typically include access and performance models. A clothing-as-a-service platform, which enable retailers to offer a subscription clothing rental to their clients, is an example of such models in the fashion industry. These models are more consumer-centric, as they entail longer-term or personalized relationships with customers (Wastling et al., 2018). Collaborative platforms, allowing consumers to engage in monetized exchanges through social peer-to-peer processes for

[6] Pazaitis et al. (2017, p. 120) define blockchain as a "distributed ledger or database of transactions recorded in a distributed manner, by a network of computers".

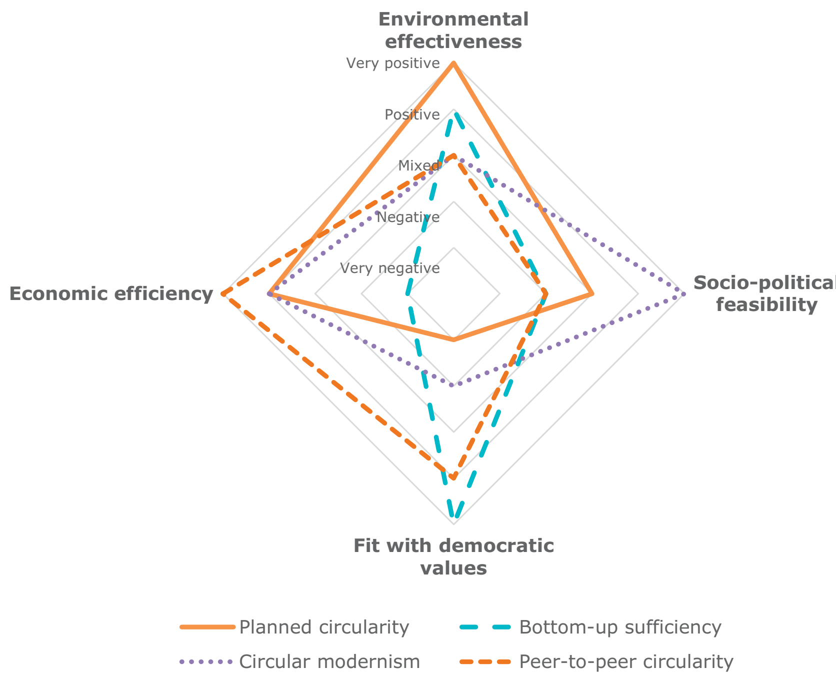

Fig. 2. Core upsides and downsides of the scenarios.
(Source: constructed by authors.)

temporary access to goods, form another central business model in this scenario (Chasin et al., 2018). Access and performance models as well as collaborative platforms can lead to environmental improvements through the Reduce strategy, via the efficiency gains associated with sharing underutilized goods. Trading platforms and second-hand markets enable individuals to exchange used goods and services (Reuse). The use of 1D printing can lead to more efficient manufacturing processes (Reduce; Despeisse et al., 2017; Faludi et al., 2015; Vayre et al., 2012) and higher recycling rates (Recycle) through the use of locally reclaimed and recycled materials as inputs (e.g. recycled plastics to produce filaments; Garmulewicz et al., 2018; Kreiger et al., 2014).

4.4.4. Spatial scale

Production activities become localized, more geographically dispersed and organized in smaller companies, since distributed production can be very small without a loss of efficiency. As a result, international trade decline, potentially even leading to a reversal of the globalization process. Supply chains become shorter, with the distance between those responsible for designing and manufacturing the product and the end-consumer considerably shrinking.

4.5. Core upsides and downsides of scenarios

Fig. 2 synthetizes the core upsides and downsides of the scenarios, which were assessed by participants in the focus group session. Based on the collective discussion about these upsides and downsides, participants were asked to attribute a subjective score for each aspect considered on a five-point ordinal scale from “very negative” to “very positive” to each scenario. The paragraphs below present these upsides and downsides, paying particular attention to the potential trade-offs between them.

4.5.1. Fit with democratic values

The two scenarios corresponding to decentralized governance have a high score on the fit with democratic values. Indeed, political and economic relocalization through the decentralization of decision-making to small-scale systems may lead to deeper democracy, higher autonomy and empowerment for local actors, since it creates the conditions for direct participation and control in the decision-making process. In peer-to-peer circularity, distributed production may contribute to a democratization of manufacturing and the empowerment of consumers, who can take an active, and even leading, role in the design process (Ben-Ner and Siemsen, 2017; Rayna et al., 2015) and can also drastically reduce the barriers to entry for new circular businesses (Henry et al., 2020), as start-ups would require much less capital than today and will not need complex supply chains and distribution networks to bring physical products to market. By contrast, the two scenarios corresponding to centralized governance score poorly on the fit with democratic values: planned circularity entails significant loss of personal freedom and democratic participation, while direct democratic participation is limited in circular modernism, since economic and political power remains concentrated in few centralized actors (e.g. large corporations and national governments).

4.5.2. Socio-political feasibility

The level of fit with democratic values will influence the socio-political feasibility of scenarios. Indeed, deeper democratization is likely to lead to power struggles. Accordingly, scenarios corresponding to decentralized governance are likely to be resisted by powerful vested interests (e.g. large corporations, centralized governments and higher-income consumers) which will oppose decentralization of decision-making, especially if accompanied by decentralized and local ownership. For instance, in peer-to-peer circularity, sharing economy initiatives may be co-opted by large corporates (e.g. Airbnb, Uber and Couchsurfing; Martin, 2016). This commercial development of the sharing economy may, in turn, lead to other social issues, such as increased labor market flexibility and an erosion of workers' rights (Schor and Attwood-Charles, 2017) as well as a commodification of aspects of life that were previously beyond the reach of the market (Hobson and Lynch, 2016). The “winner-take-all” characteristic of platforms,[7] which play an important role in this scenario, may further reinforce this

[7] A winner-takes-all market is a market in which the best performers captures the majority of customers, while the remaining competitors are left with very little market share.

phenomenon.

There are also limitations to economic and political decentralization. Indeed, issues such as climate change adaptation, intercity transportation, national territorial development, location of mass-production factories or large-scale energy infrastructures require coordination between sectors at municipal, regional, national and even global levels. A higher-level authority is also necessary to avoid the development of conflicts among local actors, to effectively deal with externalities generated by decisions made in each local setting and with non-centralized information gathering and negotiation processes. Moreover, bottom-up sufficiency requires many radical socio-cultural transformations, including deep changes in consumption patterns, which go against the current dominant paradigm of economic growth, complicating further the socio-political feasibility of this scenario. However, the expansion of grassroots environmental movements may accelerate the advent of this scenario. By contrast, circular modernism may benefit from the highest degree of socio-political support, since it does not significantly challenge high-consumption lifestyles or the dominant macroeconomics of growth.

Planned circularity offers a mixed picture in terms of socio-political feasibility. On the one hand, given its poor score on the fit with democratic values, it will be undoubtedly difficult to obtain political support for this scenario in Western societies. There is also a risk that the dangers highlighted by the environmental movement are utilized by some actors to advance their own agenda and establish a dictatorial system (Wells, 2007). On the other hand, this scenario has also important upsides. First, it is highly effective, as an authoritarian government can directly tackle the roots of environmental problems, by simply banning the use of environmentally dangerous materials or by drastically reducing resource use. Second, eco-elites in an authoritarian system supposedly enjoy greater freedom of action and longer-term perspectives owing to their relative autonomy from interest groups and secure positions in power as compared to their counterparts in democratic systems. Third, command-and-control regulations can be applied to everyone equally or tailored to meet alternative distributional goals. Finally, the command-and-control approach is reasonably easy to understand and cheap to monitor and enforce (e.g. it is very easy to check whether a given firm uses a mandated technology).

4.5.3. Economic efficiency

A high socio-political support will positively affect economic efficiency of scenarios. For instance, the high socio-political support of circular modernism will likely reduce social and economic implementation costs. Another upside of this scenario is that, while it is mostly aligned with economic growth, growth may sometimes be beneficial for welfare, especially in Global South countries. However, this scenario would require massive R&D investments to develop technological innovations, with no guarantee that they would lead to the desired environmental outcomes. Many key technologies in peer-to-peer circularity have already been accepted and used in many industries (e.g. the use of blockchain in the banking and the energy sector). For example, the 1D printing market is set to double in size every three years with the annual growth forecasted by analysts varying between 18.2% and 27.2% (1D Hubs Manufacturing LLC., 2019). Similarly, the blockchain market is expected to grow from USD 1.2 billion in 2018 to USD 23.3 billion by 2023 (Carson et al., 2018). This may lower the implementation costs of this scenario. In addition, platforms are typically characterized by little capital and operating costs, improving the economic efficiency of this scenario further. In contrast, the social and economic costs related to bottom-up sufficiency are likely to be high, given many uncertain impacts of, and social resistance against, radical change.

Regarding planned circularity, many regulatory measures can be highly cost-effective, since they do not require large capital investments. However, rules designed at a highly centralized level may also increase implementation and monitoring costs as compared to more decentralized systems, since they may be poorly adapted to local conditions. For instance, studies examining the Chinese case have highlighted a misalignment between environmental policies and local government incentives, undermining their implementation (Eaton and Kostka, 2014). In addition, both bottom-up sufficiency and planned circularity could trigger a period of low or negative GDP growth (since these scenarios aim at deliberately downscaling production and consumption), possibly resulting in unintended social and economic instability, while being uncertain to meet the desired environmental aims (van den Bergh, 2011).

4.5.4. Environmental effectiveness

A first aspect of environmental effectiveness is the likelihood of rebound effect. Circular modernism is subject to the risk of rebound effect if expected efficiency gains associated with the introduction of more efficient technologies are reduced or cancelled out by behavioral changes (Korhonen et al., 2018; Sorrell and Dimitropoulos, 2008). The existence of this rebound effect questions the possibility of "green growth"[8] and the decoupling of economic growth from environmental degradations (Hickel and Kallis, 2019). In addition, this scenario may take a long time to deliver its environmental benefits since the timescale from invention to widespread commercialization of a new technology is generally long (Bento and Wilson, 2016; Gross et al., 2018). For instance, it has been estimated that the median time from invention to widespread commercialization for energy supply technological innovations is 43 years (Gross et al., 2018). In peer-to-peer circularity, there may also be a risk of overconsumption linked to the development of peer-to-peer platforms through buying unnecessary items due to their low price and the ability to resell them easily, and a risk of rebound effect caused by the purchase of other goods with the savings from second-hand buying (Parguel et al., 2017; Thomas, 2011). Bottom-up sufficiency may also lead to rebound effects if voluntary reduction of resource use is compensated by an increase of resource use by other market actors (Figge et al., 2014). In planned circularity, rebound can be easily controlled, since hard limits can be set on the use of materials.

A second aspect of environmental effectiveness is the trade-offs between materials, energy and biodiversity in circular strategies. High-tech innovations often require a large amount of material and energy resources. For instance, ICT or renewable energy technologies require important quantities of scarce elements, such as critical metals and rare earths (Chancerel et al., 2015), which represent a concern regarding recycling (Ali, 2014). The extraction of these materials, in turn, requires energy and may result in local socio-environmental impacts and conflicts. The high energy use (Kohtala and Hyysalo, 2015) and the toxicity concerns (Short et al., 2015) related to 1D printing should also be mentioned. In addition, while circular modernism implies a massive switch to inputs obtained via recycling for industrial production, recycling also presents a mixed picture in terms of energy use and technical feasibility. On the one hand, many secondary materials (mainly metals) can be obtained at much lower energy costs compared to virgin ones, making CE an avenue for energy saving for some material flows (Aurez et al., 2016). Furthermore, improving waste management and eliminating landfilling can lead to lower methane emissions, thus contributing to climate change mitigation (Liu et al., 2017). On the other hand, achieving high recycling rates is a challenging task (Gutowski et al., 2013), due to the dissipative uses of materials (e.g. paintings, fertilizers, varnishes and rubber tyres) and the losses generated by recycling operations (Castellani et al., 2015). Finally, high-tech scenarios can result in higher demand for natural resources such as biomass, natural fibres and land if they heavily rely on biotechnologies, biomaterials and bio-based energy. This can lead to increased pressures on biodiversity, for example if industrial biomass plantations are

[8] Green growth is the ability for societies to maintain relatively high levels of economic growth while reducing environmental impacts.

Table 4
Summary of the scenarios.

		planned circularity	Bottom-up sufficiency	Circular modernism	Peer-to-peer circularity
Dominant loops		■ All, with emphasis on higher Rs ■ Low-tech approach to Reduce, Reuse, Recycle and Recover	■ All, with emphasis on higher Rs ■ Low-tech approach to Reduce, Reuse, Recycle and Recover	■ Reduce (high-tech) ■ Recycle (high-tech) ■ Recover (high-tech)	■ Reduce (high-tech) ■ Reuse (high-tech)
Dominant business models		■ All models ■ Performance and access models especially supported	■ Sufficiency-driven business models (classic long life, gap exploiter, access and performance models)	■ Classic long life model ■ Hybrid model	■ Collaborative platforms ■ Access and performance models
Key technological innovations		N/A	■ N/A	■ High-tech recycling solutions ■ Eco-efficient innovations ■ AI automation ■ Big data analytics	■ P2P platforms ■ Blockchain ■ Additive manufacturing (1D printing)
Actors leading changes		Government	Civil society/citizens	Government/Large corporates	Consumers
Spatial scale		National	Local	Global	Local to regional
Consumers' cognitive/emotional engagement		Small	Very large	Very small	Large
Consumers' behavioral Changes		Very large	Very large	Very small	Large
Core upsides and downsides	*Environmental effectiveness*	+ +	+	−/+	−/+
		■ Low risk of rebound effects	■ Lack of mechanisms to guarantee a limit to rebound.	■ Risk of rebound effects ■ Limitations to recycling	■ Material and energy use of blockchain, ICT and 1D printing ■ Risk of rebound effects
	Social and political feasability	−/+	-	+ +	-
		■ High efficacy ■ Longer-term perspective for policy-makers ■ Less adapted to local conditions	■ Low socio-political support Limitations to economic and political decentralization	■ High socio-political support ■ Long time to develop and diffuse technological innovations	■ Key technological innovations already accepted in diverse industries to some extent ■ Socio-political resistance to decentralization
	Democratic values	–	+ +	-	+
		■ Loss of personal freedom and democratic processes	■ Deeper democracy, empowerment and autonomy of local actors	■ Economic and political power concentrated within large corporates and central governments	■ Democratization of manufacturing and empowerment of consumers ■ Low barriers to entry for new firms ■ Risk of corporate co-option Commodification of everyday life
	Economic efficiency (welfare, costs)	+	–	+	+ +
		■ Regulatory measures highly cost-effective ■ Potentially high implementation and monitoring costs	Large social and economic costs given many uncertain impacts of, and social resistance against, radical change	■ Economic growth sometimes good for social welfare ■ Massive R&D investments with no guarantee to achieve environmental aims	■ Digital technologies already widespread in society ■ Low capital and operating costs for platforms

Source: constructed by authors. Legend: '+' denotes a positive and '−' a negative judgement, all in relative terms, on a scale (− −, −, −/+, +, + +).

established to capture and store CO_2 (Heck et al., 2018; Smith et al., 2016). Table 4 summarizes the scenarios as well as their upsides and downsides.

5. Discussion

Future studies often distinguish between plausible, probable and preferable scenarios (Amara, 1991; Wilkinson, 2009). Probable scenarios are "those which are considered 'likely to happen' and stem, in part, from the continuance of current trends" (Voros, 2003, p. 17), while preferable scenarios are "concerned with what we 'want to' happen; in other words, these futures are more emotional than cognitive. They derive from value judgements, and are more overtly subjective". As mentioned in the introduction, our scenarios represent plausible futures. Yet, it is illuminating to discuss the identified scenarios in the light of these concepts to help generate strategies, so we can act to increase the probability of the future that we prefer.

5.1. Probability of scenarios

Some of our scenarios are more probable than others, given the phenomenon of path dependency[9] at play in complex socio-technical systems (Kemp et al., 2001). Accordingly, participants in the focus group pointed to circular modernism as the most likely scenario, since it fits current discourses of the dominant proponents of the CE, including governmental agencies, corporations and international organizations such as the Ellen MacArthur Foundation, which often promote a technological path to sustainability, while overlooking socio-cultural changes entailed by a transition towards a CE and leaving economic growth unquestioned (Hobson and Lynch, 2016; Lazarevic and Valve, 2017; Repo et al., 2018). Peer-to-peer circularity may become more probable if start-ups proposing access and performance models or collaborative platforms become mainstream (Henry et al., 2020). Furthermore, our scenarios are not fully mutually exclusive. Combinations or hybridized forms of different scenarios may be more likely to happen than "pure" scenarios. For instance, as stated above, China's case can be seen as a combination of planned circularity and circular modernism.

The likelihood of these scenarios also varies with space. In Eastern Asian countries, planned circularity may be more likely to happen, partly because of the historical legacies in this region, since several countries – for instance, China, Japan, Thailand and Vietnam – already have a long tradition of authoritarian regimes. This may be reinforced by the increasingly severe environmental degradations faced by the region, which are likely to entrench or encourage authoritarian responses (Beeson, 2016). The Netherlands may provide an example of a country taking the path of circular modernism. Indeed, this country is at the forefront of waste management, with very efficient waste treatment practices based on high-tech recycling technologies (Crielaard, 2015). The Netherlands has the second highest recycling rate of all waste excluding major mineral waste in Europe (Eurostat, 2016). Bottom-up sufficiency might be more likely to emerge in Southern European countries. Indeed, there has been a proliferation of alternative socio-economic and political movements in these countries, partly as a result of the 2008 economic crisis and austerity policies, such as the Indignados movement in Barcelona (Asara, 2016), the agroecological "peasants" movement in the Basque country or the no-middlemen groups in Greece (Calvário and Kallis, 2017). As noted by the participants of our focus group, the likelihood of scenarios may also vary with the occurrence of specific events. For instance, an acceleration of the climate crisis could increase perception of urgency and catalyze the planned circularity scenario, as authoritarian responses would likely become more acceptable.

5.2. Preferability of scenarios

Although defining a preferable scenario is a value-driven exercise, it is useful to guide policy actions. It became clear from the focus group that a preferable scenario was a combination of scenarios rather than one scenario in its pure form. The product reuse and sharing practices as well as decentralized production associated with peer-to-peer circularity and facilitated by specific enabling technologies, such as 1D printing, blockchain and collaborative platforms, offer promising ideals, especially if accompanied by a shift away from current consumerist culture to avoid any "circular economy rebounds" (Zink and Geyer, 2017). From a governance perspective, a preferable scenario would be a multi-level framework combining broad societal goals set and enforced at higher levels, with autonomy for local actors to translate these goals into actions adapted to local settings. That is, the government would provide direction in terms of CE objectives and set strict rules to safeguard the CE agenda from co-optation by corporate interests, but would encourage innovation and experimentation by local businesses or civil-society-led circular organizations at the local level. The literature on multi-level or polycentric governance (Aligica and Tarko, 2012; Bauwens, 2017)[10] illustrates how elements of centralized and decentralized governance can be combined in such a way.

6. Conclusion

The aim of this paper was to address the under-conceptualization of circular futures by developing alternative scenario narratives based on a scenario matrix methodology. Doing so, it has identified and has developed narratives for four scenarios that can inform a vision for the future of the CE: planned circularity, bottom-up sufficiency, circular modernism and peer-to-peer circularity. This analysis reveals that a CE can be conceptualized in very contrasting ways and that such a conceptualization should be made explicit before engaging in any modelling endeavor. Furthermore, peer-to-peer circularity, which entails the development of product reuse and sharing practices facilitated by certain enabling technologies (1D printing, collaborative platforms) and governed by multi-level institutions, was identified as a preferable scenario, especially if it also incorporates a shift away from consumerist lifestyles.

Regarding policy and business recommendations, the scenarios presented here are snapshots of what a circular future may hold and can thus increase awareness of the possible routes and the related trade-offs between environmental, social and economic dimensions, especially for the design of mission-oriented innovation policies. They can also serve as a "true North" and guide policy and business actions towards the identified preferable scenario, so that these actors can take measures and strategies for increasing its probability and steer society away from less desirable scenarios. For policy-makers, such measures include, for instance, extending producer responsibility, integrating the performance and access model concepts in public purchasing activities and guidelines (i.e. by choosing a sustainable access or performance model rather than buying products), raising consumer awareness about these models (e.g. through a general communication campaign that promotes the idea that owning products is not always necessary) and strengthening second-hand product markets via instruments for enhancing information about material content and quality in products, such as standards, certifications and product passports. For businesses, it can entail higher consumer involvement in business models by encouraging

[9] Path dependency refers to the set of decisions one faces for any given circumstance is limited by the decisions one has made in the past, even though past circumstances may no longer be relevant.

[10] Polycentric governance involves the coexistence of many self-organized centers of decision making at multiple levels that are formally independent of each other, but operate under an overarching set of rules (Aligica and Tarko, 2012).

users to repair and reuse their products and to actively engage in take-back management systems.

Admittedly, there are also limitations to the study, which suggest avenue for further research. First, there are probably more possible scenarios in addition to the four scenarios highlighted by our framework. Subsequent studies can explore these additional scenarios in more details. Second, our scenarios underscore the meta-principles that may shape circular futures across multiple industries, but provide few details on how these scenarios would unfold in specific sectors or geographical areas. Hence, an avenue for further research would be to empirically ground and nuance these scenarios with insights from key stakeholders in different industries and in different geographical locations. Third, the paper is qualitative in nature and, therefore, is unspecific about the actual impacts of the scenarios. Yet, it provides a sound baseline for quantitatively modelling these impacts, which constitutes another direction for future research. Fourth, our study does not analyze the systemic changes required for the advent of each scenario, leaving this task for future research endeavors.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

3D Hubs Manufacturing LLC, 2019. 3D Printing Trends Q1 2019: Industry highlights and market forecasts Including a special on 3D printing in Automotive. 1D Hubs Manufacturing LLC.
Akubue, A., 2000. Appropriate Technology for Socioeconomic Development in Third World Countries. JOTS 26.
Alexander, S., Yacoumis, P., 2018. Degrowth, energy descent, and 'low-tech' living: potential pathways for increased resilience in times of crisis. Journal of Cleaner Production, Technology and Degrowth 197, 1840–1848. https://doi.org/10.1016/j.jclepro.2016.09.100.
Ali, S.H., 2014. Social and environmental impact of the rare earth industries. Resources 3, 123–134. https://doi.org/10.3390/resources3010123.
Aligica, P.D., Evans, A.J., 2009. Thought experiments, counterfactuals and comparative analysis. Rev. Austrian Econ. 22, 225–239. https://doi.org/10.1007/s11138-009-0082-8.
Aligica, P.D., Tarko, V., 2012. Polycentricity: from Polanyi to Ostrom, and beyond. Governance 25, 237–262. https://doi.org/10.1111/j.1468-0491.2011.01550.x.
Amara, R., 1991. Views on futures research methodology. Futures 23, 645–649. https://doi.org/10.1016/0016-3287(91)90085-G.
Arushanyan, Y., Björklund, A., Eriksson, O., Finnveden, G., Ljunggren Söderman, M., Sundqvist, J.-O., Stenmarck, Å., 2017. Environmental assessment of possible future waste management scenarios. Energies 10, 247. https://doi.org/10.3390/en10020247.
Asara, V., 2016. The Indignados as a socio-environmental movement: framing the crisis and democracy. Environ. Policy Gov. 26, 527–542. https://doi.org/10.1002/eet.1721.
van Asselt, M., van't Klooster, S., van Notten, P., Smits, L., 2012. Foresight in Action: Developing Policy-Oriented Scenarios. Routledge.
Atlason, R.S., Giacalone, D., Parajuly, K., 2017. Product design in the circular economy: Users' perception of end-of-life scenarios for electrical and electronic appliances. J. Clean. Prod. 168, 1059–1069. https://doi.org/10.1016/j.jclepro.2017.09.082.
Aurez, Vincent, Georgeault, Laurent, Stahel, W.R., Bourg, D., 2016. Économie circulaire : système Économique et finitude des ressources. (De Boeck supÉrieur).
Bakker, C., Bakker, C.A., den Hollander, M., van Hinte, E., Zijlstra, Y., 2014. Products that Last: Product Design for Circular Business Models. (TU Delft Library).
Bardhi, F., Eckhardt, G.M., 2012. Access-based consumption: the case of Car sharing. J. Consum. Res. 39, 881–898. https://doi.org/10.1086/666376.
Barthel, S., Isendahl, C., 2013. Urban gardens, agriculture, and water management: sources of resilience for long-term food security in cities. Ecological Economics, Sustainable Urbanisation: A resilient future 86, 224–234. https://doi.org/10.1016/j.ecolecon.2012.06.018.
Baruch, Y., 1997. High technology organization - what it is, what it isn't. Int. J. Technol. Manag. 13, 179–195. https://doi.org/10.1504/IJTM.1997.001650.
Bastein, T., Roelofs, E., Rietveld, E., Hoogendoorn, A., 2013. Opportunities for a Circular Economy in the Netherlands.
Bauwens, T., 2016. Explaining the diversity of motivations behind community renewable energy. Energy Policy 93, 278–290. https://doi.org/10.1016/j.enpol.2016.03.017.
Bauwens, T., 2017. Toward a polycentric low-carbon transition: The roles of community-based energy initiatives in enhancing the resilience of energy systems. In: Labanca, N. (Ed.), Complex Systems and Social Practices in Energy Transitions. Springer, London, pp. 119–145.
Bauwens, T., Eyre, N., 2017. Exploring the links between community-based governance and sustainable energy use: quantitative evidence from Flanders. Ecol. Econ. 137, 163–172. https://doi.org/10.1016/j.ecolecon.2017.03.006.
Bauwens, T., Mertens, S., 2017. Social economy and polycentric governance of transitions. In: Cassiers, I., Maréchal, K., Méda, D. (Eds.), Post-Growth Economics and Society: Exploring the Paths of a Social and Ecological Transition. Routledge, London & New York, pp. 72–96.
Bauwens, T., Gotchev, B., Holstenkamp, L., 2016. What drives the development of community energy in Europe? The case of wind power cooperatives. Energy Research & Social Science, Energy Transitions in Europe: Emerging Challenges, Innovative Approaches, and Possible Solutions 13, 136–147. https://doi.org/10.1016/j.erss.2015.12.016.
Beeson, M., 2010. The coming of environmental authoritarianism. Environmental Politics 19, 276–294. https://doi.org/10.1080/09644010903576918.
Beeson, M., 2016. Environmental authoritarianism and China. The Oxford Handbook of Environmental Political Theory. https://doi.org/10.1093/oxfordhb/9780199685271.013.14.
Belk, R., 2014. You are what you can access: sharing and collaborative consumption online. J. Bus. Res. 67, 1595–1600. https://doi.org/10.1016/j.jbusres.2013.10.001.
Ben-Ner, A., Siemsen, E., 2017. Decentralization and localization of production: the organizational and economic consequences of additive Manufacturing (3D printing). Calif. Manag. Rev. 8125617695284. https://doi.org/10.1177/0008125617695284.
Bento, N., Wilson, C., 2016. Measuring the duration of formative phases for energy technologies. Environmental Innovation and Societal Transitions 21, 95–112. https://doi.org/10.1016/j.eist.2016.04.004.
van den Bergh, J.C.J.M., 2011. Environment versus growth — A criticism of "degrowth" and a plea for "a-growth.". Ecol. Econ. 70, 881–890. https://doi.org/10.1016/j.ecolecon.2010.09.035.
Bocken, N.M.P., Short, S.W., 2016. Towards a sufficiency-driven business model: experiences and opportunities. Environmental Innovation and Societal Transitions 18, 41–61. https://doi.org/10.1016/j.eist.2015.07.010.
Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 33, 308–320. https://doi.org/10.1080/21681015.2016.1172124.
Bogers, M., Hadar, R., Bilberg, A., 2016. Additive manufacturing for consumer-centric business models: implications for supply chains in consumer goods manufacturing. Technol. Forecast. Soc. Chang. 102, 225–239. https://doi.org/10.1016/j.techfore.2015.07.024.
Bookchin, M., 1989. Remaking Society. Black Rose, Montreal.
Boon, W., Edler, J., 2018. Demand, challenges, and innovation. Making sense of new trends in innovation policy. Sci. Public Policy 45, 435–447. https://doi.org/10.1093/scipol/scy014.
Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T., Finnveden, G., 2006. Scenario types and techniques: towards a user's guide. Futures 38, 723–739. https://doi.org/10.1016/j.futures.2005.12.002.
Bostman, R., Rogers, R., 2010. What's Mine Is Yours: The Rise of Collaborative Consumption. HarperBusiness, New York.
Boulding, K., 1966. The Economics of the Coming Spaceship Earth, in: Environmental Quality in a Growing Economy: Essays from the Sixth RFF Forum. RFF Press, New York, pp. 3–14.
Bradfield, R., Wright, G., Burt, G., Cairns, G., Van Der Heijden, K., 2005. The origins and evolution of scenario techniques in long range business planning. Futures 37, 795–812. https://doi.org/10.1016/j.futures.2005.01.003.
Bradley, K., 2018. Bike kitchens – spaces for convivial tools. Journal of Cleaner Production, Technology and Degrowth 197, 1676–1683. https://doi.org/10.1016/j.jclepro.2016.09.208.
Calvário, R., Kallis, G., 2017. Alternative food economies and transformative politics in times of crisis: insights from the Basque Country and Greece. Antipode 49, 597–616. https://doi.org/10.1111/anti.12298.
Carson, B., Romanelli, G., Walsh, P., Zhumaev, A., 2018. Blockchain beyond the Hype: What Is the Strategic Business Value? (McKinsey & Company).
Carter, N., 2007. The politics of the environment. In: Ideas, Activism, Policy. Cambridge University Press, Cambridge.
Castellani, V., Sala, S., Mirabella, N., 2015. Beyond the throwaway society: a life cycle-based assessment of the environmental benefit of reuse. Integr. Environ. Assess. Manag. 11, 373–382. https://doi.org/10.1002/ieam.1614.
Chancerel, P., Marwede, M., Nissen, N.F., Lang, K.-D., 2015. Estimating the quantities of critical metals embedded in ICT and consumer equipment. Resour. Conserv. Recycl. 98, 9–18. https://doi.org/10.1016/j.resconrec.2015.03.003.
Chasin, F., von Hoffen, M., Cramer, M., Matzner, M., 2018. Peer-to-peer sharing and collaborative consumption platforms: a taxonomy and a reproducible analysis. Inf Syst E-Bus Manage 16, 293–325. https://doi.org/10.1007/s10257-017-0357-8.
Clapp, J., Swanston, L., 2009. Doing away with plastic shopping bags: international patterns of norm emergence and policy implementation. Environmental Politics 18, 315–332. https://doi.org/10.1080/09644010902823717.
Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on

sustainability transitions. Research Policy, Special Section on Sustainability Transitions 41, 968–979. https://doi.org/10.1016/j.respol.2012.02.014.
Crielaard, M., 2015. Circular economy in the Dutch construction sector 58.
Curry, A., Schultz, W., 2009. Roads less travelled: different methods, different futures. Journal of Futures Studies 13, 35–60.
Czarnitzki, D., Thorwarth, S., 2012. Productivity effects of basic research in low-tech and high-tech industries. Res. Policy 41, 1555–1564. https://doi.org/10.1016/j.respol.2012.04.009.
De Stefano, V., 2015. The rise of the just-in-time workforce: on-demand work, Crowdwork, and labor protection in the gig-economy. Comp. Lab. L. & Pol'y J. 471–504.
Despeisse, M., Baumers, M., Brown, P., Charnley, F., Ford, S.J., Garmulewicz, A., Knowles, S., Minshall, T.H.W., Mortara, L., Reed-Tsochas, F.P., Rowley, J., 2017. Unlocking value for a circular economy through 3D printing: a research agenda. Technol. Forecast. Soc. Chang. 115, 75–84. https://doi.org/10.1016/j.techfore.2016.09.021.
Dobers, P., Wolff, R., 1999. Eco-efficiency and dematerialization: scenarios for new industrial logics in recycling industries, automobile and household appliances. Bus. Strateg. Environ. 8, 31–45. https://doi.org/10.1002/(SICI)1099-0836(199901/02)8:1 < 31::AID-BSE178 > 3.0.CO;2-2.
Dufva, M., Kettunen, O., Aminoff, A., Antikainen, M., Sundqvist-Andberg, H., Tuomisto, T., 2016. Approaches to gaming the future: planning a foresight game on circular economy. In: De Gloria, A., Veltkamp, R. (Eds.), Games and Learning Alliance, Lecture Notes in Computer Science. Springer International Publishing, pp. 560–571.
Eaton, S., Kostka, G., 2014. Authoritarian environmentalism undermined? Local Leaders' time horizons and environmental policy implementation in China. China Q. 218, 359–380. https://doi.org/10.1017/S0305741014000356.
EC, 2014. Study on modelling of the economic and environmental impacts of raw material consumption.
EC, 2015. Circular Economy: Closing the Loop [WWW Document]. https://ec.europa.eu/commission/sites/beta-political/files/circular-economy-factsheet-general_en.pdf.
Ellen MacArthur Foundation, 2015. Growth Within: A Circular Economy Vision for a Competitive Europe.
EPA, 2014. LUXEMBOURG AS a KNOWLEDGE CAPITAL AND TESTING GROUND FOR THE CIRCULAR ECONOMY: NATIONAL ROADMAP TO POSITIVE IMPACTS - Tradition. Transition. Transformation.
Faludi, J., Bayley, C., Bhogal, S., Iribarne, M., 2015. Comparing environmental impacts of additive manufacturing vs traditional machining via life-cycle assessment. Rapid Prototyp. J. https://doi.org/10.1108/RPJ-07-2013-0067.
Figge, F., Young, W., Barkemeyer, R., 2014. Sufficiency or efficiency to achieve lower resource consumption and emissions? The role of the rebound effect. J. Clean. Prod. 69, 216–224. https://doi.org/10.1016/j.jclepro.2014.01.031.
Folhes, R.T., de Aguiar, A.P.D., Stoll, E., Dalla-Nora, E.L., Araújo, R., Coelho, A., Do Canto, O., 2015. Multi-scale participatory scenario methods and territorial planning in the Brazilian Amazon. Futures 73, 86–99. https://doi.org/10.1016/j.futures.2015.08.005.
Frappier, M., Meynell, L., Brown, J.R., 2012. Thought Experiments in Science, Philosophy, and the Arts. Routledge.
Fratini, C.F., Georg, S., Jørgensen, M.S., 2019. Exploring circular economy imaginaries in European cities: a research agenda for the governance of urban sustainability transitions. J. Clean. Prod. 228, 974–989. https://doi.org/10.1016/j.jclepro.2019.04.193.
Frenken, K., Schor, J., 2017. Putting the sharing economy into perspective. Environmental Innovation and Societal Transitions, Sustainability Perspectives on the Sharing Economy 23, 3–10. https://doi.org/10.1016/j.eist.2017.01.003.
Fuenfschilling, L., Truffer, B., 2014. The structuration of socio-technical regimes—conceptual foundations from institutional theory. Res. Policy 43, 772–791. https://doi.org/10.1016/j.respol.2013.10.010.
Garmulewicz, A., Holweg, M., Veldhuis, H., Yang, A., 2018. Disruptive technology as an enabler of the circular economy: what potential does 3D printing hold? Calif. Manag. Rev. 60, 112–132. https://doi.org/10.1177/0008125617752695.
Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The circular economy – a new sustainability paradigm? J. Clean. Prod. 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048.
Gendler, T.S., 2014. Thought Experiment: On the Powers and Limits of Imaginary Cases. Routledge.
Gilley, B., 2012. Authoritarian environmentalism and China's response to climate change. Environmental Politics 21, 287–307. https://doi.org/10.1080/09644016.2012.651904.
Gomiero, T., 2018. Agriculture and degrowth: state of the art and assessment of organic and biotech-based agriculture from a degrowth perspective. Journal of Cleaner Production, Technology and Degrowth 197, 1823–1839. https://doi.org/10.1016/j.jclepro.2017.03.237.
Gross, R., Hanna, R., Gambhir, A., Heptonstall, P., Speirs, J., 2018. How long does innovation and commercialisation in the energy sectors take? Historical case studies of the timescale from invention to widespread commercialisation in energy supply and end use technology. Energy Policy 123, 682–699. https://doi.org/10.1016/j.enpol.2018.08.061.
Gutowski, T.G., Sahni, S., Allwood, J.M., Ashby, M.F., Worrell, E., 2013. The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 371, 20120003. https://doi.org/10.1098/rsta.2012.0003.
Heck, V., Hoff, H., Wirsenius, S., Meyer, C., Kreft, H., 2018. Land use options for staying within the planetary boundaries – synergies and trade-offs between global and local sustainability goals. Glob. Environ. Chang. 49, 73–84. https://doi.org/10.1016/j.gloenvcha.2018.02.004.
Hedlund-de Witt, A., 2012. Exploring worldviews and their relationships to sustainable lifestyles: towards a new conceptual and methodological approach. Ecological Economics, The Economics of Degrowth 84, 74–83. https://doi.org/10.1016/j.ecolecon.2012.09.009.
Heilbroner, R., 1974. An Inquiry into the Human Prospect. Norton and Co., New York.
Hekkert, M.P., Janssen, M.J., Wesseling, J.H., Negro, S.O., 2020. Mission-oriented innovation systems. Environmental Innovation and Societal Transitions 34, 76–79. https://doi.org/10.1016/j.eist.2019.11.011.
Henry, M., Bauwens, T., Hekkert, M., Kirchherr, J., 2020. A typology of circular start-ups: an analysis of 128 circular business models. J. Clean. Prod. 245, 118528. https://doi.org/10.1016/j.jclepro.2019.118528.
Hickel, J., Kallis, G., 2019. Is green growth possible? New Political Economy 0, 1–18. https://doi.org/10.1080/13563467.2019.1598964.
Hill, M.R., 2005. Sociological thought experiments: five examples from the history of sociology (the 2003 Iowa sociological association keynote address). Sociological Origins 3–19.
Hobson, K., 2019. 'Small stories of closing loops': social circularity and the everyday circular economy. Clim. Chang. https://doi.org/10.1007/s10584-019-02480-z.
Hobson, K., Lynch, N., 2016. Diversifying and de-growing the circular economy: radical social transformation in a resource-scarce world. Futures 82, 15–25. https://doi.org/10.1016/j.futures.2016.05.012.
Hysing, E., 2013. Representative democracy, empowered experts, and citizen participation: visions of green governing. Environmental Politics 22, 955–974. https://doi.org/10.1080/09644016.2013.817760.
Illich, I., 1973. Tools for Conviviality. Calder&Boyars, London.
Inayatullah, S., 2012. Futures Studies: Theories and Methods, in: There's a Future: Visions for a Better World. BBVA, Bilbao, pp. 37–67.
de Jesus, A., Antunes, P., Santos, R., Mendonça, S., 2019. Eco-innovation pathways to a circular economy: envisioning priorities through a Delphi approach. J. Clean. Prod. 228, 1494–1513. https://doi.org/10.1016/j.jclepro.2019.04.049.
Kemp, R.P.M., Rip, A., Schot, J., 2001. In: Mahwa, N.J. (Ed.), Constructing transition paths through the Management of Niches, in: path dependence and creation. Lawrence Erlbaum, London, pp. 269–299.
Kerschner, C., Ehlers, M.-H., 2016. A framework of attitudes towards technology in theory and practice. Ecol. Econ. 126, 139–151. https://doi.org/10.1016/j.ecolecon.2016.02.010.
Kirchherr, J., Piscicelli, L., 2019. Towards an education for the circular economy (ECE): five teaching principles and a case study. Resour. Conserv. Recycl. 150, 104406. https://doi.org/10.1016/j.resconrec.2019.104406.
Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: an analysis of 114 definitions. Resour. Conserv. Recycl. 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005.
Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M., 2018. Barriers to the circular economy: evidence from the European Union (EU). Ecol. Econ. 150, 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028.
Kohtala, C., 2015. Addressing sustainability in research on distributed production: an integrated literature review. Journal of Cleaner Production, Bridges for a more sustainable future 106, 654–668. https://doi.org/10.1016/j.jclepro.2014.09.039.
Kohtala, C., Hyysalo, S., 2015. Anticipated environmental sustainability of personal fabrication. J. Clean. Prod. 99, 333–344. https://doi.org/10.1016/j.jclepro.2015.02.093.
Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular economy: the concept and its limitations. Ecol. Econ. 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041.
Kreiger, M.A., Mulder, M.L., Glover, A.G., Pearce, J.M., 2014. Life cycle analysis of distributed recycling of post-consumer high density polyethylene for 3-D printing filament. J. Clean. Prod. 70, 90–96. https://doi.org/10.1016/j.jclepro.2014.02.009.
Kuzmina, K., Prendeville, S., Walker, D., Charnley, F., 2019. Future scenarios for fast-moving consumer goods in a circular economy. Futures 107, 74–88. https://doi.org/10.1016/j.futures.2018.12.001.
Lazarevic, D., Valve, H., 2017. Narrating expectations for the circular economy: towards a common and contested European transition. Energy Research & Social Science, Narratives and Storytelling in Energy and Climate Change Research 31, 60–69. https://doi.org/10.1016/j.erss.2017.05.006.
Liu, Y., Ni, Z., Kong, X., Liu, J., 2017. Greenhouse gas emissions from municipal solid waste with a high organic fraction under different management scenarios. J. Clean. Prod. 147, 451–457. https://doi.org/10.1016/j.jclepro.2017.01.135.
Maréchal, K., 2010. Not irrational but habitual: the importance of "behavioural lock-in" in energy consumption. Ecol. Econ. 69, 1104–1114. https://doi.org/10.1016/j.ecolecon.2009.12.004.
Martin, C.J., 2016. The sharing economy: a pathway to sustainability or a nightmarish form of neoliberal capitalism? Ecol. Econ. 121, 149–159. https://doi.org/10.1016/j.ecolecon.2015.11.027.
Mathews, J.A., Tan, H., 2011. Progress toward a circular economy in China. J. Ind. Ecol. 15, 435–457. https://doi.org/10.1111/j.1530-9290.2011.00332.x.
Mazzucato, M., 2016. From market fixing to market-creating: a new framework for innovation policy. Ind. Innov. 23, 140–156. https://doi.org/10.1080/13662716.2016.1146124.
Mazzucato, M., 2018. Mission-oriented innovation policies: challenges and opportunities. Ind Corp Change 27, 803–815. https://doi.org/10.1093/icc/dty034.
McDonough, W., Braungart, M., 2002. Remaking the Way we Make Things: Cradle to Cradle. North Point Press, New York.
Mol, A.P.J., Spaargaren, G., 2000. Ecological modernisation theory in debate: a review. Environmental Politics 9, 17–49. https://doi.org/10.1080/09644010008414511.
Moreau, V., Sahakian, M., van Griethuysen, P., Vuille, F., 2017. Coming full circle: why

social and institutional dimensions matter for the circular economy. J. Ind. Ecol. 21, 497–506. https://doi.org/10.1111/jiec.12598.
Morgan, J., Mitchell, P., 2015. Employment and the Circular Economy: Job Creation in a More Resource Efficient Britain.
Nelson, R.R., 1994. The co-evolution of technology, industrial structure, and supporting institutions. Ind Corp Change 3, 47–63. https://doi.org/10.1093/icc/3.1.47.
Niaros, V., Kostakis, V., Drechsler, W., 2017. Making (in) the smart city: the emergence of makerspaces. Telematics Inform. 34, 1143–1152. https://doi.org/10.1016/j.tele.2017.05.004.
Ophuls, W., 1977. Ecology and the Politics of Scarcity. W.H. Freeman and Company, San Francisco, CA.
Parajuly, K., Kuehr, R., Awasthi, A.K., Fitzpatrick, C., Lepawsky, J., Smith, E., Widmer, R., Zeng, X., 2019. Future E-Waste Scenarios. StEP Initiative, UNU ViE-SCYCLE, UNEP IETC.
Parguel, B., Lunardo, R., Benoit-Moreau, F., 2017. Sustainability of the sharing economy in question: when second-hand peer-to-peer platforms stimulate indulgent consumption. Technol. Forecast. Soc. Chang. 125, 48–57. https://doi.org/10.1016/j.techfore.2017.03.029.
Pazaitis, A., De Filippi, P., Kostakis, V., 2017. Blockchain and value systems in the sharing economy: the illustrative case of Backfeed. Technol. Forecast. Soc. Chang. 125, 105–115. https://doi.org/10.1016/j.techfore.2017.05.025.
Pearce, D.W., Turner, R.K., 1990. The Circular Economy, in: Economics of Natural Resources and the Environment. Harvester Wheats, Brighton, pp. 29–42.
Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A., 2017. Circular Economy: Measuring Innovation in the Product Chain. PBL Netherlands Environmental Assessment Agency, The Hague.
Ramirez, R., Wilkinson, A., 2014. Rethinking the 2 × 2 scenario method: grid or frames? Technol. Forecast. Soc. Chang. 86, 254–264. https://doi.org/10.1016/j.techfore.2013.10.020.
Ranta, V., Aarikka-Stenroos, L., Ritala, P., Mäkinen, S.J., 2018. Exploring institutional drivers and barriers of the circular economy: a cross-regional comparison of China, the US, and Europe. Resources, Conservation and Recycling, Sustainable Resource Management and the Circular Economy 135, 70–82. https://doi.org/10.1016/j.resconrec.2017.08.017.
Rayna, T., Striukova, L., 2016. From rapid prototyping to home fabrication: how 3D printing is changing business model innovation. Technol. Forecast. Soc. Chang. 102, 214–224. https://doi.org/10.1016/j.techfore.2015.07.023.
Rayna, T., Striukova, L., Darlington, J., 2015. Co-creation and user innovation: the role of online 3D printing platforms. Journal of Engineering and Technology Management, Leveraging Users as Innovators 37, 90–102. https://doi.org/10.1016/j.jengtecman.2015.07.002.
Ren, S., Zhang, Y., Liu, Y., Sakao, T., Huisingh, D., Almeida, C.M.V.B., 2019. A comprehensive review of big data analytics throughout product lifecycle to support sustainable smart manufacturing: a framework, challenges and future research directions. J. Clean. Prod. 210, 1343–1365. https://doi.org/10.1016/j.jclepro.2018.11.025.
Repo, P., Anttonen, M., Mykkänen, J., Lammi, M., 2018. Lack of congruence between European citizen perspectives and policies on circular economy. European Journal of Sustainable Development 7, 249. https://doi.org/10.14207/ejsd.2018.v7n1p249.
Rifkin, J., 2000. The Age of Access: The New Culture of Hypercapitalism. Penguin, London.
Sale, K., 1980. Human Scale. Secker and Warburg, London.
Schor, J.B., Attwood-Charles, W., 2017. The "sharing" economy: labor, inequality, and social connection on for-profit platforms. Sociol. Compass 11, e12493. https://doi.org/10.1111/soc4.12493.
Schot, J., Steinmueller, W.E., 2018. Three frames for innovation policy: R&D, systems of innovation and transformative change. Res. Policy 47, 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011.
Schumacher, E., 1973. Small Is Beautiful: A Study of Economics as if People Mattered. Harper and Row, New York.
Seyfang, G., Longhurst, N., 2013. Growing green money? Mapping community currencies for sustainable development. Ecological Economics, Sustainable Urbanisation: A resilient future 86, 65–77. https://doi.org/10.1016/j.ecolecon.2012.11.003.
Shearman, D., Smith, J.W., 2007. The Climate Change Challenge and the Failure of Democracy. Praeger Publishers, Westport, CT.
Short, D.B., Sirinterlikci, A., Badger, P., Artieri, B., 2015. Environmental, health, and safety issues in rapid prototyping. Rapid Prototyp. J. https://doi.org/10.1108/RPJ-11-2012-0111.
Slater, R., Aiken, M., 2015. Can't you count? Public service delivery and standardized measurement challenges – the case of community composting. Public Manag. Rev. 17, 1085–1102. https://doi.org/10.1080/14719037.2014.881532.
Smith, P., Davis, S.J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R.B., Cowie, A., Kriegler, E., van Vuuren, D.P., Rogelj, J., Ciais, P., Milne, J., Canadell, J.G., McCollum, D., Peters, G., Andrew, R., Krey, V., Shrestha, G., Friedlingstein, P., Gasser, T., Grübler, A., Heidug, W.K., Jonas, M., Jones, C.D., Kraxner, F., Littleton, E., Lowe, J., Moreira, J.R., Nakicenovic, N., Obersteiner, M., Patwardhan, A., Rogner, M., Rubin, E., Sharifi, A., Torvanger, A., Yamagata, Y., Edmonds, J., Yongsung, C., 2016. Biophysical and economic limits to negative CO 2 emissions. Nature Clim Change 6, 42–50. https://doi.org/10.1038/nclimate2870.
Sorrell, S., Dimitropoulos, J., 2008. The rebound effect: microeconomic definitions, limitations and extensions. Ecol. Econ. 65, 636–649. https://doi.org/10.1016/j.ecolecon.2007.08.013.
Stahel, W.R., 2010. Introduction. In: Stahel, W.R. (Ed.), The Performance Economy. Palgrave Macmillan UK, London, pp. 1–7. https://doi.org/10.1057/9780230274907_1.
Stahel, W.R., Clift, R., 2016. Stocks and flows in the performance economy. In: Clift, R., Druckman, A. (Eds.), Taking Stock of Industrial Ecology. Springer International Publishing, Cham, pp. 137–158. https://doi.org/10.1007/978-3-319-20571-7_7.
Stegeman, H., 2015. The Potential of the Circular Economy.
Su, B., Heshmati, A., Geng, Y., Yu, X., 2013. A review of the circular economy in China: moving from rhetoric to implementation. J. Clean. Prod. 42, 215–227. https://doi.org/10.1016/j.jclepro.2012.11.020.
The Breakthrough Institute, 2015. An Ecomodernist Manifesto.
Thomas, V.M., 2011. The environmental potential of reuse: an application to used books. Sustain. Sci. 6, 109–116. https://doi.org/10.1007/s11625-010-0115-z.
Tress, B., Tress, G., 2003. Scenario visualisation for participatory landscape planning—a study from Denmark. Landsc. Urban Plan. 64, 161–178. https://doi.org/10.1016/S0169-2046(02)00219-0.
Uotila, T., Melkas, H., Harmaakorpi, V., 2005. Incorporating futures research into regional knowledge creation and management. Futures 37, 849–866. https://doi.org/10.1016/j.futures.2005.01.001.
Vayre, B., Vignat, F., Villeneuve, F., 2012. Metallic additive manufacturing: state-of-the-art review and prospects. Mechanics & Industry 13, 89–96. https://doi.org/10.1051/meca/2012003.
Velenturf, A.P.M., Purnell, P., Tregent, M., Ferguson, J., Holmes, A., 2018. Co-producing a vision and approach for the transition towards a circular economy: perspectives from government partners. Sustainability 10, 1401. https://doi.org/10.3390/su10051401.
Vervoort, J.M., Bendor, R., Kelliher, A., Strik, O., Helfgott, A.E.R., 2015. Scenarios and the art of worldmaking. Futures 74, 62–70. https://doi.org/10.1016/j.futures.2015.08.009.
Vetter, A., 2018. The matrix of convivial technology – assessing technologies for degrowth. Journal of Cleaner Production, Technology and Degrowth 197, 1778–1786. https://doi.org/10.1016/j.jclepro.2017.02.195.
Voros, J., 2003. A generic foresight process framework. Foresight 5, 10–21. https://doi.org/10.1108/14636680310698379.
Wanzenböck, I., Wesseling, J., Frenken, K., Hekkert, M., Weber, M., 2019. A framework for mission-oriented innovation policy: alternative pathways through the problem-solution space (preprint). SocArXiv. Doi:10.31235/osf.io/njahp.
Wastling, T., Charnley, F., Moreno, M., 2018. Design for Circular Behaviour: considering users in a circular economy. Sustainability 10, 1743. https://doi.org/10.3390/su10061743.
Weigend Rodríguez, R., Pomponi, F., D'Amico, B., 2019. Futures studies & the circular economy: an interdisciplinary approach to sustainable development. Economia Creativa 11, 38–60.
Weiss, M., Cattaneo, C., 2017. Degrowth – taking stock and reviewing an emerging academic paradigm. Ecol. Econ. 137, 220–230. https://doi.org/10.1016/j.ecolecon.2017.01.014.
Welch, D., Keller, M., Mandich, G., 2017. Imagined futures of everyday life in the circular economy. Interactions 24, 46–51. https://doi.org/10.1145/3047415.
Wells, P., 2007. The green junta: or, is democracy sustainable? International Journal of Environment and Sustainable Development 6, 208–220. https://doi.org/10.1504/IJESD.2007.014204.
Wijkman, A., Skånberg, K., 2015. The Circular Economy and Benefits for Society: Jobs and Climate Clear Winners in an Economy Based on Renewable Energy and Resource Efficiency.
Wilkinson, A., 2009. Scenarios practices: in search of theory. Journal of Futures Studies 13, 107–114.
Wrap, 2015. Economic Growth Potential of More Circular Economies.
Wynes, S., Nicholas, K.A., 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environ. Res. Lett. 12, 074024. https://doi.org/10.1088/1748-9326/aa7541.
Xue, J., 2014. Is eco-village/urban village the future of a degrowth society? An urban planner's perspective. Ecol. Econ. 105, 130–138. https://doi.org/10.1016/j.ecolecon.2014.06.003.
Yeates, L.B., 2004. Thought Experimentation: A Cognitive Approach.
Zink, T., Geyer, R., 2017. Circular economy rebound. J. Ind. Ecol. 21, 593–602. https://doi.org/10.1111/jiec.12545.