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ORIGINAL PAPER

Advancing Our Understanding of CE Loop Strategies: A Synthesizing Framework for Durable Consumer Products

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Abstract
The Circular Economy (CE) concept is widely promoted as a pathway to sustainability, yet its practical realization can appear to be challenging and unclear due to divergent definitions, interpretations and understanding about the implications and goals of a realized CE. Addressing this gap, this study develops the Circular Economy Loop Strategies (CELS) Framework, a synthesizing foundational model that defines and organizes five overarching strategies—simplifying, narrowing, slowing, intensifying, and closing—within a material flow perspective for durable consumer products, such as electronics and furniture. The framework delineates how varying CE goals (e.g., recycling vs. sufficiency) can influence material flow outcomes and, for each strategy, outlines overlaps and trade-offs while linking them to CELS characteristics: trajectory, magnitude, composition, and rate of flow. The CELS Framework was constructed through a critical review of CE literature and refined via a two-round Delphi study with 17 international experts from academia, industry, policy, and non-profit sectors. Results indicate strong consensus (89% agreement) on the framework's validity and usefulness for mapping CE strategies and evaluating their implications across different CE versions—from recycling-focused approaches to sufficiency-driven models. This research contributes to CE theory by providing a clearer conceptual foundation and vocabulary, as well as provides a foundational tool for policymakers and practitioners to support strategic planning and alignment in CE transitions. The framework highlights the need for integrated strategies to achieve environmental sustainability and serves as a starting point for future research on operationalization, prioritization, and social dimensions of circularity.

Keywords Circular economy · Sustainability transitions · Material flows · Durable consumer products · Delphi · Framework

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Introduction

A Circular Economy (CE) promises to: "…help society reach increased sustainability and wellbeing at low or no material, energy and environmental costs." [1], p. 12. While some features and objectives of the CE are generally accepted (Sect. 1.1), others are disputed and unclear, creating barriers for the CE transition (Sect. 1.2). With burgeoning proposed meanings of a CE (see e.g., [2]) and diverse interpretations of its goal [3, 4], we lack a flexible yet concise definition of a realized state of CE. This lack of clarity can create barriers to implementation, misalignment among stakeholders, and presents risks of greenwashing.

Existing frameworks, such as the 3Rs [5], 10Rs [2, 6, 7], and the Ellen MacArthur Foundation's Butterfly Diagram [8], provide useful starting points but fail to offer a comprehensive and systematic approach to defining CE loop strategies and their implications in practice. In the current literature, terms like "loops" and "strategies" are often conflated (e.g., different publications utilizing divergent meanings) and the overlaps and trade-offs between strategies are sometimes overlooked (c.f. [9], vs. [10, 11]). In addition, there is a lack of clarity regarding the effect of these strategies upon actual material flows, such as the implications for flow characteristics of *trajectory* (e.g., circular vs. linear), *magnitude* (e.g., volume of materials or products), *composition* (e.g., content and composition of the flow), and *rate of flow* (e.g., speed of movement, transition, or transformation).

Accordingly, this study investigates how a foundational and comprehensive framework can be developed to clarify what a realized Circular Economy (CE) entails for durable consumer products, using a material flow perspective. Specifically, it explores how currently defined CE Loop Strategies (CELS)— synthesized as simplifying, narrowing, slowing, intensifying, and closing material loops—can be systematically integrated, compared, and clarified in terms of their implications, overlaps, and roles in achieving circularity across different CE versions (e.g., recycling-focused vs. sufficiency or consumption-reduction focused).

We introduce the CE Loop Strategies (CELS) Framework as a novel synthesis that extends existing CE models by providing clear definitions, goals, and implications for durable consumer products. Unlike prior frameworks, it explicitly addresses synergies and trade-offs between loop strategies, incorporates material flow characteristics (trajectory, magnitude, composition, and rate), and applies these concepts to a product category with significant environmental impact. The CELS Framework was developed through a two-stage process: first, a critical review of CE literature to identify and refine loop strategies and their implications; second, a Delphi study with 17 international CE experts from academia, industry, policy, and non-profit sectors to validate and improve the framework. This iterative process ensured both theoretical rigor and practical relevance. The results include a validated CELS Framework that clarifies the definitions and roles of the five CE loop strategies, maps their overlaps and trade-offs, and connects them to material flow characteristics and life cycle stages. The study also outlines how different configurations of these strategies correspond to varying CE versions, from recycling-focused approaches to sufficiency-driven models.

The implications of this work are twofold: scientifically, it contributes to the strengthening of CE theory by providing a clearer conceptual foundation and vocabulary; practically, it offers policymakers, practitioners, and designers a tool for distinguishing and comparing CE goals and evaluating and planning CE strategies aligned with said goals. The remainder of this article is structured as follows: Sect. "Theoretical Context" reviews the theoretical

context and existing terminology; Sect. "Method" details the research method; Sect. "Conceptualizing a Realized Circular Economy" presents the finalized CELS Framework; Sect. "Results & Analysis" reports the Delphi study results; Sect. "Discussion" discusses the findings and their implications; and Sect. "Concluding Remarks" concludes with contributions, limitations, and directions for future research.

Theoretical Context

The Fundamentals of a CE

In a realized Circular Economy (CE), products, components, modules, materials, substances, and the energy embedded in the same, would all be retained as much as biophysically possible in the economic system over multiple service lives[1] [12, 13]. As such, a realized, optimized CE would preserve, use, and value stocks of objects, components, and molecules at their highest utility, for as long as possible, with the least amount of energy use [14]. Waste will be "designed out" as much as possible through e.g., design of products for optimized circulation and business models catering to consumers as "users" [11]. Waste management will be transformed into activities that enable resource recovery and foster environmental protection [1]. In a realized CE, a product's end-of-use stage is distinct from its end-of-life stage, as it (or its components or parts) is cycled through multiple service lives through a variety of "looping" activities: reuse, repair, refurbishment, remanufacturing, and recycling (Fig. 1).

Considering Fig. 1, "CE Loops", also referred to as "cycles" [10], consist of flows of product, and its components and materials in the product life cycle that contributes to its "circularity". Whilst organic and inorganic matters are integrated in resource flows [15], the focus of this paper is primarily on inorganic materials. A multitude of actors are involved in these loops (Fig. 1), such as consumers, providers and distributors – implying that "circularity" (i.e., the circular flows of materials) is not the property of individual products or services, but of an entire system of actors and mechanisms [9].

Emerging and Divergent CE Versions

While many may envision a realized CE as a fully closed, self-sustaining system, and thus frame the goal of a CE as being a "closed loop" system, this perspective is not universally accepted or viable. A "closed economy" can refer to an economic system isolated from global trade and relying on self-sufficient production, such as energy [16], or it can refer to an economy isolated from the natural world with no environmental impact. The notion of such a "closed system" is connected to the root of the CE concept as a "self-replenishing economy" [17] or a "closed-loop" economy [18, 19]. However, the feasibility of a closed economic system is heavily critiqued, primarily as being "impossible" [20, 21], due to

[1] For the purposes of this study, we define the "service life" as the period during which a product, component, or material is being used and providing functionality. A "service life" may constitute a 'cycle' via CE looping activities, such as repair, reuse, or remanufacturing. This is differentiated from the "life cycle", which encompasses the entire lifespan, including development, production, usage, and eventual disposal, essentially covering all stages from conception to end-of-life.

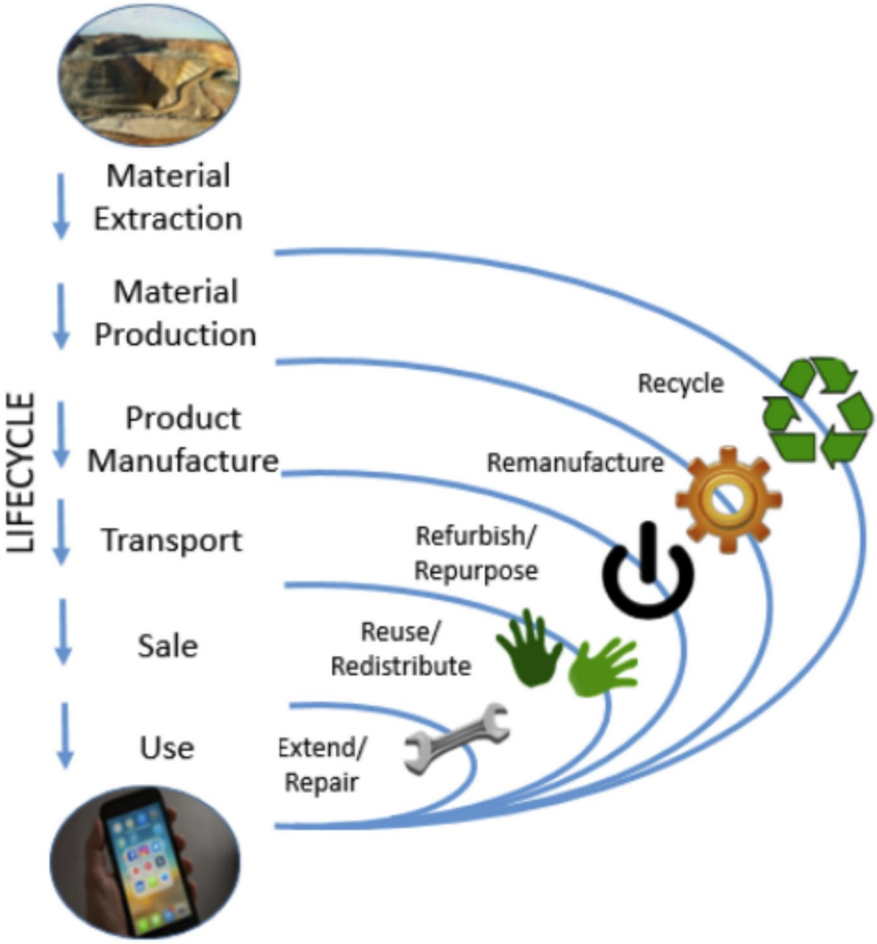

Fig. 1 The (Technical) Product (and its Components and Material) Loops (adapted from [1])

the Laws of Thermodynamics (i.e., the inevitability of entropy in any resource recovery process, leading to an inevitable loss of quality and quantity of cycled resources) and rebound effects (i.e., environmental efficiency gains leading to increased consumption and production and thus a failure to achieve an absolute reduction in environmental impacts) [22]. As such, the ability of an economic system to be closed should be regarded as a matter of "degree" [23]. In contrast, many suggest that a key aim of an environmentally sustainable CE is to regenerate nature, such as by replenishing natural capital and restoring ecosystems [23]. From this perspective, the goal of a CE should not be complete system closedness, but instead, existing in harmony with nature [24]. In practice, most researchers adopt a nuanced aspiration that accepts the reality of integrated, complex natural and economic systems, and entropy, in which: "… the circular flow of resources is kept as closed as possible" [10], and in which any negative environmental impacts from the economic system are minimized.

Beyond the fundamental material loops (Fig. 1), there are multiple emerging research themes that may complicate a common understanding of a realized CE (Sect. "Introduction"). In addition to differing purpose-based narratives, over two hundred definitions of a CE, divergent in scope and focus, can be found in the literature [25]. This results in diverging uses of central terms, such as "loops" and "circularity" (c.f. [9], vs. [10, 11]).

The diversity of CE versions, and the resulting definitions of key terms, can be explained by there being no universally agreed theoretical definition of what constitutes a CE [25–28]. As such, a CE: "… is not a theory but an emerging approach to industrial production and consumption" [29], p. 551 or an alternative approach to the organization of access to resources in our economy. To this point, while some find it a rather fuzzy umbrella concept [12, 30] lacking "substance" [20], others are of the opinion that more definite, consensual definitions are impossible [29]. While complete consensus may not be possible, less ambiguous definitions and conceptualization are desirable to align efforts and/or avoid CE becoming a catch-all term that fails to address specific issues effectively [20]. Interestingly enough, this critique also applies to the concept of sustainability at large of which a CE constitutes a more concrete concept [31].

Existing Terminology and Definitions of CE Loop Strategies and Implications

One conceptualization of CE Loops or "cycles" [10, 32] relates to the ***proximity to the user*** (Fig. 1), distinguishing between 'inner'/'smaller' loops (i.e., tighter, operating closest to the consumer/user, such as reuse and repair) and 'outer'/'larger' loops (i.e., entailing a return to an earlier stage in the product life cycle, and thus inherently more technical interventions). Smaller loops should be strategically prioritized as they require less energy and materials, and enable the retention of a greater share of inherent value of a product's functional form, relative to the larger 'loops', such as remanufacturing and recycling (Fig. 1) [11, 13, 25, 33]. For example, a repairable device would be repaired by its user before it would be recycled, thereby retaining the device's inherent value, functional-form, and functionality that would otherwise be lost or degraded by recycling.

CE Loops based on proximity to the user also align, and correspond, with different conceptualizations of ***how a CE is achieved*** via activities, or "CE Strategies" [34]. One example is the "10R framework strategies" [2, 7]; Reike et al. [6] synthesized 10 so-called "resource value retention options" as: 1) *refuse* (i.e., waste preventions, e.g., refuse unnecessary packaging); 2) *reduce* (i.e., using fewer materials and products); 3) *resell/reuse* (i.e., bringing products back into use); 4) *repair* (i.e., bringing a broken product back into working order); 5) *refurbish* (i.e., more comprehensive repairs of multiple malfunctions, or restorations); 6) *remanufacture* (i.e., disassembly, testing, and industrial restoration of components for reintegration [13]; 7) *repurpose* (i.e., adapting the product for another function or utilization than originally intended); 8) *recycle materials* (i.e., retaining the material in product and production waste; 9) *recover energy* (i.e., incineration of waste for energy generation); and 10) *re-mine* (i.e., the recuperation of material of landfilled materials).

The "CE Loop Strategies" (CELS) proposed in this study constitutes a more overarching conceptualization to which the above loops (i.e., proximity to user) or resource value retention options pertain. As such, we suggest that the CE Loop Strategies can offer a "bigger picture" of the goals and implications of various CE versions and thereby facilitate the identification of their content and comparisons. A first challenge, however, is to address the

absence of agreed definitions of the CE Loop Strategies (Sect. "Analysis of CE Loop Strategies Definitions in the Literature").

Method

Overview of the Process

To approach this challenge, our method consisted of three iterative steps, in which two interconnected and iterative stages were used. In Stage 1, we assessed and converged insights from a literature review of existing terminology and definitions of CE Loop Strategies (Fig. 2, Stage 1, Step 1) into the synthesizing CELS Framework (Fig. 2, Stage 1, Step 2). In Stage 2, the proposed CELS Framework was then tested and refined over multiple iterative steps via a Delphi survey study of relevant expert perspectives and opinions (Fig. 2, Stage 2, Steps 3 a-c). It is important to note that Delphi surveys have been integrated into sustainability and CE research in diverse ways: Where [35, 36] utilized Delphi methods to *draw-out*, *develop* and *synthesize* expert insights into their resulting, more refined frameworks and taxonomies; this work is aligned with [37] who utilized Delphi methods to *test and validate* their proposed framework.

Regarding the correctness of the CELS Framework, which relates to Delphi study participant agreement, it is important to recognize that many implications of a realized CE remain largely untested or exist as future possibilities, particularly as contributing to, e.g., "slowing" or "narrowing" of material flows. According to Future Studies, the future cannot be predicted, only explored for potential and possibilities [28, 40]. If only empirically confirmed outcomes of a CE and the CELS were to be considered in this study, we would be facing two shortcomings: 1) since contemporary "pockets" of a realized CE (e.g., a circular business) does not provide information on a CE realized at the economic scale, the amount

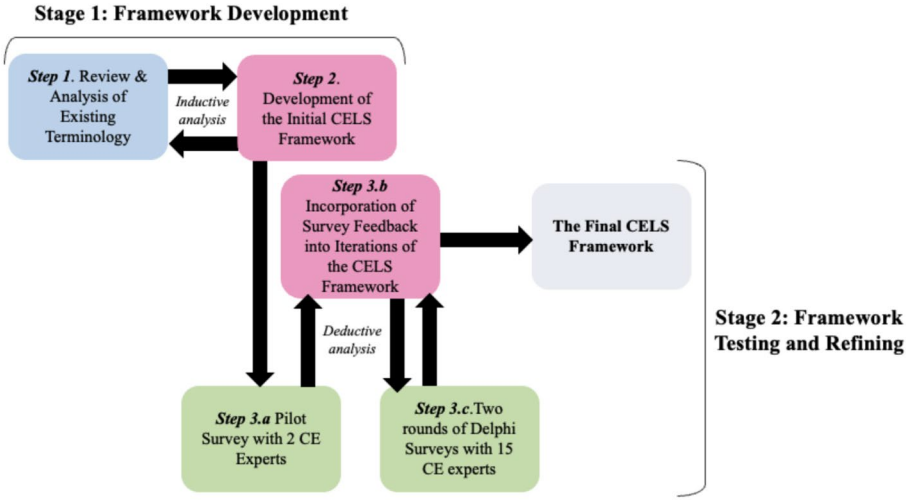

Fig. 2 The iterative two-stage approach of developing and testing the CE Loop Strategies (CELS) Framework (adapted from [37–39])

of confident extrapolation from present conditions is severely limited, thus there would be extremely few "implications" of a future state of a realized CE to study; and 2) there would be the need to include long-winded explanations of the exact conditions under which this outcome would occur. While it is essential to empirically test the potentials described in CE definitions and to identify the exact conditions under which they are realized, the primary aim of this study was to understand what a future realized CE (i.e., at the economic scale) might entail. Therefore, our focus was on exploring *potential* implication of the CELS, such as "products are multifunctional" or "products are made of recyclables" (Table 1), rather than evaluating their likelihood or probability. To this end, the goal of the Delphi study consisted of assessing whether the experts found the CELS and their proposed implications

Table 1 The CE Loop Strategies (CELS) Framework: Respective Goals, and Implications for Durable Consumer Products a Realized CE (*—Denotes a more fundamental role, however it depends on the CE version (Fig. 5), see Sect. "Discussion")

CE Loop Strategies *For Durable Consumer Products*	**CE Goals**	**Implications for** (i.e., what happens to) **Durable Consumer Products** *(i.e., at the system-, product- and components level)* The Implications below are purposefully formulated to encompass needed product design, infrastructure, and consumer behaviors
Excluding: Energy recovery, regeneration of ecosystems, and non-material efficiency (e.g., energy and water usage)		
Simplifying Reduce the total amount of material inputs into the economic system	***Reduce*** (i.e., shrinking the size of the material flows)	• Products that are not creating substantial value are eliminated from the market • Products are multi-functional [1]
Narrowing Reduce the total amount of material inputs into product units		• Physical products consist of less and/or lighter-weight materials [2] [3] • Physical products are virtualized or digitized [4] [5]
Slowing* Retain the value in products, parts, and components by keeping them in use	***Reuse***	[6] [7] • Products are durable, repairable, and upgradable • Products are reused by a second (or additional) product user • (Idle) products are repurposed to a use, or application, that is different from their original intended use or application • Products are maintained and repaired • Products are refurbished • Components are remanufactured
Intensifying Use products to their highest utilization capacity	***Maximize Product Utilization***	[8] [9] • Products are offered as a service (PSS/renting/lease) • Products are shared/loaned • Idle products are redistributed to a second (or additional) product user (i.e., a situation of use)
Closing* Retain the value of (product) materials through effective recycling to minimize the use of primary materials	***Recycle***	[10] • The materials and components within products are recycled to become feedstock materials for other products • Products are made to be recycled • Products are made of recyclables

Overlaps between the CE Loop Strategy Implication (i.e., positive or negative contributions, and interconnections to other Loop Strategies, or synergies and trade-offs)

[1] The Simplifying of loops through multi-functional products has the potential to contribute *positively* to Intensifying (i.e., maximized product utilization), since its many functions increase utilization.

[2] The Narrowing of loops through reducing material inputs, or using lighter-weight materials, in a product can contribute *negatively* to Closing through diminished recyclability of the product (e.g., when lightweight alloys or composite materials are used, which are not (yet) recyclable).

[3] The Narrowing of loops through reducing material inputs, or using lighter-weight materials, in a product can *negatively* contribute to Slowing by reducing durability and the ability to e.g., repair and refurbish the product (e.g., use of aluminum, which wears down at a faster rate than heavier alternatives).

[4] The Narrowing of loops through digitization of physical goods can *positively* contribute to Intensifying in that goods can be used simultaneously (e.g., a streamed movie vs. a DVD).

[5] The Narrowing of loops through the digitization of (otherwise) physical goods can lead to the use of an increased number of products, hence contributing *negatively* to Simplifying (e.g., watching a higher number of streamed movies compared to on DVDs) (i.e., Jevon's Paradox).

[6] The Slowing of loops through e.g., reuse and repair of (otherwise) idle products can ensure not only a longer product lifetime (i.e., Slowing), but can also contribute *positively* to Intensifying (i.e., maximized utilization) of said product.

[7] The Slowing of loops can extend product service life or lifetime, thus limiting the need for new production and consumption, and can thereby positively impact Simplifying.

[8] The Intensifying of loops has the potential to reduce the total number of products in the economic system, hence can contribute *positively* to Simplifying. However, it can also lead to the use of an increased number of products, hence having a *negative* effect on Simplifying (e.g., usage of a higher number of clothing through rental) (i.e., a rebound effect).

[9] The Intensifying of loops can be interconnected and interdependent with Slowing as increased wear and tear is likely to shorten the product's service life and increase the frequency of upkeep (e.g., maintenance and repair). However, products can be designed to withstand high utilization rates. In addition, the Intensifying of loops also has the potential to *positively* contribute to Slowing (i.e., increasing products' lifetimes) in that e.g., repair and refurbishing efforts are incentivized as products are passed on to the next user, as well as design for durability and repair/refurbishing/remanufacturing.

[10] The Closing loop strategy can contribute positively to Simplifying as the production of each new product may require relatively less primary material inputs and use relatively more secondary or cycled materials.

to be plausible and therefore worthwhile to include in the Framework as part of the vision of a future CE system.

Developing the Initial CELS Framework

In Stage 1, Step 1 (Fig. 2), we conducted a critical review of the CE literature on terminology and definitions of the CE Loop Strategies, including their implication on the production and consumption system. The review focused on seminal CE literature, such as Ghisellini et al., [1] and Bocken et al., [32], in addition to searches on Google Scholar, using the search term "circular economy 'Loop Strategies'". The findings on CE Loop Strategies, terminology, and definitions were analyzed for complementarities, overlaps, and distinctions (see Sect. "Analysis of CE Loop Strategies Definitions in the Literature" for the results). In Step 2 (Fig. 2), these findings were applied and modified to the context of durable consumer products and formulated to be as distinct as possible, according to the literature. The durable consumer products category was selected as the application for the CELS Framework due to the relatively more substantial environmental impact that results from such products [41]; In addition, the processes of acquisition and usage of such products in a realized CE are expected to impact product users (e.g., having to repair a durable product), thus enabling a research contribution to this less examined dimension within CE literature [42].

To develop the CELS Framework, we adopted a perspective and focus on material flows, and from this perspective propose a comprehensive definition for the five CE Loop Strategies (CELS), that includes: 1) their respective *implications* when it comes to durable consumer products (e.g., digitization of goods), and; 2) the CELSs' *overlaps* in terms of synergies, interconnections, and contradictions [43], denoted in bracketed numbers in Table 1. The resulting initial CELS Framework can be found in the Supplementary File.

Testing and Refining the Framework

The initial Framework was submitted for critique and testing via a Delphi study (Fig. 2, Stage 2); A methodology deemed appropriate for two primary reasons. First, given the multitudes of CE definitions and frameworks, we posit that a key part of the problem lies in the lack of consensus on what a CE entails, requiring the involvement of a wide range of actors and experts (Delphi survey participants). Second, given that conceptual frameworks run the risk of being biased, expert assessments and refinements were utilized to ensure suitable validation for the Framework (e.g., [44–46]). Two groups of participant experts were involved in the Delphi study: experts in CE theory and/or practice, and experts in Sufficiency (i.e., an alternative economic model focused on reduced consumption).

The Expert Groups

The CE & Sufficiency experts were selected based on the following individual eligibility criteria: (1) internationally recognized CE expertise (i.e., group affiliations and publications); and (2) familiarity with material flows (i.e., products, components and materials), and not simply resource conservation (e.g., energy-efficiency). To ensure that the CE expert group composition was appropriate for the task, additional considerations were incorporated into recruitment: (1) representativeness (i.e., experts with both system perspective

and specific system area expertise, such as business models and consumer behaviors, with a history of adopting both a "macro" and "micro" perspectives); and (2) coverage of the EU, UK and US [47]. Also, sufficiency (i.e., consumption reduction) experts with CE expertise were invited, based on the same criteria, to complement the insights from "traditional" CE experts (i.e., decoupled growth) to also cover more sustainable versions of a CE. Identified experts were invited to participate via direct email.

To ensure that specific CELS were not overrepresented in the mix of CE experts, recruitment targeted general practitioners who could speak to, and had familiarity with, more than one CELS. As such, practitioners working only with, e.g., repair, or a particular circular business model were deemed inappropriate for the study. Instead, practitioners in the form of business consultants with CE expertise—thus able to speak to a wider perspective—were invited.

In total, 17 experts located in the US, UK and EU, with backgrounds primarily in academia, business/industry, non-profit and policy/government (Fig. 3), took part in a two-round Delphi survey that ran over 30 days in total (Step 3; Fig. 2) (see the Supplementary File for the survey document).

Data Collection and Analysis

In accordance with Stage 2, Step 3.a (Fig. 2), a pilot survey was conducted with two CE experts to test the initial CELS Framework, and the survey as such to ensure clarity [39]. All feedback from this pilot round was implemented in the Framework and survey document if it did not counter the intention of the same (Fig. 2, Step 3.b). Next, per Step 3.c (Fig. 2) a

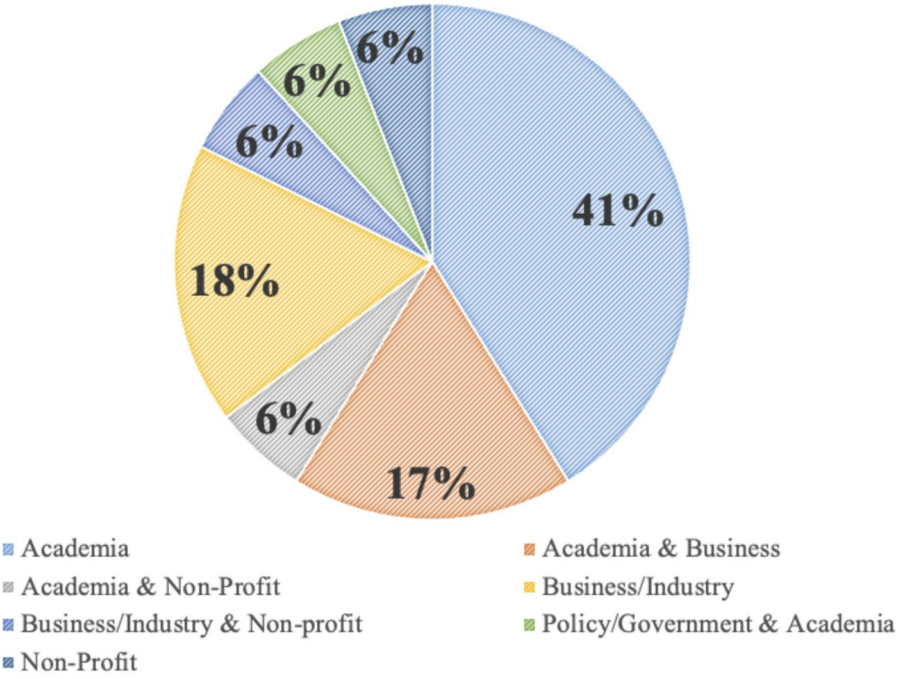

Fig. 3 The primary background of the 17 Delphi survey participants

Delphi survey, consisting of two rounds, was used to gather feedback, test, and validate the CELS Framework.

In the first survey round the Initial CELS Framework was presented with narratives [45] (i.e., each CELS and their implication, presented one by one). In Delphi studies used to verify and modify conceptual models, the panelists are commonly asked to assess the model by having them: 1) rate their level of agreement, 2) explain their standpoint, and; 3) suggest modifications, such as additions and removals (see e.g., [48]). As such, in a separate survey document, consisting of a Word document, consensus measurement and data were collected from the participants in these three forms.

Using a 7-point Likert Scale for responses, the participants were first asked to indicate their level of agreement with the CELS Framework, from "Strongly Disagree" (i.e., "1") to "Strongly Agree" (i.e., "7") [38, 49]. Second, if they indicated any agreement less than "strongly agree", they were asked to make *general comments* on their lack of agreement. In terms of any lacking clarity in comments, the researchers contacted each participant to obtain clarifications.

Unlike traditional Delphi processes that involve co-creation from the outset (i.e., problem or content identification; e.g., [50]), this study adopts a more deductive approach in alignment with [37]: the Initial CELS Framework was developed by the research team based on literature and then presented for evaluation to the Delphi participants [47] in Stage 1 (Fig. 2). As such, the "open-ended questions" commonly used in Delphi questionnaires (e.g., [39]) consisted of the presentation of assumptions about a realized state of a CE, inherent in the Framework. This method saved participants' time and encouraged engagement. It also limited their ability to influence the framework's foundational structure, which was explicitly derived from the literature, intentionally, to avoid introducing further 'new' iterations and nuances regarding CE conceptualization.

During the study, the primary task of the expert group was to provide critical feedback and commentary about: a) the (correctness of the) Initial CELS Framework content; and b) the level of detail included. Importantly, the purpose of the Delphi was not to test whether the outcome (i.e., a feature of a realized CE) was deemed likely, but to assess whether the Delphi study participants could accept the proposed implications as a *potential* outcome of a realized CE (See Sect. "Overview of the Process").

General and specific comments from expert participants was coded, first, by the area of the CELS Framework it pertained to (i.e., which part of the Framework), and second, according to the type of alternation it required. Alternation-related feedback from participants was coded and assigned to one of three categories:

- *Clarification* feedback consisted of expert comments requesting alterations to the Framework that served to increase understanding of existing framework elements. Clarifications were incorporated into the CELS Framework unless they necessitated adding significant new details, in which case all expert participants were then asked to vote on inclusion/exclusion (majority decision).
- A *remedy* was feedback from experts that required alterations to address an identified omission or misrepresentation. Remedies were always incorporated into the CELS Framework.
- A *change* consisted of feedback necessitating alterations to the main idea of the Initial CELs Framework. Changes that were suggested by > 50% of participants (all partici-

pating independently) were automatically incorporated into the Framework; changes suggested by > 25% of participants would go to a participant vote and be decided by the majority.

The second survey round (Fig. 2, Step 3.c) constituted: 1) a presentation of the refined CELS Framework, based on the feedback from survey round 1, and; 2) final consensus-measurement regarding the Framework, which was defined as over 75% of the participants agreeing with the model's accuracy (i.e., representativeness) (see e.g., [51]). For the consensus data, the Likert Scale questions from round 2 were analyzed as an average percentage of participant ratings. This captures the spread of expert input and resulted in a more conservative agreement rating compared to, e.g., median ratings.

For clarity, the evolution and final version of the CELS Framework is presented in Sect. "Conceptualizing a Realized Circular Economy", and the analysis of the literature and the Delphi study results are included in Sect. "Results & Analysis".

Conceptualizing a Realized Circular Economy

CE Product Loops and Strategies

Insights from the literature review (Step 1; Fig. 2) revealed that, despite commonalities, multiple versions or narratives of a CE exist [25, 26], with disagreement regarding: the ultimate goal of a CE, e.g., [27, 52]; what the CE loops (Fig. 1) consist of; and what is included in the CE concept (e.g., PSS models [22]). This disagreement extends to whether a CE realized at the economic scale entails a closed system or not (see Sect. "The Fundamentals of a CE"). The most common aspiration consists of keeping the system "as closed as possible" [10] and minimizing negative environmental impacts from the economic system.

Irrespective of differences in the goal and framing of a realized CE, we introduce the notion of "Aggregate CE Product Loop", as a way to consider the flow of all products in the economic system, including their inherent components and materials (Fig. 4).

Considering the Aggregated CE Product Loop (Fig. 4), the wide range of existing CE versions, definitions, or narratives, can be regarded as a span of increasing complexity, from less environmentally sustainable (i.e., a more open system, with more negative environmental impact) to more sustainable (i.e., a more closed system, with less negative environmental impact) (Fig. 5).

On this span, it becomes clear that some view a CE as only consisting of a circular trajectory of material flows brought about through recycling (Fig. 5.a), entailing a more open system (e.g., relatively greater waste and resource use). A relatively more environmentally sustainable version of CE (Fig. 5.b), perhaps the most accepted, is that of a CE which leads to relatively reduced negative environmental impact as a result of decoupling economic growth from resource consumption (e.g., [1, 34]). The third CE version calls for a CE to be wholly sustainable [53] by designing and operating the economy to maintain circular flows over time, to stay within planetary boundaries [23]. For such a more closed economic system (i.e., with minimized negative environmental impact) (Fig. 5.c), sufficiency (i.e., degrowth in consumption and production levels) is necessary (e.g., [22, 53]). Hence, while

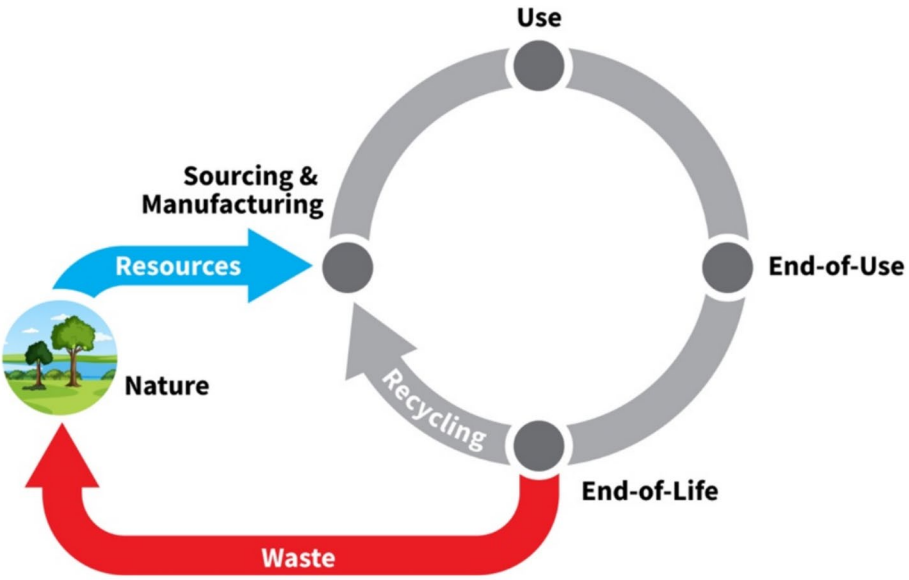

Fig. 4 The Aggregated CE Product Loop, incorporating the flow of all products in the economic system, including their inherent components and materials, from one life cycle stage to the next (i.e., grey circle); Resource inputs and outputs are represented with blue and red arrows respectively

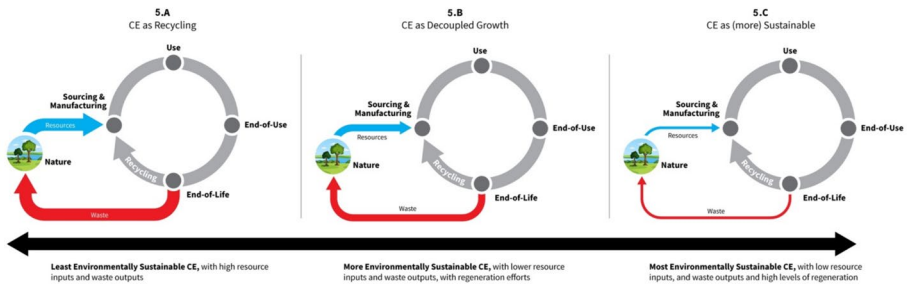

Fig. 5 Divergent Versions (goals) of a CE captured as a span ranging from "CE as recycling", or Least Environmentally Sustainable CE (5.a), to "CE as Decoupled Growth" (More Environmentally Sustainable CE) (5.b), and "Most Environmentally Sustainable CE" (5.c) (adapted from [10, 23, 25])

some see sufficiency "…as a missing link towards sustainability…" in CE theory [54], sufficiency strategies are typically seen as counterproductive to economic growth priorities established by economic actors (Fig. 5.b). In this context, it is important to note that a CE can be regarded as a steppingstone, or a process, towards sustainability, rather than an end-state [4].

In all, a realized CE can take on a wide range of characteristics and accomplish diverse goals and outcomes. The potential for such diversity, and lack of clarity and certainty regarding what a CE includes and is capable of accomplishing, is breeding tension, misconceptions, and disagreement; all of which can create and amplify barriers to its implementation [20, 55, 56].

The definition of a CE, its end goal and implications are crucial for supporting the distinction of what is indeed "circular", as well as weak vs. strong circularity [57, 58], particularly given the prevalence of "greenwashing" [59], p. 10f; enhanced understanding and alignment can allow for the identification of desirable vs. undesirable aspects, and better planning [18], otherwise, there is a risk that current efforts will miss their mark and give rise to negative unintended, long-term consequences [2, 23]. Moreover, increased understanding and clarity about the implications of a CE may help to increase market predictability, and facilitate citizen buy-in and political support for the CE transition. Lastly, an improved understanding of what a CE entails would facilitate necessary systemic approaches for successful CE adoption at multiple points of the system, e.g., the most superior recycling collection systems will ultimately fail if there is no market for recyclable materials and/or no designers integrating secondary material into products. A clearer definition and understanding of CE might help with that system-wide thinking and adoption.

To begin to address this knowledge gap, there was a need to develop a basic, minimal definition and aligned versions of what a realized state of a CE may entail, particularly as research indicates that a combination of CE versions (i.e., efficiency and sufficiency) is presumably most effective [60]. For this, we must be able to clearly define what each potential CE version (Fig. 5) entails, to reveal synergies and contradictions.

If we start from a realized CE as a resource-centric system in which materials are moved through economic and industrial systems [22, 61], then we must focus on understanding the resource flow implications of a CE, particularly for materials [15, 23, 31], before we can understand social aspects (e.g., [62]). Accordingly, we start with a material flow perspective (Fig. 4) to discern the implications of different versions of a realized CE (Fig. 5).

So-called "CE Loop Strategies", such as slowing (e.g., repair) and closing (e.g., recycling), are often mentioned as overarching strategies of "… the cycling of goods" [8, 32]. However, the very concept of "loops" and "circularity" are often unclear; "loops" in CE theory sometimes stand for keeping materials in the system, distinguishing it from, e.g., virtualization and sharing of goods [8]. Moreover, CE "loop" and "strategy" are sometimes erroneously used interchangeably (e.g., [63]). As a result, the CE loop strategies, their names, and definitions are described differently throughout the literature (Sect. "Analysis of CE Loop Strategies Definitions in the Literature").

The Circular Economy Loop Strategies (CELS) Framework

Building upon current-state definitions and explorations of CE strategies and pathways, as part of Step 2 (Fig. 2), we propose an inclusive, expansive framework with a primary objective that it must cover the minimal conditions and operations of a realized CE. Using durable consumer products (e.g., clothing, electronics and furniture) as the applied example, we propose "the CE Loop Strategies Framework" (CELS Framework) (Table 1) as a model, method, and tool for systematically and comprehensively capturing the implications of different versions of a realized CE (Fig. 5). As such, the Framework provides a method for adapting a material flow perspective to develop a common understanding of what a realized CE entails, onto which additional aspects (e.g., social aspects and human needs; [24, 27]) can be added via future research.

Table 1presents the final CELS Framework, consisting of the five CE Loop Strategies (CELS) (Table 1, column 1), their respective goals (Table 1, column 2) and their implica-

tions for durable consumer products (Table 1, column 3), considering only material management (i.e., delimiting energy recovery, regeneration of ecosystems, and non-material efficiency of products). In the CELS Framework, an asterisk (*) included for the "Closing" and "Slowing" strategies denotes how the presence of this loop was considered more "foundational" (i.e., their presence constitutes a minimum level for what is to be considered a CE). However, this assumption also inherently depends on the CE versions (Fig. 5), as discussed in Sect. "Discussion".

The CELS implications listed in column 3 (Table 1) are intentionally formulated to be broad and flexible, encompassing any necessary product design, infrastructure, and consumer behaviors, without prescribing specific system arrangements or solutions. Each implication is organized under the CELS to which it most directly relates. For instance, the virtualization or digitalization of products (e.g., converting a paper book into an eBook) is placed in the row of the Narrowing CELS in Table 1, since digitization reduces the material input going into each product unit. However, it is important to note that both the implications and—per extension—the CELS themselves may overlap, such as by yielding contradictory or synergistic effects. For example, digitization also pertains to the Intensifying CELS, since digital products can be used simultaneously by product users. In the CELS Framework (Table 1), these overlaps are clearly indicated next to relevant implications with bracketed numbers that are color-coded to correspond to the relevant overlapping (secondary) CELS, for instance, blue for the Intensifying CELS. The ten areas of overlap (or trade-offs) are explained at the bottom of Table 1; while not exhaustive, these were considered the most relevant for the Framework's intended level of detail. The CELS Framework, presented in Table 1, constitutes the validated and final Framework resulting from the completion of Steps 1 −3 in Fig. 2.

Distinguishing the CELS Framework from other CE Models

The proposed CELS Framework does not constitute "just another" CE definition or framework. Rather, it *integrates and builds upon established CE frameworks*, including the EMF's Butterfly Diagram, the 3Rs Framework e.g., [5], and the 10Rs [6, 7, 25], and existing definitions of CE 'loops' [18] while also *extending and deepening understanding* via a comprehensive set of defined, relevant CELS and their implications for durable consumer products. Ongoing debates about the nature and purpose of CELS—e.g., whether a "slowing" CELS is strictly circular, because it can take the form of "slow tourism" that is not "circular" [56]—is partially due to mismatched perceptions of scope. Our narrower and applied focus on durable consumer products offers a common understanding of the specific implications of CELS for these products, and thus a common paradigm.

Unlike existing models, the CELS Framework systematically (although not exhaustively) accounts for *overlaps* that can exist between CELS (i.e., synergies and trade-offs), thereby presenting a common starting point for future operationalization of circularity, i.e., by generating insights regarding such trade-offs that can inform and potentially benefit policy makers and practitioners. Given the many proposed definitions of CE [2], and the diverse ways in which CE is being implemented within policy [3], the CELS Framework also constitutes *a tool for discerning and comparing the implications of different versions of a realized CE* in the context of durable consumer products, primarily by shedding light on

the characteristics of circularity, beyond just the traditional trajectory of 'circular' material flows. In application, this can offer a clearer distinction between the possible versions and goals of a realized CE (Fig. 3), thus benefiting CE researchers as a foundation for further CE explorations. To this end, the CELS serves as both a scoping tool and a boundary condition [37] in defining the potential content of a realized CE.

Results & Analysis

In this section, the analysis of the literature on CE Loop Strategies is presented, followed by the results of the Delphi study, organized by: (1) the alterations that were incorporated into the CELS Framework (i.e., refinement) (Sect. "The Main Participant Feedback Implemented into the CELS Framework"; and (2) participants' feedback on Framework's usefulness, implications, and limitations (Sect. "The CELS Framework's Usefulness and Limitations").

Analysis of CE Loop Strategies Definitions in the Literature

Clarifying Reduction Loops for the Framework: In the CELS Framework (Table 1) the goal of "reduce" is expressed in two of the loop strategies. One reduction CELS is "Simplifying" [1], which in our application implies that products that are not creating substantial value are eliminated from the market (i.e., avoidance of excess consumption and production). This is commonly referred to as "reduce", "refuse" and "rethink" [6, 7] and entails a reduction to the overall volume of materials in the economic system—corresponding to sufficiency. Simplifying (i.e., sufficiency) is tentatively brought up by Ghisellini et al. [1], referencing "a simpler lifestyle" in a CE. The limited attention to the Simplifying CELS can explain by it consisting of "pseudo-loops" [63] in that they: "… [do] not address the cycling of goods" [32]. However, as the decoupling of economic growth from resource use has been debunked [64], it is becoming increasingly clear that a CE without Simplifying CELS (i.e., absolute reductions to consumption and production levels) is unlikely to be environmentally sustainable, which makes the inclusion of this CELS in the CE definition gaining traction in academia (e.g., [23, 53, 65–67]) and policy making. Nevertheless, the inclusion of Simplifying CELS represents a key departure from the core of CE theory, which traditionally focuses on efficiency and decoupled economic growth [2, 34, 63]. However, in terms of circularity, simplifying CELS addresses *the magnitude* of loops, which we return to in the discussion (Sect. "Discussion").

The second, more traditional reduction CELS is "Narrowing", which (from a material management perspective) seeks to decrease the amount of material inputs into individual product units (i.e., less materials in the design or the offering of a digitized product in place of a physical one) [1, 31, 32, 68], p. 110. This approach is sometimes distinguished from the CE concept altogether as "operational eco-efficiency" [60], presumably because it does not give rise to circularity on its own. Geissdoerfer et al. [31] define narrowing in the form of "dematerialization"—the substitution of physical products for services (i.e., performance and capacity), which overlaps with our definition of "intensifying" (i.e. PSS models, renting and sharing) (Table 1). Similarly, Konietzko et al., [9] defines narrowing as "maximizing user capacity" from having fewer products in operation at the same time (i.e., Table 1, *Intensifying*).

A second controversial CELS is "intensifying" (i.e., avoiding idle products, such as PSS models), which according to some, do not pertain to circularity, or sustainability [22]. However, it can reduce systemic material inputs and outputs [34] (Fig. 5) and is therefore included in the CELS Framework.

Importantly, a CE without a simplifying CELS may give rise to rebound effects, such as when money saved by repairing (i.e. *slowing)* instead of buying new is used to acquire another product that cancels out the lessened environmental impact and is not compatible with a more closed system [22, 69] (Fig. 5). On this note, for narrowing (Table 1) to have a positive net effect, it also requires slowing (i.e., a time consideration): the net benefits of material reductions achieved as a result of product dematerialization (e.g., designed elimination of material weight) may not be realized if accompanied by an increase in the manufacturing rates of such products see [32]. Moreover, to make recycling (a closing CELS) environmentally feasible, overall reductions (i.e., those that can be achieved via simplifying CELS) are also necessary, given the high energy demand and inevitable value loss in recycling processes [69].

Overlaps & Distinctions Between the CE Loop Strategies' Implications: Not only are the types of CELSs discussed in the literature somewhat different, but different implications are also assigned, due to the many overlaps. "Intensifying" as access-based consumption (i.e., the product user is not assuming ownership) is sometimes grouped under both "reduce" strategies (i.e., simplifying and narrowing) as it allows for the use of less material in the economic system by increasing the utility of already existing products [67], p. 110, [70]. Another overlap can be seen in how the Intensifying CELS in the form of PSS models—renting and sharing—also can contribute to "slowing" since the passing of products between different users can extend products' lifetimes [70]. Acknowledging this, Bocken et al. [32] organized "intensifying" under "slowing", while Geissdoerfer et al. [31] separate the two—a distinction majority of the experts in this study agree with since their implementation, or operationalizing, are different (e.g., reuse vs. sharing).

Geissdoerfer et al. [31] separate "Intensifying" (e.g., absence of ownership) from "dematerializing" (our Narrowing, see Table 1) and organize the implications of renting and leasing (i.e., some PSS models) under "dematerializing", as it is not a physical product that is sold, instead the "product" is the performance or capacity provided by the product (i.e., dematerialized). "Intensifying", in their definition, consists only of sharing. The result of this study shows that the experts do not agree with this as we are focusing on the implications of the CE Loop Strategies (Table 1, column 3).

The Importance of System-Level Perspective: The definition of the CELS implications can vary depending on the system-level perspective taken (e.g., household vs. business v. entire economic system). Using the example of PSS models, from the product provider perspective, PSS models ideally incentivize the employment of Slowing CELS (e.g., design products for durability and ensure that their products are repaired and maintained) e.g., [9]. At the larger system level, however, PSS models entail utilization maximization (i.e., intensifying) since they are thought to disincentivize households from keeping idle products, due to the recurring fee for continued usage; users are thereby incentivized to return underused or unused products—as opposed when a product is already bought and paid for. The return of an idle product to the PSS provider, and the subsequent opportunity for someone else to use the product can lead to simplifying (i.e., *fewer products* in the economic system), as well as intensifying (i.e., *fewer idle products*)—both at the system and household level. As such,

PSS business models could arguably constitute an implication of intensifying, simplifying, and slowing loop strategies—depending on the system-level perspective. In this paper, we favor a systems view (Fig. 4), meaning that PSS models and sharing are organized under primarily the Intensifying CELS, while the Narrowing CELS consist of designing products with less or no material (i.e., excluding the provision of a physical product as a service, which in our definition pertains to "Intensifying"). These overlaps across the Loop Strategies and system levels are, however, important to note and consider (see Overlaps in colored bracketed numbers, defined at the bottom of Table 1).

Under "reduce", Henry & Kirchherr [67], p. 110 include: (1) minimizing the use of hazardous materials and substances that can hamper recycling (i.e., closing) and reuse (i.e., slowing), as well as; (2) incorporating as little primary material as possible in product design (i.e., closing). However, these applications are different from both dematerializing and narrowing as they entail the reduction of certain types of materials, not materials overall. More importantly, these applications pertain to "closing" as they enable the transition of what is traditionally considered waste into a secondary material [32]—and are therefore organized as such in Table 1.

As shown in this section, the CELS Framework (Table 1) brings enhanced clarity to the existing CE literature regarding the name, number, goal and implications of CE Loop Strategies.

The Main Participant Feedback Implemented into the CELS Framework

The (final) CELS Framework received an average acceptance rate of 89.3% (measured using a Likert scale of 1—7) from the group of 17 experts.

Remedies Implemented

Two remedies (i.e., perceived misrepresentation; Sect. "Testing and Refining the Framework") in the initial Framework were identified.

Remedy#1: The Foundational Nature of Slowing and Closing

One participant identified the perceived illusion from the CELS Framework that the CE Loop Strategies were "equal" and that the implementation of each one, individually and in isolation, could be considered a CE. For example, narrowing can be implemented in a linear economy, but on its own, cannot make a CE [56]. To acknowledge this, asterisks were introduced next to "Slowing" and "Closing" in the Framework to denote their foundational role in a CE. Following this refinement of the CELS Framework introduced in round 2, a second participant commented that:

> "[all] these strategies are as foundational for any circular economy as slowing and closing are. Why would even a growing economy need to take up unnecessary volumes of stuff that cause issues that they then have to resolve? These economies may as well be designed "narrower" in a material sense from the get-go."

Similarly, a third participant pointed out how Simplifying is on a different "level" compared to the other CE Loop strategies; "Simplifying is the goals of all the other strategies, i.e. that is the overall goal of a circular economy." This potential contribution of the other loop strat-

egies to Simplifying is exemplified in Overlaps 7 and 10 in Table 1, albeit not exhaustively. Importantly, both of these comments speak to the assumption of an as-much-as-possible "closed loop"—a sustainable CE (Fig. 5). This is discussed more in Sect. "Discussion".

Remedy #2: Changing Product Lifetime to Service Life in Overlap 9

The second remedy was related to Overlap 9 in Table 1, which originally stated that the Intensifying of loops can interact negatively with Slowing since intensified usage of product leads to increased wear and tear, and thereby shortening the product's "lifetime" (see Supplementary File Introduction for the survey document). A participant pointed out how "lifetime" was erroneous; the correct term is "service life." This was remedied in the refined Framework (Table 1).

This feedback relates to Overlap 6 (Table 1), which states that:

> "The Slowing of loops through, e.g., reuse and repair of (otherwise) idle products, can ensure not only a longer product lifetime (i.e., Slowing), but can also contribute positively to Intensifying (i.e., maximized utilization) of said product."

The above overlap captures how Slowing CELS plays a role in maximizing product utility (e.g., taking an unusable, broken product out of storage to instead have it be repaired for ensuing use). To this point, two participants commented that slowing is necessary for intensifying to be relevant in CELS and that the implications of "Idle products are distributed to a situation of use", listed as an implication for Intensifying (Table 1), also pertains to Slowing. To this, two other participants questioned whether repair, refurbishing, and repurposing are characterized as contributing to intensifying; in that case, all slowing loop implications contribute to intensification, which—they argued—begs the question of why Slowing and Intensifying are even different CELS. To this end, although the two CELS are interconnected and interrelated, they can also differ; as brought up by another participant, Intensifying shortens, or ideally eliminates, a product's idle time and thereby *maximizes utilization* by increasing the intensity of usage—some of which is done through the Slowing CELS. These efforts can shorten the product's service life (rather than lifetime—the refinement implemented to Overlap 9 outlined above). Slowing, on the other hand, increases value utilization by *lengthening the product's lifetime* (i.e., the overall time that the product is used), regardless of frequency of use. Importantly, as Overlap 9 (Table 1) states, these two strategies are not mutually exclusive as products can be made to be highly durable to withstand both more intense *and* longer uses. As such, while different, these two CELS share some of the implications, but not the goal nor stakeholder agencies, and should therefore be distinguished for the CELS Framework to be meaningful.

Alterations Implemented Through Voting

Voting was used to make decisions about, and changes to, content and details in the second survey round.

Voting #1 The Loop Strategy name "Simplifying"

According to over 25% of the respondents, the Loop name "Simplifying" was found less suitable because its implications (i.e., multifunctional products necessitate products being more complex) did not fit with the name. Instead, "refusing" or "limiting" was proposed, among others. These alternatives were put up for voting in round 2.

Although several of the other participants, who had not commented on the loop name, agreed with the criticism, Simplifying gained the majority votes as the other loop names were considered too narrow, as well as having negative connotations (i.e., that products fulfilling needed functions would be excluded), such as feeling "restrictive". To this, one participant suggested adding the following to the definition of Simplifying: "… without limiting the functionality and utility achieved". One participant commented that: "In a way, it is sort of "Maximizing" or "Optimizing" as the same amount of 'value' could be available with less material by eliminating non-valuable products and more efficiently using material to create products providing more value per material unit." This speaks to the overlap between Simplifying and Narrowing. Also, one respondent found "Limiting" too close to the other CELS "Narrowing" (Table 1).

Next, addition of Overlaps 7 and 10 were deemed "clarifications", but since their additions added significant details, they were subject to voting in round 2.

Voting #2 Overlap 7

Overlap 7, stating that: "The Slowing of loops can extend product service life or lifetime, thus limiting the need for new production and consumption, and can thereby positively impact Simplifying" was added in response to feedback on the role of slowing in simplification. In feedback to this voting, three participants brought up how this holds true only in the absence of rebound effects (i.e., given that slowing replaces the acquisition of an additional product).

Voting #3 Overlap 10

One participant suggested that the minimization of the use of primary materials and the use of recycled materials in products (i.e., pertaining to the Closing CELS) should be moved to "Simplifying". In response, the research team proposed Overlap 10, saying that "The Closing loop strategy can contribute positively to Simplifying as the production of each new product may require relatively less primary material inputs and use relatively more secondary or cycled materials." Its inclusion was approved, finding that less primary material is needed to enter the economic system (two participants) although the relation between closing and simplifying was found to be non-causal, but rather indirect. Also, one participant pointed at the need for absolute consumption reductions for recycling to be able to play this role, hence the role of simplifying for recycling to be able to lead to (i.e., support) simplifying.

Clarifications Introduced Without Voting

Several clarifications (i.e., to increase understanding of what was already in the material) in terms of the wording of the Implications, as well as the Overlaps and examples were introduced in round 2 (cf., Supplementary File).

The implication of Simplifying was originally worded "Unnecessary/Excess consumption and production is avoided" to denote the system level of this CELS (Supplementary File, Sect. "Introduction"). However, several suggestions for adjusted formulations were proposed, such as: "non-essential products are not consumed", and the "need for material inputs is reduced". As such, in round 2, a clarification was introduced with the implications: "Products that are not creating substantial value are eliminated from the market". This was selected by the research team to be consistent with the product focus of the remaining Loop Strategy Implications in the Framework (see Table 1). However, in round 2, one participant

reacted to this clarification by pointing out the inconsistencies with the use of the word "value" with the Framework's restricted considerations for material flow. As such, it constituted a breach of the framework's underlying delimitations and assumptions (i.e., model "defensibility") [71]. Also, the term "value" is debated in the sustainable consumption literature and remains undefined, thereby introducing complexity (one participant). As such, this clarification should perhaps have been subject to voting.

Participant disagreements and underrepresented views are summarized in the Supplementary File. These diverging views show the need for a common CE framework.

The CELS Framework's Usefulness and Limitations

The participants' thoughts on the usefulness and limitations (i.e., areas of less usefulness) of the CELS Framework is presented in Table 2.

General Usefulness

Given the diverse areas of expertise and practice of people who are tasked with operationalizing CE strategies, the CELS Framework was considered by participants to be "very valuable" as an educational tool (i.e., for stakeholders with less CE knowledge) and as a communication tool that can support improved alignment and understanding amongst diverse expert groups and areas of expertise (Table 2). The proliferation of CE-related definitions and terminology is increasingly problematic. For example, the slowing and closing implications are often inappropriately "lumped together and mis-used" (one participant). This need for a common vocabulary could also be seen in another example of divergent opinions about whether it is "products" or "components" that are subject to remanufacturing. In the remanufacturing process, products are disassembled into their components' parts. These components may, themselves, be remanufactured, and placed into an inventory of components to be used as part of repair or maintenance activities (e.g., component remanu-

Table 2 Areas of Usefulness & Limitations of the Framework, as Identified by the Participants

Relative usefulness of Framework	Comments Received from Participants (not summative[a])
Useful (with specific uses proposed)	
Product Design and Manufacturers/Product providers	4
Policymakers	3
Education & Academia	1
All of the Above	6
Useful (general)	1
No/Limited Usefulness (specific)	
Product Design and Manufacturers/Product providers	2
Policymakers	1
Education & Academia	0
Products Users	2
No/Limited Usefulness (general)	2

[a]Participants are counted once for each stakeholder they mentioned. For example, if someone mentioned both businesses and policymakers, they appear on each of these table rows

facturing), or these components may, themselves, be remanufactured and then reintegrated back into the same original product (e.g., product remanufacturing). That remanufacturing can be performed at different levels (component vs. product) can cause terminology confusion, as evidenced by 3 out of 17 experts wanting the CELS Framework to say that it is *products* that are remanufactured, while 14 felt that *component* remanufacturing was appropriate. This distinction matters because it highlights how different perceptions and depth of knowledge regarding practical systems (e.g., industrial operations or supply chain configuration) can affect the degree of (mis)alignment. In summary, to establish a common understanding and agreement, the CELS Framework can serve to clarify the terms, what is meant, and what the implications are for durable products (one participant).

The Framework was found to be: "… useful to understand the spectrum of strategies that are available to use materials more sustainably." (one participant, echoed by a second participant). Another participant found that: "A well-defined Framework for [CE] Loop Strategies constitutes the basis of analysis of CE solutions, therefore it is extremely useful for understanding, designing and implementing CE strategies.". On this note, the CELS Overlaps were mentioned the most in terms of the CELS Framework's usefulness (four participants), presumably because it helps to: "… see the connections between the various [CE loop] strategies, and how they affect one another". As such, the Framework showcased how the achievement of the synergies between the CE Loop Strategies will require policies and strategic planning to ensure that each actor does their share (one participant).

Theoretical and Managerial Implications

In terms of managerial implications of this work, the CELS Framework provides managers, policymakers, and product designers with a practical, foundational tool for planning and aligning CE strategies with implementation. By clarifying the goals, overlaps, and trade-offs among five key strategies for durable products (c.f., [6, 12, 13, 15, 20, 22, 25, 43, 54–56, 62, 63, 65, 72]), the CELS Framework can support more informed decision-making about which strategies to prioritize based on organizational objectives and resource constraints. The framework also helps identify the most relevant life cycle stages and system scales for implementation, supporting integrated approaches that minimize rebound effects and optimize material flows.

From a theoretical perspective, this study advances CE theory by synthesizing diverse and numerous CE representations and concepts into a single coherent framework that connects loop strategies to material flow characteristics and establishes common vocabulary for CE research (c.f., [1–7, 9–11, 25]). By reducing ambiguity and enabling comparative analysis of different CE versions (e.g., recycling-focused vs. sufficiency-driven) (see Sect. "Discussion" for more on this), and by incorporating expert consensus through a Delphi method [37, 48, 49], the CELS Framework strengthens conceptual clarity and offers a foundation for future research on operationalization, prioritization, and integration of social and economic dimensions within CE transitions [66, 69, 73].

Limitations

The key criticism of the CELS Framework itself consisted of how it adds marginal newness in an already crowded space in CE research of various definitions and frameworks (four par-

ticipants); one participant claimed that: "… there is a clear definition of CE loop strategies (slowing, narrowing, closing and regenerating) that are well accepted. What is proposed is a marginal change…" This statement is against the findings of the literature review which could not identify any comprehensive definitions of the CE Loop Strategies (Sect. "Analysis of CE Loop Strategies Definitions in the Literature"). Also, this participant overlooks simplifying and intensifying loop strategies. While some participants pointed out the need to move away from theoretical definitions and focus on applications of a CE, others noted the ability of the CELS Framework to accomplish just that—speaking to how a CE is frequently defined, but lacks consensus [25].

The remaining weakness of the CELS Framework can be seen as areas of development for future iterations of the Framework. Foremost, the Framework does not support the prioritization of goals and design-tradeoffs, such as what is environmentally optimal (e.g., a product that is long-lived vs. made from recycled content vs. made from bio-based material)(two participants). Similarly, an e-book (i.e., Table 1; Intensifying) is not necessarily more environmentally preferable compared to a printed book, due to how material intensive e-readers are (one participant). Similarly, the Framework does not consider maximal value retention options (three participants). For example, the repurposing (or downcycling) of a window frame into wall art is not truly circular, it is just keeping something out of the landfill (one participant). This, of course, has to do with the delimitation of environmental aspects from the CELS Framework and the strict focus on material flows in a realized CE.

In terms of the level of details, while some found the CELS Framework to be overcomplicated, some pointed out that "reality is more complex than this" (one participant). For usefulness, the Framework need to be simplified (i.e., reduce the level of detail) or at least change the graphic representation, with the overlaps, e.g., organized on the side of the CELS Descriptions, or use a causal loop diagram as a companion (three participants). As such, a Table is perhaps not the ideal vehicle for conveying these ideas. One participant found that the CELS Framework "… doesn't translate easily into accessible language for conversations about behaviour change in a wide sense including in households, business operations and strategies, and policy", indicating that it is more suitable for product designers and manufacturers and policymakers (Table 2). However, the purpose of the CELS Framework is not primarily to be a tool for transition, but for evaluating different CE versions (Fig. 5; Sect. "Discussion").

Importantly, the CELS Framework depicts potential or possibilities of a CE. Taking an example that one participant raised of multifunctional products (e.g., a cell phone with a built-in camera); a realized CE may lead to fewer products being acquired (i.e., simplifying) due to products being multi-functional, or it might not, depending on the specific circumstances (e.g., the product user might decide to buy a camera with additional capabilities, compared to the built-in camera). However, according to the contemporary understanding of how a realized CE would function, a multifunctional product has the *potential* to reduce the number of products in the system (i.e., simplifying). As such, due to this potential, "multifunctional products" are included as a CELS implication under Simplifying (Table 1). The difficulties in feeling confident in making estimations on the potentials of a future state was reflected in another participant's comment: "I don't have further comments, which is why I 'strongly agree', but I do not exclude that this view could change in the future".

Discussion

The following sections present evaluation and reflections of the main authors based upon insights, challenges, and research extension opportunities revealed through the development and multiple-round testing of the CELS Framework, from the advancement of a common vocabulary to the implications of CELS for diverse CE goals (versions, e.g., recycling-focused, vs. sufficiency-focused; Fig. 5).

A Common "Loop" Vocabulary

To support the development of a common vocabulary there is a need to increase the clarity of the distinct concepts of loops and circularity, and related terms.

CE Loop Characteristics

Like many of the visual representations of CE in the literature, CE Loops can be said to have four critical characteristics (Fig. 6).

A first, key characteristic of CE Loops (i.e., the flows of products, components and materials in the economic system that contributes to circularity) is their ***trajectory*** (or direction of flow), which within a CE should be 'circular', reflecting the various CELS as they

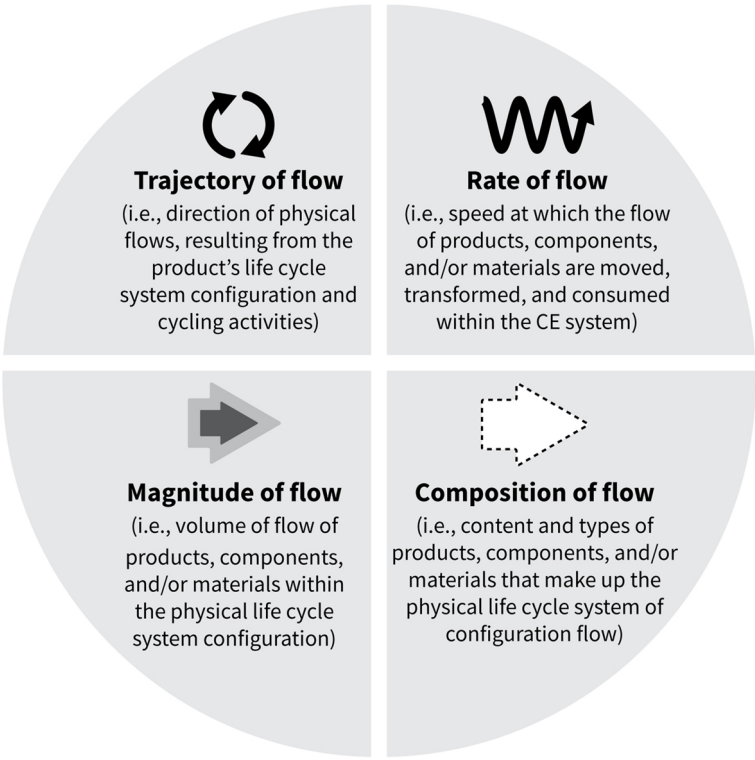

Fig. 6 The Four Characteristics of CE Loops

affect the physical flow of materials, components and products. First, the primarily circular shape can come from the employment of recycling ("closing") at the end-of-life (EOL) stage (Fig. 4)—the primary loop. However, recycling only closes the loop for materials, not products and components; as such, it may not be the best or primary desired pathwayto more advanced circularity (Fig. 5). To this point, a second type of loop can be referred as "connecting" as it ties a product's end of service life (or EOU) to the start of its subsequent (next) service life cycle, thereby closing the loops at the product and component level (i.e., achieve enhanced circularity). This connecting form of circular "trajectory" can be enabled via multiple CELS, which we return to below.

Where the goal of a CE also encompasses enhanced environmental sustainability (Fig. 5), CE Loops possess relevant characteristics in addition to (circular) trajectory (Fig. 6). The ***magnitude*** of the flows (i.e., the volume or quantity of materials and products) describes the physical size of each CE Loop's trajectory that constitutes the economic system (Fig. 4). The ***composition*** of the flows refers to their content (e.g., types and proportions of materials that comprise the flow), while ***rate of flow*** refers to the speed at which the products, components, and/or materials flow through the system (Fig. 6).

Connecting the CE Loop Strategies to the Loop Characteristics

As indicated in the CELS Framework (Table 1), CE Loop Strategies are diverse; however, they can be organized based on the characteristics (Fig. 6) of the CE Loops that may be targeted (or affected) by the adoption of a CELS (Fig. 7.a). For example, the adoption of a *slowing* CELS will primarily affect the CE Loop characteristic, *rate of flow,* which would—if successful—be *decreased*. Changes to these CE Loop characteristics are brought about through specific CE Loop "activities" (i.e., reuse and sharing), which, in turn, result in CE Loop "implications" (i.e., what is happening to/in the Loop for the loop activities to be pos-

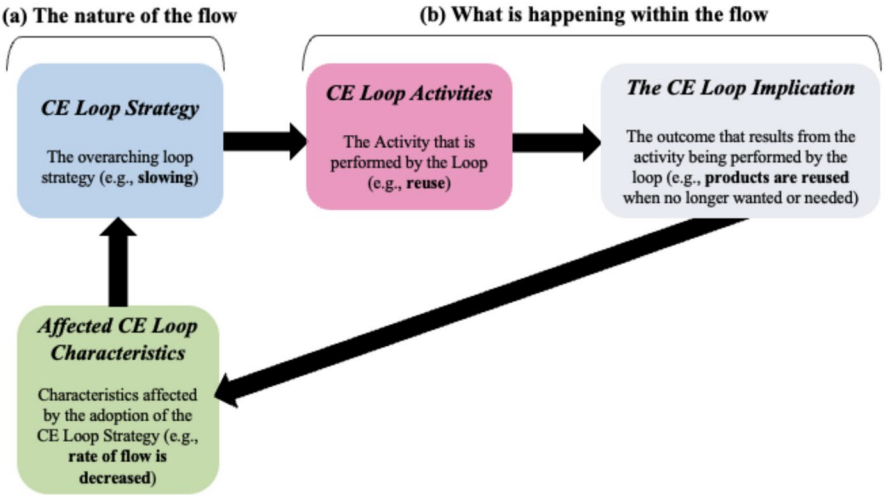

Fig. 7 The connection between CE Loop Strategies (CELSs) (Table 1) and CE Loop Characteristics (Fig. 6), reflected as *the nature of the flow* (i.e., outcome), 7(**a**); and the distinction between CE Loop Activity and CE Loop Implications, reflected as *what is happening in the flow* (i.e., process to get to the outcome), 7(**b**)

sible) (e.g., products are reused) (Fig. 7.b). These implications are listed in column 3 in the CELS Framework (Table 1).

These terms and their distinction are important for creating common understanding, aligned expectations, and thus more effective adoption of CELS.

Accordingly, CELS should be adopted based on the desired outcome (e.g., the impact upon the CE Loop characteristics) (Figs. 7.a and 8). Figure 8 demonstrates that multiple, diverse, and parallel CELS are needed to comprehensively address the trajectory, magnitude, composition, and rate of flow of materials and products within a realized CE (i.e., CE Loop characteristics).

For example, the adoption of a Simplifying CELS may lead to shifts in the magnitude and composition of material and product flows within a CE, but alone, will not meaningfully affect the trajectory or rate of flows of products and materials within a CE. Importantly, the CELS and its corresponding effect upon the CE Loop characteristics (Fig. 8) can have varying relevance and implications for "the degree" of circularity achieved (i.e., degree of system closedness and harmony with nature; Sect. "The Fundamentals of a CE" and Fig. 5).

The CE Loop Strategies at Different System Levels

The pursuit of CE Loop Strategies can have varied implications at different levels of the economic system and at different product life cycle stages (Fig. 9). For example, a *sSimplifying* CELS is a relatively higher-order strategy that requires system-level interventions. Implementation is largely limited to actors and decision-makers involved at the 'sourcing & manufacturing', and 'use' stages of the life cycle (Fig. 9).

Considering higher levels of environmental sustainability, as shown in Figs. 8 and 9, the reductions to the total amount of material input to, and output from, the economic system (i.e., degree of system closedness) may come—over time—out of a combination of *simplifying* (i.e., reducing the quantity of products by systemically lowering production and consumption levels), *narrowing* (i.e., using less materials per product units by changing the

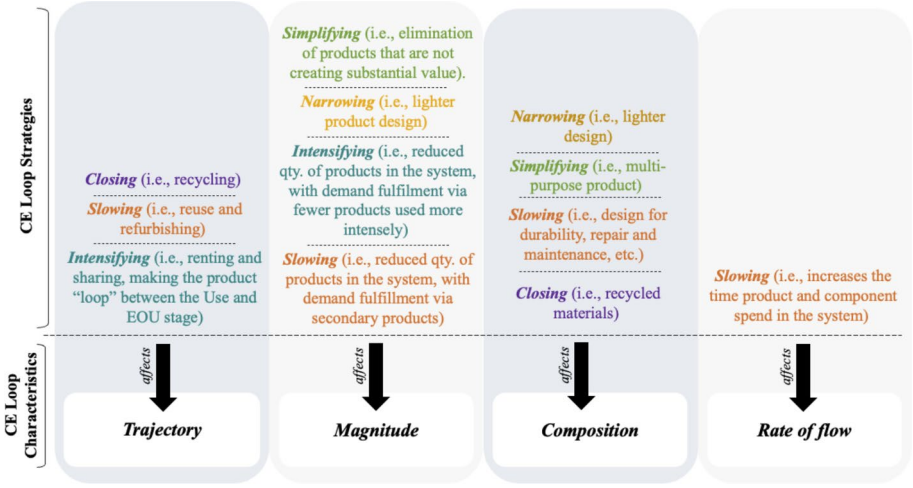

Fig. 8 Categorization of CE Loop Strategies, based upon the CE Loop characteristic(s) that are most affected by the associated CE Loop activity and CE Loop implications of the CELS

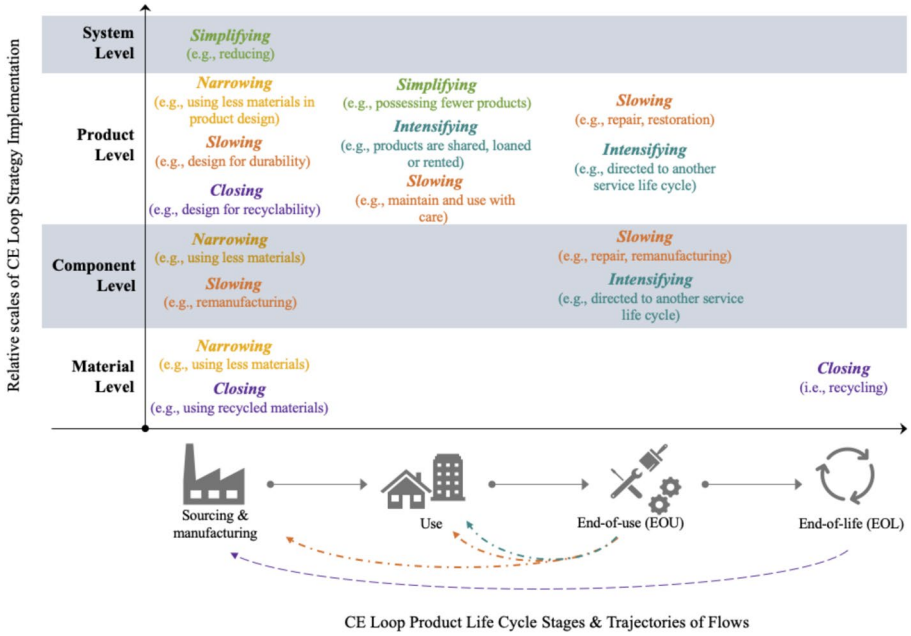

Fig. 9 The relative scales (y-axis), and the corresponding product life cycle stage (x-axis) at which the CE Loop Strategies are most optimally implemented (Fig. 4). While some consider that parts or components can still be salvaged at the EOL [74], EOL typically implies that there is no value left in the product or component form, only the material; hence that is what flows to "Sourcing & Manufacturing" from the EOL stage in Fig. 9. If there is any value left in the product or components, it is at EOU (not EOL), and those components or the whole product can be reused, repaired, refurbished, remanufactured, etc.—hence the components flow to the sourcing & (re)manufacturing stage while the product goes to the use stage (Fig. 9). While the *intensifying* CELS primarily takes place at component and product levels, it can also take place and be measured at material and system levels, i.e., material intensity of an economy [75, 76]. For durable consumer products, *intensifying* at the materials-level, is operationalized as a *closing* (e.g., recycling) CELS, as depicted in Fig. 9.). Inspired by [37]

product's design), *slowing* (i.e., prolonging product lifetimes—meaning increasing the time spent in the system, preferably at their highest value), *intensifying* (i.e., avoid idle materials or assets and instead optimize the utilization rates of products)[5], and *closing* (i.e., returning materials to the system as secondary materials). To this point, poor implementation of one CELS can negatively affect other loop strategies (see e.g., Overlap 5 in Table 1). This shows how the configuration of CELSs determines the environmental impact from the economic system (Fig. 8).

The CELS in Different CE Versions

The selection and implementation of CELS will differ, depending on the predominant CE version in play (Fig. 10). A CE that is primarily focused on the Closing CELS (via recycling) will be less effective at achieving desired changes in the magnitude, composition, and rate of flow within a CE (Fig. 10.A). In contrast, the strategic integration of multiple diverse CE Loop Strategies of intensifying, narrowing, and slowing (Fig. 10.B) and the addition of simplifying (Fig. 10.C) can increasingly contribute to the achievement of diverse and

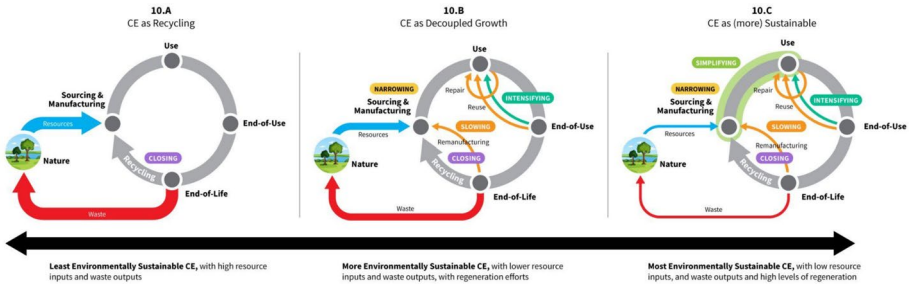

Fig. 10 The CELS in each CE version (c.f. Figure 5)

important shifts in the characteristics of a realized CE that may also lead to sustainability and greater harmony with nature (Figs. 10.B and 10.C, respectively).

Importantly, as captured in the CELS Framework, some of the CELS can be considered more "foundational", such as Closing and Slowing, while the others might be considered more "additional" or at least complementary for enhanced system "closedness" depending on the CE version (Fig. 10). However, the Narrowing CELS (e.g., using less materials in a product), if adopted on its own, will not address the linearity of an economy [56]. Figure 10 also captures how, in the context of durable consumer products, "CE Loops" can be defined as the configuration of flows into CE relevant systems or cascades in primary loops (i.e., the closing in gray main circle; Fig. 10) and connecting loops (i.e., arrows within the gray main circle; Fig. 10.B-C).

Fundamentally, Fig. 10 captures how the CELS Framework can function as a tool for discerning and comparing the implications and inherent limitations of different CE versions, depending on which CELSs and CE Loop characteristics that are relevant for said goal.

Concluding Remarks

The proliferation of CE-related definitions and terminology constitutes an increasing problem for establishing common understanding and agreement. As stated by one Delphi survey participant in our study: "… a realized CE cannot materialize without a well-established framework and understanding of what a CE transition entails." A fully implemented CE can be configured in multiple ways, under various goals (i.e., "CE versions"), such as one based on decoupled growth vs. post-growth/degrowth (i.e., the trajectory of economic growth). The implications of these goals, or end-states, need to be better understood to ensure a strategic transition efforts and desirable CE transition outcomes.

To improve foundational alignment of what a realized CE entails when it comes to material flows of durable consumer products, we introduced and tested the CE Loop Strategies (CELS) Framework, achieving 89% agreement among 17 participating experts.

Building on these findings, we also outline the characteristics of CE loops (i.e., trajectory, magnitude, composition, and rate of flow). We propose that although the trajectory of the material flow is circular, such a flow is not necessarily environmentally sustainable; such an outcome requires additional characteristics beyond the loop trajectory in the form of the rate, magnitude, and composition—determining the nature and conditions of material inputs and outputs to the economic system (i.e., degree of system "closedness") and degree

of harmony with nature. Accordingly, CELS that do not bring about circular trajectory of flows can still be essential, and, therefore, should be combined as parallel and aligned strategies for advancing toward a sustainable CE (Fig. 10.C). The system scales and stage of the product life cycle at which these loops can be most optimally implemented are also outlined. Lastly, the CELS Framework is used as a tool for evaluating and comparing the implications of material flows in different versions of a CE (i.e., with differing goals) (Fig. 10).

In terms of ***scientific contributions*****,** this paper presents a framework for CE Loop Strategies that builds on previous scattered notions of simplifying, narrowing, slowing, intensifying, and closing, and applies them to an important sector – consumer durables. We also extend our understanding of the CE concept by elaborating the characteristics of CE loops (i.e., trajectory, magnitude, composition, and rate of flow), system scales and relevant product life cycle stages. Together, these proposed concepts offer a clearer distinction between, and implications of, CE versions (Fig. 10)—strengthening the CE concept.

According to the Delphi study participants, the CELS Frameworks' main strength lies in how it maps the CE strategies available, whilst also acknowledging the overlaps (i.e., synergies and contradictions), and thereby the trade-offs, between the CELSs. As such, the CELS Framework can be used as a tool for designing strategic implementation of CELS —given the goal of a CE, such as decoupled growth vs. sufficiency (Fig. 10).

In terms of ***practical or societal implications***, the CELS Framework constitutes a starting point for developing policies and strategic planning to ensure that each actor can fulfill their share in achieving the CELS synergies and avoiding, or mitigating, contradictions. This is particularly important given that there is a consumption and production side to each CELS, which must be coordinated within (i.e., intra-CELS), in addition to across other Loop Strategies (i.e., inter-CELSs) to optimize material flows in a realized CE across the economic system (Fig. 8). As such, the concepts proposed in this paper have the capacity to help policymakers and practitioners design and implement more optimal strategies for circularity. Also, enhanced insights into the implications of a CE that this can generate may help to increase market predictability, and facilitate citizen buy-in and political support for the CE transition. However, further operationalization of the Framework is needed to demonstrate these benefits.

The material flow perspective adopted in this paper—with the purpose of developing a common understanding of what a realized CE entails—can be expanded in ***future research*** by adding, for example, social aspects and human needs [24, 27]. To this end, the Framework's weaknesses, as identified by the experts, can be remedied in future research, such as missing considerations for priorities between CELSs and implications in terms of degree of value-retention and environmental impact. Although normative, the CELS Framework should be explored for its potential to contribute to positivistic, practical CE theory development [76], such as how and when (i.e., under what specific conditions) reuse contributes to slowing, intensifying and/or simplifying. The CELS Framework can also be used to expand knowledge on different actor roles, such as the in the research underrepresented role and experience of consumers [42, 77] in a realized CE, considering activities and decisions expected from these individuals in the different loop activities and implications (Fig. 7).

It is important to acknowledge that the Delphi study results could have been different had the participants had more access to each other's feedback (i.e., a modified Delphi). Also, follow-up interviews could have resulted in more depth. As such, the CELS Framework is to be regarded as a basic conceptual framework for future research to further develop and validate.

While a majority of the participants found the CELS Framework useful, some pointed out the lack of newness of the CELS Framework, with one participant commenting that there are already too many CE frameworks and definitions. Still, the concept of a CE remains unclear—speaking to a lack of consensus that could partly been seen in this study. As such, there is a need to develop common and agreeable definitions as "translations" between the vast number of stakeholders involved in the CE arena.

The CELS Framework offers managers and policymakers a practical tool for aligning CE strategies by clarifying goals, overlaps, and trade-offs, enabling informed decisions on prioritization and implementation across life cycle stages. Theoretically, it consolidates fragmented CE concepts into a coherent framework linked to material flow characteristics, establishes a common vocabulary, and provides a foundation for future research on operationalization, prioritization, and integration of social and economic dimensions.

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Declarations

Disclaimer One of the authors (Milios, L.) confirms the responsibility of the authors for the choice and presentation of information contained in this paper, as well as for the opinions expressed therein, which are not necessarily those of UNESCO and do not commit this Organization.

References

1. Ghisellini P, Cialani C, Ulgiati S (2016) A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J Clean Prod 114:11–32. https://doi.org/10.1016/j.jclepro.2015.09.007
2. 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

3. Feiferytė-Skirienė A, Stasiškienė Ž (2021) Seeking circularity: circular urban metabolism in the context of industrial symbiosis. Sustainability 13(16):9094. https://doi.org/10.3390/su13169094
4. Leipold S et al (2023) Lessons, narratives, and research directions for a sustainable circular economy. J Ind Ecol 27(1):6–18. https://doi.org/10.1111/jiec.13346
5. Wilson DC, Velis CA, Rodic L (2013) Integrated sustainable waste management in developing countries. Proc Inst Civ Eng-Waste Resour Manag 166(2):52–68. https://doi.org/10.1680/warm.12.00005
6. Reike D, Vermeulen WJV, Witjes S (2018) The circular economy: new or refurbished as CE 3.0? — exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. Resour Conserv Recycl 135:246–264. https://doi.org/10.1016/j.resconrec.2017.08.027
7. J. Potting, M. P. Hekkert, E. Worrell, and A. Hanemaaijer, "Circular Economy: Measuring innovation in the product chain," PBL Netherlands Assessment Agency, Jan. 2017. [Online]. Available: http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf
8. Ellen MacArthur Foundation, "Growth within: A circular economy vision for a competitive Europe," Cowes, UK, 2015. [Online]. Available: www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf
9. Konietzko J, Bocken N, Hultink EJ (2020) Circular ecosystem innovation: an initial set of principles. J Clean Prod 253:119942. https://doi.org/10.1016/j.jclepro.2019.119942
10. ISO, "59004:2024 Circular economy — Vocabulary, principles and guidance for implementation," Edition 1, 2024.
11. Ellen MacArthur Foundation, "Towards The Circular Economy: Economic and business rationale for an accelerated transition Vol. 1," 2013. [Online]. Available: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf
12. Moraga G et al (2019) Circular economy indicators: what do they measure? Resour Conserv Recycl 146:452–461. https://doi.org/10.1016/j.resconrec.2019.03.045
13. IRP, "Re-defining Value – The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy," The International Resource Panel, Nairobi, Kenya, 2018.
14. W. R. Stahel, *The circular economy: a user's guide*. London ; New York: Routledge, Taylor & Francis, 2019.
15. Velenturf APM, Archer SA, Gomes HI, Christgen B, Lag-Brotons AJ, Purnell P (2019) Circular economy and the matter of integrated resources. Sci Total Environ 689:963–969. https://doi.org/10.1016/j.scitotenv.2019.06.449
16. Müller MO, Stämpfli A, Dold U, Hammer T (2011) Energy autarky: a conceptual framework for sustainable regional development. Energy Policy 39(10):5800–5810. https://doi.org/10.1016/j.enpol.2011.04.019
17. W. Stahel, "The Product-Life Factor," in *An Inquiry into the Nature of Sustainable Societies, the Role of the Private Sector*, S.G.O, Ed., Huston, Texas, USA: The Mitchell Prizes, 1984.
18. Murray A, Skene K, Haynes K (2017) The circular economy: an interdisciplinary exploration of the concept and application in a global context. J Bus Ethics 140(3):369–380. https://doi.org/10.1007/s10551-015-2693-2
19. Mathews JA, Tan H (2011) Progress toward a circular economy in China: the drivers (and inhibitors) of eco-industrial initiative. J Ind Ecol 15(3):435–457. https://doi.org/10.1111/j.1530-9290.2011.00332.x
20. Corvellec H, Stowell AF, Johansson N (2022) Critiques of the circular economy. J Ind Ecol 26(2):421–432. https://doi.org/10.1111/jiec.13187
21. Giampietro M, Funtowicz SO (2020) From elite folk science to the policy legend of the circular economy. Environ Sci Policy 109:64–72. https://doi.org/10.1016/j.envsci.2020.04.012
22. Zink T, Geyer R (2017) Circular economy rebound. J Ind Ecol 21(3):593–602. https://doi.org/10.1111/jiec.12545
23. Velenturf APM, Purnell P (2021) Principles for a sustainable circular economy. Sustain Prod Consum 27:1437–1457. https://doi.org/10.1016/j.spc.2021.02.018
24. Calisto Friant M, Vermeulen WJV, Salomone R (2024) Transition to a sustainable circular society: more than just resource efficiency. Circ Econ Sustain 4(1):23–42. https://doi.org/10.1007/s43615-023-00272-3
25. Kirchherr J, Yang N-HN, Schulze-Spüntrup F, Heerink MJ, Hartley K (2023) Conceptualizing the circular economy (revisited): an analysis of 221 definitions. Resour Conserv Recycl 194:107001. https://doi.org/10.1016/j.resconrec.2023.107001
26. Bauwens T, Hekkert M, Kirchherr J (2020) Circular futures: what will they look like? Ecol Econ 175:106703. https://doi.org/10.1016/j.ecolecon.2020.106703
27. Calisto Friant M, Vermeulen WJV, Salomone R (2020) A typology of circular economy discourses: navigating the diverse visions of a contested paradigm. Resour Conserv Recycl 161:104917. https://doi.org/10.1016/j.resconrec.2020.104917

28. Weigend Rodríguez R, Pomponi F, Webster K, D'Amico B (2020) The future of the circular economy and the circular economy of the future. Built Environ Proj Asset Manag 10(4):529–546. https://doi.org/10.1108/BEPAM-07-2019-0063
29. 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
30. Blomsma F, Brennan G (2017) The emergence of circular economy: a new framing around prolonging resource productivity. J Ind Ecol 21(3):603–614. https://doi.org/10.1111/jiec.12603
31. Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ (2017) The circular economy – a new sustainability paradigm? J Clean Prod 143:757–768. https://doi.org/10.1016/j.jclepro.2016.12.048
32. Bocken NMP, 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(5):308–320. https://doi.org/10.1080/21681015.2016.1172124
33. Wieser H, Tröger N (2018) Exploring the inner loops of the circular economy: replacement, repair, and reuse of mobile phones in Austria. J Clean Prod 172:3042–3055. https://doi.org/10.1016/j.jclepro.2017.11.106
34. Kjaer LL, Pigosso DCA, Niero M, Bech NM, McAloone TC (2019) Product/service-systems for a circular economy: the route to decoupling economic growth from resource consumption? J Ind Ecol 23(1):22–35. https://doi.org/10.1111/jiec.12747
35. Franzo S, Urbinati A (2023) Managing resource loops in circular supply chains: a taxonomy of multi-sided platforms in the B2B setting. Ind Mark Manage 115:185–197. https://doi.org/10.1016/j.indmarman.2023.09.016
36. Urbinati A, Chiaroni D, Chiesa V (2017) Towards a new taxonomy of circular economy business models. J Clean Prod 168:487–498. https://doi.org/10.1016/j.jclepro.2017.09.047
37. Gbededo MA, Liyanage K (2020) Descriptive framework for simulation-aided sustainability decision-making: a delphi study. Sustain Prod Consum 22:45–57. https://doi.org/10.1016/j.spc.2020.02.006
38. Beiderbeck D, Frevel N, Von Der Gracht HA, Schmidt SL, Schweitzer VM (2021) Preparing, conducting, and analyzing Delphi surveys: cross-disciplinary practices, new directions, and advancements. MethodsX 8:101401. https://doi.org/10.1016/j.mex.2021.101401
39. Skulmoski G, Hartman F, Krahn J (2007) The delphi method for graduate research. J Inf Technol Educ Res 6:001–021. https://doi.org/10.28945/199
40. A. Wilkinson, "Strategic foresight primer," European Political Strategy Center, 2017.
41. Vita G, Rao ND, Usubiaga-Liaño A, Min J, Wood R (2021) Durable goods drive two-thirds of global households' final energy footprints. Environ Sci Technol 55(5):3175–3187. https://doi.org/10.1021/acs.est.0c03890
42. Shevchenko T, Saidani M, Ranjbari M, Kronenberg J, Danko Y, Laitala K (2023) Consumer behavior in the circular economy: developing a product-centric framework. J Clean Prod 384:135568. https://doi.org/10.1016/j.jclepro.2022.135568
43. Blomsma F, Tennant M (2020) Circular economy: preserving materials or products? Introducing the resource states framework. Resour Conserv Recycl 156:104698. https://doi.org/10.1016/j.resconrec.2020.104698
44. Kabir MH, Mahbubul Alam M (2021) Developing a conceptual model for identifying determinants of climate change adaptation. J Climate Change 7(1):25–35. https://doi.org/10.3233/JCC210003
45. Hamilton AL, Coldwell-Neilson J, Craig A (2014) Development of an information management knowledge transfer framework for evidence-based occupational therapy. Vine 44(1):59–93. https://doi.org/10.1108/VINE-12-2012-0051
46. Atlasi R, Chakoli AN, Niakan Kalhori SR, Moradi S, Naemi R (2021) Design and validation of the conceptual model of scientometric system in research centers. J Scientometric Res 10(2):175–183. https://doi.org/10.5530/jscires.10.2.32
47. M. Jayawardena *et al.*, "Delphi Technique: How Expert Panels Predict Emerging Opportunities and Challenges in Renewable Energy," Jan. 2022, https://doi.org/10.1596/IEG167125.
48. Parker G, Kastner M, Born K, Berta W (2021) Development of an implementation process model: a delphi study. BMC Health Serv Res 21(1):558. https://doi.org/10.1186/s12913-021-06501-5
49. Rowe G, Wright G (1999) The delphi technique as a forecasting tool: issues and analysis. Int J Forecast 15:353–375
50. De Silva WPM, Jayasena S, Thennakoon P, Perera BAKS (2025) Circular economic strategies for maximising the end-of-life value of modular buildings: a Delphi study. SASBE. https://doi.org/10.1108/SASBE-09-2024-0366
51. Slater J, Falkenberg T, Rutherford J, Colatruglio S (2018) Food literacy competencies: a conceptual framework for youth transitioning to adulthood. Int J Consum Stud 42(5):547–556. https://doi.org/10.1111/ijcs.12471
52. Bruel A, Kronenberg J, Troussier N, Guillaume B (2019) Linking industrial ecology and ecological economics: a theoretical and empirical foundation for the circular economy. J Ind Ecol 23(1):12–21. https://doi.org/10.1111/jiec.12745

53. Schröder P, Bengtsson M, Cohen M, Dewick P, Hofstetter J, Sarkis J (2019) Degrowth within – aligning circular economy and strong sustainability narratives. Resour Conserv Recycl 146:190–191. https://doi.org/10.1016/j.resconrec.2019.03.038
54. Garcia-Ortega B, Galan-Cubillo J, Llorens-Montes FJ, de-Miguel-Molina B (2023) Sufficient consumption as a missing link toward sustainability: the case of fast fashion. J Clean Prod 399:136678. https://doi.org/10.1016/j.jclepro.2023.136678
55. Calisto Friant M, Reid K, Boesler P, V. Vermeulen WJ, Salomone R (2023) Sustainable circular cities? Analysing urban circular economy policies in Amsterdam, Glasgow, and Copenhagen. Local Environ 28(10):1331–1369. https://doi.org/10.1080/13549839.2023.2206643
56. M. Babri, H. Corvellec, and H. Stål, "The circular economy: a geometry lesson." Accessed: June 03, 2024. [Online]. Available: https://www.socialeurope.eu/the-circular-economy-a-geometry-lesson
57. Simamindra RS, Rajaonarivo L (2024) A global analysis of circular economy initiatives: weak or strong sustainability? J Clean Prod 467:142830. https://doi.org/10.1016/j.jclepro.2024.142830
58. Rocha CS, Antunes P, Partidário P (2023) Design for circular economy in a strong sustainability paradigm. Sustainability 15(24):16866. https://doi.org/10.3390/su152416866
59. J. D. Russell, "Market Transformation for Value-Retention Processes as a Strategy for Circular Economy," Thesis, Rochester Institute of Technology, 2018. [Online]. Available: https://scholarworks.rit.edu/theses/9858/
60. Figge F, Thorpe AS (2023) Circular economy, operational eco-efficiency, and sufficiency. An integrated view. Ecol Econ 204:107692. https://doi.org/10.1016/j.ecolecon.2022.107692
61. Sauvé S, Bernard S, Sloan P (2016) Environmental sciences, sustainable development and circular economy: alternative concepts for trans-disciplinary research. Environ Dev 17:48–56. https://doi.org/10.1016/j.envdev.2015.09.002
62. Clube RKM, Tennant M (2023) What would a human-centred 'social' circular economy look like? Drawing from Max-Neef's human-scale development proposal. J Clean Prod 383:135455. https://doi.org/10.1016/j.jclepro.2022.135455
63. Georgantzis Garcia D, Kipnis E, Vasileiou E, Solomon A (2021) Consumption in the circular economy: learning from our mistakes. Sustainability 13(2):601. https://doi.org/10.3390/su13020601
64. T. Parrique *et al.*, "Decoupling debunked: Evidence and arguments against green growth as a sole strategy for sustainability.," European Environmental Bureau., 2019.
65. N. M. P. Bocken, L. Niessen, and S. W. Short, "The Sufficiency-Based Circular Economy—An Analysis of 150 Companies," *Front. Sustain.*, vol. 3, 2022, Accessed: June 06, 2022. [Online]. Available: https://www.frontiersin.org/article/https://doi.org/10.3389/frsus.2022.899289
66. Bauwens T (2021) Are the circular economy and economic growth compatible? A case for post-growth circularity. Resour Conserv Recycl 175:105852. https://doi.org/10.1016/j.resconrec.2021.105852
67. M. Henry and J. Kirchherr, "Conceptualising circular start-ups," in *The Routledge Handbook of Waste, Resources and the Circular Economy*, 1st ed., T. Tudor and C. Jc. Dutra, Eds., First Edition. | New York : Routledge, 2020.: Routledge, 2020, pp. 104–117. https://doi.org/10.4324/9780429346347.
68. Sorrell S, Gatersleben B, Druckman A (2020) The limits of energy sufficiency: a review of the evidence for rebound effects and negative spillovers from behavioural change. Energy Res Soc Sci 64:101439. https://doi.org/10.1016/j.erss.2020.101439
69. Allwood JM (2014) Chapter 30 - Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies. In: Worrell E, Reuter MA (eds) Handbook of Recycling. Elsevier, Boston, pp 445–477
70. Tunn VSC, Van Den Hende EA, Bocken NMP, Schoormans JPL (2020) Digitalised product-service systems: effects on consumers' attitudes and experiences. Resour Conserv Recycl 162:105045. https://doi.org/10.1016/j.resconrec.2020.105045
71. Checkland P (1995) Model validation in soft systems practice. Syst Res 12(1):47–54. https://doi.org/10.1002/sres.3850120108
72. Bengtsson M, Alfredsson E, Cohen M, Lorek S, Schroeder P (2018) Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. Sustain Sci 13(6):1533–1547. https://doi.org/10.1007/s11625-018-0582-1
73. Dalhammar C et al (2021) Enabling reuse in extended producer responsibility schemes for white goods: legal and organisational conditions for connecting resource flows and actors. Circ Econ Sustain 1(2):671–695. https://doi.org/10.1007/s43615-021-00053-w
74. Efthimiou GC, Kalimeris P, Andronopoulos S, Bartzis JG (2018) Statistical projection of material intensity: evidence from the global economy and 107 countries. J Ind Ecol 22(6):1465–1472. https://doi.org/10.1111/jiec.12667
75. Cleveland CJ, Ruth M (1998) Indicators of dematerialization and the materials intensity of use. J Ind Ecol 2(3):15–50. https://doi.org/10.1162/jiec.1998.2.3.15

76. Mignacca B, Filippelli S, Strazzullo S, Tiburzi L, Urbinati A, Kirchherr J (2025) Building circular economy theories: a practical-oriented perspective and a way forward. J Ind Ecol. https://doi.org/10.1111/jiec.13622
77. Milios L (2022) Engaging the citizen in the circular economy: transcending the passive consumer role. Front Sustain 3:980047. https://doi.org/10.3389/frsus.2022.980047
78. Mah A (2021) Future-proofing capitalism: the paradox of the circular economy for plastics. Glob Environ Polit 21(2):121–142. https://doi.org/10.1162/glep_a_00594

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