Onto-DESIDE GA number: 101058682

ONTO-DESIDE

DELIVERABLE

D5.3 Multi Flow Circular Value Network Design & Development Method – Second iteration

Deliverable number	D5.3
Deliverable name	Multi Flow Circular Value Network Design & Development Method – Second iteration
Work package	WP5
Lead partner	UHAM
Contributing partners	-
Deadline	2025-11-30
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Project information

Project summary

Circular economy aims at reducing value loss and avoiding waste, by circulating materials, components or product parts before they become waste. Today, lack of support for sharing data in a secure, quality assured, and automated way is one of the main obstacles that industry actors point to when creating new circular value networks. Together with using different terminologies and not having explicit definitions of the concepts that appear in data, this makes it very difficult to create new ecosystems of actors in Europe today. This project will address the core challenges of making decentralized data and information understandable and usable for humans as well as machines. The project will leverage open standards for semantic data interoperability in establishing a shared vocabulary (ontology network) for data documentation, and a decentralized digital platform that enables collaboration in a secure and privacy-preserving manner.

The project addresses a number of open research problems, including the development of ontologies that need to model a wide range of different materials and products, not only providing vertical interoperability but also horizontal interoperability, for cross-industry value networks. As well as transdisciplinary research on methods to find, analyse and assess new circular value chain configurations opened up by considering resource, information, value and energy flows as an integral part of the same complex system. Three industry use cases, from radically different industry domains, act as drivers for the research and development activities, as well as test beds and demonstrators for the cross-industry applicability of the results. The developed solutions will allow for automation of planning, management, and execution of circular value networks, at a European scale, and beyond. The project thereby supports acceleration of the digital and green transitions, automating the discovery and formation of new collaborations in the circular economy.

Project start date and duration

1st of June 2022, 36 + 6 months (incl. extension)

Project consortium

No	Partner	Abbreviation	Country
1	Linköping University	LiU	Sweden
2	Interuniversitair Micro-Electronica Centrum	IMEC	Belgium
3	Concular Ug Haftungsbeschrankt	CON	Germany
4	+Impakt Luxembourg Sarl	POS	Luxembourg
5	Circularise Bv	CIRC	The Netherlands
6	Universitaet Hamburg	UHAM	Germany
7	Circular.Fashion Ug (Haftungsbeschrankt)	FAS	Germany
8	Lindner Group Kg	LIN	Germany
9	Ragn-Sells Recycling Ab	RS	Sweden
10	Texon Italia Srl	TEXON	Italy
11	Rare Earths Industry Association	REIA	Belgium
12	Prague University of Economics and Business	VSE	Czech Republic

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0.2	2025-11-21	Karin Wannenberg	Internal Reviewer	RS
1.0	2025-11-27	Fenna Blomsma	WP5 leader	UHAM

Table of Content

Abbreviations

CE	Circular Economy
CEAP	Circular Economy Action Plan
WP	Work Package
UHAM	University of Hamburg
MFM	Multi-Flow-Metabolism
M	Month
T5	Task within work package 5 of Onto-DESIDE
D5	Deliverable within work package 5 of Onto-DESIDE
DRM	Design Research Methodology
DS	Descriptive Study
PS	Prescriptive Study
Bv1/2	Version Beta 1/2 (of the Multi-Flow Value Chain Method)
CAP	Collective Action Planning (Method)

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Summary

This deliverable presents the advancement of the Multi Flow Metabolism framework into a method that supports the innovation of circular economy value chains. Presented here is the second iteration of the Multi-Flow Method: a method focusing on how best to bring a systemic perspective to understanding circular value chains and its constituting flows. The Multi-Flow Method serves to create innovation capacity for designing and developing circular economy value chains. The method was developed through a scientific foundation and process (based on Design Science), whilst working with real world applied cases (the use cases of Onto-DESIDE and additional cases beyond the project). That is: a first version was created using insights from the use cases and tested with them. Subsequent revision and testing followed. Learnings and insights from this process served to further advance the method.

The current version that is the outcome of the process described within this report consists of two parts: 1) the Flow Analysis through generative tensions, and 2) defining Ecosystem Requirements. A full explanation of the process can be found in Guide 1, which is part of the Training deliverables of the project (WP7). In this report, we include a brief summary of the method and explain our steps of arriving at this second iteration since the last deliverable D5.2. Crucially, the method has evolved into a sensemaking tool, that uses the tensions to support interrogating the flows of the value chain and how it will behave as a result of how the flows are structured. With this, we depart from the previous version that was centred around the Circularity Design Framework. Lastly, we include an outlook for continued development.

1 Introduction

Today society faces many severe environmental challenges, such as biodiversity loss, resource depletion and climate change. Many of these consequences can be traced back to the predominant linear economic system as the current 'take, make, use, dispose" paradigm has led to the consumption of resources beyond the regenerative capacity of our ecosystems[1,2]. It becomes apparent in society's excessive resource usage: at the moment, humanity uses the equivalent of 1.7 earths[3]. The number increases to 2.8 earths if everybody would live like an average EU resident. A radical shift in current production and consumption patterns and the organisation thereof is required[4]. Circular Economy (CE) is regarded as a promising alternative approach which simultaneously respects planetary boundaries and ensures economic and societal well-being[5,6]. However, despite its potential, the implementation of a CE is still at a nascent stage.

Amongst other barriers, the lack of support for sharing data in a secure, quality assured, and automated way is one of the main obstacles that industry actors point to when attempting to create new circular value networks. The use of different terminologies and the absence of consistent definitions make it difficult to create new ecosystems of actors in Europe today. Onto-DESIDE has addressed these challenges by leveraging open standards for semantic data interoperability in establishing a shared vocabulary (ontology network) for data documentation, as well as a decentralized digital platform that enables collaboration in a secure and privacy-preserving manner. The project made decentralized data and information understandable and usable for humans as well as machines and has developed a data sharing platform for the digitalised CE. That said, the research required to bring Onto-DESIDE to a successful conclusion in the future was twofold. On the one hand, the transdisciplinary project required research in the field of ontology modelling and for the development of an ontology-based data sharing platform. This work was conducted by work package (WP) 3 and 4 in close collaboration with WP2. On the other hand, given that Onto-DESIDE aimed to contribute to the transformation of the European industry into a CE, further research and knowledge creation regarding the design of circular value networks was required. That is: it's necessary to know what the value chain will look like and how it will function, before the data and information flows can be put in place. Within Onto-DESIDE, creating the necessary innovation capacity for the design and development of these value chains was led by the team of the University of Hamburg (UHAM) (WP5). The report at hand is the third deliverable by WP5 and constitutes the second iteration of the tool and method – and focuses on the process that was followed to create it. More on the method itself can be found in the deliverables as part of WP7 Training (Guide 1).

This introductory chapter continues with a short overview of the concept of CE and briefly presents the preceding research that builds the foundation for the work in Onto-DESIDE, namely the Multi-Flow-Metabolism (MFM) developed by Blomsma and colleagues[7]. This is followed by an overview of the tasks of WP5 before the objectives of this deliverable are described. Section 1 concludes with an outline of the remainder of the report.

1.1 Introduction to Circular Economy

In essence, Circular Economy is an umbrella concept that groups a wide variety of strategies, all for the purpose of value retention, reduction of value loss or alternative ways of value creation[1,7,8]. In its early stages, CE focused on waste and resource management strategies that aimed at extending product and material life through strategies such as recycling and remanufacturing[8]. While such circular strategies are still an integral part of the implementation of a CE, the understanding of a circular economy now extends to that of a systemic concept, requiring deep change in the structure of business and industry. That is, CE encompasses a wide range of strategies that promote product, component and material conservation, efficiency, and productivity, e.g., recycling, reuse, maintenance, and manufacturing. Moreover, CE also involves strategies that look more directly at how value can be created or value loss reduced from a system point-of-view, e.g., for all stakeholders[7]. The concept of CE thus requires a rethinking of not only how resources flow through

systems, but also who benefits and in what way, in order to realise the urgently required shift from the current linear economic model to a circular economic system[4,9]. This implies that more holistic and collaborative approaches are required[4,9].

As an alternative economic model which can support sustainable development efforts, CE has received attention from scholars, businesses, and policy makers[1,2,10]. This, for example, is reflected in the European Union's "Circular Economy Action Plan" (CEPA). As an important part of the European Green Deal, the CEPA "paves the way for a cleaner and more competitive Europe"[11] and thus aims to directly influence business and the way it operates. Onto-DESIDE contributes to the realisation of this action plan as the developed solutions will allow for the automation of planning, management, and execution of circular value networks, at a European scale, and beyond. However, despite the recognition of the potential of a (European) circular economy, the implementation of holistic circular value networks is still in its infancy, partly due to a lack of understanding and ways to influence the complex system that circular networks represent.

Previous research has shown that multiple flows play an integral part for a robust circular metabolism. That is: the industrial metabolism - the 'flows' that make up the lifeblood of systems such as economies - can be seen as consisting of resource- (e.g. physical), energy-, information- and value-flows[12–15]. It is when these flows are aligned and work collaboratively that metabolisms function harmoniously and within planetary boundaries. This occurs when value is provided to all relevant stakeholders by means of physical flows that respect the carrying capacity of the planet and which are facilitated by sustainable energy flows and supported by relevant information when needed. When large-scale metabolism changes happen—for example, when systems grow or advance into a new system state—these 4 flows, together with the accompanying infrastructure and technology, reconfigure collectively as an integrated whole, giving rise to new systemic flow patterns[13–16].

Within CE the relevance of these flows is also acknowledged: see, for value flows, for example, work by Bocken et al.[17] or Pieroni et al.[18]; for information flows see the work by Kristoffersen and colleagues[19]; and see for energy flows the work by Cullen[20], Allwood and colleagues[21], or Bakker and colleagues[22]. So far, in CE, these 4 flows are studied with either an exclusive focus on one flow, or as a set of two, usually in relation to resources. However, Blomsma and colleagues[7] have recently shown that considerations regarding these 4 flows feature prominently and - crucially - *together* in circular oriented innovation. They are considered in relation to each other and designed together. For this reason, the Multi-Flow Metabolism (MFM) model was proposed to bring together these 4 flows (see Figure 1) and to emphasise their co-dependence in creating a sustainable circular metabolism.

However, at present, no comprehensive or authoritative guidance exists as to what a robust circular metabolism looks like – and how these 4 flows can be made into a coherent whole that operates within planetary boundaries. Previous efforts to provide such guidance primarily take the form of circular design frameworks that propose a variety of design principles[2]. Examples of such frameworks are: Material Efficiency, which focuses primarily on the relationship between the production and circulation of materials and energy[21,23]; Cradle-to-Cradle which highlights three main principles: waste equals food, current solar income should be used, and diversity should be celebrated and diversity should be celebrated[24,25]; and the Blue Economy which proposes a list of 20+ such principles, including cascading through multiple kingdoms, replacing something with nothing, and generating multiple benefits[26]. These frameworks have several shortcomings. They a) do not systematically cover all fours flows, b) have limited scientific underpinning, and/ or they can c) vary wildly in the number and type of principles they propose, resulting in little trust in them. This means that there is a gap as to what guidance to adhere to when designing robust, sustainable, and circular metabolisms.

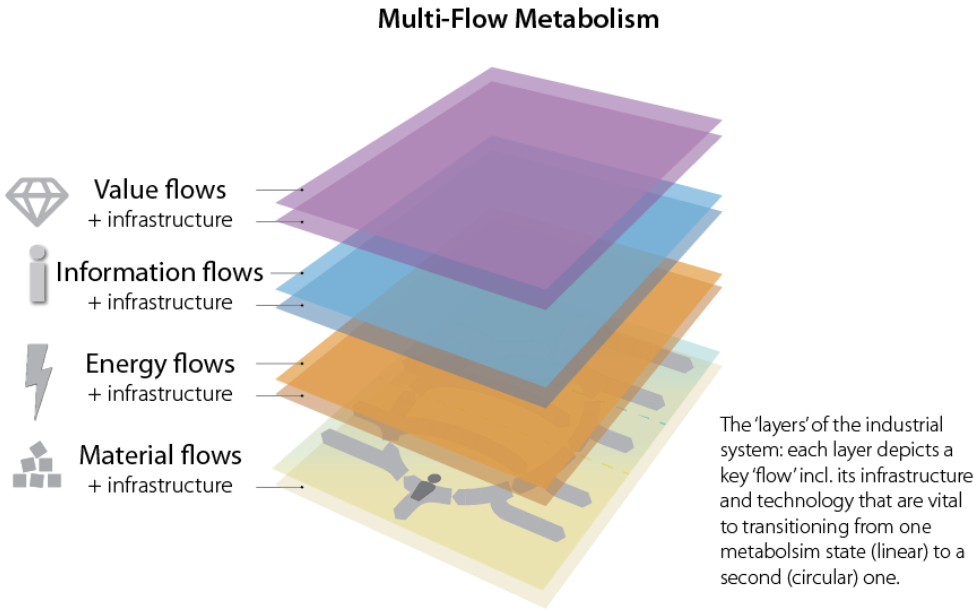

Figure 1 The Multi-Flow Metabolism by Blomsma et al. (2022)

For change agents within business and other organisations this hinders the design and implementation of circular value chains, as it means that tools and methods to scan for and identify improvement opportunities that consider these 4 flows holistically are lacking. Considering both the pressing need to transition to more sustainable and circular industrial systems[27,28], as well as the current willingness and momentum to act[11,29]; this gap needs addressing urgently. Therefore, as part of the WP5 work within Onto-DESIDE, the MFM will be further developed into a method and tool that addresses this gap.

1.2 Tasks and Deliverables of Work Package 5

WP5, titled "Multi flow circular value network design & development method", was led by UHAM. WP5 has (further) conceptualised, developed, validated, and implemented tools and approaches that transform the MFM model into a method for the accelerated development of systemic circular solutions. The goal of this WP was to create innovation capacity that will close the gap between idea and action for a CE and to turn the MFM into a strategic tool for use within Onto-DESIDE and beyond.

WP5 consisted of three tasks (T5):

- T5.1: Review state of knowledge (M1-18) – lead: UHAM
- T5.2: Operationalisation & maturing (M10-30) - lead: UHAM, participants: CON, POS, CIRC, FAS, RS
- T5.3: Consolidation of method (M25-42) (incl. project extension) - lead: UHAM

and three deliverables:

- D5.1: State of knowledge review – report (amended to M11 with approval of EU project manager)
- D5.2 Multi flow circular value network design & development method Version 1 – report (amended to M27 with approval of EU project manager)
- D5.3 Multi flow circular value network design & development method Version 2 – report (M42).

The three tasks have built on each other, yet they were also interrelated and overlapped in time. The first task laid the foundation for the work within WP5, through an assessment of the current state of knowledge and practice around resource- (e.g. physical), energy-, information- and value-flows in the context of value chain design. A structured review drew from and consolidated knowledge and guidance for the design of these four flows from across different fields such as systems and complexity science, as well as the circular economy and supply chain fields. D5.1 summarised the findings of the initial state of knowledge review. This task, however, continued until month (M) 18. In combination with the second task, T5.2, the outcomes of D5.1 were further developed and operationalised by turning them into a first version of guiding tools and methods. The developed methods were tested with the help of the industry partners and adjusted in an iterative approach. D5.2 also had a project milestone associated with it, i.e., Milestone 10: "First version of MFM methods", which subsequently culminated in delivering T5.3: consolidation of methods (M42) and D5.3. The work done in T5.2 and T5.3 was used for the development of part of the training materials within WP7. The corresponding task in WP7 was also led by UHAM. This final report, D5.3 describes the finalised methods and tools, including a short summary of how they are to be used. For a comprehensive overview of how WP5 connects to the broader Onto-DESIDE workflow and its relationship to other WPs, please refer to D2.1 "Project Requirements and Research Methodology".

In summary, WP5 developed a method and tool for the design and development of circular value networks with the end goal to support the use-cases within Onto-DESIDE (WP6), but that can serve a wide variety of other circular value chain efforts beyond the project. The latter also refers to the method's integration as part of the Circularity Thinking toolkit. This allows for the systemic aspects of this toolkit to be strengthened and offers the Multi-Flow Method a platform for further dissemination. Moreover, WP5 had a reciprocal relationship with the other WPs in that it provided the frameworks and methods to study circular value networks within Onto-DESIDE. In turn, the methods brought forward in WP5 were based on a sound theoretical foundation and the requirements of the industry cases (WP6), scoped by WP2. Where possible, WP5 outcomes were translated into ontological and further technical requirements for the construction of the Circular Economy Ontology Network and the Open Circularity Platform by WP3 and WP4.

1.3 Preceding Deliverable D5.1: State of Knowledge Review and Remaining Gaps

The "State of Knowledge Review" report (D5.1) reviewed and synthesised the then-current understanding of resource (e.g., physical), energy, information, and value flows in the context of value chain design. It summarised what was already known about the principles for how circular value chains are understood to operate, as well as current thinking on how resource, energy, information, and value flows interact. This work confirmed that little comprehensive guidance existed on how to design and develop circular value chains in a way that enables the four flows to function coherently as an integrated whole. Existing guidance tended to address only pairs of flows (e.g., resources and information, or resources and energy, etc) rather than considering all four flows and their interactions. We therefore synthesised this into a more comprehensive overview, resulting in a framework called *the Circularity Design Framework*. The framework consisted of 5 primary categories (the *Circular Metabolism Factors*), supported by second-order principles (Circular Enablers) and third-order principles (Implementation Actions). This served as input for developing the first version of tools and methods in D5.2.

1.4 Preceding Deliverable D5.2: Multi-Flow Circular Value Network Design & Development Method – Version 1

Building on D5.1, D5.2 operationalised these concepts into the first iteration of a practical method - the Multi-Flow Method - to support systemic design and improvement of circular value chains. Using Design Research Methodology, the team developed and tested the method with three industry use cases (construction, electronics, textiles) as well as other experts. The method evolved through iterative cycles:

- Version Beta 1 (Bv1) introduced two main components: Flow Analysis (six mapping tasks for different flows and system environment) and Action Organisation (steps to cluster, prioritise, and plan actions).
- Feedback and evaluation led to Version Beta 2.1 (Bv2.1), which aimed to streamline mapping tasks, integrated root causes across flows, added a refinement step for actions, and introduced considerations of actors' spheres of influence.

Version Beta 2.1 (Bv2.1) was a more time-efficient and structured approach that aimed to help practitioners identify root causes of barriers and enablers and courses of systemic action. The following steps were planned for the second iteration to allow for further improvement: an updated literature review to advance the Circular Metabolism Factors, further refinement planned through additional expert interviews, and testing with participants outside the project.

1.5 Objective of this Current Deliverable

The objective of this final deliverable D5.3, is to explain the developments in the second refinement stage, the content of which was already delivered as part of the Training deliverables in WP7. This deliverable contains two practical guides aimed at disseminating the project results, one of which is exclusively dedicated to explaining and facilitating the tools that are the result of the process explained here (see Guide 1).

Our starting point was an overall review of the method as delivered in D5.2 and to take up the improvement opportunities identified (see Table 9 in D5.2 for more details). One of the priorities was to reconsider the organisation and integration of the Circular Metabolism Factors. Although participants in the use cases evaluated them positively, the discussions about barriers and enablers were time-consuming and often failed to uncover the underlying patterns. This created a high risk of *analysis paralysis* and, without facilitation, made it hard to know what endpoint to aim for. For this reason, we updated and re-reviewed the literature (see D5.1) to explore how it could be organised to better align with the method's goals. New insights led us to adopt *generative tensions* as the main organising principle instead of the Circular Metabolism Factors, setting the second iteration of the method on a new course. In the below we explain this in more detail and describe what this meant for the second iteration as finalised in training Guide 1.

The remainder of this report is structured as follows. Section 2 explains Design Research Methodology (DRM). It clarifies where this current deliverable is located in the process, and what was learned through the steps followed for this second iteration. Section 3 briefly summarises the resulting changes to the method. Section 4 closes with the outlook and the next steps beyond the Onto-DESIDE project.

2 Research Approach

In this section, we describe the research process, indicating which steps informed the first iteration and which led to the second. As planned, we follow the Design Research Methodology (DRM), a design research approach well suited to developing artefacts such as tools and methods together with their application steps.

2.1 Design Research Methodology

A design science perspective serves to:

- Extend the boundaries of human and organisational capabilities by creating and evaluating innovative artefacts that address real-world problems and improve existing situations[30–32];
- Bridge theory and practice by generating actionable, field-tested design knowledge that supports intentional change towards more desirable system state[30,33,34].

These objectives make design research a suitable approach for WP5, which aims to build innovation capacity for robust circular value chains by developing principles of value network dynamics and chain robustness. As circular value chains are only an emergent phenomenon - they exist but are not yet dominant in our economies - it is necessary to learn both from the guidance that is available from system and complexity science (which has studied a wide variety of aspects of systems), as well as from early examples from practice. As such, different streams of knowledge need to come together in a format that can be used with and by practitioners.

Specifically, WP5 used Design Research Methodology (DRM) by Blessing and Chakrabarti[30]. DRM consists of an iterative process, where, after an initial research clarification, descriptive and prescriptive phases follow each other until an approach is sufficiently mature. Here, the descriptive phases are aimed at understanding (aspects of) the tool or application process, where the prescriptive phases codify these learnings and insights into (visual) aids or templates that can be used as boundary objects in innovation processes. Figure 2 illustrates the generic process of DRM on the left (ibid.), and how it is applied within WP5 on the right. Building on the work presented in D5.2, which covered the DRM method development up to Prescriptive Study II, this deliverable continues the process by reporting on the subsequent stages from Descriptive Study III onwards. Next, we summarise the preceding steps in D5.2, followed by more detail on the steps that followed.

2.2 Preceding Steps: Summary of D5.2 Method Development

The Research Clarification, the focus of D5.1, confirmed gaps and defined the goal: to translate systemic principles into practical guidance for the respective flows. D5.2 then followed this up with two cycles of descriptive and prescriptive studies. Descriptive Study 1 (DS1) involved interviews with three industry use cases (construction, electronics, textiles) to understand barriers, enablers, and systemic challenges. Insights were synthesised into key themes that informed the design of the method.

In Prescriptive Study 1 (PS1), these insights were used to create the first version of the Multi-Flow Method (Beta 1), structured around two parts: Flow Analysis (six mapping tasks for different flows and system environment) and Action Organisation (steps to cluster, prioritise, and plan actions). This version was tested in workshops with the use cases, generating observations and formal feedback.

Descriptive Study 2 (DS2) evaluated the method's usability and effectiveness, identifying improvement opportunities. Based on this, Prescriptive Study 2 (PS2) produced Version Beta 2.1, which streamlined mapping tasks, integrated root causes across flows, added a refinement step for

actions, and introduced considerations of actors' spheres of influence. A first facilitation guide was also developed. For the details regarding these previous steps, we refer to the D5.2 report.

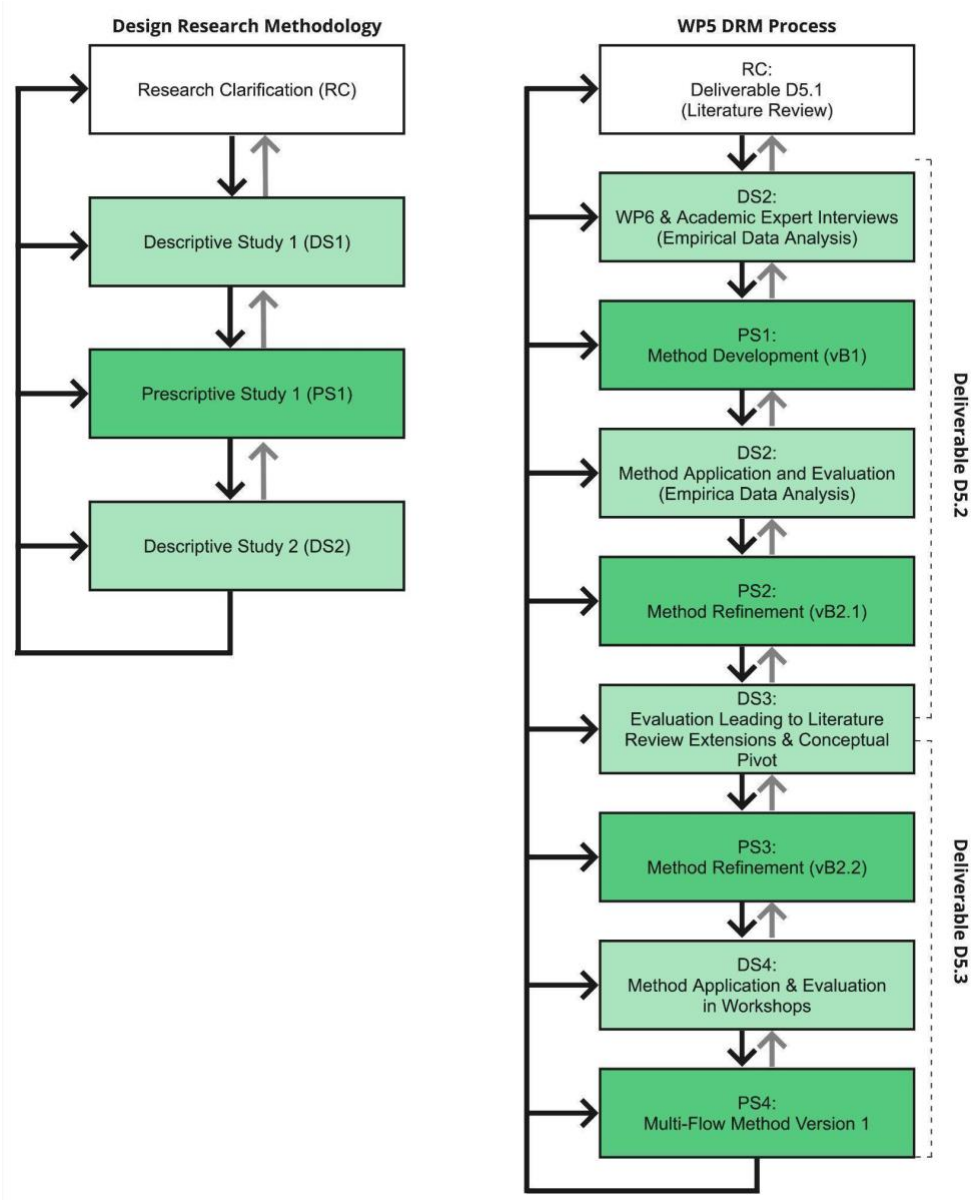

Figure 2 Design Research Methodology Process of WP5

2.3 DS3 – Descriptive Study 3

The starting point for DS3 was the list of method improvement opportunities summarised in Deliverable D5.2 (see Table 9, p. 42). This table presented the evaluation of method version vB1 and distinguished between improvement opportunities that could be implemented immediately - these were integrated into the Multi-Flow Method vB2.1 submitted with D5.2 - and those that required more substantial development work in the next iteration cycle. Among the latter was the need to reconsider how the Circular Metabolism Factors were organised and integrated within the method. While use-case partners had previously evaluated the factors as relevant and applicable (see D5.1), their integration into the method proved challenging. During the use-case workshops, participants did not find the prompts associated with the Circular Metabolism Factors intuitive. The evaluation showed that although participants implicitly drew on the factors in their reasoning, they were unsure how to respond when these were posed directly through the Generate Actions questions (see D5.2).

This aligned with our own observations: the existing prompts did not consistently lead participants to systemically meaningful considerations. Instead, discussions tended to converge once again on lists of barriers and enablers.

In response, we proposed in D5.2 to "review the metabolism factors with the intended use in mind: refine and rearticulate to make MFs both distinct from each other as well as meaningful in a value chain context" (D5.2, p. 44). Building on this, we decided to return to the literature reviewed in D5.1 with the aim of revisiting the development of the Circularity Design Framework and retrace the assumptions we had made along the way in organising and structuring these. In particular, the goal was to re-examine the defined categories (the Circular Metabolism Factors) to make them more distinct and more clearly articulated so that they would become clearer and easier to use. We thus returned to the existing literature with openness to further exploration and the possibility of identifying new conceptual directions. As a first step, we revisited the category development stage of the Circularity Design Framework and re-examined the first-order principles. A closer inspection of the second- and third-order principles allocated to each Circular Metabolism Factor highlighted the need to investigate the relationships between the factors more thoroughly. While we had recognised the factors' interdependencies during the initial development of the framework (D5.1), we had not yet examined their implications in depth. Revisiting the original framework brought these connections back into focus (see Figure 3).

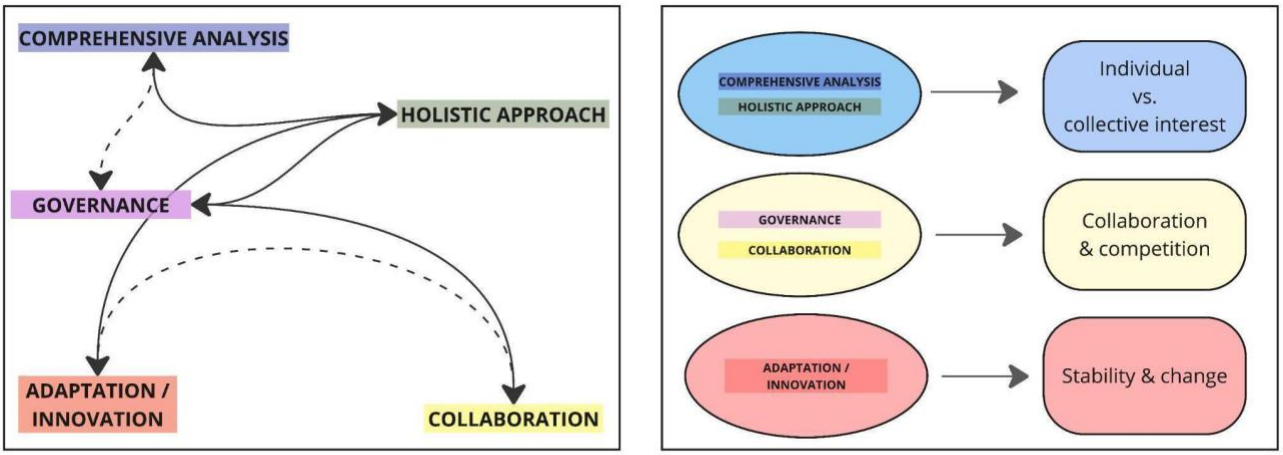

Figure 3 Reconceptualisation Process: Moving from Circular Metabolism Factors to Tensions

As we explored the interconnectivity of the factors in more detail, it became apparent that some of the (parts of the) first- and second-order principles could be meaningfully combined. Several factors and enablers assigned to the five original metabolism factors overlapped conceptually, suggesting that the framework could be simplified without losing explanatory power. Re-evaluating what could be grouped together - and what could not - pushed us to rethink the categories more fundamentally. As we revisited the data and reassessed how principles fit within each group, it became clear that some elements pointed in opposite directions. In several instances, these differences were not merely mismatches (e.g. wrong placement) but reflected opposing orientations of the same underlying dynamic - two sides of the same coin. Recognising that some principles pulled in contrasting yet interdependent directions led us to see these not as classification errors but as signs of deeper systemic tensions within circular value chains. This insight became the starting point for the tensions-based framing.

Additionally, the re-opened discussions around the metabolism factors also brought questions of specificity to the foreground. While the evaluations of the Circularity Design Framework (D5.1) and the metabolism factors (D5.2) confirmed that these categories are relevant for circular value chains,

they also revealed an important limitation: in their current form, the factors also apply to linear value chains. In other words, the metabolism factors were not yet specific enough to capture what is distinct about circular systems.

These three observations led to the reduction and reframing of the original five Circular Metabolism *Factors* into three Circular Metabolism *Tensions*. This was achieved by merging: 1) Comprehensive Analysis and Holistic Approach into “Individual vs. Collective Interest", 2) Governance and Collaboration into “Collaboration & Competition”; and 3) Adaptation and Innovation capacity into “Stability & Change” (see Figure 3). The tensions capture the dynamic forces within complex dynamic systems, of which circular value chains with complex feedback loops are a specific instance, reflecting the competing or complementary priorities, challenges, and interdependencies that shape system behaviour.

To obtain feedback and validation for our reframing - from metabolism factors to tensions - we conducted interviews with experts in complexity science, systems thinking, and Earth System Science. All experts agreed to participate in multiple sessions, which allowed for in-depth discussions and iterative refinement of our conceptual developments (see Table 1). The three experts responded positively to the shift and confirmed that the newly adopted framing of tensions aligns well with core concepts in systems thinking and complexity science. A key result of the expert interviews was the renaming of tensions – from Circular Metabolism Tensions – to *generative* tensions to better capture their exploratory and insight-generating character. The key learnings from these expert sessions are summarised in Table 1.

Table 1 DS3: Summary of Expert Interviews (DS3-1)

DS3-1 Interviews
Purpose: Initial sense-check on conceptual changes

#	Research Background	Meetings / Duration
1	Complex systems applied to sustainability and economics	1) 10/09/2024 (90 min) 2) 17/09/2024 (60 min) 3)08/10/2024 (60 min) 4) 12/11/2024 (60 min) 5)19/11/2024 (60 min) 6) 17/12/2024 (60 min) Total: 6h 30 min
2	Complexity science and evolutionary systems	1) 19.11.2024 (90 min) Total: 1h 30 min
3	Earth system science and tipping points	1) 19.11.2024 (90 min) 2) 17.01.2024 (45 min) Total: 2h 15 min

DS3-1 Interviews - Key learnings

- The tension framing reflects core systems characteristics and aligns well with systems thinking.
- One expert noted that, similar to biological systems, the tensions operate along spectra rather than fixed categories.
- Tensions themselves are not problematic; they are inherent to complex systems and can drive system evolution.
- Although the tensions are familiar concepts within the experts’ fields, their application to value chains was viewed as a novel and useful contribution.
- Discussions helped refine the tensions into their current form:
  - Individual vs. Collective Interest
  - Robustness vs. Adaptability
  - Concentration vs. Distribution
- The experts highlighted additional systems-thinking dimensions underpinning each tension:
  - Individual vs. Collective Interest: links to issues of scale
  - Concentration vs. Distribution: relates to density
  - Robustness vs. Adaptability: shaped by temporal dynamics
- Time and space emerged as cross-cutting considerations; while only partially integrated so far, these dimensions may require further development.
- From a practical standpoint, experts advised that the set of principles should remain small; thus, the decision to work with three main tensions was reinforced.

At the same time, we decided to extend and update the literature review conducted for D5.1. The review was expanded to include papers published after our initial review (2022) and to incorporate Scopus as an additional database. Using the same keywords, search strings, and inclusion criteria, the extended search identified further papers for assessment. Following the established four-step screening process, 21 papers were selected for full inclusion. The existing and new papers were then coded according to the tensions framing. This process further confirmed the validity of the reframing, as the newly identified literature could also be meaningfully allocated to the three first-order principles, i.e., the generative tensions.

Based on the initial validation from the experts and the insights they provided, we arrived at 3 main tensions:

Tension name	The tension explained
Individual vs. Collective Interest	Alignment between individual actors' goals and the collective interest / the system's requirements (for it to be circular).
Robustness vs. Adaptability	Enabling the system to evolve while remaining functional.
Concentration vs. Distribution	Balancing control, governance of the system

To further confirm these tensions and to explore their usability and practicality in supporting practitioners to generate insightful understandings of their value chains, we conducted additional research interviews and hosted research workshops during a research stay at the Global System Institute at the University of Exeter. We conducted a total of eight interviews with experts spanning a wide range of fields, including Circular Economy research, sustainable value chain design, complexity science, Earth System science, and geography (see Table 2). The interviews confirmed that the tensions resonate strongly with experts across disciplines and align well with established systems-thinking concepts. They also highlighted that the tensions can serve as boundary objects—helping surface underlying dynamics, bridge perspectives across actors, and support deeper reflection than traditional barrier–enabler approaches. Further key learnings are summarised in Table 2.

After completing the research interviews, two workshops were hosted (see Table 3). The first workshop took place at the Exeter Centre for Circular Economy and involved researchers primarily working in the fields of Circular Economy and sustainable value chain design. The second workshop was held at the Global Systems Institute and brought together participants from a wider range of disciplinary backgrounds.

Table 2 DS3: Summary of Expert Interviews (DS3-2)

DS3-2 Interviews
Purpose: Confirmation of generative tensions and further work

#	Research Background	Meetings / Duration
1	Complex Systems & Systems Thinking and Circular Economy	24.03.2025 (70 min)
2	Sustainability, Social Sciences, Circular Bioeconomy	25.03.2025 (55 min)
3	Complex systems, Earth system & climate science, Sustainability science	25.03.2025 (65 min)
4	Complex Systems and Circular Economy	25.03.2025 (75 min)
5	Regenerative Economy, innovation, technology	28.03.2025 (55 min)
6	Intersection of individual and systems change, social-ecological systems	01.04.2025 (80 min)
7	Global systems, transitions, sustainability	02.04.2025 (65 min)
8	Sustainable Futures	03.04.2025 (50 min)

DS3-2 Interviews - Key learnings

General learnings about generative tensions

- Tensions move beyond barrier/enabler thinking and acknowledge the dynamic nature of circular systems.
- They help surface what truly matters in a value chain and encourage participants to think differently than they usually would.
- Tensions can function as boundary objects, supporting shared understanding across diverse actors.
- They enable pooling of perspectives to identify the key systemic challenges and dynamics.
- Their high level of abstraction is useful: being too specific too early would limit their applicability.
- The tensions reflect core features of complex systems and were recognised as such by experts.
- Even though they originate in systems language, they remain accessible and understandable for industry and government audiences. A caution was raised that systems thinkers may overcomplicate matters; clarity and usability need to be preserved.

Insights regarding individual tensions

- Individual vs. Collective Interest
  - Resonates with the well-known system tension between agency and structure.
  - Closely linked to questions of scale (individual, group, organisation).
  - Experts noted its connection to ambivalence in decision-making and behaviour.
- Robustness vs. Adaptability
  - Connects to concepts such as antifragility, resilience, flexibility, and efficiency.
  - Linked to exaptation as a mechanism for system robustness.
  - Relates to “evolving conditions” and broader theories of change.
- Concentration vs. Distribution
  - Tied to structural aspects of systems and distribution of resources or information.
  - Shows conceptual overlap with Individual vs. Collective Interest, especially around power dynamics.
- Cross-cutting dimension: Time
  - Time was confirmed as a cross-cutting factor affecting all tensions.
  - Temporal change forces tensions to evolve, and long/short time horizons influence system balance.

Learnings on how to work with tensions

- Further work is required to support practitioners in using tensions in a generative (not evaluative) way.
- Applying broad system rules to specific contexts is challenging and may require additional scaffolding.
- Experts offered examples of mechanisms through which systems manage tensions today: evolutionary selection, democratic processes, ethical rules, social rituals, habits and practices.
  - These mechanisms are interconnected but distinct; recognising their differences is important for interpretation.
- Game theory was suggested as a useful perspective for operationalising tensions.
- Explore early-warning signals for each tension to detect when a system is approaching imbalance.
- Consider how to nudge the system in productive directions, linked to ideas such as “catalytic probes”.

Since the conceptual framing of tensions had already received positive responses throughout the interviews, the primary focus of the workshops was to explore how people work with the tensions in practice. The workshops were designed to understand how participants interpret the tensions, how they respond to them, and what kinds of conversations the tensions trigger.

Participants worked in small groups and were asked to engage with each tension using the following guiding questions:

1. What are examples of these tensions? Where have you come across these tensions?
2. Choosing one tension: how can it be addressed? What are the mechanisms for this?
3. How did you realise the balance was off? What signs indicated this?

The key takeaways from the workshops include that participants could easily identify real-world examples of the tensions, confirming their relevance, but found it much more challenging to define how to work with them in practice. A summary of the workshop learnings is provided in Table 3.

Table 3 DS3: Summary of Workshops

DS3-Workshops Purpose: Application of tensions in practice		
1	Hosted at: Exeter Centre for Circular Economy Expertise of participants: Circular Economy, Sustainable value chain design, Sustainable Transitions	Date: 26.03.2025 Duration: 60 min Participants: 6 in person, 7 online (total 13)
2	Hosted at: Global Systems Institute, University of Exeter Expertise of participants: Earth System Science, Complexity Science, Geography, Design Science, Circular Economy, Sustainable Transitions	Date: 03.04.2025 Duration: 90 min Participants: 12 in person
DS3- Workshops - Key learnings • Participants recognised the tensions from their work and were able to identify concrete real-world examples, confirming the tensions' relevance and accessibility. • Time was mentioned as an influential factor shaping how tensions play out in practice. • Some participants found it relatively easy to pinpoint problems and articulate how tensions manifest, but substantially more difficult to propose ways of working with or addressing the tensions. Others tended to jump prematurely toward solutions and needed to remind themselves to fully explore and understand the problem dynamics first. • The workshops highlighted the importance—and difficulty—of defining system boundaries, especially when working with hypothetical cases involving diverse actors. Questions such as "What is part of the system, and what is not?" arose frequently and shaped how participants interpreted the tensions.		

These insights formed the foundation for the continued development of the Multi-Flow Method in the subsequent prescriptive study.

2.4 PS3 – Prescriptive Study 3

Based on the insights gained through DS3, we developed the next iteration of the Multi-Flow Method (vB2.2). The overall structure of the mapping tasks for each flow was retained, meaning that each flow continued to be mapped separately - using the resource flow mapping as the foundation - and that the same general logic was followed for each flow.

For comparison, in the Multi-Flow Method vB2.1 the instructions consisted of:

1. Map the flow to create a shared picture,
2. Analyse what the key mechanisms or root causes of the challenges are, and
3. Generate actions on how to influence the value chain by addressing key mechanisms.

The updated version (vB2.2) introduced several significant conceptual changes. For the first time, the method was explicitly framed around the generative tensions. This new conceptual foundation required replacing the original Generate Actions questions, which had been based on the Circular Metabolism Factors. That said, each mapping task now followed a revised set of steps.

Step 1 remained the same: mapping the flow to create a shared picture.

Step 2 introduced the key conceptual shift: exploring the flow through the generative tensions. In essence, users were asked to examine each side - or each extreme - of a tension and then assess whether the current balance in the system was appropriate. For example, in the case of the tension Individual vs. Collective Interest, participants explored questions such as: Is the individual taken care of? Is the collective taken care of? Is the balance right?

Each of these overarching questions was supported by further prompts. For instance, the exploration of whether "the collective is taken care of" was guided by additional questions such as:

- What does value mean for the ecosystem?
- What would collective success look like?
- Are any collective needs neglected because no one owns them?
- Where do actors collaborate or invest in shared success?

Step 3 required participants to summarise the key takeaways from the discussion and identify patterns that emerged across actors, flows, or issues. This included outlining what recurring dynamics were present in the ecosystem and placing these insights into the system patterns repository. The introduction of patterns was motivated by the need to help participants look beyond individual observations and understand *why* certain problems persist and *why* particular dynamics continue to recur. The patterns step supports participants in uncovering the deeper systemic pressures, trade-offs, and drivers that influence how the value chain functions.

Step 4 then focused on the development of ecosystem requirements. Based on the identified patterns, users were asked to determine what the system already offers to address these patterns (offerings) and what is still missing (needs). This step sought to translate the observed dynamics into practical insights for system development.

In summary, the development from the Multi-Flow Method vB2.1 (D5.2) to vB2.2 introduced three major conceptual advancements: the implementation of generative tensions as the main framing, the introduction of patterns, and the formulation of ecosystem requirements.

2.5 DS4 – Descriptive Study 4

Following the developments made in Prescriptive Study 3, we tested the updated method in two workshops. The first workshop took place with a flat glass value chain group consisting of multiple actors, including recyclers, glass producers, building owners, consultants and other relevant stakeholders. This group represented an active circular value chain initiative aiming to increase the recycling of flat glass in their region. Despite the high technical recyclability of flat glass, most of it currently ends up in landfill. The group's ambition to shift towards closed-loop recycling made them an ideal test bed for the method.

We hosted a workshop for this group, attended by 18 actors (see Table 4). Prior to the in-person session, we conducted preparatory work online with a smaller subset of participants. This included mapping the resource flows and value flows of their value chain, which allowed the workshop itself to focus directly on testing the newly introduced developments of the method. The workshop evaluation showed that the shift to generative tensions enabled participants to engage in deeper conversations about the underlying reasons for their challenges, rather than merely producing a list of barriers. Participants were able to identify a crucial mismatch of incentives that currently prevents flat glass recycling from operating effectively. The workshop also highlighted a key practical insight: participants require clear and targeted inspiration prompts to begin engaging with the tensions. Striking an appropriate balance is essential—providing enough prompts to initiate discussion without

overwhelming participants with excessive information or inadvertently locking them into a particular solution suggested by the examples.

In addition to testing the updated Multi-Flow Method, this workshop also provided the opportunity to assess its integration with another method currently being developed within the Circularity Thinking framework: the Collective Action Planning (CAP) method. While the Multi-Flow Method extends the Circularity Thinking toolkit by identifying ecosystem requirements (offerings and needs), the CAP method translates these requirements into actionable steps. CAP supports users in:

1. Understanding where constraints to implementing circular solutions reside,
2. Understanding the nature of those constraints,
3. Evaluating and prioritising activities to address them, and
4. Developing implementation roadmaps and learning journeys.

CAP is being developed in parallel to the Multi-Flow Method, outside the Onto-DESIDE project but within the broader Circularity Thinking framework. Testing the two methods together was an important step in evaluating how the Multi-Flow Method connects to the broader Circularity Thinking workflow and ensuring that both methods operate as a coherent sequence rather than as isolated components.

Table 4 DS4: Summary of Workshops

<table>
<tr><td colspan="3">DS4-Workshops
Purpose: Testing of Multi-Flow Method</td></tr>
<tr><td>1</td><td>Flat Glass Value Chain</td><td>Date: 29.04.2025
Duration: 6 hours
Participants: 18 (in person)</td></tr>
<tr><td>2</td><td>Circularity Thinking Training</td><td>Date: 26.06.2025
Duration: 90 min
Participants: 11 total (4 participants in the Multi Flow Method testing session)</td></tr>
<tr><td colspan="3">DS4- Workshops - Key learnings
The full-day workshop enabled productive and in-depth conversations among participants.
The prompts provided for working with the tensions were perceived as too numerous and at times as not specific enough to effectively guide discussions.
Although groups focused on a single flow at a time, their conversations naturally drew on multiple flows, showcasing the interconnected nature of flow dynamics again.
Participants tended to discuss both sides of a tension (e.g., individual interests and collective interests) without really engaging with the tension between them.
While the method is designed to foster system-level insight, participants also need space to discuss individual actor perspectives to ensure that outcomes remain usable.
The rich discussions did not automatically translate into concrete action points, indicating that a clearer translation step may be needed.
One suggestion was to begin in stakeholder-specific groups to align on challenges, and only then mix groups for the solution-development phase.
Additional support may be required when working with hypothetical cases—or the hypothetical scenario must be specified more clearly to support deeper engagement.</td></tr>
</table>

The second workshop took place as part of an online Circularity Thinking training with 11 participants. Participants first participated in workshops for each preceding step of Circularity Thinking, allowing them to gain a good foundation on the parts, such as the Circularity Compass. Afterwards, a smaller subgroup of four participants took part in a focused workshop on the Multi-Flow Method. In this workshop, participants worked with a hypothetical use case, meaning that none of them were actual experts in the value chain used as the example. While this limited the depth of insights participants could reach, the discussions nevertheless showed that the method worked at a conceptual level.

Taken together, the two workshops offered important validation of the updated method while also highlighting areas for further refinement. These learnings directly informed the adjustments made in the next prescriptive iteration.

2.6 PS4 – Prescriptive Study 4

The evaluations conducted in DS3 confirmed that the conceptual changes introduced to the method worked well: they improved the quality and depth of the discussions. While PS3 resulted in major conceptual revisions to the method, only minor adjustments were required in PS4.

Specifically, we refined Step 3, where patterns are identified. While vB2.2 introduced the concept of patterns in general terms, the updated version established a clear distinction between existing patterns and desired patterns. The aim of this refinement was to support users in identifying and organising the systemic patterns that explain how the system currently functions, while filtering and prioritising the most critical ones. These existing patterns then serve as the foundation for envisioning how the system could function differently. In this step, users first make current patterns explicit and then define desired patterns that illustrate how tensions could be resolved, worked around, or productively embraced.

The adjustments made in PS4 resulted in the Multi-Flow Method Version 1, as published in Training Guide 1. The Multi-Flow Method Version 1 is further explained in the following section.

3 Multi-Flow Method explained

This section briefly presents the method that came out of the last iteration, with the new steps and templates. It is described as used in a workshop. For a detailed overview, please consult the finished guide that is part of the training material, published as D7.7. The complete guide also contains a follow-along example looking at building doors.

3.1 Steps 1-3: Getting Ready to Apply the Multi-Flow Method

Before applying the Multi-Flow Method, three preparatory steps establish the groundwork. These steps were already part of the existing steps of Circularity Thinking, of which the Multi Flow Method is an extension:

1. **Map Resource Flows**
   The process begins by setting the scope and tracing the lifecycle of materials, components, and products—from extraction to end-of-life. This qualitative mapping creates a shared picture of what's relevant, how resources move and where blind spots exist.

2. **Identify Structural Waste**
   Using the "Big Five" waste patterns (premature end-of-life of material and product, underused material and product capacity, and excess or harmful use), the analysis highlights where value leaks occur. This step surfaces hotspots and root causes, moving beyond visible discards to systemic inefficiencies.

3. **Sketch a Circular Configuration**
   Based on waste hotspots, circular strategies such as reuse, repair, remanufacturing, and recycling are combined into a synergistic configuration. Trade-offs, enabling conditions, and potential rebound effects are noted.

After following these steps, there is a thorough understanding of the problems in a value chain, and a first sketch of what circular strategies are needed across the value chain to address current problems and create new benefits.

3.2 Step 4: The Multi-Flow Method

So far, the focus has been on physical resource flows; other flows, their integration, and the systemic forces shaping circular value chains remain hidden. This step addressed this gap by combining multiple flows, examining tensions, identifying patterns, and defining ecosystem requirements. The four sub-steps are as follows (see Figure 4).

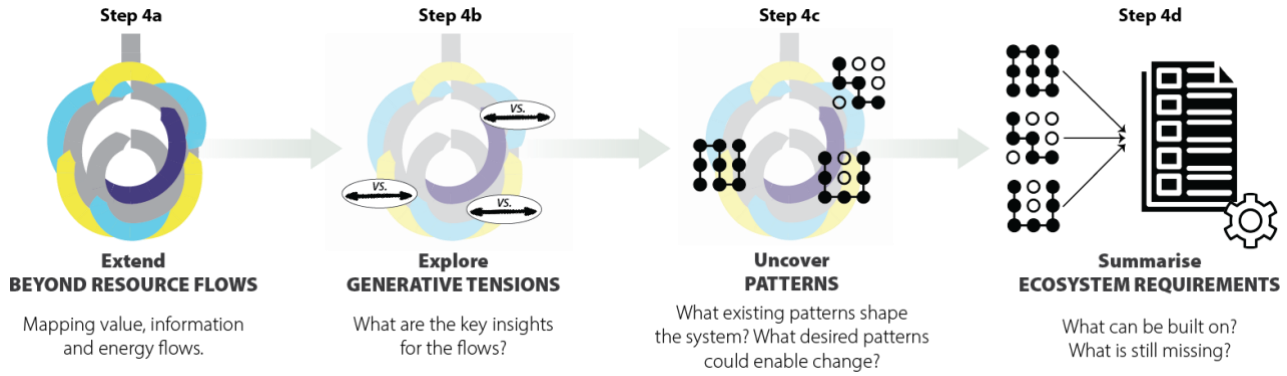

Figure 4 Sub-steps of the Multi-Flow Method

3.2.1 Step 4a – Extend Beyond Resource Flows

The first task is to expand the view beyond materials, components and products. Circular strategies depend on costs and gains, information and data, and energy as much as on physical resources. Therefore, this sub-step layers three additional flows onto the resource map:

- **Value Flows:** Map how money, incentives, and benefits move across the system. Identify who benefits, but also who pays, and where value losses occur.
- **Information Flows:** Capture what data is needed, by whom, and when. Highlight gaps that undermine coordination and trust.
- **Energy Flows:** Show where energy is required, consumed, or wasted, and types and sources.

The goal is not exhaustive detail but a shared picture of the most important interdependencies that influence circular strategies.

3.2.2 Step 4b – Explore Tensions

The next step is to move beyond what is visible and uncover why the flows behave as they do. Simply listing barriers and enablers does not explain persistent misalignments or recurring problems, nor how seemingly separate barriers and enablers may share common underlying causes. This step therefore introduces a deeper lens: **generative tensions** - looking for the forces that shape the dynamics of a circular value chain. These tensions are structural conditions that must be balanced, navigated, or - in some cases - resolved for circular strategies to succeed.

Purpose of Step 4b

The aim of this step is to interpret the flow mappings through three systemic tensions that frequently appear in circular transitions:

1. **Individual vs. Collective Interest**
    - *What it means*: Explores how the goals of individual actors align—or conflict—with the goals of the system as a whole.
    - *Why it matters:* Circular strategies require collaboration, but misaligned incentives often push actors toward short-term gains at the expense of system-wide benefits.
    - *Example:* Demolition contractors prioritise fast disposal because it is cheaper for them, even though the system loses valuable materials that could be reused.

2. **Robustness vs. Adaptability**
    - *What it means:* Looks at the balance between stability and flexibility in contracts, processes, and relationships.
    - *Why it matters:* Robust systems provide reliability and trust, but too much rigidity prevents adaptation to new technologies or disruptions. Conversely, excessive adaptability can undermine confidence and continuity.
    - *Example:* Fixed demolition contracts lock actors into disposal practices, leaving little room to integrate reuse opportunities when they arise.

3. **Concentration vs. Distribution**
    - *What it means:* Examines how resources, power, and information are allocated across the system.
    - *Why it matters:* Excessive concentration can create bottlenecks and dependency, while excessive distribution can lead to fragmentation and weak coordination.
    - *Example:* Large demolition firms dominate recovery processes because they hold contracts and equipment, while smaller refurbishers struggle to access opportunities. Digital marketplaces centralise transactions, creating efficiency but risking exclusion of smaller actors.

How the step works

The process begins by revisiting the flow maps created in Step 4a. Participants select one flow—resource, value, information, or energy—that appears most critical or problematic. Using the tensions as interpretive lenses, the group discusses how these opposing forces manifest in the system. Guiding questions help structure the conversation:

- For **Individual vs. Collective Interest**:
    - What is the goal of the individual actors—and can they reach it?
    - What is the goal of the value chain as a whole—can it be reached?
    - Do current arrangements reward collaboration or reinforce individual optimisation? Where do some actors bear costs that benefit others, and how does this affect participation?

- For **Robustness vs. Adaptability**:
    - Do existing contracts and standards provide security or restrict flexibility?
    - Can the system adjust when disruptions occur, or is it locked into rigid paths?

- For **Concentration vs. Distribution**:
    - Who controls access to resources, data, or financial benefits?
    - What is the effect of the current concentration or distribution on efficiency or dependency?
    - Would a different approach enhance resilience or complicate coordination?

Flow-specific guiding questions are also provided, see the next page Table 5. Insights are captured on post-its and placed on the flow map at the relevant points. Each note should express a clear cause-effect relationship rather than a generic barrier. For example:

- Instead of “reuse is too expensive,” write “current pricing structures make disposal cheaper than reuse.”
- Instead of “information is missing,” write “lack of standardised data formats prevents buyers from verifying product compatibility.”

Outputs of Step 4b

The outcome of this step is a set of *key insights* that explain why flows take their current shape. These insights move beyond symptoms to reveal underlying dynamics such as misaligned incentives, rigid governance structures, or power imbalances. They provide the raw material for the next step—*pattern identification*—where recurring dynamics are organised into systemic patterns and paired with desired alternatives.

Table 5 Multi-Flow Method Step 4b: Flow specific guiding questions for tension exploration

	Resource Flows	Value Flows	Information Flows	Energy Flows
Individual vs. Collective Interest	• Are actors incentivised to maximise their own short-term use of resources, or to preserve shared long-term availability? • Who benefits from discarding or extracting resources, and who bears the costs of loss or scarcity? • Do current arrangements reward collective recovery of resources, or reinforce individual disposal practices?	• Where do some actors bear costs that benefit others, and how does this affect participation? • Do current value exchanges encourage collaboration across the system, or pull actors in different directions? • When value is created, does it stay with the actor who generated it, or does it spill over to benefit others in the system?	• Are organisations rewarded for keeping information to themselves / sharing information with the value chain? • What are they gaining/ losing by sharing/ not sharing? • What risks emerge from not sharing/ sharing wrong/ unintentionally sharing?	• Do actors optimise energy use mainly for their own operations, or in ways that benefit the system as a whole? • Are savings from efficiency or recovery kept within single firms, or shared across the value chain? • Does competition over energy costs hinder collaboration on shared energy solutions?
Robustness vs. Adaptability	• Do existing supply contracts and standards provide security, or restrict flexibility when resource quality or availability changes? • Can the system adjust when disruptions occur (e.g. shortages, impurities), or is it too dependent on fixed supply chains? • Does stability in resource flows build confidence, or reduce the space to experiment with circular alternatives?	• Do financial arrangements (e.g. contracts, pricing models) provide security, or lock actors into rigid paths? • When conditions change, can value flows adapt — or are they too fixed to respond? • Does stability in value exchange build trust, or prevent experimentation with new circular practices?	• Is the way information moves in this system rigid? Or flexible when things change? • What happens when unexpected things happen? • Does the system rely on fixed routines? Or can it adjust when things change?	• Are energy supply arrangements (e.g. contracts, infrastructure) providing stability, or locking the system into rigid paths? • When disruptions occur, can the system shift to alternative energy sources, or is it too dependent on one option? • Does reliance on stable but carbon-intensive energy provide short-term security at the cost of long-term adaptability?
Concentration vs. Distribution	• Is access to key resources concentrated in a few actors, or spread more widely across the system? • Does concentration create efficiency and control, or vulnerability to bottlenecks and dependency? • Would more distributed access to resources enhance resilience, or complicate coordination?	• Is value capture concentrated in the hands of a few actors, or distributed more widely across the system? • Does concentration of financial power create efficiency, or dependency and exclusion? • Would broader distribution of value strengthen resilience, or complicate coordination?	• Is access to information concentrated among a few actors, or broadly shared across the system? • Who controls the key information needed to make decisions, and who is left dependent on them? • Does concentrating information in a few hands make the system more efficient, or more vulnerable?	• Is access to affordable energy concentrated in a few hands, or distributed fairly across actors? • Does centralised energy provision create efficiencies, or make the system vulnerable to bottlenecks and disruptions? • Would distributed and decentralised energy models increase resilience, or add coordination challenges?

3.2.3 Step 4c – Uncover Patterns: Identifying the System Dynamics

Once tensions have been explored and key insights captured, the next task is to organise these insights into *patterns*—recurring dynamics that explain why the system functions as it does. Patterns move the analysis beyond isolated observations and provide a systemic explanation for persistent issues.

Purpose of Step 4c
Patterns reveal the underlying structures and behaviours that hold the system in place. They show how incentives, rules, and practices interact across flows, creating dynamics that either block or enable circular strategies. By identifying these patterns, the analysis shifts from listing problems to understanding why they persist.

How the step works
Begin with the insights generated in Step 4b. These notes often describe cause-effect relationships linked to tensions. Next:

- Cluster related insights and rephrase them as *systemic statements*, not one-off actions. For example:
    - Instead of "provide spare parts," write "repair becomes the default because spare parts and knowledge are consistently accessible."
- Identify *existing patterns*—the dynamics that currently dominate and hinder circularity.
- Define *desired patterns*—alternative dynamics that would enable circular strategies to succeed. Desired patterns should describe systemic shifts, such as "market mechanisms ensure consistent pricing and quality for reused products."

Outputs
A set of paired patterns:

- *Existing patterns* highlight misalignments (e.g., demolition contracts incentivise disposal over recovery).
- *Desired patterns* describe new dynamics (e.g., recovery and resale become financially and logistically more attractive than disposal).

These patterns provide a bridge to the next step, where they are translated into actionable ecosystem requirements.

3.2.4 Step 4d – Summarise Ecosystem Requirements: From Analysis to Action

Patterns describe how the system behaves; ecosystem requirements specify what the system must provide to make desired patterns possible. This final sub-step moves the process from interpretation to preparation for implementation.

Purpose of Step 4d
The goal is to define the conditions—capabilities, infrastructures, and relationships—that enable the desired patterns. These conditions are grouped into two categories:

- *Offerings:* Existing elements that can be scaled or adapted (e.g., selective dismantling practices, digital marketplaces).
- *Needs:* Missing elements that must be created (e.g., incentive structures, standardised quality frameworks, inclusive governance models).

How the step works

Review the desired patterns from Step 4c and look for overlaps or common themes.

- For each pattern, identify what already exists and what is missing:
  - *Offerings*: Current practices, tools, or networks that can support the desired change.
  - *Needs*: Critical gaps that prevent the desired pattern from becoming reality.
- Capture these as concise, actionable statements. For example:
  - *Offering*: "Established networks of reuse brokers with experience matching supply and demand."
  - *Need*: "Policy incentives to make recovery financially more attractive than disposal."

Outputs

A repository of ecosystem requirements that provides a clear picture of:

- What can be built upon.
- What must be developed to enable systemic change.

This marks the conclusion of the Multi-Flow Method. The analysis has progressed from mapping flows to identifying tensions, uncovering patterns, and specifying requirements—creating a structured foundation for planning interventions and scaling circular strategies. A method that builds on this and that supports collective action planning integrating both standard plan-and-control approaches as well as experimentation and learning was developed in other work extending the Circularity Thinking approach.

4 Multi-Flow Method: Outlook

Whilst we have travelled far and learned much within the last 3,5 years advancing the Multi-Flow Method, follow-on activities and next steps remain. Here we outline some of what is planned.

4.1 Continued Empirical Work

We plan to conduct additional case studies and are currently exploring potential collaborations and facilitated sessions with other organisations. The primary aim of this continued empirical work is to apply the Multi-Flow Method across a broader range of contexts. So far, the method has been used within the Onto-DESIDE use cases, with the flat glass value chain, and through hypothetical examples in workshop settings.

In the future, we hope to apply the method in different industries, use cases addressing various circular strategies, and value chains that involve other types of actors. These contexts will allow us to test the method under diverse conditions and examine its applicability across different system configurations. Previous experience with Circularity Thinking has shown this allows the different tools to further mature.

In addition to practice-based settings, we also intend to further explore the usability of the Multi-Flow Method in educational and training contexts. The Circularity Thinking toolkit has already been used widely in teaching and training environments to help students and professionals understand circular value chains and what factors must be considered. The Multi-Flow Method offers similar potential: it can help students learn how systems thinking can be applied in a practical and structured manner while also teaching core principles of the circular economy.

By applying the method in a wider range of case studies and contexts - both practical and educational - we aim to continue improving and refining the Multi-Flow Method.

4.2 Continued Method Development

We have learned a great deal about the types of prompts and guidance needed to support users of the Multi-Flow Method in its current version. The continued empirical work outlined above will help us further strengthen and refine the existing components of the method. At the same time, we also recognise the opportunity to further expand the method.

In its current form, the Multi-Flow Method functions primarily as a sense-making tool. It helps users understand how generative tensions surface in their value chains, and it supports them in identifying the underlying systemic patterns that shape value chain behaviour. Users can see why certain challenges persist and how tensions influence flows, relationships, and incentives.

However, the method does not yet address how to actively work with the tensions or what desirable patterns might look like for resolving or navigating them. At present, the development of desirable patterns is left entirely to participants during workshops. We believe that additional guidance on *how* to generate new system configurations would be beneficial and clarify potential pathways for addressing current undesirable patterns, in order to better support users as they move through the process. In this sense, the method could become more prescriptive as well as more generative - helping participants not only interpret their value chain with a systems lens but also envision and explore potential pathways forward.

Based on the current developments and the conceptual work that accompanied the shift from Circular Metabolism Factors to generative tensions, we see Paradox Theory as a promising avenue for further advancing the method's conceptual foundation (see also below).

4.3 Continued Integration of the Multi-Flow Method into Circularity Thinking

The Multi-Flow Method is designed to function as part of the broader Circularity Thinking toolkit. With Circularity Thinking continuing to evolve, a key focus going forward is to strengthen the integration points between the Multi-Flow Method and the methods that precede and follow it in the Circularity Thinking workflow. Further refinement will be aimed at ensuring that insights generated through the Multi-Flow Method - such as patterns and ecosystem requirements - can be carried forward seamlessly into subsequent steps of the method, in particular in the action planning steps of the Collective Action Planning (CAP) method. While the two methods align conceptually and have already been tested together - for example, during the flat glass case workshop in Descriptive Study 4 - further alignment is needed at the level of concrete steps and facilitation prompts. This refinement is expected to continue over the coming months.

The workshops also highlighted that the workshop design and facilitation setup require further development. This insight is twofold. First, the workshop design must be strengthened so that practitioners can independently facilitate the Multi-Flow Method (without UHAM guidance) while still achieving the desired depth of analysis. Second, it will be important to develop effective ways to facilitate the method using hypothetical cases, enabling application in teaching settings and broader training contexts.

In addition, a more easily accessible platform is currently developed for Circularity Thinking that will serve both as an entry point for organisations seeking support and as a foundation for project acquisition and collaboration. Integrating the Multi-Flow Method into this platform will ensure that it becomes part of a coherent, modular suite of tools for research, education, and practice. In this way, the Multi-Flow Method will benefit from the strategic collaborations, such as with EIT Climate-KIC, that support the dissemination and development of Circularity Thinking.

4.4 Forthcoming Academic Papers

The academic work underpinning the development of the Multi-Flow Method is, at the time of writing, being consolidated into three research papers. These papers document and theorise the conceptual, empirical, and methodological insights generated across the different DRM phases. Together, they translate the project's results into academic contributions and situate the method within broader scholarly debates.

The first paper addresses the persistent gap in the integration of resource-, energy-, information-, and value-flows within circular value systems. It demonstrates that, despite substantial progress in Industrial Ecology and Circular Economy research, these flows are still not conceptualised or operationalised as an interconnected metabolic whole. Drawing on complexity science and Earth System Science, the paper develops a research agenda that examines how flows reconfigure during large-scale system change and calls on the scientific community to advance this line of inquiry. In doing so, it positions the study of metabolism change - and the natural laws and principles that govern it - as a critical frontier for enabling sustainable circular systems.

The second paper makes both a conceptual and methodological contribution. Conceptually, it argues that circular economy practice requires sense-making tools that help practitioners 'see' and interpret systemic dynamics, rather than relying on prescriptive lists of barriers and enablers. That is: systems thinking does not come naturally to most people, and helping them see and discuss different system dynamics is the first step towards designing effective circular value chains. This makes sensemaking tools a vital part of the process. Methodologically, the paper reflects on our own design-science process and challenges the linear assumptions underlying standard literature reviews, proposing iterative and reflexive review practices better suited to complex systems.

The third paper develops the conceptual foundations for working with generative tensions in circular value chains. Drawing on paradox theory, it examines how actors can navigate tensions and what implications this has for defining desirable system patterns. The paper aims to contribute theoretically by clarifying how tensions can be actively worked with - rather than merely identified - and practically by outlining what this means for designing and managing circular ecosystems. Collectively, these three papers contribute to a growing body of expertise on circular value chain design, strengthening the scientific foundations on which the Multi-Flow Method is built.

Taken together, the continued empirical work, conceptual development, integration into the Circularity Thinking framework, and accompanying academic publications demonstrate that the Multi-Flow Method is both an evolving research endeavour and a growing practical capability. As these strands progress in parallel, they will continue to reinforce one another - advancing the scientific understanding of circular value chains while strengthening the method's usability, robustness, and impact across contexts.

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