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The circular economy operating and stakeholder model "eco-5HM" to avoid circular fallacies that prevent sustainability

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ABSTRACT

A complete operating model for circular economy (CE) would benefit policymakers, firms, academia, society and NGOs for informed decision-making relating to CE operations, tactics and strategic goals. The current prevailing paradigm of a CE operating model encompasses three CE levels: *micro-level* for firms, *meso-level* for eco-industry parks and symbiosis, and *macro-level* for governments and regions. This is arguably an incomplete model, causing circular fallacies, such as problem shifting, poor prioritization, and optimization of the wrong system.

In this paper, a CE operating- and also stakeholder-model is explored through theory integration (TI) of CE and the related fields of sustainability, economy, governance and management. TI from these fields has a potential to unlock compounding knowledge for operations and informed decision-making for CE. The result of this TI is the "eco Quintuple Helix Model" (eco-5HM) which integrates the three CE levels with the hierarchical triple bottom line (TBL), nine ecosystem boundaries, three decision-making levels and the 5HM. The eco-5HM comprises five operation and stakeholder levels – firms, governments, academia, society and environment – each with their own systems, operations, interactions, scales and indicators. This CE operating model can better inform decision-makers for CE operations and tactics to achieve the strategic goal of sustainability.

1. Introduction

The circular economy (CE) aims to integrate its related fields of sustainability, economics, governance and management to achieve sustainable outcomes (Geissdoerfer et al., 2017; Murray et al., 2017). Such transdisciplinary approaches are complex but necessary to achieve sustainability (Jäger, 2007; IPCC, 2021). CE uses various models to navigate through the complexity underpinning these approaches. Prominent CE models are the three CE operating levels of micro, meso and macro (Ghisellini et al., 2016); R-frameworks (Reike et al., 2018); and ReSOLVE (EMF, 2015). The fields related to CE also introduced several models, for example the triple bottom line (TBL) from Elkington (1997) and Life Cycle Assessments (LCA).

The use of models aids complex decision-making as they provide high-level visual overviews and comprehension. This is particularly the case for operating models that create clarity on operations, tactics and strategies (Bilgen and Ozkarahan, 2004; McNair and Vangermeersch, 2020). Measurable indicators in models can further inform decision-making through monitoring, predicting, comparing and benchmarking (Camp, 1989; Drucker, 1999; Taplin et al., 2013). However, a model can fall short of optimal decision-making when it is incomplete or misspecified (MacKenzie et al., 2005). Such models lead to fallacies of sub-optimal decisions because problems are shifted to externalities that are missing in the model (Heal, 1998; Korhonen, 2004).

An initial review by the authors of models and their application in the CE uncovered several concerns. It was found that models were interpreted and applied quite differently in each study. Also, relationships between models remained unexplained and many studies gave little argumentation for selecting one model over another. Another concern is that some models seemed to be detached from, or lack, a proper theoretical foundation. The significance of these concerns is that empirical studies and decisions seek validation through these models and their application. Such concerns have even led to a recall of the TBL by the author who coined this term (Elkington, 2018). Section 3.1 elaborates on this initial review.

There is also an opportunity to further review models from CE and its related fields for adaptation and integration as well as reflection and comparison for incompleteness and misspecifications. Integrating fields and models could further unlock compounding knowledge on better-

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informed decision-making for optimizing CE operations. Policymakers, managers, academics and other decision-makers could benefit from this. A review of CE-related literature through the method of theory integration (TI) explicitly based on models is novel.

This paper aims to establish an improved operating model for the CE to achieve sustainability by expanding the three CE levels and integrating various models from related fields. This transdisciplinary approach is presented in the structure of this paper: Section 2 explains the method of TI; Section 3 reviews models from CE and the related fields of sustainability, economics, governance and management; Section 4 integrates relatable models into CE literature; Section 5 discusses application and findings; and Section 6 presents our conclusions.

2. The method of theory integration

This paper uses TI which "aims at revising extant conceptualizations by introducing alternative frames of reference to propose a novel, enhanced perspective" (Lindgreen et al., 2021:A5). TI assimilates and combines evidence from previously developed theories and models of alternative frames (Hirschheim, 2008; Jaakkola, 2020). The conditions for TI are that the theories and models to be adapted must relate to: (1) tools, (2) tasks, (3) theoretical constructs and (4) models (Kock, 2009; Stinchcombe, 1987). Another preferred condition of TI is that the theories and models come from more general and established fields (Jaakkola, 2020; Lindgreen et al., 2021; Yadav, 2010).

The search for theories and models focused on the fields of sustainability, economy, governance and management because these fields are more general and established than the CE, and they are related to the CE. Governance and management in particular were seen as potentially holding relevant models on operating the CE. This search was aided by the multidisciplinary backgrounds of the authors and various keyword searches for highly cited references presenting CE theories and models.

The various theories and models were iteratively compared with parallels in CE literature. However, for the narrative of this paper, the results are presented differently. First, the relevant CE models are introduced, emphasizing the three CE levels as an (aspiring) operating model. This is followed by the relevant results of each field review. Relevant results are the theories and models with parallels and potential for integration into CE. Other, less relevant, theories and models that were found have been disregarded to keep this paper concise.

Models in this paper are presented with Euler's diagrams, a type of Venn diagram (Chen and Boutros, 2011). These figures help in conveying, comparing and integrating the introduced models. Euler's diagrams find application in many fields, particularly for complex systems and cybernetics. The diagrams are composed of circles to visualize the types of (dependent) relationships: overlapping or disconnected; overarching or constituent; and larger, smaller or equally-sized (but not proportionate). Each circle represents a level which can be identified as either actor, driver, system, process, scale, dimension, element, entity, stakeholder or other. The identities of the levels are argued for in 5.2, the discussion section. Models help in presenting relations yet decision-makers should always be aware that they are simplifications and a reduction of reality (Pesqueux and Damak-Ayadi, 2005).

3. Review of models in the circular economy and related fields

3.1. The field of the circular economy

CE is still a burgeoning field (Homrich et al., 2018). The three CE levels, R-frameworks and ReSOLVE are commonly used models for managing CE operations (EMF, 2015; Murray et al., 2017; Kirchherr et al., 2017). The three CE levels are widely interpreted as constituting a CE operating model (Geng and Doberstein, 2008; Ghisellini et al., 2016; Kirchherr et al., 2017) and have been extensively developed with scales and indicators (e.g. Saidani et al., 2019; VITO, 2018). The next three paragraphs elaborate on their origin, development and contentiousness.

The three CE levels originate in the scientific literature with descriptions of the implementation of CE policies from (People's Republic of) China (Geng and Doberstein, 2008; Yuan et al., 2006; Park et al., 2010; Zhu and Huang, 2005). China premiered extensive CE policies for sustainable development involving 109 firms at the micro-level, 33 eco-industrial parks at the meso-level, and seven eco-cities and 19 eco-provinces at the macro-level (Geng et al., 2012).

The three CE levels and their scales are not clearly defined, with various conflicting interpretations (Moraga et al., 2019). To improve consistency for the purposes of comparison and benchmarking CE operations, the diagram in Fig. 1 was synthesized from the literature as the most logical representation of the three CE levels and their scales. Micro-level scales include actions arising from, or associated with, consumers, products and firms (Ghisellini et al., 2016; Kirchherr et al., 2017). Arguably, industry sectors may also be added as an overarching scale, as there are relevant CE studies on this topic (e.g. Kayal et al., 2019; Lèbre et al., 2017). Meso-level scales are represented through urban-industrial symbiosis, supply chains using end-of-life products and eco-parks (Domenech et al., 2019, van Bueren et al., 2021). This is an extension of the original single scale where eco-park as interfirm symbiosis was not limited only to eco-(industrial) parks (Chertow, 2000; Ghisellini et al., 2016). In Fig. 1, macro-level scales are represented with XL for the planet; L for continents; M for large provinces, states and smaller countries; and S for cities and XS for neighborhoods (van Bueren et al., 2021), providing a demarcation that allows for comparisons of regions with a similar size and population.

A review of the related literature shows extensive research on indicators for the CE on the three levels (Corona et al., 2019; Saidani et al., 2019; Sassanelli et al., 2019). Many indicators are so specialized that their relationship to the CE's purpose of reaching sustainability is unclear (Kristensen and Mosgaard, 2020; Harris et al., 2021; Temesgen et al., 2021). There is also an abundance of indicators on circular manufacturing and a shortfall on circular energy and circular food, while the latter are arguably of higher priority and impact (Springmann et al., 2018; van Bueren et al., 2022). This gives rise to misgivings about a circular fallacy arising from incomplete and misspecified models.

R-frameworks are derived from a hierarchy of three or more CE operations starting with the letter "r", e.g. reduce, reuse and recycle (Reike et al., 2018). The ReSOLVE-framework is an acronym for six CE tactics (regenerate, slow, optimize, loop, virtualize and exchange) (EMF, 2015). The whimsical formulations and their origin based in practice gives little credibility to their comprehensiveness as models. Also, many of the CE operations and tactics have heterogeneous interpretations and struggle with meaningful indicators. These frameworks relate to the three CE levels as CE operations and tactics within each level. ReSOLVE specifically targets firms (micro-level).

The aforementioned models have practical applications, but arguably all lack a theoretical foundation, an unambiguous definition, and academic arguments on how they work, relate, or inform decision-making as complete operating models.

3.2. The field of sustainability

The field of sustainability is more established than that of the CE, and given that achieving overall sustainability is the goal for CE, sustainability models should be well integrated into CE models. The review conducted for this paper found that although many sustainability models are mentioned in CE literature, arguably they are often poorly integrated. This section describes only the theories and models with parallels and potential for TI with the CE.

A variant of Elkington's TBL is the hierarchical TBL from ecological economics. This model depicts the ecosystem overarching society in turn overarching the economy (Cato, 2012; Daly, 1991; Pearce et al., 1989). This model closely relates to the planetary boundaries model, whereby society cannot grow beyond the ecosystem boundaries (Boulding, 1966; Meadows et al., 1972). These boundaries were later defined as nine

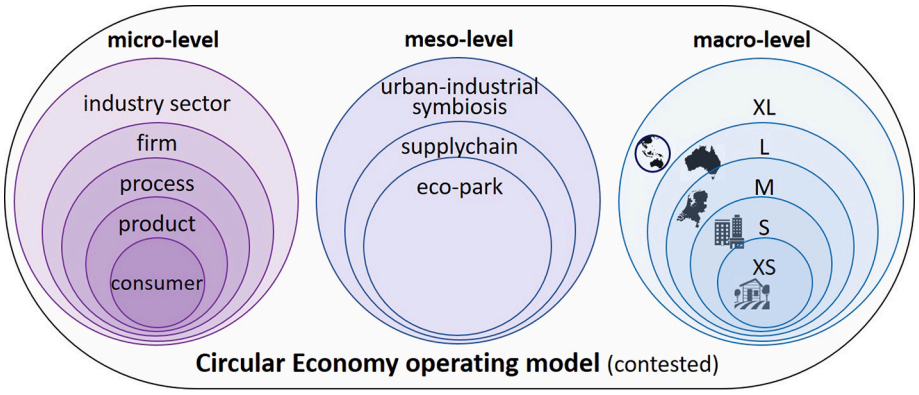

Fig. 1. The frequently described CE operating model comprising three CE levels, as contested by this paper. Scales in each level depict the current development for assessments. For the macro-level, scales are: XL (global), L (continent, supra-international, large country), M (large province, small country), S (city, small province, municipality) and XS (neighborhood). Modified from van Bueren et al. (2021). Note that this paper supports the scales presented in the model, but contests that the three levels constitute to a complete operating model.

regional and planetary boundaries which are tipping points that would cause a system collapse if they overshoot the physical limitations of the planet (Rockström et al., 2009). The most researched boundary (particularly in relation to the CE) is climate change produced by anthropogenic carbon dioxide (and equivalent) emissions (e.g. IPCC, 2021; Stern, 2006). However, other boundaries are also at risk of being overshot (Steffen et al., 2015; Persson et al., 2022).

The strategic goals of sustainability (and thus for the CE) can be defined by the nine planetary boundaries. The hierarchical TBL model extended with the ecosystem boundaries is depicted in Fig. 2. The Sustainable Development Goals (SDG) (UNSDG, 2016) are strategic goals which are very relatable to aforementioned theories but arguably not systematic enough to avoid problem shifting (Economist, 2015; Schleicher et al., 2018). These sustainability theories find references in CE literature, but relationships with the three CE levels as an operating model are unclear.

The field of sustainability uses spatial scales for the ecosystem similar to the XL–XS scales at the macro-level in the CE field, namely: biosphere, biome, landscape, ecosystem and plot (Hein et al., 2006). Unfortunately, they do not align with government or geographic boundaries and are often fuzzy (Levin, 1992; Cash et al., 1998).

The field of sustainability sometimes uses categorizations based on the initiator: firms (with environmental and social programs), governments (on any scale) and NGOs (non-government organizations) (Van Marrewijk, 2003; Lambin and Thorlakson, 2018). Sustainability NGO examples are World Wildlife Foundation and Greenpeace. There is a similarity between sustainability categorization by initiator and CE levels, whereby firms and governments match with the micro and macro-levels (see Fig. 3). Collaboration between firms and governments are known as public–private partnerships (PPP) (Wang and Ma, 2021), which can also be understood as the overlap between firms and governments. PPP arguably matches with the meso-level. CE NGOs (e.g. Ellen MacArthur Foundation and Circle Economy) play a significant role in initiating the CE, yet arguably are not another CE level.

Life cycle assessment (LCA) models are also common in the field of sustainability and are highly standardized (ISO, 2006). LCAs evaluate the environmental consequences of decision-making (Hauschild et al., 2018). A sustainability LCA is typically based on carbon dioxide emissions and/or other planetary boundaries (Spreafico, 2022), but can also include societal elements (Jørgensen et al., 2008). LCAs are widely applied in the CEto support decision-making at the micro-level for products and processes (Peña et al., 2021).

3.3. The field of economics

Economics is often categorized into micro-economics and macro-economics. Micro-economics is the study of the behavior of individuals and firms regarding scarce resources (Colander, 2000). The study of individuals adds legitimacy for "consumers" as an important scale in the CE micro-level, which seems currently under-investigated for the CE. Macro-economics is the study of resources in regions on any scale (O'Sullivan and Sheffrin, 2003). Meso-economics is not a term generally used in economics.

An indirectly related finding is that outdated neoclassical economics has the TBL hierarchy reversed, with the level economy overarching society and ecosystem (Temesgen et al., 2021). The authors observe that this outdated model is a fallacy still persisting in some CE literature and practice. No contribution to advancing a CE operating model from the field of economy was found, despite similarities in terminology and meaning.

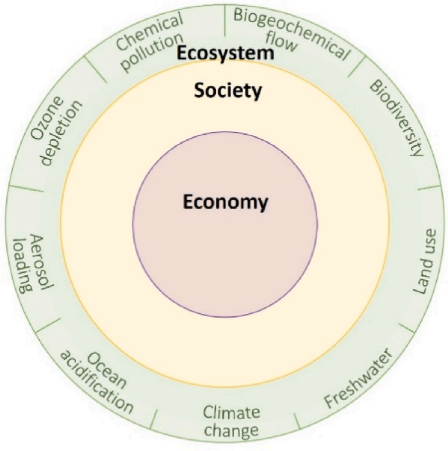

Fig. 2. Model of the hierarchical triple bottom line (TBL), extended with nine ecosystem boundaries. (Authors' interpretation of combined models from Elkington, 1997, Pearce et al., 1989, Cato, 2012 and Rockström et al., 2009).

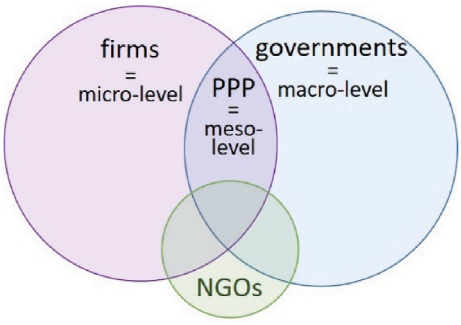

Fig. 3. Sustainability categorization by initiator, adapted to CE levels. Interpretation of common sustainability categorization depicted by the authors.

3.4. The fields of governance and management

The fields of governance and management are concerned with decision-making to plan and commit to a particular course of action (Mintzberg et al., 1976). There are three types/levels of decision-making: the operational level is for short-term, continuous and daily processes; the tactical level is for mid-term processes, such as yearly action plans and policies; and the strategic level is for setting long-term goals. The decision-making levels need to connect by informing the shorter-term, and supporting the longer-term. (Ackoff, 1974; Harrington and Ottenbacher, 2009; McNair and Vangermeersch, 2020). Despite decision-making being central in the management field, Mintzberg (1994) acknowledges that many organizations make fallacies as they fail to align operations and tactics for long-term strategic change. Adapting this theory and terminology creates clarity as to how CE operations, tactics and strategies relate, as explained in the following paragraph.

The strategic goal of a CE is sustainability; strategic-level decisions are to keep society and the economy within ecosystem boundaries and the TBL in the long term. To achieve this, the tactical level needs to set CE tactics, e.g. to virtualize products or to loop a supply chain. These tactics will inform the operational level for daily operations, such as reusing products and recycling materials. This also provides an explanation of how several models relate to each (see Fig. 4). Note that these relationships are not consistent in CE literature, and not per se incorrect: the operations from the R-framework can also be understood as tactics, and some ReSOLVE tactics can be understood as operations.

CE fallacies occur when strategic-level decisions focus solely on the economy (profit optimization), instead of the full TBL. Even when the ecosystem is considered, this is too often only on climate change (e.g. net zero by 2050), which may actually pressure other ecosystem boundaries (such as land use). CE fallacies also occur when CE tactics are considered without supporting strategic goals. For example, looping material resources may not necessarily support the strategic goal of sustainability, as some recycling leads to increased emissions (Astrup et al., 2009), and biofuels may be carbon neutral yet require significant use of land and biogeochemicals (Engström et al., 2020).

Another operating model in the fields of governance and management is the triple helix model (3HM). This model emphasizes stakeholder interactions between government, firms and academia to develop knowledge, innovation policies and systemic innovation (Leydesdorff and Etzkowitz, 1996, 1998). Government and firms are levels that occur in both helix literature and CE levels. In a discussion about academia, helix authors Caryannis and Campbell stated that: university researchers properly informed, empowered, and supported are bound to emerge as the architects of a prosperity that is founded on a solid foundation of scientific and technological knowledge, experience, and expertise and not in fleeting and conjectural "financial engineering" schemes. (2011:329).

It could be argued that academia also has a role for operating the CE as academia may be considered an additional operation level.

An extension on the 3HM is the Quintuple Helix Model (5HM), extending with (civil) society and the (natural) ecosystem. Specifically, society has the systems of media, culture, values, lifestyle, art and creativity that contribute through co-evolution, co-specialization and diversity (Carayannis and Campbell, 2009, 2011). The ecosystem drives eco-innovation and eco-entrepreneurship for "interdisciplinary analysis and transdisciplinary problem-solving in relation to sustainable development" (Carayannis and Campbell, 2010:42). Are society and the ecosystem also operation levels for the CE?

One Euler's diagram depiction of the 5HM seems particularly suitable for TI into CE as it can be interpreted as an integration of the three CE levels: the hierarchical TBL, ecosystem boundaries and the 5HM. This is the model from Carayannis and Campbell (2010) (see Fig. 5). Here, the three CE levels are represented with firms and governments overlapping at the meso-level (as in the case of PPP or symbiosis). Academia is added as an additional CE level, as the third circle. This matches the conventional depiction of the 3HM. Arguably, this 3HM can represent the economy level; the model also depicts the hierarchical TBL with society and ecosystem overarching the economy (compare Fig. 5 with Fig. 2).

This interpretation of the 5HM (Fig. 5) can be understood as a CE operating model. At the operational level, the five levels all have CE operations that are vital to achieving sustainability. How these levels interact (as stakeholders) is essential for better-informed decision-making at the tactical level on CE operations. Simultaneously, tactical decisions can be reviewed as to how they relate to the (overarching) ecosystem boundaries and TBL as the goals from the strategic level.

TI of CE levels, hierarchical TBL, ecosystem boundaries, three decision-making levels and 5HM meets the four conditions for the method of TI from Kock (2009) and Stinchcombe (1987), as the models in each field relate to.

(1) tools – all models cover operation levels, their relations and enable assessments across various scales
(2) tasks – all models aim to create development, policymaking and knowledge-driven eco-innovation
(3) theoretical constructs – the constructs of ecosystem, society, economy, firms, governments and academia are all levels that evidentially relate to each other
(4) models – the models are not conflicting but complementary to each other.

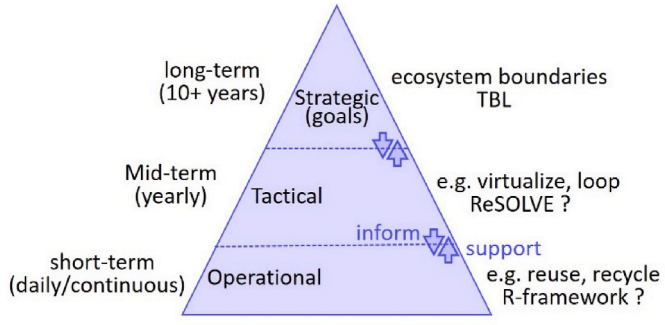

Fig. 4. Decision-making levels (strategic, tactical and operational) from the fields of governance and management (Ackoff, 1974; Harrington and Ottenbacher, 2009; McNair and Vangermeersch, 2020), adapted for the CE. The authors also suggest an explanation on how several models relate.

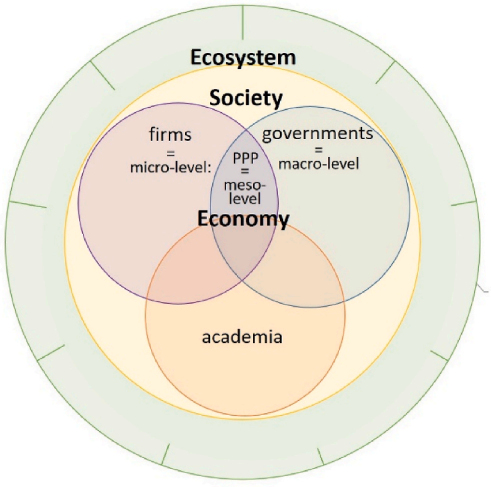

Fig. 5. Quintuple Helix Model (5HM) as extension of CE levels and triple bottom line (TBL), modified from Carayannis and Campbell (2010).

The TI also enriches the 5HM and vice versa. The 5HM can integrate the TBL, ecosystem boundaries decision-making levels and CE levels. A parallel study reviewing literature on helix models (van Bueren et al., 2023) found this TI is also an expansion and extension to the 5HM. This extended 5HM will hereafter be called "eco-5HM."

4. Integrating the additional CE levels

The previous section found theories and models as alternative frames of reference for the CE. Now to enable TI, this section introduces these theories and models to the context of the CE, combining and assimilating them together. Empirical and theoretical evidence of the original theories and models are tested on their validity in the new context and then extended with the CE context, creating a novel and enhanced perspective.

The TI is centered on a new CE operating model – the eco-5HM – integrating the three CE operation levels with the 5HM, TBL, ecosystem boundaries and decision-making levels. The following subsections are a further review of the integrated models to extend the theory for the additional CE levels on their operations, interactions, scales and indicators (as summarized in Fig. 6). TI is also helping here to describe the current state of knowledge and gaps per level.

4.1. Circular economy operations

While existing CE literature has described three CE operation levels, TI of the 5HM suggests five levels. It is arguably a fallacy to exclude academia, society and the ecosystem from a CE operating model. Table 1 gives examples of CE operations for each level, illustrating that all five levels are essential to operate the CE.

A key point in helix models is that the levels need to collaborate. A 3HM indicator can be adopted and revised to measure the success of collaboration between the CE levels. The 3HM indicator is the number of patents and publications from partnerships between academia, government and/or firms (Leydesdorff and Meyer, 2006; Leydesdorff et al., 2014). An eco-5HM indicator can be collaborated patents befitting sustainability and CE. The European Commission already employs this as one of ten key indicators (EC, 2018).

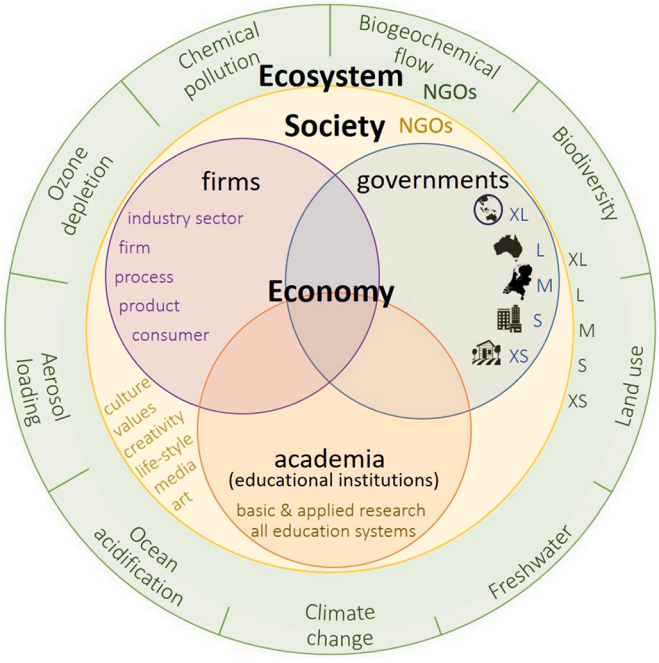

Fig. 6. The eco-5HM as CE operating and stakeholder model with scales and systems. The model presents all stakeholders (in black) and their relations, depicted by circles. The stakeholders operate on multiple scales and systems (in color). The strategic goals of a CE are to operate within the ecosystem boundaries and optimize the TBL. To achieve this, stakeholders need to set tactics to align all operations through all scales and systems. The eco-5HM integrates and expands the three CE operating levels, hierarchical TBL, nine ecosystem boundaries, three decision-making levels, 3HM and the 5HM. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
CE operation examples for each of the eco-5HM levels. This is not a comprehensive overview, and whimsically selected on words primarily starting with an "r", as fashioned in the CE literature.

CE levels	CE operations
ecosystem	regenerate, regrow, replenish, absorb, carbon sink
society	refuse, reduce, reuse, repair, repurpose, realize, respect
academia	rethink, realize, research, report, educate, demonstrate
firms	refurbish, remanufacture, recycle
government	regulate, enforce, judge, stimulate, mainstream/scale up

4.2. Academia level for the circular economy

Academia as a CE level operates through monitoring, eco-knowledge creation, creating new CE tactics, disseminating, educating and conceiving the strategic goal of sustainability. The original 5HM emphasized innovative research. In the eco-5HM, academia may arguably be more broadly interpreted as incorporating all educational institutions with basic and applied research, and all other education systems. Academia also interacts (as overlap in the Euler's diagrams) with the other levels to apply and valorize eco-knowledge and eco-innovation. Interaction with firms and governments creates CE technology transfer and employability. Interaction with society is through education and disseminating awareness of more sustainable behavior (Suárez-Eiroa et al., 2019; Steg and Vlek, 2009). Interaction with the ecosystem is through the creation of better monitoring and understanding of systems (particularly the nine ecosystem boundaries), as well as recommending interventions when needed. There seems to be no need to categorize academia into scales.

Indicators specific to academia could be based on publications and education relating to the CE and sustainability. Data on CE publications per region have already been explored (e.g. Geissdoerfer et al., 2017), but education in quality and quantity, and its impacts is less explored.

4.3. Society level for the circular economy

The society level operates in the CE as an actor for societal needs and can positively contribute to the CE with sustainable behavior (examples provided in Table 1). Systems constituent to society (beside the levels of government, firms and academia) are media, culture, values, lifestyle, art and creativity. Carayannis and Campbell (2019) state that the plurality and diversity of these systems create "happy accidents" contributing to helix innovations. We argue that many happy accidents are often staged by marketing, with the intention to nudge (and reinforce) society into certain behaviors. For decades, marketing has nudged society using societal systems to serve a consumerist linear economy of "take-make-dispose". Societal systems can nudge consumerist behavior to create gratification from possessions and decadence (see Table 2, middle column for examples). We argue that these systems can also drive eco-innovation and nudge sustainable behavior (also supported by Holbert et al., 2003). Societal systems can nudge toward a circular society to create gratification from sharing ("access to" instead of "owning"), health and nature (see Table 2, right column for examples).

Nudges can lead to social tipping points of rapid societal change where sustainable behavior becomes the norm (Otto et al., 2020; Winkelmann et al., 2022). Social tipping points have the same rhetoric as ecosystem tipping points. There is a research gap within CE on these

Table 2
Examples of societal systems supporting either consumerism or a circular society.

Society systems	Examples supporting a consumerist, linear economy	Examples supporting a circular economy
Media	Fashion magazines, *Fast & Furious* films	David Attenborough documentaries, *Don't Look Up* film
Culture	Western steaks and fast food	Asian Buddhist cuisine
Values	Measuring success in life on income and the size of your car	Living car free by using public transport and share cars
Lifestyle	Shopping, over-eating, cosmetic surgery	Veganism, exercise in nature
Art	Las Vegas casino architecture	*Politicians discussing global warming* sculpture by Isaac Cordal (2013)
Creativity	Fast fashion, luxurious gift packaging	Bring your own cup/bag, repair clothes, vegetable garden

societal systems and tipping points. Moreover, a circular society is not yet integrated as part of a complete CE operating model (see also Jaeger-Erben et al., 2021; Hobson et al., 2021).

An indicator for the "helix of society" (for interaction with other levels) could be relevant to NGOs (quantity times quality of impact). An indicator of the "level of society" could be consumer footprints and the proportion of circular society within all society (quantity times quality). This could be assessed for any scale (XL–XS), or even smaller: at household scale "XXS" or individual scale "XXXS".

4.4. Ecosystem level

The ecosystem level operates in the CE by providing and regenerating resources as well as absorbing waste (Boulding, 1966; Daly, 1991; Pearce et al., 1989). Its operational capacity is limited by nine ecosystem boundaries. The operational capacity will be reduced drastically when pressures overshoot boundaries (Rockström et al., 2009). Society and other constituents depend on the operations of the ecosystem as it is the most overarching level (as depicted in Figs. 2, 5 and 6). Thus, overshoot should be avoided to also avoid operational systems collapse of society and economy.

The ecosystem is also an actor and driver for creating knowledge, innovation and innovation policies related to CE and sustainability. Examples are countries with dense populations that excel in recycling (e.g. the Netherlands, Singapore and Taiwan). Recycling is an eco-innovation responding to the shortage of space for landfill and the shortage of natural resources. Another example is flood-threatened countries excelling in water technology and management (e.g. the Netherlands and Singapore).

The ecosystem boundaries (with tipping points) can be assessed on any scale (XL–XS) (Hein et al., 2006; Steffen et al., 2015). Suitable indicators have been developed by the sustainability and ecology fields to assess the risk of overshoot, although this is still challenging (Clift et al., 2017). CE indicators addressing sustainability of the ecosystem should focus more on these boundaries and arguably less on recycling, which can be a fallacy for sustainability (Astrup et al., 2009; Korhonen et al., 2018; Zink and Geyer, 2017). Current CE literature often falls short of assessing all nine systems comprehensively (Spreafico, 2022). This shortfall could lead to problems shifting, for example a "solution" for mitigating climate change may lead to pressure on other systems. A region with a full CE will not overshoot any ecosystem boundaries. The region is also (net) self-sufficient, ensuring that the region will not shift problems to other regions (van Bueren et al., 2022). Additionally, an indicator for the "helix of ecosystem" could be relevant to NGOs (quantity times quality of impact).

5. Discussion

5.1. The purpose of the Eco-5HM

With the benefit of hindsight, it is an obvious fallacy to believe that micro–macro-levels alone can achieve sustainability. The additional CE levels are logical and have already received attention in CE literature. The proposed model helps to reveal circular fallacies as it visualizes where problems will be shifted to (they are internalized), which stakeholders contribute positively/negatively, a more complete systems approach and links between short-term and long-term decision-making. Thus, more clarity is created as opposed to using only one or several models like the three CE operation levels – TBL, ecosystem boundaries or 5HM. As a result of this, the integrated and more complete eco-5HM can contribute to better-informed decision-making for policymakers, businesses, academia, NGOs and their collaborations for a CE, for sustainability management and for eco-innovation.

By providing a high-level visual overview and comprehension, the eco-5HM can help in better informed decision-making for operations and tactics, on stakeholders, strategic goals, indicators, communication and prevention of problem shifting (Table 3 presents examples).

5.2. Five circular economy levels as stakeholder model

The five CE levels can be identified as stakeholders, which raises the question: is the eco-5HM not only an operating model, but also a stakeholder model? Indeed, stakeholder models are another model to be considered from the field of management. Stakeholders are any group (or individual) that affect or is affected by operations of an organization (Freeman et al., 2010). Research mostly centers around firms, and there is not an exhaustive or complete list of stakeholders (Fassin, 2009), but certain stakeholders are frequently mentioned in prominent stakeholder models (e.g. Freeman et al., 2010; Friedman and Miles, 2002; Donaldson and Preston, 1995), and also for CE-related stakeholder models (Casalegno et al., 2020; Schaltegger et al., 2019). Arguably, these

Table 3
Examples of how the eco-5HM contributes to decision making. Other models would guide to a more limited scope of tactics and operations, and more likely lead to sub-optimal decision making or fallacies for missing stakeholders or strategic goals.

Use of Eco-5HM	Example: food-waste of meat, because it reached the expiration-date.	Example: reducing carbon footprint from energy
Stakeholders: to identify who are involved in causes or solutions.	Involved stakeholders are government (because expiration regulation), firms (selling the meat), society (consuming the meat), and ecosystem (burdening systems).	Involved stakeholders are government (for regulation), firms (creating and selling this energy), society (requiring energy), and ecosystem (climate change, but also growing biomass).
Tactics and operations: to check how they contribute to strategic goals, and which stakeholders may be involved.	1. Firms can cook nearly expired meat and preserve in cans. 2. Academia could develop technology to check if the meat quality is actually bad. 3. Society could choose to consume less meat, and more plant-based protein instead.	1. Shift to biomass as renewable energy 2. Shift to solar energy as renewable energy. 3. Academia can develop energy saving technology.
Strategic goals: to check if goals are supported, and to avoid problem-shifting.	Continue tactic 3: Plant-based diets reduce ecosystem pressures, and provides health benefits (Willett et al., 2019).	Continue tactic 1: Biomass would pressure other ecosystem systems (land use, biogeochemical, …)

stakeholders are all constituents of CE levels: firms with top management, employees, financiers and shareholders; government with civil servants and political groups; academia with critics; society with customers, the general public, communities and media; and ecosystem with NGOs, environmentalists and suppliers. The original meso-level (e.g. eco-park) would not be identifiable as stakeholder, yet in the eco-5HM it is now interpreted as overlap between firms and government as PPP. One study (Arsova et al., 2021) already linked the 5HM as a potential stakeholder model for the CE. Indeed, the eco-5HM can be understood as a stakeholder model, but this requires deeper study for elaboration.

Most helix models do not identify the levels as stakeholders but rather as helices. This is because helix models emphasize the interaction between stakeholders. Helix literature is divided among 3HM and 5HM authors as to whether or not society and ecosystem are helices. An argument not to recognize them as helices is that they are not (self) conscious interacting human actors and for that reason they are unable to develop the dynamic mechanism and theoretical system of helix innovation (e.g. Zhou and Etzkowitz, 2021). Society and ecosystem are different indeed, yet: (1) society and ecosystem can (and should) be represented by NGOs as is noted in the sustainability field (see Fig. 3), which enables them to interact in discussions; (2) are governments, academia, and particularly firms (all plural) consciously interacting as one stakeholder? They have internal conflicts themselves; and (3) regardless of their consciousness, society and ecosystem are undeniably actors and drivers in a model for eco-innovation and very reactive when their tipping points overshoot.

5.3. The glocal scale

In addition to conventional scales of XS–XL, helix literature describes a trans scale as "glocal" (Carayannis and Alexander, 2006). The glocal scale helps the helix model to internationalize knowledge and innovation (e.g. van Bueren and Goh, 2016). As the aim of the helix models is "to create competitiveness with other regions" (Carayannis and Campbell, 2010, 2011; Leydesdorff and Etzkowitz, 1996, 1998), glocal seems counterintuitive for this aim. However, a CE operating sustainably within ecosystem boundaries would benefit greatly from internationalizing knowledge and eco-innovation. Much CE literature has already focused on comparing and benchmarking regions around the world (van Bueren et al., 2021), but how to internationalize best practice and CE technology transfer has not been explored as much. Glocal dissemination of knowledge and eco-innovations with the eco-5HM presents a research opportunity for a local and global CE.

5.4. Circular economy policies from China

The three CE levels originated from CE policies in China and were widely described in CE academic literature as only these three levels. However, a review of the actual policies found a role for academia: "The state encourages and supports research, development and promotion of science and technology regarding circular economy, as well as the publicity, education, popularization of scientific knowledge and international co-operation on circular economy" (China, 2008, Article 7). It also found a role for society: "Citizens shall have a better sense of resource conservation and environmental protection, consume reasonably and save resources" (China, 2008, Article 10). It is unclear why CE literature paid so little attention to these two levels, and how Articles 7 and 10 have been implemented.

5.5. Contribution to the quintuple helix

The eco-5HM contributes to a CE but does TI of the eco-5HM also contribute to the helix literature? A quick review of helix-innovation literature suggests a significant gap on CE and ecosystem sustainability altogether. This led to a separate parallel publication with a systematic literature review on helix literature about sustainability, focusing on TI of key sustainability concepts into helix innovations (see van Bueren et al., 2023).

6. Conclusion

The famous aphorism says, "All models are wrong, but some are useful" (Box, 1976), but Box also added that scientists must be alert to what is "importantly wrong". China's CE policy unintentionally led to an incomplete CE operating model with just three CE levels. There are also other widely used models relating to CE operations, but it is unclear what their exact relations are and when to use which model. The lack of a complete operating model means a failure of informed decision-making for policymakers, firms, academia, society and NGOs. This leads to circular fallacies as decisions are made without taking into consideration essential CE operations, tactics, strategic goals, stakeholders, impacts and their relationships.

The key contribution of this paper is an improved CE operating and stakeholder model, the Eco Quintuple Helix Model (eco-5HM). The eco-5HM was created through theory integration (TI) of the fields of CE, sustainability, economy, governance and management. The eco-5HM integrates the models of three CE operating levels, hierarchical TBL, nine ecosystem boundaries, three decision-making levels, the 3HM and the 5HM. The eco-5HM comprises five levels of stakeholders (governments, firms, academia, society and ecosystem). Their scales, systems and respective relations are depicted in Fig. 6. The mutual strategic goals of stakeholders are to operate a CE within the ecosystem boundaries and to optimize the TBL. To achieve this, stakeholders need to set tactics to align all operations. The eco-5HM creates clarity on strategic goals and stakeholders for tactics and operations to avoid circular fallacies.

This paper advances prior research and practice by expanding the original CE levels of firms and governments to also include society, the ecosystem and academia. These additional stakeholder levels should also be included in research and development to operate the CE more comprehensively. TI from CE-related theories and models also found CE operations, tactics and indicators for the additional levels.

- *Society* should nudge sustainable behavior toward social tipping points to transform consumerist into circular societies. Nudges can operate through systems such as media, culture, values, lifestyles, art and creativity. Indicators can be consumer footprints.
- The *ecosystem* operates by providing and regenerating resources as well as absorbing waste. Its local and global capacity to operate is limited by nine ecosystem boundaries. Overshoot will drastically lower ecosystem capacity, therefore ecosystem indicators should address these boundaries in their capacity to operate as strategic goals.
- *Academia*, as all educational institutions, operates by monitoring systems, creating awareness, education, eco-knowledge and eco-innovation in the CE. Indicators include patents, publications and education that relates to sustainability and CE. The levels of society and ecosystem are overarching operation levels as the economy depends on them (and not vice versa). They are often underrepresented by lack of "representative human actors", but NGOs can take up this role.

CE and related fields confirm that governments, society and the ecosystem operate on various regional scales. A demarcation of XL–XS scales is arguably most suitable to align operations. Another scale is the glocal scale for knowledge and eco-innovation dissemination to achieve a global CE within global ecosystem boundaries.

CRediT authorship contribution statement

Bart J.A. van Bueren: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Kevin Argus:** Supervision, Writing – review &

editing. **Usha Iyer-Raniga:** Supervision, Writing – review & editing. **Mark A.A.M. Leenders:** Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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