The Circular Decision-Making Tree: An operational heuristic

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Abstract

Despite sparse exceptions in a few industries, our current economy remains largely linear. Because of the need to limit extraction of raw materials and reduce the amounts and impacts of waste, countries and businesses are challenged to transition to a circular economy: an economic system in which the used materials are reused, reduced, or recycled, but not wasted. Yet transitioning from a linear to a circular economy implies societal-level structural changes, bringing about tradeoffs and uncertainties for decision-making in policy and business. Despite frameworks and methodologies existing to help inform on such decisions like the waste hierarchy and R-imperatives, leading reports and studies indicate that the aspiration to become circular has not sufficiently translated into impact. We hypothesize that one reason is a lack of applicable decision-support heuristics offering the necessary support for preferentially allocating resources towards innovations of highest-quality contributions to the circular economy. Here we propose a stepwise, input-responsive heuristic: the circular decision-making tree. It allows policymakers, investors, or entrepreneurs to navigate trade-offs and support deciding on circular innovations, preferentially according to the magnitude of their true contribution to a circular economy. For this study, we have verified the heuristic in a series of usability workshops across four application contexts (Netherlands, Brazil, United Kingdom, and South Africa). A total of n=50 stakeholders from policymaking, industry, and academia have reflected on the internal logics and applicability of the decision-making tree. We conclude with critical remarks and highlighting further application potentials for supporting transition dynamics towards a circular economy.
1. Introduction

1.1. Circular economy and the Dutch context
In response to ever-increasing waste production and interrelated socio-environmental challenges, governments, businesses, and scholars have begun to embrace and support the concept of a circular economy (CE) (Geissdoerfer et al., 2017). The CE is a radically different economic paradigm that prioritizes the reduction of raw material extraction through value retention and regenerative design (Blomsma & Brennan, 2017; Ellen MacArthur Foundation, 2021).

CE draws its influence from various disciplinary backgrounds, including industrial ecology (IE) (Blomsma & Brennan, 2017), which has provided many theoretical and methodological tools used in the efforts of monitoring, measuring, and effectuating progress in sustainable development (Saavedra et al., 2018). The underlying purpose of adopting CE practices is to ultimately reduce virgin material consumption, eliminate waste, and decouple growth from material use (Ghisellini et al., 2016; Murray et al., 2017; Campbell-Johnston et al., 2020). Thus, not all movements within circularity contribute equally to accelerating the desired transition to CE. Because a core value of CE is highest value preservation (Zink & Geyer, 2017), it is possible that a circular innovation may contribute to the acceleration of CE – but at a low magnitude, relative to an alternative innovation that scores higher in a hierarchy of CE value retention options. Furthermore, the Waste-Resource Paradox (WRP) (Greer et al., 2021) elucidates that closing a loop through waste-based innovation (Henry et al., 2020) and turning a waste into a resource may reinforce undesirable linear pathways by incidentally creating a demand for said waste, reinforcing its production rather than deinstitutionalizing and breaking down its comfortable position in the supply chain.

There are certainly great forces influencing decisions made on the CE, such as risk-aversion, stranded assets in linear business cases, path dependency of existing practices, locked-in institutions, and market
fluctuations—which may prove difficult to penetrate or circumvent. However, another key challenge for amplifying the transition to CE is the still apparent lack of “circular oriented governance and decision-making” (Brown et al 2021; p.1). A particular obstacle that prevents or mitigates sound circular decision-making is that many stakeholders dealing with the CE still tend to overlook the different quality of contributions to CE, or may lack responsive and adaptive decision-making support to navigate start-to-finish in selecting the most impactful circular innovation considered. Brown and colleagues (2021) argue similarly, when pointing to the current challenges of aligning circular innovation partners upon a shared circular purpose and “developing a circular oriented value capture model focused on collective outcomes” (p.13).

The lack of transparency about the collective impact of CE innovation becomes concrete at the EU level. “Of the 36 CE Green Deals and 32 CE Best Practices, almost all aim at increasing recycling... [Yet,] recycling, and low-grade recycling in particular, is still very much a linear solution. In addition to aiming for less resource consumption and waste generation, it is also important for a circular economy to focus on creating less environmental impact (including more value for ecology), and generating more added value for the economy” (PBL, 2017, p. 39). This is the set of obstacles through which our Circular Decision-Making Tree (CDMT) is designed to support and guide. Given that time, funding, and policy support are limited resources, it is critical that those resources allocated towards meeting the goal of full circularity are making the greatest impact per unit of support. To avoid low-value and low-impact CE solutions, we must prioritize and strategize for higher-quality circularity proposals, solutions, and implementations.

One of the biggest current challenges in CE is that, to make a transition from a linear to a circular economy happen, governance should be structured and actions should be taken in such a way that short-term decisions are aligned with the desired long-term change. Transition management is an appropriate approach to engaging with sustainability transitions (Rotmans et al., 2001). Specifically,
“transition management is a generic governance approach that is based on existing strains of thought in governance and policy studies, but because of its integrative character, its explicit link to complexity theory and its explicit use of sustainable development as guiding principle, it constitutes a fundamentally new governance approach” (Loorbach, 2007, p. 79). While attempts are being made, progress in true impact requires a clear vision of both the future goal and of the inherent tradeoffs that will occur when designing policy to reach it.

Among diverse countries that have committed to CE targets, the Netherlands is a prominent pioneer in the pushing of circular economy (taking substantial steps towards their stated goal of full circularity by 2050) (Rijksoverheid, 2021). The Netherlands Environmental Agency corroborated the logic behind the CDMT in asserting: “A more ambitious CE transition towards substantially lower resource and material consumption and less generation of waste will preferably be based on high-circularity strategies, such as smarter manufacturing and use of products, and extending the lifetime of products and product components. Recycling alone, and low-grade recycling in particular, is still closely related to a linear economy” (PBL, 2017, p. 7). Despite the clear vision of preferred pathways, circular targets are still failing to be met (PBL, 2021). The struggle of even a frontrunning country in circularity, such as the Netherlands, to meet targets indicates that our current strategies in decision-making around amplifying the circular economy are not effective in a meaningful enough way.

This need for a circular decision-making logic led to the development of the framework we propose here. The main objective of our contribution is to help actors systematically distinguish innovations in circularity preferentially according to their long-term potential impact and contribution towards the circular economy. The conceptualization and creation of the CDMT emerged from the identified need to direct scholars and practitioners towards the highest-quality circular innovation to support, by acting as a reference in discerning between innovations and policies according to their potential positive contribution to CE.
1.2. Problematization
Despite stated ambitions at various geographical scales to become more or fully circular, these visions fall short of effectively translating into actions in practice (PACE, 2021; Towa et al., 2021; PBL, 2017; PBL, 2021). We hypothesize that this is rooted in a fundamental problem observable in current practices of decision-making: often, decisions are made based on linear decision-making principles. Funding and support for circular innovation is commonly indiscriminate and disproportional to the potential contribution of the innovation towards the transition to a circular economy (CE) - meaning, the “most circular” innovations are not necessarily the ones that receive the most support, in terms of policies, funding, or accolades. The current way of decision-making can be counter-productive to CE because of its support for incremental innovation (Ritzén & Sandström, 2017). For example, accelerating and scaling up an innovation that uses a waste as an input to the business model further ingrains the production of this waste in the economy. “Business-as-usual” linear pathways are deeply rooted in society, and increasing “sustainable” innovations that fit within this scheme further reinforce these existing path dependencies – meaning, while incremental change may offer small gains in sustainable practices, its adoption reinforces the current way of operating and presents another barricade for transformative innovation to overcome. Thus, there is a need for a change towards a different type of decision-making logic, following the rationale to close the identified gap in circular decision-support heuristics.

1.3. Existing models, knowledge gap, and CDMT added value
Some related tools have been developed for predicting or informing decisions with an environmental impact, but none currently exist to assist practitioners in navigating their decisions operationally. These static models or schemes often capture only a moment in time and consider only a single factor of a decision, as the basis for evaluation (e.g. the waste hierarchy); use inconsistent categorizations and terminologies, causing confusion amongst actors (e.g. the R-imperatives); or give a deceivingly precise quantitative result – when in fact many assumptions and estimations are put into the model – and do
not allow the decision-maker autonomous operation [e.g. life cycle assessment (LCA)]. In the field of decision-making, the bounded rationalities and other challenges around environmental policy and practice uncovered in multi-criteria decision analyses (MCDA) lead to uncertainties, indicating a need for an input-responsive, flexible heuristic to help guide decision-makers through these issues (Kalbar et al., 2012; Kalbar et al., 2016). This interdisciplinary gap between science and implementation in practice calls for a resource productivity-oriented framework (van Ewijk & Stegemann, 2016), which the CDMT attempts to offer. The decision tree builds on some of the existing commonly referenced frameworks as introduced below.

The waste hierarchy is a widely supported guide for waste management that prioritizes waste treatment options to reduce environmental impacts in preferential order (Hultman & Corvellec, 2012; van Ewijk & Stegemann, 2016; Dijkgraaf & Vollebergh, 2004). Despite its value and popularity, the hierarchy offers limited specification, implementation of prevention, and guidance for choosing amongst the levels of the hierarchy – often resulting in stimulating optimization of the reigning linear economy rather than the radical change necessary for approaching the new circular paradigm. The various R frameworks – hierarchies of CE value retention options for practitioners – are frequently referenced as the “how-to” of CE (Campbell-Johnston et al., 2020). However, the number, sequence, and terminology of these R-imperatives are inconsistent across frameworks, countries, and supranational organizations like the EU, the UN, and the OECD, who create their own contradictory syntheses of these in their complex political decision-making processes (ibid; Hultman & Corvellec, 2012; Reike et al., 2018). An LCA is a tool from Industrial Ecology used broadly in practice to assess the environmental impacts of a product or service throughout its life cycle, i.e. during raw material acquisition, production, use, and end-of-life waste management (Finnveden et al., 2009). Traditionally, it compares “either-or” decisions; most LCAs are not designed to help select the “best” option from a large pool and do not give guidance through various steps of decisions. The user must already understand the meaning/environmental translation,
relativization, and impact of the output value, as well as when and why it would be appropriate to apply this tool. One of the most well-known and applied tools in the field of decision-making is an MCDA, used to discover and measure decision maker and stakeholder considerations about various (mostly) non-monetary factors in order to compare alternative courses of action (Huang et al., 2011). However, this among other classical theories on decision-making aim to model and predict the behavior of decision-makers but do not aid in decision-making (Groeneveld et al., 2017; Smith, 1979).

Thus, while significant research has been conducted in the fields of waste management, environmental assessments, and decision-making, there remains an interdisciplinary gap between science and practice. Based on the concept of the Waste-Resource Paradox (WRP) (Greer et al., 2021) – which cautions against immediate enthusiasm for waste-based innovations (Henry et al., 2020) and relates to the question of whether an innovation is truly sustainable/permissible in a circular economy – we offer a new framework for decision-making in the transition to a CE. The distinct logic in the CDMT evolves from the WRP dilemmas for CE (for example, the unintentional reinforcing of linear pathways through attempts at circular innovation) is based on the basic need for circular decision-making.

We recognize both the value and limitations of the aforementioned tools and frameworks, and we build on these in the CDMT. What the existing approaches are lacking is guidance amongst circularity levels, schemes that give an inclination to optimize rather than transform, confusion across sustainability rhetoric, assessment tools that often require a related scientific background to understand the meaning of, and abundant information lacking a guiding heuristic to aid in practical decision-making. Instead, our proposed CDMT flows step-by-step through circular decisions in a logical sequence from start to finish, also integrating and indicating the appropriate time to reference and apply the other tools (which have partial value, but fail to provide orientation on diverse options). In the acceleration of the transition to a circular economy, we hypothesize that the CDMT can be helpful in mitigating such hinderances and that it is useful to provide orientation and information on hierarchically preferable contributions to a CE.
through its operational and applicable format across sectors and societal domains. Based on the aforementioned arguments, this paper provides answers to the following guiding research question:

How can decision-makers in government and business be supported in more effectively translating circularity visions into meaningful impact (by allocating their resources according to the highest potential contribution to the transition to a circular economy)?
2. Methods

To form a solid theoretical and applicable foundation for the heuristic, we conducted a thorough literature review around circular economy, decision-support tools, circular frameworks, national and international waste directives, and environmental assessment methods and modeling. We then developed a framework based on empirical observations and building on tools stemming from industrial ecology and social sciences. This collective knowledge was compacted into one visualization and interactive tool designed for user-friendliness and backed by research. A total of 50 stakeholders reflected on the internal logics and applicability of the CDMT.

We validated the heuristic and assumptions of the CDMT. Thereafter, we first tested it in the Netherlands in two successive workshops. Seventeen stakeholders - principally from policy, research, and government – participated in the two workshops. Here we unpacked implicit risks, hampering factors, trade-offs, and organizational dilemmas that factor into circular decision-making. In the second workshop with similar participants (in terms of numbers and fields of expertise). We investigated the CDMT’s usefulness to stakeholders and the soundness of its internal logics. We exemplified the pathways of the CDMT stepwise, illustrated with a case on plastics. After the initial introduction to the tool, participants joined working groups to explore and discuss the tool individually and then collectively. In a plenary session following, the results from all working groups were conglomerated in an interactive session, collecting feedback from actors for tweaking the tool from the practical perspective of various sectors.

To approach the development of a multi-contextual heuristic, we reflected upon stakeholder feedback from both the Global North and Global South, synthesizing and integrating the feedback from participants to improve the logics, usability, and mapping of the tool in their respective contexts. We tested the tool in collaboration with international project partners in their distinct geopolitical contexts:
in Bristol, UK; São Paulo, Brazil; and Cape Town, South Africa. These contexts were selected for two primary reasons: firstly, in the context of the international research project Waste FEW ULL; secondly, for their differences in and diversity of circularity challenges, material stocks and flows, and governance contexts, in order to see the generic ability of the CDMT to be robust in these different contexts. In all contexts, a combination of researchers and practitioners working on topics related to the circular economy gave feedback on the logics and design of the CDMT. To guide the discussion, the following guiding questions were used as prompts, replicated in each of the four contexts:

- Are there uncertainties, paradoxes, and dilemmas of decision-making that you consider barriers in the transition to a circular economy? What examples have you come across in your work or other area of activities?
- Do you agree with the internal logics of the CDMT? (What would you add or adjust for better usability?)
- (How) and for whom could the CDMT’s procedural logics support decision-making?
- What (if any) is the added value of the CDMT in helping distinguish innovations with higher-level contributions to a circular economy?

In the Netherlands and the UK, workshops with group discussions were conducted, while in Brazil and South Africa, structured group interviews based on a protocol of guiding questions were utilized in a similar manner. Each of the four investigative groups from Global South and Global North reported answers through a replicable reporting template, the results of which were synthesized into a table of international reflections on the CDMT’s feasibility of application and potential added value.
3. CDMT structure and logic

This section explores the observed need to make circular decision-making logics actionable for decision-makers of different kinds. We define a circular decision-making logic and structure, drawing on existing frameworks. Building upon this, we also describe the CDMT and its potential added value for society.

3.1. Circular decision-making logics and actors

We define circular decision-making (CDM) logic to be an alternative logic based on a new economy paradigm, wherein transformational decisions are made for a radical new way of operating (in) society, rather than operationalization of (i.e. improvement of the existing) the linear economy and its inherent processes. In line with the two fundamental principles of CE, it prioritizes first the least virgin material extraction from the earth possible, followed by a cascading order of highest possible value retention of materials already in the system. The heuristic presented in the following subsection is built with this CDM logic as its backbone, created for practitioners to internalize and reference to make stronger and more transformative changes. It is designed to be useful for a broad audience of actors and organizations (see Table 1).

Here, we translate “actors” to mean “applicants” or “users”. These actor groups selected were based on a combination of our workshop results. The “other” actors in Table 1 can include but are not limited to: senior advisors and department heads within ministries speaking out recommendations for legislation, circular entrepreneurs in the design phase, innovation teams at organizations looking to improve corporate strategy, seed funders in a selection phase, and consumers before buying into a product or service. Specifically, it can help break down and operationalize decision-making for people in government or business that need to select projects, investments, or solutions; policymakers selecting between proposals; companies deciding what innovations to fund within their business, partners, and value chain partners; architects and engineers considering high-quality circular ways to go about the
creation of a new construction, particularly in terms of materials used; and for entrepreneurs and designers developing, evaluating, and selecting between new circular product business model ideas, prior to moving forward with their launch.

*Table 1: Key actors in decision-making for transitioning to circularity*

<table>
<thead>
<tr>
<th>Actor (within)</th>
<th>Explanation</th>
<th>Reference/Literature</th>
</tr>
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<tbody>
<tr>
<td>Government</td>
<td>Government and policymakers have a key role in enabling mechanisms for shorter loop value retention options, setting targets, and in directing economic activities towards more circularity; they are therefore also a key audience who could benefit from and make a greater impact with this tool.</td>
<td>Reike et al. (2018)</td>
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<tr>
<td>Business</td>
<td>A number of scholars have stressed the lack of appropriate CE tools and a shared language, such as in the context of CE-inspired business model innovation. In order to profit from CE, businesses can analyze what their own supply chain position means for participation and application of feasible circular process innovations.</td>
<td>Antikainen and Valkokari (2016); Bocken et al. (2017); Lewandowski (2016)</td>
</tr>
<tr>
<td>Designer/manufacturer</td>
<td>An issue in supporting the proper waste management for plastic lies on whether to regulate (taxation, incentives, responsibility) the manufacturer or consumer. Most of the time, it is focusing on consumer where it is guilt for the usage, poor separation, and not taking part in recycling efforts. However, the roles of the designer and manufacturer should also be emphasized. Consumers purchase according to the choice offered without having the complete knowledge or information on the material composition. The manufacturer could encourage redesign or design for disassembly, among other impactful solutions.</td>
<td>Klemeš et al. (2020)</td>
</tr>
<tr>
<td>Funder/investor</td>
<td>Major players in the financial industry such as banks, private equity funds, venture capital investors, and governmental funders are showing increasing enthusiasm for circular ventures and innovations because of the high potential for financial returns associated with lower resource dependency, less exposure to linearity risks, and ability to meet stakeholder expectations. Furthermore, an awareness within these high-agency incumbents is growing that the transition to a circular economy will also require public sector financial resources in the form of grants and loans to support research, development, innovation, and procurement, and physical construction of appropriate infrastructure.</td>
<td>Geissdoerfer et al. (2017); Ellen MacArthur Foundation (2017); Domenech and Bahn-Walkowiak (2019); Geng et al. (2019); Milios (2018), via Dewick et al. (2020)</td>
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<tr>
<td>Further actor groups</td>
<td>It can apply to all actors in the current institutional and economic context engaging in CE that lack decision-making support. The support tool takes a systematic and systemic approach to waste reduction in a circular context, and it is designed as a living framework that can be re-evaluated and adapted in changing contexts. It allows for flexibility and autonomy through its non-prescriptive nature and by highlighting tradeoffs, in which the decision-maker has the ability to superimpose their organizational values onto the scientific support of the tree. For example, this could include grassroots or citizen initiatives, civil society initiatives, Ecovillages, or Transition Towns that could benefit from incorporating circular decision-making logic in the form of this actionable tool.</td>
<td>Study workshop results</td>
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As shown by Table 1, different groups and actors all have different ways of engaging with circularity transition. What is needed and valuable across the board is the translation of abstract notions and
scientific knowledge into actionable, logical steps in a decision-making process – and a transformative new strategy towards circular decision-making, distinct from the generic everyday approach by professionals within these actor groups.

3.2. Presentation of CDMT tool

The CDMT utilizes the CDM logic with a transition management approach – which is built around the idea that societal change is too complex to manage, but can be influenced in their directionality (Rotmans & Loorbach, 2009) – to navigate through paradoxes and dilemmas in a decision-making context, focusing on material stocks and flows. The circular decision-making logic embedded in the proposed framework is aiming to increase collective directional and intentional contribution to CE more substantially than by just closing loops.

Link Figure 1
The heuristic is broken down into three main columnal sections, grouped according to logical chronological order of steps to consider during a circular decision:

The first column addresses the chronologically first and “Operational” aspect, i.e. the initial innovation conceptualization, design, and production before scaling. The CDMT directs the user to incrementally consider the possibilities from the best option down, rather than simply “improving” environmental desirability from the bottom up. This means: the higher up on the tree the innovation ranks, the higher circularity potential it has. Once a practical choice between circular ideas/initiatives is made, the user advances to the second stage.

The second and “Strategic” column prompts the decision-maker to examine the selected circular innovation’s diffusion potential, going beyond considerations of the innovation in isolation, and focuses on the selected diffusability and scalability potential. The CDMT encourages the decisionmaker to consider deeper questions about the innovation’s scalability, replicability, and diffusability — important factors into an innovation’s potential impact on circular economy beyond the local. This critical observation includes considerations of economies of scale, capital gains and financial feasibility, and the possibility of scaling in another cultural, political, social, or economic context.

Because of the importance of reflexive learning in the continuous progression towards a circular economy, the third and final “Reflexive” column prompts the user to evaluate and monitor the impact of the innovation selected. This includes identifying key factors and indicator values to predict and evaluate the impact of the circular innovation. After this assessment, the user may repeat the analysis for further material and energy flows. This evaluation and monitoring step brings the decision process full circle, concluding with a component of reflection for future learning. To make the logics and process of the tool more transparent and tangible, we move to a practical illustration of this tool with a case in the following subsection.
The CDMT offers an actionable decision-making framework aiming to balance between inclusion of comprehensiveness of complexity modeling and usability of the heuristic in practical application contexts through straightforwardness. To maintain its simplicity while accounting for factors outside of the tool’s immediate scope, the heuristic includes links to other tools and frameworks at the appropriate time (rather than replacing them entirely). The CDMT is designed to be generic, replicable, and independent of certain sectors or material types. It was created to be universally applicable across geopolitical boundaries, so that any decision-maker in any context could apply the tool to their situational crossroad. The CDMT outlines a multitude of possible decision point uncertainties, answers, and resulting pathways – also allowing for comparison of many innovations simultaneously – to help decision-makers navigate the process from start to finish. Lastly, the CDMT offers autonomy to the user and holds three key principles core: learning, flexibility, and reflexivity.

3.3. Practical illustration of CDMT decision-making flow and application, from an actor perspective

3.3.1. The exemplary case of the construction sector in the Netherlands

The construction of buildings, including upstream supply chains, is also estimated to account for nearly 6% of global final energy use and responsible for 11% of global CO₂ emissions (Abergel et al., 2017). Because of the practical efforts begun in the Netherlands in CE, we have chosen a sectoral example from the Netherlands to illustrate the tiers and logical flow of the CDMT. There, the construction industry accounts for around 50% of the total material consumption (Rijkswaterstaat, 2016). As a result, the Dutch construction sector generates approximately 25 million tonnes of construction and demolition waste (CDW) per year and occupies around 46% of the total national waste (Eurostat, 2017).

Through a combination of initiatives implemented, the Dutch construction sector claims an impressive 95% recycling rate, i.e. “circularity” (Schut et al., 2016). However, this percentage does not describe the
quality of the contribution to CE or distinguish between different types of recycling, and it ignores a principal element of CE: highest value preservation of all materials. The EU follows a similar operationalization of the term circularity, whereby the use of mineral waste as an aggregate for new roads or the burning of wood waste for energy counts the same as deconstructing a modular building to re-use these materials. As stated by Oorsprong (2018), “The required EU rate does not favor the most sustainable recovery operations at all and increases the risk for down-cycling materials with a high resource value.”

Indeed, less than 3% of the recycled materials are returned to the construction usage, while the majority of them serve as foundation components of the road infrastructure. This means that most concrete waste is down-cycled and its value is not effectively recovered, which actually fails to meet the CE requirement (Ghisellini et al., 2018; Yu et al., 2021). Following the logic of the CDMT elucidates that a lack of waste does not (necessarily) equate to full or optimum circularity achieved. The common collective (mis)understanding of circularity constitutes a significant barrier against the true progression towards a circular economy that breaks down (rather than optimizes) the current linear economy regime. In the following subsection, we offer a sectoral illustration of how a practitioner could use the CDMT, with as example a department head of circularity/public administrator within a ministry, advising a minister on the next CE project to support in the Dutch construction sector.

3.3.2. Exemplification of CDMT flow of logics, from a decision-maker's perspective

a. First consideration: Dematerialization

When comparing existing or potential initiatives to support within the circular economy, the department head of circularity within the ministry would first consider the question “Is a waste stream being created?” The answer being yes, he or she could follow the “yes” arrow extending from the first box to the next question – then arriving at the next question, “Can the waste stream be dematerialized?”, i.e.
reduce the amount of material required for a product or process (Thomas, 2003). The CDMT positions dematerialization as the first in line of consideration, because reducing material use to preemptively prevent waste production is overwhelmingly the most efficient pathway to overall waste reduction from a product or process - especially so in the built environment (Bizcocho & Llatas, 2019; Cleary, 2014; Gentil et al., 2011).

As an example, Moynihan and Allwood (2014) have empirically demonstrated the widespread practice in current designs to use over-dimensioned structural steel members, thus uncovering the existing potential for structural mass reduction. Liew et al. (2017) and Hawkins et al. (2020) have focused on construction innovation to achieve material efficiency by exploring shape-resistant structural systems, or pointing out to optimization methods as an effective tool to achieve material efficiency in practice (D’Amico and Pomponi, 2018), as well as maximizing the potential for deconstruction and reuse of structural components (Bukauskas et al., 2018; Brütting et al., 2019). Material efficiency can also be achieved through inherently better building forms, that reduce the required materials whilst offering the same function (D’Amico and Pomponi, 2019).

If the waste in the construction sector cannot be dematerialized entirely, the CDMT flow would lead the decision-maker to next consider the subsequent “partial dematerialization.” Therefore, the CDMT indicates to choose one of the proposals related to dematerialization as the next selected project, over other lower-circularity initiatives (and then to advance to the next column to the right, considering the proposed innovation’s potential for diffusion and/or scaling, to understand its potential for more widespread impact).

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\text{b. Second consideration: Material substitution}
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In the hypothetical scenario that no project proposals for dematerialization are proposed, the next consideration would be the possibility of material substitution: substituting in a suitable alternative
material with a lower negative environmental impact intensity while fulfilling the same function (D’Amico et al., 2021). As related to the construction industry, D’Amico et al. (2021) found that replacing concrete floors with cross-laminated timber in steel structural systems, with a global focus, could mean a greenhouse gas emission saving potential range of 20-80 Mt CO$_2$e (95% confidence interval) - with an average around 50 Mt CO$_2$e in the case of full uptake of the hybrid construction system by 2050. This approach, whilst innovative, does not require any technological development nor upskilling of current professional practice – thus making it an immediately viable solution to accelerate decarbonization.

If the advantage of a material substitution (or lack thereof) is unclear at the time of the decision, the CDMT directs decision-makers to the appropriate tool for the situation to inform the decision at the current stage: in this case, an LCA. If the decision-maker believes that “no,” a full material substitution is not possible or environmentally desirable, the CDMT offers the option to create a more favorable material mix - i.e., a combination of a partial amount of the currently used material and an environmentally favorable material.

c. Third consideration: Material recovery and reuse

If material substitution is not a viable route, the next alternative following the flow of the CDMT is that of closing loops through (waste) material reuse. In the example of the construction sector, Madaster is a Dutch initiative that helps centralize urban mining of building materials, a form of higher value preservation for maintaining materials in the current usable state or form. This can help recover and reuse materials already created, but pieces gathered and left are not guaranteed to be a match for a prospective construction work. This again is a case of an innovative business model that can help optimize our current system, but does not create a radical change towards an institutionalized alternative practice. It can prolong an existing material’s end-of-life phase if another builder or actor finds value in the leftover piece, but moving upstream in the intervention process could even reduce the need for companies like Madaster
that are concerned with recovery. For such a business model to succeed economically and environmentally, a continuous market for the second-hand building materials from their inventory is assumed; yet, there is no guarantee that there will be a demand for the supply. In principle, the recovered materials would be used in another construction project; but in effect, they may end up needing to go to waste anyway or be used in a very low-value format. Furthermore, the construction sector regime remains the same: continuing to produce and use (nearly) the same type and amount of materials for a project. Thus, extraction and production remain the same in principle, with this recovery process only slowing loops and contributing to a larger material stock in the system. While slowing life cycles has a place in CE, it should not be the first option. It is a valuable initiative temporarily, but it is not transformative if the material production in the respective system remains unchanged.

*d.* *Fourth consideration: Cascaded recycling, open-loop recycling, or down-cycling*

If none of the aforementioned options are considered viable possibilities within their context, only then should the lower-value repurposing (e.g. recycling) be selected as the most desirable circular innovation. Following this logic would indicate for the case example at hand that breaking down the construction materials into rubble to bolster the foundation underneath current roads and those still to be built would be the last option, in terms of contribution to a circular economy. The CDMT would thus contradict the current manner of dealing with construction waste in the Netherlands, and its logics indicate that other, higher-quality and higher-value retention options should be explored before supporting an innovation that may constitute an optimization of the linear economy regime in place.
4. Reflections on the CDMT

4.1. International critical reflections on replicability and generalizability

As part of the international research project Waste FEW ULL, the authors of this study teamed up with colleagues addressing waste inefficiencies and circular economy in the Netherlands, United Kingdom, South Africa, and Brazil. Due to the project context, we were able to collaborate with these living lab contexts that address waste inefficiencies and circular innovations in these diverse cities and countries and reflect on the replicability of the CDMT heuristic in these different contexts of the Global South and Global North.

The CDMT was developed in and reflected upon in the Dutch context, but it was important to also go beyond this to test the tool. The aforementioned countries are all on different pathways towards circularity. The Netherlands is a pioneering country in the circular economy; we also wanted to test the tool in more following countries in this context that face different challenges, thereby testing how generic the applicability of tool is by bringing it into these contexts.

The Netherlands Environmental Agency corroborates the logic behind the CDMT in asserting: “A more ambitious CE transition towards substantially lower resource and material consumption and less generation of waste will preferably be based on high-circularity strategies, such as smarter manufacturing and use of products, and extending the lifetime of products and product components. Recycling alone, and low-grade recycling in particular, is still closely related to a linear economy” (PBL, 2017, p. 7). Yet, circular targets are still failing to be met (PBL, 2021). The struggle of even a frontrunning country in circularity, such as the Netherlands, to meet targets indicates that our current strategies in decision-making around amplifying the circular economy are not effective in a meaningful enough way.

The results of the workshops in the Dutch and UK contexts and the interviews with local stakeholders in the Brazilian and South African contexts that were designed to test and validate the CDMT offered
feedback on the usability and internal logics of the decision tree. It was discussed if and how the CDMT procedural logics could support decision-making and its application contexts as a guiding scheme. These results are detailed below in Table 2:
<table>
<thead>
<tr>
<th>Context</th>
<th>Participants involved</th>
<th>Valued functions/Perceived assets of the tool</th>
<th>Critical reflection/feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td>Researchers in academia, Think Tank/researchers in practice, Consultancy, Policy-making</td>
<td>Accurately reflects decision points and uncertainties in practice (consultancy and policy)</td>
<td>Trade-offs (e.g. with energy) and further system changes to be expected</td>
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<tr>
<td></td>
<td></td>
<td>Useful when communicating/interacting with suppliers, as a way to evaluate circularity impact with a common reference</td>
<td>Architectural or urban design context it might be hard to ever say yes to the questions</td>
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<td></td>
<td></td>
<td>Flexible in ability to apply when drawing up contracts (project leaders could raise this issues)</td>
<td>Best applied at a high/management level</td>
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<td></td>
<td></td>
<td>Challenges incrementalism and encourages more transformative decisions</td>
<td>Outcomes directly leading to circularity are not guaranteed</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Researchers in academia, Policy, Activism, Non-profit, Civic entrepreneurship, Community co-operators</td>
<td>Emphasizes the hierarchy in often-overlooked differences in contribution to CE</td>
<td>Single waste-stream focus</td>
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<td></td>
<td></td>
<td>Creates a “CE architecture”: ability to articulate between systems, boundary object role</td>
<td>Entropy increases challenges in using the tool, because dispersed or mixed waste streams will be harder to address, e.g. smart phones with many components</td>
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<tr>
<td></td>
<td></td>
<td>Added value may also be theoretical, demonstrating the need for more inter-sectoral or collaborative decision making that goes beyond individual organizations</td>
<td>Considerations on scale, i.e. assumes upscaling is a goal, which it may not always be</td>
</tr>
<tr>
<td>South Africa</td>
<td>Municipal waste management, Provincial government, Policy-making, Living lab management and academia</td>
<td>Directs decision-makers to collect more data or to be prompted for existing evidence</td>
<td>Might be missing crucial steps that give or improve the evidence that is necessary for decision-makers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alerts decision-makers to be more critical in the application and evaluation of the flow and implications</td>
<td>Could propose mechanisms for implementation and upscaling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provides understanding and awareness about mechanisms for implementation and upscaling</td>
<td>What tools could be put in place to enable the ‘Further Analysis’ section that could support an enabling process to map the acceleration potential</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very useful if stakeholders are involved in the process and are able of participate freely in the development of decisions</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Policymaking, Food technical production, Ministry for Agriculture and Food Supply, Non-profit, Researchers in academia</td>
<td>Fills a gap for a management tool lacking in current practices, especially at the ministry level</td>
<td>Could be built upon and adapted for other links in the value chain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Offers alternative to current majority bottom-up, chaotic planning by integrating increased rationality and structure in problem-solving</td>
<td>Effects of waste treatment and processing not captured</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Locates interested parties and plans the strategy for good management of processes by mapping all working fronts from the beginning</td>
<td>Future developments of the tool could include a typology of characterization of waste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supports public policymaking and implementation and increase better time management performance by structuring next steps in user’s current work</td>
<td>Many decisions depend on the technological trajectory</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Socio-political definition of responsibilities for waste disposal is a factor</td>
</tr>
<tr>
<td>Across all contexts</td>
<td>All of the above</td>
<td>Convincing consensus on structural logics (of a new perspective on sustainable practices and strategic planning)</td>
<td>Should be paired with cost/benefit analyses within the status-quo of markets (account for capital, value distribution, ROI)</td>
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<tr>
<td></td>
<td></td>
<td>Helps broaden vision outside daily practices, encouraging systems thinking outside one’s immediate sphere</td>
<td>An accompanying sectoral example makes logics clearer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal logics helps problem framing around the quality of circular interventions. Helps identify dilemmas and paradoxes</td>
<td>Does not account for regulatory patterns on waste treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Follows a logical path and draws attention to upscaling (to know what technology should be used and the viability of the innovation)</td>
<td>Power relations between actors, managers, companies, and waste management contractors are large and diverse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Catalyzes important reflection exercises and discussion on circularity processes and principles at multiple layers of companies, between and within public departments</td>
<td></td>
</tr>
</tbody>
</table>
We find that the CDMT is already fulfilling several functions in multiple practical contexts in its current form. The Dutch workshops highlighted its accurate reflection of decision points, its ability to challenge incrementalism, and its value when communicating across supply chains or when drawing up contracts. The UK workshops coined its ability to create a “CE architecture,” acting in a boundary object role and giving the user the ability to articulate between systems. In South Africa, it was noted to offer autonomy and co-creative decision-making, and the Brazilian interviews flagged its potential as a management tool and as a complementary alternative to more common bottom-up approaches.

4.2. Critical synthesis
The participants in all four contexts collectively indicated that the CDMT would be a useful tool to be introduced to managers, aid in procurement decisions, and creating awareness in suppliers of such circularity questions. Common across all contexts, they reported that it stimulates reflexivity about the diversity of circular options and highlights the inherently differing quality levels of different waste streams and circular innovations. It was asserted that the tree’s logics and design are solid and useful, particularly in helping to identify dilemmas and drawing attention to the impact of upscaling.

Further results included support of its usability for multiple layers of companies: providing a common understanding of shared values, the meaning of circularity to a more refined sharpness, and the implementation practices needed to select, support, and carry out circular initiatives within their sphere of influence. The tool can be used very practically during business and policy decisions, but also has additional function for stimulating discussions and aligning organizational visions and values. From the study, the CDMT was also indicated to be a useful tool for governments and civil servants/legislators, e.g. for when projects proposals are being assessed or for procurement – supporting our hypothesis about intended audience and impact.

A common present critical reflection concerned economic influences currently not being present in the tool, because all decisions in reality are embedded in market and socio-economic contexts that deal
with tradeoffs and challenges. Decisions on waste inefficiencies and material considerations are in some ways embedded in cost-benefit tradeoffs, and this should be further addressed in later versions of the tool. Furthermore, this first version of the tree does also not include the influence of regulatory patterns on waste treatment or power dynamics.

While academics were more critical about specific details of the tree, practitioners were very supportive of the tree’s value for practice in its current form. From the results of the workshops and interviews, we see certain functions the tool as being validated in a promising way. At the same time, we consider the critiques based upon which we offer recommendations for future in the following subsection.

4.3. Own reflections and future research recommendations

The Circular Decision-Making Tree bridges the gap between science and policy by providing orientation during decisions concerning circularity, highlighting and communicating a hierarchy of preferrable contributions in varying impact levels to CE, and stimulating debate and reflection across sectors and societal domains. This can be particularly of interest to parties pertaining to the regime-niche: actors or organizations with innovative (niche) thought patterns or actions operating within the incumbent (regime) context (Greer et al., 2020). Because of the unique positioning of these actors, the CDMT would be a very suitable heuristic to apply when striving for and supporting the application of innovative (in this case, circular) solutions at a higher or more mainstream level, e.g. designing new circular processes within a company, selecting the best initiative from their respective research and development team, or improving product design. Other contexts for applying the tool include group management decisions, conversation-starting across and within departments, and for adding transparency and value alignment throughout value chains. This is especially valuable, as important decisions are rarely made by a single person; usually, decisions are made in a group, and often spanning department boundaries. Thus, it can
be of much added value to have a boundary object for different actors in decision-making collectives to have a common framing for discussion.

This guiding scheme is not intended to be all-encompassing - but rather, to improve on existing circularity frameworks like the waste hierarchy and R-imperatives (which do also not inform on economic or social concerns), and to offer an operational heuristic that directs decision-makers towards preferred circular pathways. We understand that decisions are also largely based on investment costs, phase-out costs, the price of a shifting industry, politics, and other socio-economic implications like impact on the workforce. However, there is always an inverse correlational relationship between inclusivity of complexity and usability; the CDMT strives for a best compromise in the tradeoff between the two. Interestingly, the mostly commonly used existing circularity frameworks also miss these aspects, so we consider the CDMT as the next developed step by helping to operationalize preferred pathways. Still, we acknowledge the added value of these elements and therefore encourage future researchers to build on this presentation of the CDMT through agent-based modelling, social modelling on actors’ behaviors and preferences, and factoring economic consequences and market considerations into this first tool offered here.

To include additional meaningful factors in the original tool without overcomplicating the basic heuristic, the CDMT directs the user to a complementary tool at a decision point when it becomes out of the scope of the heuristic. For example, when the decision-maker is unclear on what would be a more sustainable material to substitute for the current waste stream, the user is directed to an LCA. When considering uncertainty in cost-effectivity, the user is directed to a related tool, e.g. a cost-benefit analysis (CBA). It is our opinion that referring to other frameworks such as these can allow the tool to keep its visual simplicity while offering important information beyond the Circular Decision-Making Tree’s main focus of differentiation.
5. Conclusions

The CDMT is an outcome-focused, novel framework for navigating circular decisions around material flows in products, processes, industrial sectors, and economies that builds on work from and additionally contributes to industrial ecology. It focuses on the potential role of decision-makers in industry, practice, and policy in reducing environmental burdens and increasing sustainability. Given the apparent challenge of navigating decision options across alternative circular innovations, we have introduced the CDMT as a heuristic that proved its usefulness and potential in four application contexts. The CDMT is adaptive and responsive to user input, offering step-by-step guidance through a selection process between circular innovations or proposals for circular initiatives, through a hierarchical process of coming to the optimally impactful solution - while still allowing for autonomy and flexibility in the decision-making, as the tool is not rigidly prescriptive in nature. The use of this heuristic in practice can contribute to the transition to a circular economy by helping decision-makers consider and distinguish between the quality of an innovation’s contribution to CE. In this way, practitioners can use the CDMT to make the best use of resources allocated to progression towards a CE by indicating the best choice out of a pool of circular initiatives and facilitating interorganizational dialogue. Building on the development of this initial, general CDMT, it would be interesting for future researchers to incorporate secondary criteria beyond the foundational circularity component, in a version of the CDMT adapted for use catering to a specific field, e.g. economic cost/benefit, social justice, social impacts, or environmental impacts such as CO₂ emissions or biodiversity. In this way, multiple versions of the tree specific to different secondary criteria could be developed, while keeping the first version of the CDMT in this paper as the original frame of reference. Our final recommendation for future research is to test the tool in further workplaces, policy, and industry contexts to assess its impact on circular decisions in practice.
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Data availability statement

Data sharing is not applicable to this article as no new quantitative data were created or analyzed in this study.
References


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https://www.ellenmacarthurfoundation.org/


**Figure legend:**

Figure 1: The Circular Decision-Making Tree (CDMT)
Appendix: CDMT figure assumptions

- With “scaling”: human, material, financial resources/capacity to scale (economies of scales, limits to growth, etc.)
- Energy requirements implicitly but not explicitly weighed
- Not a huge trade-off with energy use, chemicals, or other environmentally harmful manifestations of burden shifting
- Social dimension of sustainable development not integrated (e.g. implications for labor force)
- All other components/factors remain reasonably constant (e.g. enormous transportation demands are not needed to receive the new material substituted)
- Recycling and material processing cause material and energy losses