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Executive Summary

Circular economy business models (CEBMs) can reduce resource use while strengthening regional value creation, yet adoption remains slow due to three support gaps: limited transparency over circular cases and value chains, methodological complexity in multi-perspective business model development and validation, and difficulty translating modelling outputs into implementation-relevant capabilities. Following a Design Science Research approach (Johannesson and Perjons, 2021), this deliverable develops the DECIDE Toolbox as an integrated artefact combining a CEBM Catalogue and Value Chain Generator, a modelling workflow linking Business Model Canvas, e3Value, BPMN and System Dynamics through structured mapping logic, a Monitoring Dashboard with a semantic Data Platform, a Digital Service Implementation Recommender, and a Digital Learning Concept. The toolbox is demonstrated on a whey valorisation case and evaluated through Train-the-Trainer workshops, World Café discussions, DSIR capability workshops and nine pilot cases across the Danube region, indicating that the integrated workflow supports validation of CEBMs by generating decision-relevant evidence on economic, ecological and social outcomes.

Introduction

In the European Union's transition to a climate-neutral and resource-efficient economy, the circular economy plays a central role (Directorate-General for Environment (European Commission), 2020). Circular Economy Business Models (CEBMs) address pressing economic, environmental and regional development challenges by slowing and reducing resource consumption and emissions, enabling the reuse of secondary material flows, and strengthening regional value creation. Their establishment, however, is complex: viable CEBMs typically emerge across sectors and along multi-stage, cascading value chains that may involve different circular strategies, ranging from material recovery and component reuse to cross-sectoral valorisation of by-products and residual flows (Kirchherr *et al.*, 2018; Lüdeke-Freund, Gold and Bocken, 2019). Their economic feasibility is difficult to assess without structured access to material-flow, partner and case knowledge. Specifically, this complexity manifests in uncertainties regarding the quantity, quality, and temporal availability of reverse flows of secondary materials timing (Antikainen and Valkokari, 2016; Rizos *et al.*, 2016; Bianchini, Rossi and Pellegrini, 2019), in the need to integrate and coordinate a multitude of complementary actors along forward and reverse value chains (Geissdoerfer *et al.*, 2020) and in delayed or uncertain economic returns resulting from financing constraints and long-term investment risks (Holly *et al.*, 2023). As a consequence, CEBMs are adopted only slowly in practice (Fraser, Haigh and Conde Soria, 2023) and rarely scale beyond successful individual cases. In the following, these challenges are addressed along the development process of CEBMs, from early identification through multidimensional analysis and validation to implementation planning and further development.

A central challenge in CEBM development arises already in its first phase: the identification of circular value creation opportunities for a given company, region, or material flow (Pieroni, McAloone and Pigosso, 2021). This requires knowledge about valorisation paths for by-products and residual materials, suitable partners from different sectors and already realised pilot cases (Fraccascia and Yazan, 2018; Kirchherr *et al.*, 2018; Takacs, Brunner and Frankenberger, 2022). In practice, this knowledge is rarely concentrated in one place, a phenomenon described in the industrial symbiosis literature as an information barrier (Chertow, 2007): companies know their own domain but not the valorisation potential of their material flows in other sectors; regional actors and intermediaries know the companies in their region but not the circular value chains that could be realised with them. Initial responses exist in the form of curated case collections (Ellen McArthur Foundation, 2021; European Investment Bank, 2024) and specialised value chain generators (D.1.2.2). These reach their limits in different ways: static case collections cannot be continuously extended and lack a standardised, comparable representation of the cases they contain; AI-based generators, in turn, focus on material-flow linkages without a business-model perspective (Zhao *et al.*, 2026) or are limited to specific sectors such as the bioeconomy, a gap that becomes particularly visible in regionally heterogeneous areas such as the Danube region. These aspects are referred to in the following as the *transparency and orientation gap*.

Once a CEBM idea has been identified, the question arises of how it can be developed into a viable business model and systematically evaluated prior to implementation. Business model development is an iterative, multi-phase process (Foss and Saebi, 2017; Taran, Boer and Nielsen, 2021) in which initial concepts are articulated, refined, and assessed for feasibility in order to reduce uncertainty and enable informed decisions prior to implementation (Osterwalder *et al.*, 2010; Wirtz and Daiser, 2018). In practice, business model innovation often begins with a Business Model Canvas (BMC), which structures the BM and supports stakeholder communication (Osterwalder *et al.*, 2010; John, Kundisch and Szopinski, 2017). However, the BMC offers only a static representation with limited formal semantics. It does not capture networked interactions, feedback loops or delays, nor does it provide a causal narrative linking its strategic assumptions to economic, environmental and social outcomes. A systematic evaluation therefore requires complementary modelling perspectives, actor and value flow analysis, process detailing and dynamic simulation, which become more economically precise as implementation approaches (Cosenz and Noto, 2018; Gilsing *et al.*, 2022; Fauser, Hertweck and Scheerer, 2024). Despite this need, systematic pre-launch evaluation and multidimensional assessment remain underrepresented in the BMI literature (Echterhoff, 2018; Wirtz and Daiser, 2018; Ksouri-Gerwien, 2024).Established tools are fragmented, insufficiently embedded in an overarching BMI process (Athanasopoulou and De Reuver, 2020; Fruhwirth, Ropposch and Schindler, 2020; Gilsing *et al.*, 2022). When several modelling languages are combined to capture different perspectives on the same business model, the absence of integrated tool environments leads to media breaks and to the loss of assumptions, parameters and traceability across modelling languages and analysis steps (Fruhwirth, Ropposch and Schindler, 2020; Szopinski *et al.*, 2020; Pérez-Blanco *et al.*, 2025). These aspects are referred to in the following as the *development and validation gap.*

Beyond identification and validation, the question arises of which organisational, technological, and infrastructural capabilities and which human resources are needed to actually implement and operate a CEBM, a question that remains underrepresented in the BMI literature overall (Echterhoff, Hirschter and Gausemeier, 2016; Wirtz and Daiser, 2018; Gilsing *et al.*, 2022). The modelling outputs from the validation phase provide important indications in this regard. They implicitly address many implementation-relevant aspects, such as required activities, resources, actors, exchanges, processes and system-related requirements. However, these insights often remain distributed across different modelling perspectives and are not necessarily accessible to all stakeholders involved in implementation. What is missing is an abstract layer that makes these requirements explicit and enables different stakeholders to discuss the necessary capabilities across organisational boundaries without immediately moving into detailed process, organisational or technical design. Following the ArchiMate understanding, a capability is understood as an ability that an active structure element, such as an organisation, person or system, possesses (*ArchiMate® 3.2 Specification*, 2022). In this work, capabilities are therefore used as relatively stable, high-level descriptions of what an organisation, actor network or supporting IT environment must be able to do, without already specifying detailed processes, organisational units or technical systems. Capability modelling can therefore serve as an abstraction layer through which model-based insights are made explicit and structured as accessible, stakeholder-oriented and implementation-relevant capability requirements. Initial approaches that link business model patterns with required business and IT capabilities exist (Küller, 2022; Küller *et al.*, 2026) but have so far not been transferred to the circular context. A capability perspective is valuable not only

during implementation planning. It can further support the development phase by revealing implementation-relevant aspects that may remain implicit or underrepresented in purely modelling-based analyses. In addition, it enables a structured comparison between required capabilities and those already available within the company or the regional actor network. These aspects are referred to in the following as the *implementation and capability gap*.

The present deliverable addresses these three support gaps through the DECIDE Toolbox, an integrated methodological and tool-based framework for the identification, analysis, development, documentation, and implementation planning of CEBMs The toolbox consolidates components developed across several deliverables and structures them in relation to the three identified gaps: for identification and orientation, the Value Chain Generator (D.1.2.2) and the CEBM Catalogue (D.1.2.7); for multidimensional modelling and validation, the CEBModeler with Business Model Canvas, e3Value and BPMN (D.1.2.1) as well as the System Dynamics-based Circular Economy Value Chain Simulator (CEVCS) (D.1.2.4) and for implementation and capability planning, the Digital Service Implementation Recommender with Capability Catalogue and Capability Maps (D.1.2.3). As cross-cutting infrastructure, a shared data platform (D.1.2.6) links modelling outputs indicators, and case knowledge across the individual components, while a dashboard built on top of it (D.1.2.5) provides stakeholders with simplified access to these results without requiring them to operate the underlying modelling tools themselves. The framework is complemented by training materials (D.1.2.8) and systematic validation in pilot cases (D.1.2.9). The toolbox thus supports not only the development of new CEBMs prior to market entry but is equally suited for the structured documentation, analysis, and optimization of existing CEBM configurations as well as for their comparison and transfer across regions, sectors, and companies (Activity 1.4). Its development follows a Design Science Research approach according to Johannesson and Perjons (2021). The central research question is:

RQ: How can an integrated toolbox support the transparent identification, modelling, validation, and implementation planning of Circular Economy Business Models across regional, sectoral, and organisational contexts?

The remainder of the deliverable is structured as follows: Chapter 2 reviews the state of the Art on CEBM development, modelling and capability mapping, Chapter 3 presents the DSR approach, Chapter 4 explicates the problem along the three gaps, Chapter 5 derives the requirements, Chapter 6 describes the design of the toolbox components, Chapter 7 demonstrates applicability through a case and Chapter 8 evaluates the artefact and Chapter 9 summarises the contributions.

Literature Review

The development and modelling of Circular Economy Business Models (CEBMs) has become a key area of interest in research and practice. However, this topic remains fragmented across disciplines such as environmental sciences, industrial engineering, information systems and sustainability research. To better understand how existing research supports the identification, development, validation and implementation of CEBMs, a structured literature review was conducted. This review builds on a prior literature analysis conducted for PACIS (Fauser, Hertweck and Scheerer, 2024) and which initially focused on a selected set of publications addressing modelling languages, knowledge transfer across modelling languages, method integration, simulation-based assessment and SDG related modeling. In a subsequent version of the underlying deliverable D.1.2.4, the review was expanded to 21 contributions to capture a broader range of modelling and tool-related approaches. The present version further extends the review to 35 contributions by including more recent work on CEBM knowledge representation, catalogue-based access, knowledge graphs, CEBM/service catalogues, industrial symbiosis platforms and capability-based implementation support.

The review is structured around four overarching analytical concepts. First, CEBM theory and context provides the conceptual foundation by examining CEBM definitions, value creation logics, circular strategies, CEBM types, value networks, reverse flows and adoption-related uncertainties. Second, the transparency and orientation perspective addresses how circular value creation opportunities can be identified and made accessible, including resource-to-value pathways, reusable case knowledge, knowledge graphs, CEBM/service catalogues, industrial symbiosis platforms and potential partner constellations. Third, the modelling-based development and validation perspective examines how CEBMs can be progressively designed, modelled, refined and assessed before implementation. This includes the analytical insights offered by different modelling languages, the ability to reuse and refine knowledge across modelling languages, the feasibility of transformation and integration between methods, and the role of business model simulation for economic, ecological and social assessment. Fourth, the implementation and capability perspective examines how CEBM concepts can be translated into operational, organisational and IT capabilities.

The literature was identified in three stages, following established practices for concept-centric literature reviews (Webster and Watson, 2002). Stage 1 — the PACIS basis — applied keyword-based searches using the terms *Circular Economy Business Models* and *Circular Economy Business Modelling Languages* in Google Scholar and the AIS Electronic Library, yielding 5,995 hits from which the most-cited and topically relevant publications were selected as the initial core. Stage 2 extended this core through targeted searches and backward/forward snowballing along the research questions identified after the PACIS submission, focusing on prototyping, SD-based business model simulation, multi-method integration and tool support. Stage 3, conducted for the present version, added contributions from the related research domains of CEBM knowledge representation, industrial symbiosis and capability-based implementation support, identified

through targeted searches and snowballing from the contributions of Stage 2. Across all three stages, contributions were included if they offered substantive insight into one of the four analytical concepts and were peer-reviewed or represented widely-cited research artefacts.

Following the concept-centric approach proposed by Webster and Watson (2002), the updated concept matrix (Table 1) organises the analysis around four overarching concepts: (A) CEBM Theory and Context, which establishes the conceptual foundation and the three support gaps that motivate the toolbox design: (B) Transparency and Orientation Gap, (C) Modelling-based Development and Validation Gap, and (D) Implementation and Capability Gap. Each concept is further specified through sub-concepts that capture more detailed analytical dimensions and allow the contributions and limitations of the reviewed literature to be assessed systematically. Scores reflect the degree to which each contribution addresses the respective sub-concept (++ fully, + partially, O marginally, — not addressed) and are subject to final validation.

Table 1: Concept matrix

Author	**A1: CEBM Types & Value Creation Logic**		**A2: Network Dynamics & Reverse Flows**	
Nußholz (2018)	++		+	
Geissdoerfer et al. (2020)	++		+	
Salvador et al. (2021)	+		+	
Vorraber & Müller (2019)	+		++	
Bianchini et al. (2019)	+		++	
Antikainen & Valkokari (2016)	+		++	
Rizos et al. (2016)	O		+	
Author	**B1: CEBM Identification & Opportunity Recognition**	**B2: Case Collections & Catalogue Approaches**	**B3: AI / NLP / Knowledge Graph Approaches**	**B4: Industrial Symbiosis Platforms & Stakeholder Access**
Zhao et al. (2026)	+	—	++	+
Davis & Aid (2022)	+	—	+	+
Yeo et al. (2019)	+	—	++	+
Grimmel et al. (2024)	+	O	++	+
Bozkurt et al. (2021)	+	++	—	+
Chertow (2007)	+	—	—	+
Fraccascia & Yazan (2018)	+	—	—	++
Author	**C1: BMI Process & Pre-Launch Evaluation**	**C2: Static & Process Modelling (BMC, e3Value, BPMN)**	**C3: Dynamic Modelling & SDG-related Assessment**	**C4: Multi-Method Integration & Tool Support**
Fauser et al. (2024)	++	+	+	++
Szopinski et al. (2022)	+	++	+	++

D'Souza et al. (2018)	+	+	—	O
Athanasopoulou & De Reuver (2020)	++	+	+	+
Gilsing et al. (2022)	++	+	+	+
Torres et al. (2023)	O	++	—	+
Caetano et al. (2017)	O	++	—	++
Abdelkafi & Täuscher (2016)	O	+	++	+
Cosenz & Noto (2018)	+	+	++	+
Cosenz et al. (2020)	+	+	++	+
Cosenz & Bivona (2021)	+	+	+	+
Ksouri-Gerwien (2024)	++	+	++	+
Szopinski et al. (2020)	+	+	O	++
Pérez-Blanco et al. (2025)	+	++	—	++
Pieroni, McAloone & Pigosso (2021)	+	+	+	+
Meertens et al. (2012)	O	++	—	++
Gordijn et al. (2005)	O	++	—	++
Author	**D1: Dynamic Capabilities for CEBM**	**D2: Capability Mapping & EAM**	**D3: Pattern–Capability Linkage**	**D4: Organisational & Institutional Aspects**
Khan, Daddi & Iraldo (2020)	++	—	—	++
Bocken & Geradts (2019)	++	—	—	++
Teece (2018)	++	O	O	+
Küller (2022, 2026)	O	++	++	+

Level of fulfilment: ++ = fully addressed (100%) | + = partially addressed (66%) | O = marginally addressed (33%) | — = not addressed (0%). Scores subject to final validation

Concept A: CEBM Theory and Context

CEBMs are understood as value-creation logics that extend product lifetimes and close material loops (Nußholz, 2018). Nußholz (2017) defines a circular BM as follows: "A circular business model is how a company creates, captures, and delivers value with the value creation logic designed to improve resource efficiency through extending the useful life of products and parts and closing material loops" (e.g., through durable design, repair, and remanufacturing). At the BM level, Geissdoerfer et al. (2020) distinguish four types: Cycling (reuse/remanufacture/recycling), Extending (longevity/maintenance/repair), Intensifying (higher utilization/sharing), and

Dematerializing (service/software substitution). CEBM innovation (CEBMI) can affect BM elements, their relations and the value network (Geissdoerfer *et al.*, 2020; Salvador *et al.*, 2021). This is particularly relevant because CEBMs often depend on new partner constellations, customer segments and cross-organizational reverse flows, which create uncertainty regarding the quantity, quality, timing of returns (Antikainen and Valkokari, 2016; Rizos et al., 2016; Bianchini, Rossi and Pellegrini, 2019; Vorraber and Müller, 2019). The relationship between forward and reverse flows in CEBMs is illustrated in Figure 1, which depicts the typical product lifecycle (Design → Production → Distribution → Use → Recovery) alongside the cascading and closed-loop strategies that distinguish circular from linear value chain configurations. Pieroni, McAloone and Pigosso (2021) further consolidate this view by proposing a four-stage process model (prepare, sense, seize, transform) specifically for CEBMI within manufacturing companies, providing a structured framing of the activities that distinguish CEBMI from generic BMI. Vorraber & Müller (2019) broaden the NBM view to include motivational, legal and requirement-specific exchanges, thereby further increasing the complexity for development and validation. In early phases, actors prioritize feasibility, economic viability and risk minimization (Wirtz and Daiser, 2018; Fauser and Hertweck, 2022; Fauser, Hertweck and Scheerer, 2024). These characteristics define requirements for modelling methods that can represent network structures, value exchanges, operational processes and multidimensional impacts.

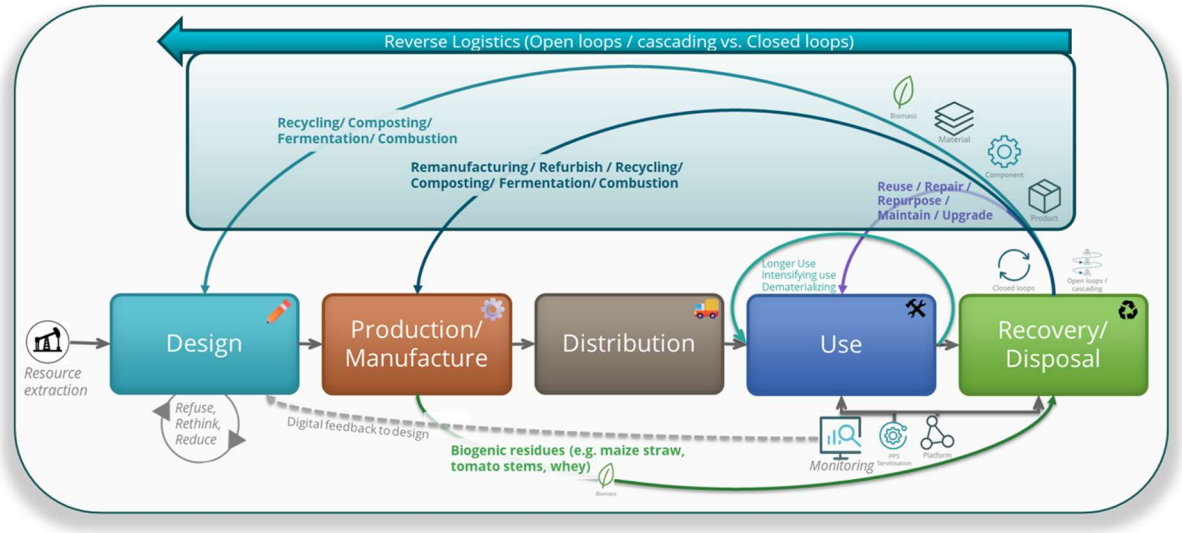


Figure 1: Reference model for circular economy

Concept B: Transparency and Orientation Gap

The development of new business models typically starts from an initial business idea, which must then be refined, assessed and translated into a viable configuration. For circular business models, this early phase is shaped by two related challenges. First, an awareness dimension: many companies and regional actors lack fundamental familiarity with CE principles, R-strategies and the strategic opportunities they offer, which limits their ability to recognise CE as a viable option in the first place (Rizos *et al.*, 2016; Kirchherr *et al.*, 2018; Pieroni, McAloone and Pigosso, 2021). Second, an information dimension: even where CE is on the strategic agenda, the relevant knowledge about material flows, valorisation pathways, technologies, potential users, partners and already

implemented cases is typically fragmented across actors, sectors and regions. Several streams of research and practice address the information dimension, but each covers different parts of it.

First, curated case collections such as the EIB Catalogue of Circular City Actions and Solutions (European Investment Bank, 2024), the Ellen MacArthur Foundation Case Study Collection (Ellen McArthur Foundation, 2021) and national best-practice catalogues, such as the Spanish circular economy catalogues (Spanish Ministry for Ecological Transition, 2021a, 2021b), document already implemented circular economy initiatives. These collections are valuable for inspiration and orientation, as they make existing practices visible, partially comparable and usable as starting points for new business model ideas. However, they are often provided as static documents or editorially maintained collections, use different case structures and provide limited support for continuous extension, systematic search, comparison or computational processing.

Second, Natural Language Processing (NLP)-, artificial intelligence (AI)- and knowledge-graph-based approaches support the identification and representation of potential waste-to-resource relationships and industrial symbiosis opportunities. Yeo et al. (2019) introduced an early NLP pipeline combining Named Entity Recognition and Relation Extraction for waste-to-resource relationships. Davis and Aid (2022) addressed the encoding bottleneck through embedding-based linking, while Zhao et al. (2026) constructed a large Waste-to-Resource Knowledge Graph using Large Language Models. Grimmel et al. (2024) integrated existing W2R databases into a unified graph database. These approaches are highly relevant for identifying possible material-flow linkages. However, they mainly focus on waste-to-resource relationships and provide only limited support for interpreting these linkages as circular business model opportunities, for example through structured case-level information on technologies, input materials, conversion processes, outputs, R-strategies, SDG contributions, domains, implementation status or places of operation. Some approaches, such as Zhao et al. (2026), provide code repositories and locally executable prototypes, which is valuable for transparency, verification and further development. However, such solutions may still require technical expertise to operate and are not equivalent to low-threshold public web platforms for practitioners.

Third, industrial symbiosis platforms address what the literature has long described as the information barrier between providers and recipients of residual flows (Chertow, 2007), by supporting information sharing and the matching of waste supply and demand. Fraccascia and Yazan (2018) show that online information-sharing platforms can improve the economic and environmental performance of industrial symbiosis networks, understood as networks of firms that exchange residual materials, energy, water or by-products. These platforms are valuable for identifying potential resource matches and facilitating industrial symbiosis. However, their primary focus is on operational matching and information exchange rather than on providing a structured and extensible repository of circular business model cases.

Finally, service-catalogue approaches provide a methodological reference point for structuring heterogeneous domain knowledge and making it accessible to different user groups. Bozkurt et al.(2021) demonstrate how a service catalogue with structured case descriptions along defined attributes and a platform-based access layer can support the structuring, publication and retrieval

of complex domain knowledge. While this methodological logic is in principle transferable to CEBMs, its application to CEBM case knowledge requires adaptation to circular-economy-specific dimensions such as R-strategies, material flows, SDG contributions and cross-sectoral actor constellations, an adaptation that has not yet been systematically realised.

Taken together, existing approaches exhibit complementary limitations: curated case collections lack extensibility and standardisation; NLP-, AI- and knowledge-graph-based approaches focus primarily on material-flow knowledge and omit business-model perspectives; industrial symbiosis platforms focus on operational matching rather than on supporting CEBM development as an integrated activity; and service-catalogue approaches have not yet been systematically applied to CEBM case knowledge. No existing approach combines (i) a structured, extensible representation of CEBM cases, (ii) platform-based access for diverse stakeholders, and (iii) an explicit business-model perspective covering actors, value creation and capture, and process configuration. This gap motivates the design of a CEBM-oriented service catalogue approach.

In the DECIDE project, this gap is addressed through the DECIDE CEBM Service Catalogue (D.1.2.7), which provides short, standardised and practitioner-oriented case summaries. By offering low-threshold, web-based access to concrete CE cases without requiring prior expertise or technical setup, the CEBM Catalogue addresses both dimensions of the early-phase challenge: it raises awareness of CE opportunities through visible, easy-to-grasp examples and it provides structured access to case knowledge in a comparable format. The Service Catalogue is positioned as an entry point to the Toolbox: identified cases may inspire business model innovation workshops or, in biomass-related contexts, guide the use of the Value Chain Generator (D.1.2.2) to explore input materials, conversion technologies and regional markets. In both cases, the resulting ideas can be formalised through business model modelling with BMC, e3Value and BPMN (D.1.2.1) and further refined and simulated through the Circular Economy Value Chain Simulator (D.1.2.4) and translated into capability-oriented implementation plans through the Digital Service Implementation Recommender (D.1.2.3).

Concept C: Modelling-based Development and Validation Gap

Different modelling languages are used to represent BMs depending on phase and objective (Tesch and Brillinger, 2017; Szopinski *et al.*, 2022). In the academic literature, a distinction is made between static and dynamic modelling languages for business modelling (Szopinski *et al.*, 2022). Static languages capture key elements and attributes at a point in time; the BMC (Osterwalder *et al.*, 2010) as one that is widely used in early phases, such as analysis and ideation (Echterhoff, Hirschter and Gausemeier, 2016; Szopinski *et al.*, 2022). Researchers and practitioners have criticized the static nature of such approaches because it constrains systematic option testing and trade-off analysis among BM variants (Athanasopoulou and De Reuver, 2020). Static models lack temporal dynamics, feedback and delays, which restrict their applicability for assessing the impacts of BM variations under changing conditions. This limitation is particularly relevant for CEBMs, which operate as interdependent network BMs and must coordinate reverse flows, non-monetary value and changing actor roles across the value network (Rizos *et al.*, 2016; Bianchini, Rossi and Pellegrini, 2019; Vorraber and Müller, 2019; Geissdoerfer *et al.*, 2020; Fauser, Hertweck and Scheerer, 2024).

e3V (Gordijn, 2002) extends BM modelling towards inter-organizational value logics, actors, transactions and value exchanges (money, goods, services, intangible assets), enabling scenario exploration and network-level feasibility and profitability assessments, but its foundational logic remains static and therefore limited for temporal dynamics and feedbacks (D'Souza *et al.*, 2018; Szopinski *et al.*, 2022; Fauser, Hertweck and Scheerer, 2024; Ksouri-Gerwien, 2024).

As companies move closer to BM implementation, modelling needs become more quantitative and operationally precise (Gilsing *et al.*, 2022). This is reflected, for example, in financial cost–benefit analyses and simulations, including business process (BP) simulations (Gilsing *et al.*, 2022). In practice, financial analyses are often implemented as spreadsheet-based business cases (BC) (Ksouri-Gerwien, 2024). The focus in this phase is on quantitative, multi-criteria evaluation of BM alternatives to inform implementation decisions (Gilsing *et al.*, 2022). BP simulation is frequently instantiated in BPMN models within discrete-event simulators. Torres et al. (2023) show that BPMN and e3V are complementary: BPMN captures operational workflows and tasks, while e3V represents economic transactions and value exchanges between actors. Integrating e3V and BPMN enables a holistic analysis of processes logic and value network logic, making inefficiencies and their economic impacts visible. This supports more informed decisions on process improvement and value network optimization. But both perspectives remain limited for long-term dynamic simulation with feedback loops.

Hence, dynamic modelling is needed to test BMs under scenarios and uncertainty and to evaluate alternatives (Bouwman *et al.*, 2018; Athanasopoulou and De Reuver, 2020; Szopinski *et al.*, 2022). To address the limitations of static approaches, dynamic modelling methods have emerged, most prominently SD. SD has proven to be a promising method for simulating complex business structures and evaluating their dynamic behavior over time (Forrester, 1958; Sterman, 2000). Stocks/flows, feedback loops and delays are explicit, enabling scenarios and sensitivity analyses across economic, ecological and social effects (Forrester, 1958; Sterman, 2000; Abdelkafi and Täuscher, 2016; Cosenz, Rodrigues and Rosati, 2020; Ksouri-Gerwien, 2024). SD thus supports SDG-related indicators, but an end-to-end, workflow-based integration across modelling languages remains missing (John, Kundisch and Szopinski, 2017; Szopinski *et al.*, 2022).

Research on BM development tools show that, despite numerous proposed tools, there is still no consensus regarding which functions such tools should provide, particularly with respect to evaluation- and simulation-oriented functions and stronger "framework support" to narrow the gap between BMs and the IS/process layer (Szopinski *et al.*, 2020). This gap is particularly relevant because BMs are commonly positioned as a bridge between strategy and implementation, linking value-creation logic to BP and the supporting IS (Al-Debei and Avison, 2010). In practice, a variety of tools is often required to model the different perspectives and languages needed for holistic understanding and validation of a BM, which can lead to undesired media breaks when switching between tools (Pérez-Blanco *et al.*, 2025). Increasingly, integrated modelling environments that combine business and process modelling notations have emerged, e.g., Pérez-Blanco et al. (2025) integrate BMC, e3V, Service Blueprint, Process Chain Network, and BPMN within a model-driven environment. However, the approach focuses on integrated model creation, without simulation support, the resulting models are not directly usable for quantitative assessment (Pérez-Blanco *et al.*, 2025). However, achieving strong integration between business and process notations remains

challenging, and SD-based sustainability-oriented evaluation is not covered in their scope. This reinforces the tool-related challenge highlighted in the BMDT research agenda (Szopinski *et al.*, 2020): evaluation/simulation support and process/IS-level integration remain key areas for advancing tool support beyond isolated notation implementations.

At the level of concrete approaches, D'Souza et al. (2018) demonstrate e3V-based viability checks for NBMs without multi-language integration, which risks inconsistencies, information loss, and higher modelling effort (Caetano *et al.*, 2017). Caetano et al. (2017) show that transforming a BMC into an e3V model requires additional business-model information and they integrate BMC, e3V and ArchiMate into an ontology to detect inconsistencies. Gordijn et al. (2005) compare the e3V ontology with the BMOntology, highlighting similarities, differences, and integration possibilities to enhance the representation, design, and analysis of BMs. Likewise, Meertens et al. (2012) combine BMC and ArchiMate and annotate entities with prices/costs to enable economic statements, but without simulation. Related frameworks, especially for dynamic business modelling languages, combine BMC, e3V and SD, but still leave key operational aspects unspecified. For example, (Cosenz and Noto, 2018; Cosenz, Rodrigues and Rosati, 2020) embed SD within BMC-oriented templates, yet they do not specify which BMC elements are translated into SD stocks/flows, how it is refined, how knowledge is transferred across representations and what additional data is required. Ksouri-Gerwien (2024) employs e3V early in the process, but the role of e3V in subsequent SD models and the corresponding transfer steps are not described. BM simulation, especially in the context of the CE, is also an emerging research area. SD, in particular, is increasingly used for prototyping and evaluating BMs due to its capacity to represent causal feedback structures and long-term system behavior (Ksouri-Gerwien, 2024). Overall, most approaches still lack systematic, iterative transfer and mapping of BM prototypes across languages, including reusable transformation rules, parameter handover and traceability.

In summary, organizations lack a specialized, integrated methodology and corresponding tool support to develop, analyze and validate CEBMs. Three gaps persist: (i) principle-based integration across structural, network/economic, process and dynamic perspectives; (ii) mechanisms for preserving and refining knowledge when switching perspectives between ML and (iii) the identification of decision-relevant evidence on economic, ecological and social impacts. In practice, a coherent end-to-end workflow is missing that connects ideation to network/economic analysis, process design and dynamic simulation. These gaps align closely with Fruhwirth et al. (2020) research directions, which emphasize decision-oriented evaluation support, workflow-level orchestration of specialized methods and software-enabled consistency across representations.

Concept D: Implementation and Capability Gap

Beyond the identification and modelling of CEBMs, their implementation requires a systematic understanding of the organisational, technological and human capabilities needed to operate them. Teece's (Teece, 2010, 2018) framework of dynamic capabilities "sensing, seizing and reconfiguring" provides a widely adopted conceptual foundation for explaining how firms identify opportunities, mobilise resources and adapt existing structures. In the CEBMI context specifically, dynamic capabilities have been positioned as essential for enabling firms to sense circular

opportunities, seize them through new business model configurations and reconfigure existing operations accordingly (Pieroni, McAloone and Pigosso, 2019; Khan, Daddi and Iraldo, 2020). Bocken and Geradts (2020) further argue that organisational design choices can either enable or constrain the dynamic capabilities required for sustainable business model innovation, indicating that capability development is shaped not only by technical considerations but also by institutional and strategic aspects of the firm.

While dynamic capabilities provide a high-level lens, the practical operationalisation requires mechanisms for mapping required business and IT capabilities to business model patterns and for assessing whether they are available within the focal organisation or its value network. Capability mapping has emerged as a methodological approach within enterprise architecture management, supported by modelling standards such as ArchiMate (The Open Group, 2022) and related capability-based planning approaches. These approaches enable the structured representation of business and IT capabilities, their interdependencies, and their alignment with organisational objectives, providing a basis for systematic gap analysis between required and available capabilities. In the business model innovation context, Küller (Küller, 2022; Küller *et al.*, 2026) develops an approach that links business model patterns in the renewable energy sector with required business and IT capabilities, providing a starting point for translating business model designs into implementation-oriented capability requirements.

However, this approach has not been transferred to the circular economy context. The linkage between business model patterns and capability requirements is particularly relevant for CEBMs because they typically involve cross-sectoral actors, reverse flows, new coordination tasks, sustainability-related information needs and digital support requirements. Existing capability-based approaches have only limited coverage of the circular economy context and do not yet systematically translate CEBM patterns, modelling outputs or circular value creation logics into capability-oriented implementation requirements. Overall, the systematic linkage between CEBM design and the corresponding organisational, business and IT capabilities remains underdeveloped, particularly at the intersection of CEBM design and implementation planning, where modelling outputs from the validation phase are not consistently translated into capability-oriented implementation requirements. In the DECIDE project, this gap is addressed through the Digital Service Implementation Recommender (D.1.2.3), which is designed to support the derivation of capability-oriented implementation requirements for CEBMs and the comparison between required capabilities and those available within the focal organisation or its regional value network.

Synthesis

In summary, organisations lack a specialised, integrated methodology and corresponding tool support for the identification, development, validation and implementation of CEBMs. Three support gaps persist across the reviewed literature. First, a transparency and orientation gap: companies and regional actors face limited access to structured and comparable knowledge about circular value creation opportunities, including material flows, valorisation pathways, technologies, partners and implemented examples. Existing curated catalogues, knowledge graphs and

industrial symbiosis platforms address parts of this gap, but remain limited in terms of extensibility, standardisation, business-model-oriented case metadata or low-threshold accessibility for non-technical stakeholders.

Second, a modelling-based development and validation gap persists. Existing approaches remain fragmented across structural, network/economic, process and dynamic perspectives. Mechanisms for preserving and refining knowledge when switching between modelling languages are limited, and existing tools often create media breaks, resulting in loss of assumptions, parameters and traceability across modelling steps. As a result, the generation of decision-relevant evidence on economic, ecological and social impacts remains only partially supported. These observations align with the research directions identified by Fruhwirth, Ropposch and Schindler (2020), which emphasise decision-oriented evaluation support, workflow-level orchestration of specialised methods and software-enabled consistency across representations.

Third, an implementation and capability gap remain. The systematic linkage between CEBM patterns, modelling outputs and the organisational, business and IT capabilities required for implementation is still underdeveloped. In particular, existing approaches provide limited support for translating design decisions and modelling results into capability-oriented implementation requirements and for assessing whether these capabilities are available within the focal organisation or its wider value network.

In practice, a coherent end-to-end workflow is missing that connects opportunity identification, business model design, network and economic analysis, process modelling, dynamic simulation and capability-oriented implementation planning. The DECIDE project addresses these gaps through an integrated Toolbox that combines a CEBM Catalogue, a Value Chain Generator, a multi-method modelling environment with BMC, e3Value and BPMN, the Circular Economy Value Chain Simulator (CEVCS) for dynamic simulation, and a Digital Service Implementation Recommender for capability-oriented implementation planning. Rather than providing isolated tools for individual phases, the Toolbox is designed to connect outputs across components, enabling iterative refinement and the identification of dependencies, bottlenecks and implementation requirements across regional, sectoral and organisational contexts.

Methodology

Design Science Research (DSR) is a design-oriented research paradigm aimed at developing artefacts based on practical problems and evaluating them systematically (Hevner *et al.*, 2004). Given the dynamic nature of the CEBM, which is influenced by various external factors, a problem-oriented, iterative methodology such as DSR is particularly suitable. (Hevner *et al.*, 2004) provide a valuable conceptual framework and guidelines for DSR, though they remain quite generic. (Johannesson and Perjons, 2014) offer a more detailed method for concretizing Hevner's approach, consisting of five core activities: Explicate Problem, Define Requirements, Design and Develop Artefact, Demonstrate Artefact, and Evaluate Artefact. DSR typically identifies four types of artefacts: constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices) and instantiations (implemented prototypical systems) (Hevner *et al.*, 2004; Johannesson and Perjons, 2014). Depending on the project, these artefact types may be combined to address multi-layered problems.

Explicate Problem: This activity aims to answer the question: “What is the problem that some stakeholders in practice experience and why is it important?” The problem should be formulated precisely and justified in terms of its relevance. Only problems of general interest are the focus of DSR projects. Additionally, the root cause analysis must be identified as the basis of the problem.

Define Requirements: Based on the formulated problem and its underlying root cause, we derive the requirements for a solution. The central question here is: “What artefact can solve the explicated problem, and which requirements are important for stakeholders?” During this activity, the type of artefact is outlined, addressing the requirements.

Design and Develop Artefact: The third activity involves creating an artefact that addresses the explicated problem and fulfills the defined requirements. The goal is to "Create an artefact that addresses the explicated problem and fulfills the defined requirements."

Demonstrate Artefact: The application of the developed artefact must be demonstrated using a use case. The critical question is: “How can the developed artefact be used to address the explicated problem in one case?”

Evaluate Artefact: Unlike demonstration, which shows the basic applicability of the artefact, the evaluation aims to answer: "How well does the artefact solve the explicated problem and fulfill the defined requirements?"

The following Table 2 describes the individual types of artefacts based on the explanations of Johannesson and Perjons (Johannesson and Perjons, 2014).

Table 2. Types of artefacts	
Artefact	**Description**
Constructs	Constructs support the formulation of problems and characteristics of different possible solutions. They provide a basis for discussing problems and solutions and are the smallest conceptual atoms to analyze and communicate phenomena in practice. Examples include a class in Unified Modeling Language (UML) or a method in Java.
Models	Based on related constructs, models support the construction of other artefacts. They provide the structure needed for other artefacts. Examples include a drawing in the construction of a building or a database model used in the development of a database system.
Methods	Methods provide guidelines and processes for developing solutions to related problems. They can describe how to create artefacts and can vary in formalization, from highly formalized algorithms to informal rules of thumb or best practices. Examples include database design, change management initiatives, and web service development.
Instantiations	Instantiations are working systems that can be used in practice, such as a Java program that implements a search algorithm or a database for electronic medical records.

In Figure 2, the method framework of Johannesson and Perjons (Johannesson and Perjons, 2014) is illustrated. The individual activities are related to each other and form logical input-output relations. Neither Johannesson and Perjons (Johannesson and Perjons, 2014) nor Hevner et al. (Hevner *et al.*, 2004) outline a strict procedure. They view the research process as innovative and knowledge-intensive, where inflexible structures would be a hindrance. Therefore, it is possible to jump between activities to realize the required flexibility. Johannesson and Perjons provide guidelines for carrying out the activities and describe research strategies for each, which can be used to select the appropriate research methods. No research strategy or method is excluded in advance from a design science project; it depends on the project's characteristics, which determine which one fits the purpose. In large DSR projects, it is common to use several research strategies and methods (Johannesson and Perjons, 2014). Additionally, the activities are linked to the knowledge base, which provides valuable information for performing the tasks. According to Johannesson and Perjons (Johannesson and Perjons, 2014), the knowledge base includes models and theories from several fields of science, as well as existing artefacts that are similar in function or structure. It should be clarified how a new artefact differs from the already existing artefacts and what additional benefits it can provide (Johannesson and Perjons, 2014). The relevant knowledge can be identified in academic publications, including textbooks and journal and conference research papers.

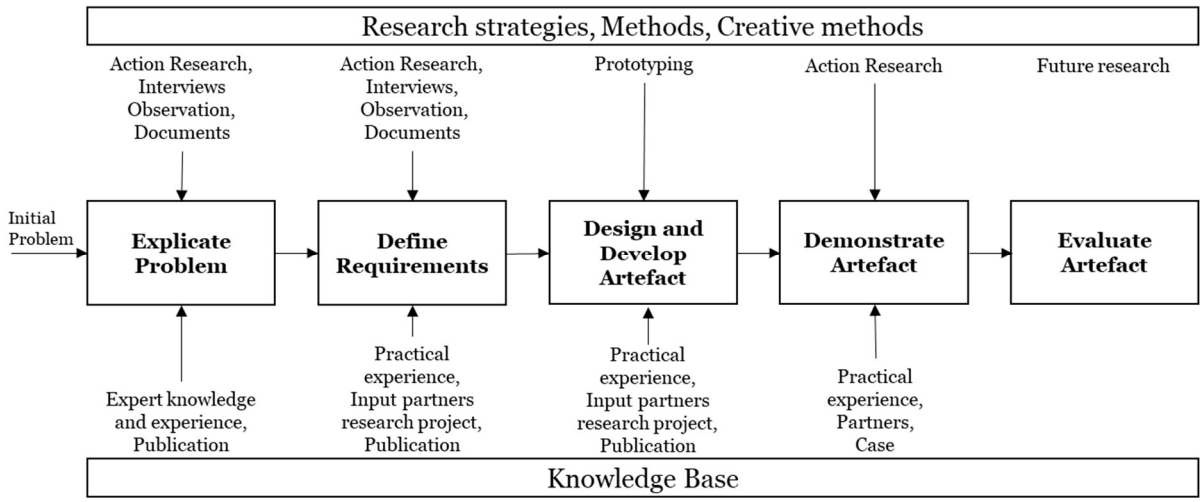


Figure 2: DSR method framework Instantiation (own representation)

Different Research Strategies and Research Methods can be used for each activity. A research strategy represents an overall plan for conducting a research study. In this context, the research study serves as a tool for selecting which research methods to use in which activities and for what purpose. The research methods provide information on how data should be collected and analysed, e.g., through questionnaires, interviews, or statistical procedures. To sum up, a research strategy is a higher-level guide, while a research method is a technique or tool for carrying out a specific task. For each activity in the DSR process, Johannesson and Perjons (Johannesson and Perjons, 2014) describe different research strategies and methods. Figure 3 shows the relationship between research strategies and methods. In the first step, a researcher will select one or more research strategies. For each research strategy, the researcher chooses one or more appropriate data collection methods and the appropriate data analysis method. Within a design science project, a variety of research strategies and methods can be used.

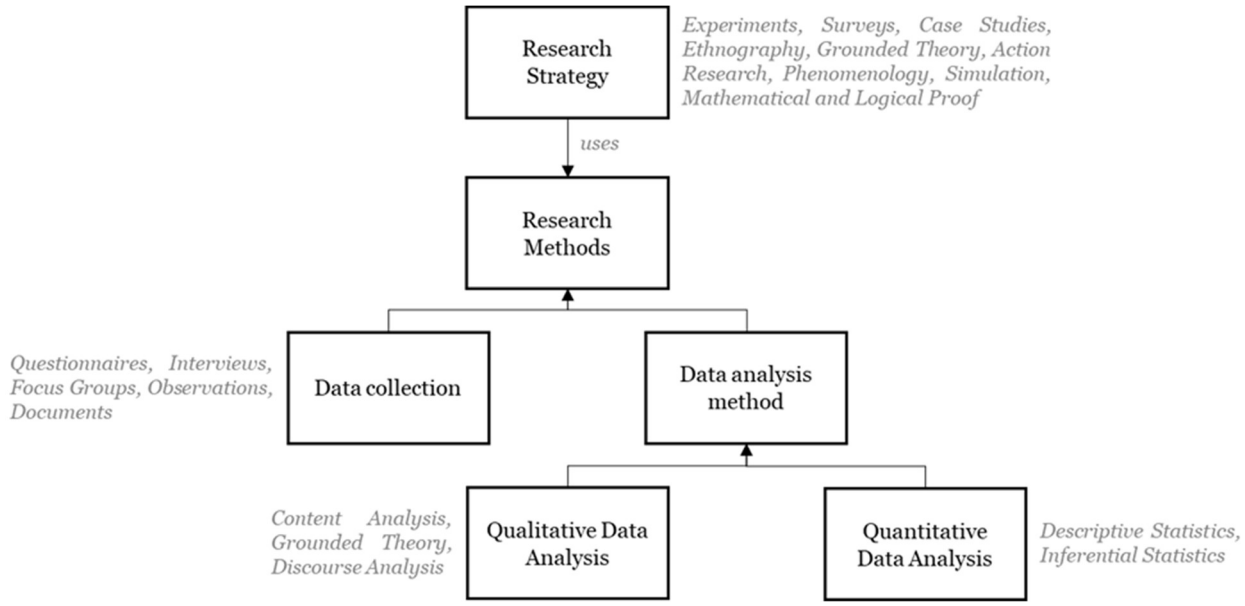


Figure 3: Overview research strategies methods

Following the DSR process described by Johannesson and Perjons (2014), this research is structured around the activities Explicate Problem, Define Requirements, Design and Develop Artefact, Demonstrate Artefact, and Evaluate Artefact. The empirical basis of the research is the EU Interreg DECIDE project, which involves 16 partners from ten Danube-region countries, including six universities, seven regional catalysts and three SMEs. DECIDE aims to develop practical tools and methods for CEBM identification, analysis, development, validation and transfer across regions. The project context provides access to diverse stakeholders, pilot cases, training activities, project workshops and validation data, making it suitable for a practice-oriented DSR study embedded in a multi-actor and international environment.

Within this empirical setting, the first two DSR activities — Explicate Problem and Define Requirements — were addressed through action research (Baskerville, 1999), supported by three data collection methods to increase construct validity and reliability (Yin, 2009): interviews, participant observation and document analysis. These activities served to identify the practical challenges experienced by stakeholders and to derive requirements for an integrated toolbox supporting CEBM identification, modelling, validation and implementation planning. Based on the identified problems and requirements, the Design and Develop Artefact activity combined iterative prototyping with literature analysis to translate the derived requirements into an integrated methodological and tool-based framework: the DECIDE Toolbox. The artefact combines a CEBM/service catalogue and value chain generator for early orientation, a multi-method modelling environment based on BMC, e3Value and BPMN, a System Dynamics-based Circular Economy Value Chain Simulator, a data platform and dashboard for integrated access to modelling and indicator results, and a Digital Service Implementation Recommender for capability-oriented implementation planning. The Demonstrate Artefact activity is addressed through the application of the Toolbox to selected DECIDE pilot cases and through a shared whey-based training case, in which the dairy by-product whey is transformed into whey protein concentrate and lactose. The training case provided a common basis for applying, explaining and comparing the integrated modelling workflow across project partners. The Evaluate Artefact activity is operationalised through the D.1.2.9 Validation Process and Documentation. In the terminology of the DECIDE project, this activity is described as validation; in DSR terms, it fulfils the role of artefact evaluation by assessing how well the Toolbox addresses the explicated problems and defined requirements. The validation follows a formative and summative orientation with regard to the completed project artefact and its application in training, showcase and pilot cases. It combines evidence from internal testing, Train-the-Trainer sessions, World Café feedback, learning-material development and pilot case applications.

Explicate Problem

Following Johannesson and Perjons (2021), the Explicate Problem activity aims to formulate the initial practical problem precisely, position and justify it and identify its underlying causes. In this deliverable, the relevant practice is the identification, analysis, development, validation, optimisation and implementation planning of CEBMs. The stakeholders affected by this problem are companies, particularly SMEs, as well as regional catalysts such as business support organisations, cluster managers and regional development agencies. SMEs are particularly relevant because the development and implementation of CEBMs typically require knowledge, data, financial resources, partner access and methodological capabilities that are not consistently available in smaller organisations (Rizos *et al.*, 2016; Kirchherr *et al.*, 2018). Regional catalysts are relevant because CEBMs frequently depend on cross-sectoral value networks, industrial symbiosis opportunities and the coordination of complementary actors across organisational and regional boundaries (Chertow, 2007; Albino and Fraccascia, 2015; Fraccascia and Yazan, 2018; Geissdoerfer *et al.*, 2020). In this context, companies are expected to identify circular opportunities, develop viable business model configurations, assess their potential impacts and prepare implementation decisions, while regional catalysts act as intermediaries by identifying region-specific potentials, facilitating actor alignment across sectors and supporting the transformation of circular opportunities into concrete business model initiatives.

The relevance of this problem extends well beyond any single project context. The European Union has positioned the circular economy as a central element of its Green Deal and sustainable growth strategy, allocating substantial public and private investment to support the CE transition (Commission, 2020; European Investment Bank, 2023). Despite this strategic commitment, global CE adoption remains low, with the Circularity Gap Report indicating a decline from 9.1% in 2018 to 7.2% in 2023 (Fraser, Haigh and Conde Soria, 2023) and CE practices in many European regions continue to focus on waste management rather than on CEBMs that embed circularity in value creation and enable the slowing and closing of resource cycles (European Court of Auditors, 2023). The problem is further amplified by regional heterogeneity: differences in institutional settings, resource availability, infrastructure, governance capacities and actor constellations affect whether closed-loop systems and circular value chains can be established, whether actors can be coordinated across sectors and whether CEBM configurations can be transferred or scaled between regional contexts (Arsova *et al.*, 2021; Henrysson and Nuur, 2021; Tapia *et al.*, 2021). This pattern is particularly evident in transition regions with heterogeneous development levels, institutional structures and industrial focal points, such as the Danube area in which the DECIDE project operates. It is, however, symptomatic of a broader European and global challenge that motivates the development of integrated, transferable methodologies for CEBM identification, analysis, development, validation, optimisation and implementation planning.

The development and implementation of CEBMs is associated with challenges that address several phases of business model development: from access to relevant case knowledge, through the modelling and validation of network-based business models with reverse flows, non-monetary

value exchanges and delayed returns (Antikainen and Valkokari, 2016; Vorraber and Müller, 2019; Holly *et al.*, 2023), to the translation of design decisions into capability-oriented implementation requirements. These challenges can be traced to three interrelated support gaps that the literature review and the empirical observations from the DECIDE pilot cases identify as the underlying causes of the overall problem.

The first is a *transparency and orientation problem* with two related dimensions: an awareness dimension and an information dimension. CEBM development typically starts from an initial business idea and the development of such ideas depends on knowledge about by-products, residual materials, valorisation pathways, technologies, potential partners and already implemented cases. In practice, this knowledge is distributed across actors, sectors and regions, and many companies and regional catalysts furthermore lack a fundamental familiarity with CE principles and the strategic opportunities they offer (Rizos *et al.*, 2016; Kirchherr *et al.*, 2018; Pieroni, McAloone and Pigosso, 2021). Existing case collections, knowledge-graph-based approaches and industrial symbiosis platforms provide partial support but each remains limited in different respects: curated case collections lack extensibility and standardisation, AI- and knowledge-graph-based approaches focus primarily on material-flow knowledge and exclude business-model dimensions and industrial symbiosis platforms focus on operational matching rather than on supporting CEBM development as an integrated activity. As a result, companies and regional catalysts often lack low-threshold, structured and business-model-oriented access to the case knowledge they need to identify which circular opportunities are relevant for a specific company, material flow or regional context.

The second underlying cause is a *development and validation problem*. Business model development is a complex and iterative process that requires continuous refinement across multiple stages (Foss and Saebi, 2017; Taran, Boer and Nielsen, 2021). Initial BM concepts are typically articulated, refined and assessed for feasibility to support informed decision-making prior to implementation (Osterwalder *et al.*, 2010; Wirtz and Daiser, 2018). For CEBMs, this development is associated with additional uncertainties, as value creation emerges within networks of complementary, often cross-sectoral actors and involves changing business logics, such as the transition from product to service, participation in cascading value chains, the establishment of closed loops with take-back systems or platform-based constellations, as well as the coordination of forward and reverse flows (Rizos *et al.*, 2016; Bianchini, Rossi and Pellegrini, 2019; Geissdoerfer *et al.*, 2020; acatech, 2021). To manage risks prior to implementation, experimentation and pre-launch evaluation, such as prototyping, are widely recommended (McGrath, 2010; Thompson and MacMillan, 2010; Gassmann, Frankenberger and Csik, 2017), yet prototyping, systematic pre-launch evaluation and implementation-oriented planning remain underrepresented in business model innovation research compared to analysis and ideation (Echterhoff, Hirschter and Gausemeier, 2016; Wirtz and Daiser, 2018; Ksouri-Gerwien, 2024).

In practice, business model innovation often begins with analysis and ideation in creative workshops, resulting in an initial Business Model Canvas (BMC) (Osterwalder *et al.*, 2010). The BMC is a useful method for structuring business models, promoting communication among stakeholders (John, Kundisch and Szopinski, 2017) and structuring subsequent activities, but it remains a static representation that does not capture actor networks, value exchanges,

operational processes, feedback structures or long-term economic, ecological and social effects. Complementary modelling approaches address parts of this problem — e3Value for actor constellations and value exchanges, BPMN for operational activities and cost drivers, and System Dynamics for feedback structures and long-term system behaviour, including effects relevant to the Sustainable Development Goals (Cosenz, Rodrigues and Rosati, 2020), but existing approaches provide limited guidance for transferring assumptions, parameters and insights across these modelling perspectives. Several authors therefore highlight a lack of established tools for evaluating business models prior to launch and note that existing approaches are insufficiently embedded in an overarching business model innovation process, leading to media breaks and the loss of assumptions and traceability across modelling steps (Athanasopoulou and De Reuver, 2020; Fruhwirth, Ropposch and Schindler, 2020; Gilsing *et al.*, 2022; Fauser, Hertweck and Scheerer, 2024; Ksouri-Gerwien, 2024).

Methods for refining business models, simulating their impact, iteratively improving them and systematically transferring knowledge between modelling languages remain underdeveloped in both research and practice (D'Souza et al., 2018; Szopinski et al., 2022; Ksouri-Gerwien, 2024). There is no universal solution for modelling and visualizing CEBMs, making it necessary to develop adapted, multifunctional modelling approaches capable of integrating multiple modelling languages and supporting transparency, effective prototyping, scenario analysis, and transferability in practice.

The third underlying cause is an *implementation and capability problem*. Even when a CEBM has been identified, modelled and assessed, stakeholders still need to understand which organisational, technological, infrastructural and human capabilities are required to implement and operate it. Existing modelling outputs can indicate relevant actors, processes, resources, costs and dependencies, but these insights are not automatically translated into capability-oriented implementation requirements. While dynamic capabilities and capability-based approaches are discussed in the CE literature as relevant conceptual foundations (Teece, 2010; Khan, Daddi and Iraldo, 2020; Pieroni, McAloone and Pigosso, 2021) and capability mapping through standards such as ArchiMate supports the structured representation of business and IT capabilities (*ArchiMate® 3.2 Specification*, 2022), it remains unclear which technologies and capabilities are associated with specific CEBM design and R-strategies and which capabilities should be present within a company for the implementation of a concrete business model. This creates a gap between CEBM analysis and validation on the one hand and implementation planning on the other, which is particularly relevant for SMEs and regional catalysts.

The explicated problem can therefore be formulated as follows: companies and regional catalysts lack an integrated, practice-oriented support environment that connects CEBM opportunity identification, multi-perspective modelling and validation and capability-oriented implementation planning. This problem is relevant because fragmented support makes it difficult for stakeholders to identify promising circular opportunities, to assess their economic, ecological and social implications, to preserve assumptions and traceability across modelling steps and to derive implementation requirements that can guide concrete decisions. The problem is feasible to address at least partially because existing methods and tools already support individual aspects, but require integration, adaptation to the circular economy context and translation into a coherent

toolbox. The empirical observations from the DECIDE pilot cases, presented in Section 4.2, further substantiate this problem analysis and provide a basis for the identification of specific, addressable sub-problems that motivate the design of the DECIDE Toolbox.

Empirical Grounding - The DECIDE Project

The problem analysis follows an action research and case study research logic and uses participatory modelling workshops (Ssebuggwawo, Hoppenbrouwers and Proper, 2009; Riemer, Holler and Indulska, 2011) to elicit requirements, document BMs from multiple perspectives and iteratively test and refine an integrated multi-view modelling method.

The DECIDE Toolbox was developed and validated across multiple pilot cases within the DECIDE project, drawn from the Danube region and covering CEBMs from sectors including food, batteries, smart cities, textiles and packaging. Across these engagements, recurring practitioner problems were observed that hinder pre-launch validation and implementation-oriented decision-making. The observations from the pilot cases are aligned with the literature-based gap analysis from Section 4.1 and consolidated into a set of twelve identified problems that motivate the design of the DECIDE Toolbox.

Observations related to the transparency and orientation gap

In the early phases of CEBM development across the DECIDE pilot cases, practitioners frequently expressed difficulties in identifying which circular opportunities were relevant for their specific company, material flow or regional context. These observations were further substantiated by complementary qualitative interviews with actors from economic development, innovation support, consulting and regional development. The interviews were analysed to identify recurring information needs, barriers and support requirements (D.2.2.1 & D.2.2.2). Many companies, particularly SMEs, but also regional catalysts, had only limited familiarity with circular economy principles, R-strategies and the range of already implemented CEBMs. For companies, such examples serve as orientation for developing their own business models, while they support regional catalysts to recognise circular potentials, bring relevant actors together and initiate corresponding business model initiatives. The findings further indicated that concepts such as industrial symbiosis, cascading value chains or cross-sectoral waste-to-resource pathways are often difficult to grasp in practice unless they are illustrated through concrete case examples and actor constellations. Beyond access to existing CEBM examples, practitioners often lacked transparency regarding how residual streams and by-products could be transformed into potential value chains and linked to suitable partners, valorisation technologies and possible market applications. Existing case collections, knowledge platforms or industrial symbiosis tools were either not known to practitioners, required technical setup or did not provide business-model-

oriented case descriptions. This points to the need for low-threshold, structured access to both CEBM case knowledge and value-chain-oriented knowledge that supports awareness of circular opportunities and information access in the early orientation phase. In addition, marked regional differences in CEBM awareness were observed within the Danube area, with companies, public authorities and regional support actors in countries such as Germany, Austria or Slovenia tending to be more familiar with CE concepts than actors in other regions of the Danube area.

Observations related to the development and validation gap

Many CEBMs modelled in the project exhibited complex network structures with multiple actors, resource flows and value exchanges. Stakeholders often found it difficult to visualise and understand these relationships, consistent with findings from academic literature (Bianchini, Rossi and Pellegrini, 2019; Geissdoerfer *et al.*, 2020). Although actors such as IT service providers or logistics partners can be listed within the BMC, the canvas does not explicitly specify their concrete contributions to value creation, the nature of their interactions or the dependencies on supporting infrastructures required for successful operations. During the pilot modelling it was identified that a transparent representation of value flows is essential for effective business model development, understanding, communication and analysis (Ksouri-Gerwien and Vorbohle, 2023; Ksouri-Gerwien, 2024). CEBMs are typically implemented as network business models under substantial uncertainty, including variable reverse flows and evolving actor roles, which single, static representations cannot adequately capture (D'Souza et al., 2018; Szopinski et al., 2022; Fauser, Hertweck and Scheerer, 2024). These observations relate directly to the complexity of NBMs and the transparency of value exchanges.

The ability to efficiently create and simulate BM prototypes proved crucial for validating economic viability and enabling iterative stakeholder discussions about alternative configurations. However, we observed methodological knowledge gaps among practitioners, especially SMEs and regional catalysts, regarding systematic, customer-centric BM development and the translation of early BM concepts into evaluable BC variants. These observations align with the broader gap that workflow-based integration and formalized transfer mechanisms across modelling perspectives (BMC, NBM, process modelling and dynamic simulation) remain insufficiently developed (Echterhoff, Hirschter and Gausemeier, 2016; Fruhwirth, Ropposch and Schindler, 2020; Fauser, Hertweck and Scheerer, 2024). This motivates problems related to economic viability analysis, systematic BM development, BM-to-BC translation and workflow-based integration.

Process modelling proved particularly valuable when domain knowledge was limited or when a BM required deeper operational clarification. It addresses the gap for implementation-oriented refinement of CEBMs (Al-Debei and Avison, 2010). BPMN supports to externalize and structure process knowledge such as activities, handovers, responsibilities, throughput times, resource needs, capacities and cost drivers, thereby enabling feasibility checks and the identification of operational bottlenecks. Without a process model, assumptions about activities, timing, costs and operational constraints remain implicit, making it difficult to reliably parameterise SD models or assess operational feasibility prior to implementation.

Furthermore, stakeholders also required assessments beyond financial viability, including ecological and social outcomes. This multidimensional assessment was particularly relevant in cross-regional cases, where context-specific factors such as available resources, infrastructure or actor constellations influenced the suitability and performance of CEBM. Long-term and multidimensional evaluation was therefore often insufficiently supported. System Dynamics emerged as a particularly valuable method in this context, enabling the representation of feedback structures, parameter effects and multidimensional outcome variables including return on investment, CO_2 savings and employment effects across different scenarios (Abdelkafi and Täuscher, 2016; Cosenz, Rodrigues and Rosati, 2020)

A further observation across pilot cases concerns the accessibility of modelling results. Even when modelling outputs were technically available across the different modelling languages, stakeholders frequently struggled to interpret these outputs in an integrated manner. Stakeholder consultations during the DECIDE pilot cases revealed that modelling results from individual perspectives are difficult to consolidate, that the relationships between outputs from different modelling languages are not immediately apparent and that stakeholders require simplified, integrated views to support informed decision-making. This points to a need for an accessible, multi-perspective integration layer that consolidates modelling outputs and presents them in a stakeholder-oriented format.

Observations related to the implementation and capability gap

The implementation and capability gap became evident across the DECIDE pilot cases when the modelling outputs were considered in relation to how the modelled CEBMs could be implemented in practice. The BMC, e3Value, BPMN and System Dynamics models provided detailed insights into actors, value exchanges, processes, resources, dependencies and potential impacts. However, these outputs did not automatically translate into concrete implementation requirements. Capabilities provide a suitable abstraction level for this translation because they describe what an organisation, actor network or supporting digital infrastructure must be able to do without immediately specifying detailed processes, organisational units or technical systems. In the pilot context, this raised the question of which business and IT capabilities are needed to operate a modelled CEBM and whether these capabilities are available within the focal organisation or its regional value network. This is particularly relevant because new or substantially changed circular business models often require a broad set of organisational, technological and network-related capabilities, making prioritisation difficult for implementation planning. The methods initially used in the pilots did not adequately support the systematic comparison between required and available capabilities or the identification of capability gaps that need to be addressed before implementation. This observation reflects the broader literature gap identified in Section 4.1 and motivated the need for a capability-oriented extension of the toolbox. This extension provides an initial structure for selecting, assessing and further specifying relevant business and IT capabilities for CEBM implementation.

Identified Problems

The observations from the DECIDE pilot cases, aligned with the scholarly gaps identified in Section 4.1, converge on twelve interrelated problems that motivate the development of the integrated DECIDE Toolbox. The problems are organised along the three support gaps that structure the overall problem analysis.

Problems related to the transparency and orientation gap

(i) Awareness and low-threshold access to CEBM case and value-chain knowledge. Companies and regional catalysts in the DECIDE pilot cases frequently lacked familiarity with CE principles, R-strategies and already implemented CEBMs that could serve as orientation for their own developments or regional initiatives. Beyond case examples, practitioners also lacked transparency on how residual streams and by-products could be linked to potential waste-to-resource pathways, suitable partners, technologies and market applications. Existing case collections and knowledge platforms were either not known, required technical setup or did not provide accessible, business-model-oriented guidance. This points to a need for low-threshold, structured access to both CEBM case knowledge and value-chain-oriented knowledge for early-phase orientation and for recognising growth, scaling or diversification potential within existing circular business models.

(ii) Ecosystem complexity in network business models. CEBMs are typically implemented as network business models involving multiple actors, resource flows and interdependent value exchanges. Stakeholders, particularly SMEs and regional catalysts, frequently struggle to visualise and understand multi-actor structures and dependencies. Although actors such as IT service providers or logistics partners can be listed in a BMC, their concrete contributions to value creation, interaction patterns and infrastructure dependencies remain implicit. This lack of transparency impedes effective stakeholder alignment and validation of network-based value creation (Bianchini, Rossi and Pellegrini, 2019; Geissdoerfer et al., 2020).

(iii) Transparency of value exchanges. Value exchanges between actors and customers must be made explicit to support shared understanding and informed decision-making. In DECIDE pilot cases, stakeholders consistently required a clear representation of who provides what to whom, under what conditions and with what economic reciprocity. This need is particularly pronounced in CEBMs, where non-monetary exchanges such as regulatory compliance, environmental contributions or social value are integral parts of the value network (Vorraber and Müller, 2019).

(iv) Systematic, customer-centric BM development. Many practitioners, especially SMEs and regional actors, lack structured methods for developing customer-centric and sustainable BMs from ideation to a formalized BM representation. Knowledge gaps in systematic BM development were observed across DECIDE cases, and the transition from creative workshop outputs to

structured, evaluable BM artefacts remain poorly supported (Fauser & Hertweck, 2022; Fauser et al., 2024).

(v) Economic viability analysis. Determining and comparing the economic viability of alternative BM configurations is a critical pre-launch requirement. Practitioners require tools that support quantitative scenario analysis and what-if comparisons across different actor constellations, pricing models, and resource assumptions. Current approaches provide limited support for this type of evidence-based decision-making prior to implementation (D'Souza et al., 2018; Athanasopoulou & De Reuver, 2020).

(vi) From business model to business case. Translating BM representations, such as those captured in a BMC, into operational variants and quantified business cases is critical for ensuring practical implementation. This transition requires formalised mapping and parameter handover mechanisms that current approaches do not provide systematically (Ksouri-Gerwien, 2024; Gilsing et al., 2022).

(vii) Operational process detail and feasibility assessment. Without a process model, assumptions about activities, timing, costs and operational constraints remain implicit, making it difficult to reliably assess the operational feasibility of a business model. Experience from DECIDE pilot cases showed that creating System Dynamics models without proper process context proved challenging, only with BPMN-based process detail could both dynamic and static aspects, such as costs and process times, be accurately captured. BPMN proved particularly valuable when domain knowledge was limited or when a business model required deeper operational clarification, for example in the food sector pilot where throughput times, machinery costs and material quantities needed to be precisely specified before System Dynamics modelling could begin. This underscores the role of process modelling as a necessary intermediate step between network-level business model analysis and dynamic simulation (Gilsing et al., 2022; Torres et al., 2023).

(viii) Multidimensional evaluation and transferability. Integrated support for assessing the economic, ecological, and social impacts of CEBMs over time is often lacking. In cross-regional DECIDE pilots, context-specific factors — such as available resources, infrastructure, or actor constellations — significantly influenced CEBM suitability and performance, highlighting the need for scenario-based, context-sensitive impact analysis. Stakeholders often lack tools for context-sensitive impact analysis, scenario testing and adaptation (Lewandowski, 2016). SD emerged as a particularly valuable method in this context, enabling the representation of feedback structures, long-term dynamics, and multidimensional outcome variables, including ROI, CO_2 savings, and employment effects (Abdelkafi & Täuscher, 2016; Cosenz et al., 2020).

(ix) Workflow-based integration and iterative transformation. Systematic, workflow-based integration and formalised transfer mechanisms across modelling languages and development stages, BMC, e3Value, BPMN, and SD, remain insufficiently developed. This includes the iterative transformation from static to dynamic models, the consolidation of insights across methods, and the preservation of assumptions and traceability throughout the modelling process. The absence of such integration leads to media breaks, information loss, and inconsistencies across

representations, reinforcing calls for an end-to-end, decision-oriented workflow (Fruhwirth et al., 2020; Szopinski et al., 2020; Pérez-Blanco et al., 2025).

(x) Accessible interpretation of modelling results and multi-perspective integration. Across the DECIDE pilot cases, stakeholders encountered difficulties in interpreting modelling outputs from individual modelling languages such as BMC, e3Value, BPMN or System Dynamics, particularly when the results were technically detailed or required method-specific knowledge. These difficulties increased when outputs from multiple modelling perspectives had to be consolidated and related to each other. This limited their usefulness for decision-making and points to a need for simplified visualisations and an accessible integration layer that presents modelling results in a stakeholder-oriented format.

Problems related to the implementation and capability gap

(xi) Translation of modelling outputs into capability-oriented implementation requirements. Across the DECIDE pilot cases, modelling outputs from BMC, e3Value, BPMN and System Dynamics provided complementary insights into actors, processes, resources, value exchanges and dependencies. However, the translation of these insights into concrete capability-oriented implementation requirements remained difficult. Practitioners required support in identifying which business and IT capabilities would be needed to implement and operate the modelled CEBM.

(xii) Capability gap analysis for CEBM implementation. Beyond identifying required capabilities, stakeholders in the DECIDE pilot cases needed support in assessing whether these capabilities were already available within the focal organisation or its regional value network. The systematic comparison of required and available capabilities, including the identification of capability gaps that need to be addressed before implementation, was not adequately supported by the methods initially used in the pilots, namely BMC, e3Value, BPMN and System Dynamics.

By systematically combining methods for CEBM identification, multi-perspective modelling, integrated result interpretation and capability-oriented implementation planning, the DECIDE Toolbox provides a coherent response to these twelve interrelated problems. This integrated support enables improved stakeholder understanding and collaboration, evidence-based decision-making and the effective development and scaling of circular economy business models across regional, sectoral and organisational contexts.

Define Requirements

The second activity defines the requirements for the artefact. First, we outlined the artefact's basic characteristics and type. The diversity of problems identified across the empirical observations and the literature present a challenge for consolidating them into a unified approach. In our experience, a methodological artefact best addresses the identified problems. As outlined by (Johannesson and Perjons, 2021), a method provides guidelines and processes for how to solve a problem and achieve certain goals. It encompasses a collection of procedures grounded in concepts, with outcomes represented through notation (Goldkuhl, 1997). This combination of procedures, concepts and notation forms a cohesive method component, allowing for the integration of models, instances or other methods to achieve specific objectives.

The DECIDE Toolbox is designed to support the identification, analysis, development, validation, optimisation and implementation planning of CEBMs by integrating complementary methodological perspectives across the three support gaps identified in Section 4. To address the transparency and orientation gap, the toolbox provides structured access to CEBM case knowledge through a CEBM-Catalogue and to value-chain-oriented knowledge through a Value Chain Generator. The Value Chain Generator additionally supports the optimisation and extension of existing CEBMs by helping to identify new value creation potentials, for example through alternative valorisation technologies for the same feedstock or through the connection of complementary value chains to an existing business model. To address the development and validation gap, the toolbox integrates the Business Model Canvas (BMC) for ideation, provides structured methods for mapping BMC elements to e3Value for network business model modelling and scenario calculation, uses BPMN for operational and process-level detail and integrates System Dynamics for the dynamic, multidimensional simulation of economic, ecological and social impacts over time. A Dashboard component consolidates modelling outputs across these perspectives into accessible, stakeholder-oriented visualisations. To address the implementation and capability gap, the toolbox extends these modelling perspectives with the Digital Service Implementation Recommender (DSIR). The DSIR provides an initial capability catalogue structured according to circular business model patterns, based on (Lüdeke-Freund, Gold and Bocken, 2019) and supports the identification of relevant business and IT capabilities for CEBM implementation. Building on this catalogue, a capability-map-based modelling concept can be used to represent and further specify selected capabilities in relation to a specific CEBM context. Modelling, the process of creating purpose-oriented abstractions, is a long-standing practice in business informatics (Frank *et al.*, 2014), utilising both qualitative and quantitative methods to gather relevant information. It represents a system through concepts to aid understanding, knowledge acquisition or simulation of a subject. Simulation, widely used across scientific disciplines, optimises planning by replicating real-life situations to analyse past occurrences or predict future outcomes based on hypothetical scenarios.

The DECIDE Toolbox combines practical software tools with methodological guidance to support users in creating, transforming and applying model representations. The CEBM Catalogue and the Value Chain Generator are implemented as web-based components, providing low-threshold access for companies and regional catalysts. The BMC, e3Value and BPMN modelling perspectives are implemented within a practical software environment based on the ADOxx metamodelling platform, designed for SMEs and regional catalysts. System Dynamics modelling is supported via Vensim. The Dashboard consolidates modelling results from the different perspectives into a stakeholder-oriented view. The DSIR capability map for modelling is implemented within the ADOxx environment, while the underlying capability catalogue is provided as a structured reference resource for stakeholder use.

The artefact's requirements were identified and refined through a combination of action research and case study research, complemented by participatory and collaborative modelling with stakeholders (Ssebuggwawo, Hoppenbrouwers and Proper, 2009; Riemer, Holler and Indulska, 2011). These research strategies provided the methodological framing for developing and adapting the artefact. Empirical input was gathered through workshops during DECIDE partner meetings, a Train-the-Trainer session, a subsequent dedicated World Café documented in D1.2.9, qualitative stakeholder interviews, observations from pilot case modelling and feedback from project partners, industry representatives and academic experts. This iterative process supported the continuous refinement of the artefact and helped align the methodology with practical challenges encountered during CEBM identification, development, validation, optimisation and implementation planning.

In conclusion, this argumentation leads to the following research goal, addressed through the conception of the artefact: *Supporting the identification, development, validation, optimisation and implementation planning of CEBMs, including network-based business models in the context of the circular economy, with a focus on economic, ecological and social viability, accessible result interpretation, capability-oriented implementation support and the practical transferability of such models across diverse regional and sectoral contexts.*

Based on this research goal and the identified problems, we derived the artefact requirements. Following Johannesson and Perjons (2021), requirements should be linked to the underlying problems from which they are derived. Table 3 therefore presents the derived requirements and maps them to the corresponding problems.

Table 3 Mapping requirements to problems

Problem	Requirements
Transparency and orientation gap	
P(i): Awareness and low-threshold access to CEBM case and value-chain knowledge	Low-threshold access to CEBM case and value-chain knowledge: Provide a structured, web-based access layer to CEBM case descriptions, R-strategies and value-chain-oriented knowledge (residual streams, valorisation pathways, partner constellations, market applications) that

	supports awareness and early-phase orientation for both companies and regional catalysts and enables the identification of optimisation and extension potentials for existing business models.
Development and validation gap	
P(ii): Ecosystem complexity in NBMs& P(iii): Transparency of value exchanges	Network business model modelling and visualisation: Support the modelling and graphical visualisation of multi-actor structures, actor roles, dependencies and value exchanges (including tangible and intangible, monetary and non-monetary flows) to enable shared understanding and stakeholder alignment.
P(ii)+P(iii)+P(v): NBM modelling & calculation	NBM modelling & calculation: Model NBM elements (actors/customers, resources, processes, tangible/intangible value exchanges) and support visualization and calculation of multiple BM variants (incl. interactions).
P (iv): Systematic, customer-centric BM development	Systematic and customer-centric BM development support: Provide a structured method that guides companies and regional catalysts from initial ideation to a formalised, evaluable BM representation
P (v): Economic Viability Analysis	Viability & scenarios: Quantify and compare alternative BM configurations; scenario-based results
P(vi): From a BM to a business case (BC)	BM-to-business-case transformation: Transformation guidelines from BMC to a NBM and guidelines to quantify the model.
P(vii): Operational process detail and feasibility assessment	Operational process detailing and feasibility assessment: Capture activities, roles, handovers, throughput times, resource needs, capacities and cost drivers via BPMN, providing operational context for feasibility checks and as parameter basis for dynamic simulation.
P(viii): Multidimensional evaluation and transferability	Multidimensional, dynamic impact evaluation: Enable the simulation and evaluation of economic, ecological and social impacts over time, with support for scenario analysis, sensitivity analysis and assessment of transferability across regional and sectoral contexts.
P(ix): Workflow-based integration and iterative transformation	Workflow-based methodological integration: Provide methodological integration and formalised transfer mechanisms across modelling languages and stages (BMC → e3Value → BPMN → System Dynamics), preserving assumptions, parameters and traceability across the modelling process.
P(x): Accessible interpretation of modelling results and multi-perspective integration	Accessible multi-perspective result integration: Consolidate modelling outputs from BMC, e3Value, BPMN and System Dynamics into accessible, stakeholder-oriented visualisations that support informed decision-making across modelling perspectives.

Implementation and capability gap	
P(xi): Translation of modelling outputs into capability-oriented implementation requirements	Capability catalogue and criterion-based capability identification: Provide a structured capability catalogue that allows the identification of relevant business and IT capabilities for CEBM implementation based on criteria such as R-strategy, CEBM type or design strategy.
P(xii): Capability gap analysis for CEBM implementation	Capability mapping and gap analysis: Support the structured mapping of required capabilities and the systematic comparison with available capabilities within the focal organisation and its regional value network, enabling the identification of capability gaps that need to be addressed before implementation.

Design and Develop Artefact

The third activity focused on designing and developing the artefact. In the context of the DECIDE project, this artefact takes the form of a modular method that supports the identification, development, validation, optimisation and implementation planning of CEBMs. It combines various modelling languages, tools and supporting components to address the three support gaps identified in Section 4, the transparency and orientation gap, the development and validation gap, and the implementation and capability gap. The method enables users to iteratively design, assess, refine and plan the implementation of business models from strategic, operational, dynamic and capability-oriented perspectives.

This chapter is structured into two main sections. The first section provides an overview of the DECIDE Toolbox, including its methodological phases, modelling languages, supporting tools and relevant actor roles. The Toolbox serves as a methodological framework for identifying circular value creation potentials, developing new circular business models, analysing and optimising existing ones and preparing their implementation. In this context, the transparency and orientation gap is addressed through the CEBM Catalogue and the Value Chain Generator, which provide structured access to CEBM case knowledge and value-chain-oriented knowledge. The second section describes the core modelling phases of the methodology in detail. For each phase, it specifies the modelling language used, the methodological activities performed and the mappings and transformations applied between modelling approaches. The section integrates the practical use of the Business Model Canvas (BMC), e3Value, BPMN, System Dynamics and the Digital Service Implementation Recommender (DSIR), highlighting their contributions to a multi-perspective analysis and implementation-oriented planning of CEBMs. These mappings support the integration of strategic, value-oriented, operational, dynamic and capability-oriented perspectives and contribute to semantic consistency across the modelling process. directly with each other. Cross-cutting components of the Toolbox, particularly the Data Platform, the Dashboard and the e-learning and training material, are described in the corresponding components chapters. While the Data Platform and Dashboard support the technical integration and accessible presentation of modelling outputs, the e-learning and training material supports the consistent application, interpretation and transfer of the Toolbox across different user groups.

DECIDE Toolbox Overview

The DECIDE Toolbox is a methodological framework that supports both static and dynamic business modelling in the context of the CE. It provides a structured approach to analysing existing business models, identifying circular innovation potentials and developing, validating and planning the implementation of new business models through an iterative multi-method process. The Toolbox addresses the three support gaps identified in Section 4, the transparency and orientation gap, the development and validation gap, and the implementation and capability gap, by combining web-based access to CEBM case and value-chain knowledge, multi-perspective modelling and capability-oriented implementation support into a coherent methodological framework. While the artefact is classified as a method in Design Science Research, the DECIDE Toolbox represents its operational instantiation, offering modular procedures, modelling tools, and flexible guidance that can be adapted to different use cases.

The DECIDE Toolbox provides the foundation for analysing real-world examples from the Danube Region, cataloguing them and identifying potentials for transnational and cross-sectoral business model transfer. The aim is to support companies and regional catalysts in the following areas:

- Identifying value creation potentials in line with CE principles
- Analysing and assessing existing business models in terms of their ecological, economic, and social performance
- Identifying optimisation and extension opportunities in existing business models
- Developing and validating new circular business models
- Supporting capability-oriented implementation planning, including the identification of required business and IT capabilities and the assessment of capability gaps
- Facilitating the transfer and scaling of circular business models across regions.

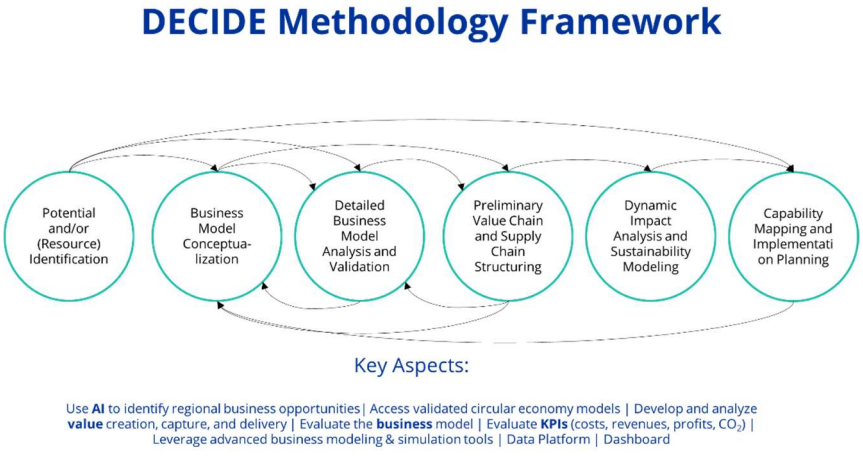


Figure 4: DECIDE Methodology Framework

We distinguish four key target groups with different application needs. (i) Companies with side streams or waste flows, seeking valorisation strategies (e.g., breweries with spent grain). (ii) Circular innovators and solution providers, creating value by using those side streams (e.g., insect farms) (iii) Use-oriented business models, such as Product-as-a-Service, sharing or repair services. (iv) Regional catalysts, including BSOs, cluster managers and local development agencies that coordinate and facilitate regional innovation.

The DECIDE method is designed to be flexible and modular. Depending on the context and needs of the user, components can be selectively applied and combined. By combining proven modelling methods and tools, the DECIDE Toolbox enables a multi-perspective analysis that integrates the strategic, operational and dynamic and capability-oriented dimensions of a business model. The methodological structure and modular logic of the Toolbox are illustrated in Figure 4. This figure highlights the iterative nature of the approach and shows that individual phases can be repeated, skipped, or rearranged depending on the specific use case and existing knowledge. It emphasizes that the Toolbox is not a linear procedure but a flexible method that allows users to enter at different points and tailor the methodology to their context. Depending on the use case, data availability, and maturity of the business idea, phases can be reordered, repeated, or partly skipped. For example, an existing process model can be used to inform the BMC and e3Value model, while a BMC can be refined into e3Value before detailed BPMN modelling is conducted. Figure 5 complements this view by linking each phase to the corresponding modelling language and illustrating how the associated tools support different aspects of business model development.

The method starts with Potential and (Resource) Identification, which focuses on the identification of promising opportunities for circular innovation. This is supported by the CEBM Catalogue (D.1.2.7) and the AI-driven Value Chain Generator (D.1.2.2), which analyse regional material flows, by-products and business potentials. Beyond the initial identification of new CEBMs, both components also support the identification of optimisation and extension potentials for existing business models, for example when alternative valorisation technologies are applied to the same feedstock or when adjacent value chains can be linked to an existing CEBM. In the Business Model Conceptualization phase, business ideas are structured using the Business Model Canvas (BMC), capturing value logic based on value creation, value delivery, value capture and value proposition. The BMC is collaboratively developed with stakeholders, either through a comprehensive innovation workshop or a simplified format, depending on the maturity of the business idea. Although the BMC provides a high-level strategic overview, it often remains ambiguous regarding the specific value exchanges between actors and the distribution of costs and revenues across the network. To address these limitations, the BMC is translated into an e3Value network business model in the Detailed Business Model Analysis and Validation phase. This step quantifies value exchanges between stakeholders, links operations with infrastructure and resource requirements, thereby supporting CAPEX/OPEX estimation, and enables early-stage financial validation based on what-if scenarios. In the next phase, Preliminary Value Chain and Supply Chain Structuring, BPMN is applied to model the selected CEBM as an operational process, capturing key activities, involved actors, dependencies, and required resources. The modelling approach is participatory, involving stakeholders in workshops and interviews to elicit operational knowledge (Prilla et al., 2011; Riemer et al., 2011; Ssebuggwawo et al., 2009). In the Dynamic Impact Analysis and Sustainability Modelling

phase, System Dynamics is used to simulate long-term ecological, economic and social impacts. To structure SD modelling consistently across cases, we adopt the Dynamic Business Modeling for Sustainability Canvas (Cosenz, Rodrigues and Rosati, 2020), which restructures the BMC into seven SD-oriented dimensions to link business model structure to economic, environmental and social outcomes over time. Finally, in the Capability Mapping and Implementation Planning phase, the technical and organisational requirements of the business model are analysed using the Digital Service Implementation Recommender (DSIR), which leverages ArchiMate to map relevant business and IT capabilities. The DSIR builds on a pattern-oriented capability catalogue structured along established CEBM Patterns (Lüdeke-Freund, Gold and Bocken, 2019) and supports the identification of relevant capabilities, the structured mapping of required capabilities and the systematic comparison with available capabilities for capability gap analysis. Each phase is described in detail in the corresponding sections below.

Each phase is supported by a dedicated tool or method that enables both qualitative and quantitative evaluation of circular economy business models (CEBMs). These include:

- The Circular Economy Value Chain Generator and CEBM Catalogue for opportunity identification.
- The Circular Economy Business Modeller (implemented on ADOxx) for BMC, BPMN, and e3Value modelling.
- The Digital Service Implementation Recommender (DSIR) (using a subset of ArchiMate, implemented on ADOxx) for capability-oriented implementation planning, building on a pattern-oriented capability catalogue structured along established CEBM patterns and R-strategies (Lüdeke-Freund, Gold and Bocken, 2019) to derive case-specific capability profiles and capability maps that support implementation planning and gap analysis
- The Circular Economy Value Chain Simulator (based on System Dynamics in Vensim) for impact assessment and scenario-based decision support.
- The DECIDE Dashboard consolidates modelling results from the different perspectives into accessible, stakeholder-oriented visualisations, while the DECIDE Data Platform (D.1.2.6) provides the underlying semantic data infrastructure for storing and exchanging model representations across components.

Since the DECIDE Toolbox is intended to be applied by project partners, companies and regional catalysts with heterogeneous prior knowledge of circular economy concepts, modelling languages and digital tools, it is complemented by structured e-learning and training material. This cross-cutting enabling component supports users in understanding the purpose, required inputs, modelling steps, expected outputs and interpretation of the individual toolbox components, without constituting a separate methodological phase.

The structure of the DECIDE Toolbox can also be interpreted along the three high-level activities of the dynamic capabilities framework as defined by Teece (2007) and adapted for circular economy business model innovation by Pieroni, McAloone and Pigosso (2019, 2021): (i) sensing, the identification of opportunities and the generation of new business model ideas; (ii) seizing, the systematic design and testing of new business model concepts and configurations; and (iii) transforming, the building of new competences and capabilities required for implementation and

organisational renewal. Within the DECIDE Toolbox, sensing is supported by the CEBM Catalogue and the Value Chain Generator, seizing is supported by the BMC, e3Value, BPMN and System Dynamics modelling perspectives, and transforming is supported by the Capability Mapping and Implementation Planning phase based on the DSIR.

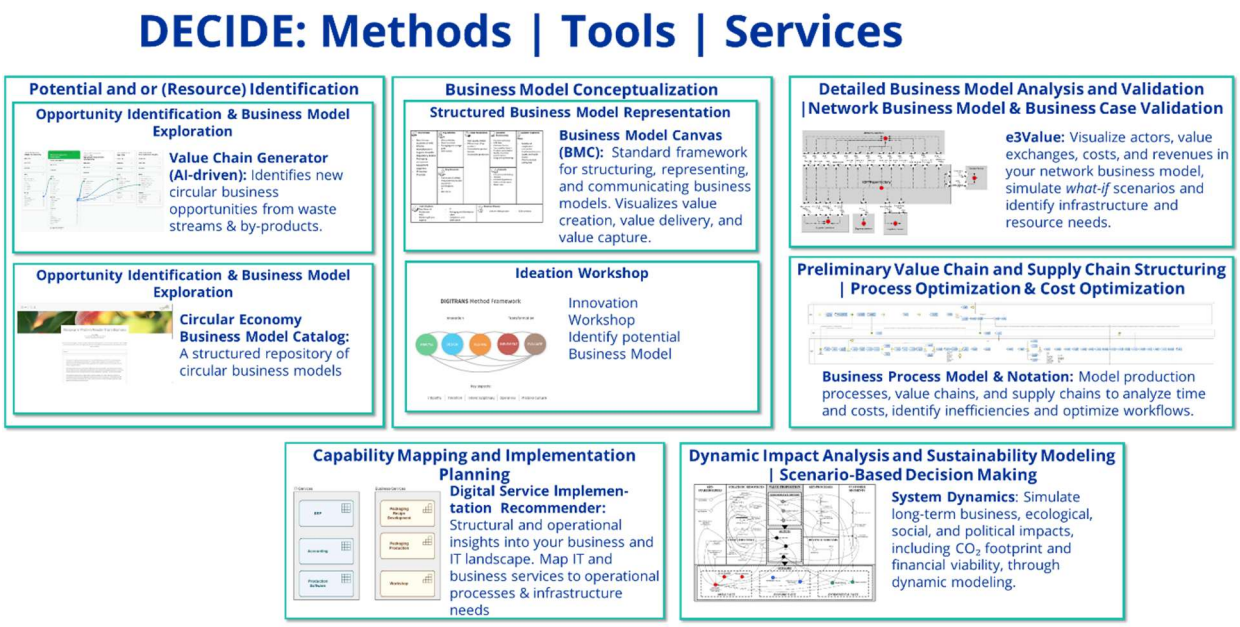


Figure 5: DECIDE Methods, Tools and Services; Appendix 1 – DECIDE Methods, Tools and Services.jpg

As illustrated in Figure 5, integrating these tools ensures consistency across strategic, operational, infrastructural, dynamic and capability-oriented dimensions. Together, they form a coherent framework for designing, testing, and refining and planning the implementation of CEBMs through both static and dynamic modelling approaches. A central feature of the DECIDE approach is the integration of multiple modelling languages, such as BMC, e3Value, and BPMN, to achieve a consistent and comprehensive representation of business models. The mapping between these modelling languages plays a crucial role in connecting strategic, operational, and value-oriented perspectives. This integration supports the efficient transfer of concepts, ensures consistency across different layers and forms the basis for the simulation and validation of business models. In this framework, the BMC acts as a semantic pivot linking the e3Value and BPMN models, where elements of the value and process models are connected to corresponding BMC building blocks, enabling traceability across modelling perspectives. For the dynamic analysis, a System Dynamics model is derived using a BMC-inspired structure following the Dynamic Business Modelling for Sustainability Canvas (Cosenz, Rodrigues and Rosati, 2020). Together, this integration connects value logic, process logic, dynamic performance analysis and capability-oriented implementation planning.

In addition, Figure 6 provides a more technical perspective on the integration of modelling tools, data exchange and simulation components. The ADOxx-based DECIDE Modeller supports BMC, e3Value, BPMN and the DSIR within a shared modelling environment, implemented through the DECIDE Library, including the metamodel, functions and Olive connectors. Model data is exported from ADOxx via Olive and a REST API to an RDF transformation service, where it is transformed into RDF representations and stored in a knowledge graph in GraphDB based on a DECIDE-specific ontology (D.1.2.6). System Dynamics models are created in Vensim and exchanged using the XMILE standard, an open XML-based format for representing SD models. The resulting semantic structure enables interoperability between modelling languages and provides the data basis for downstream applications, including the DECIDE Dashboard as a blockchain-protected digital monitoring tool (D.1.2.5).

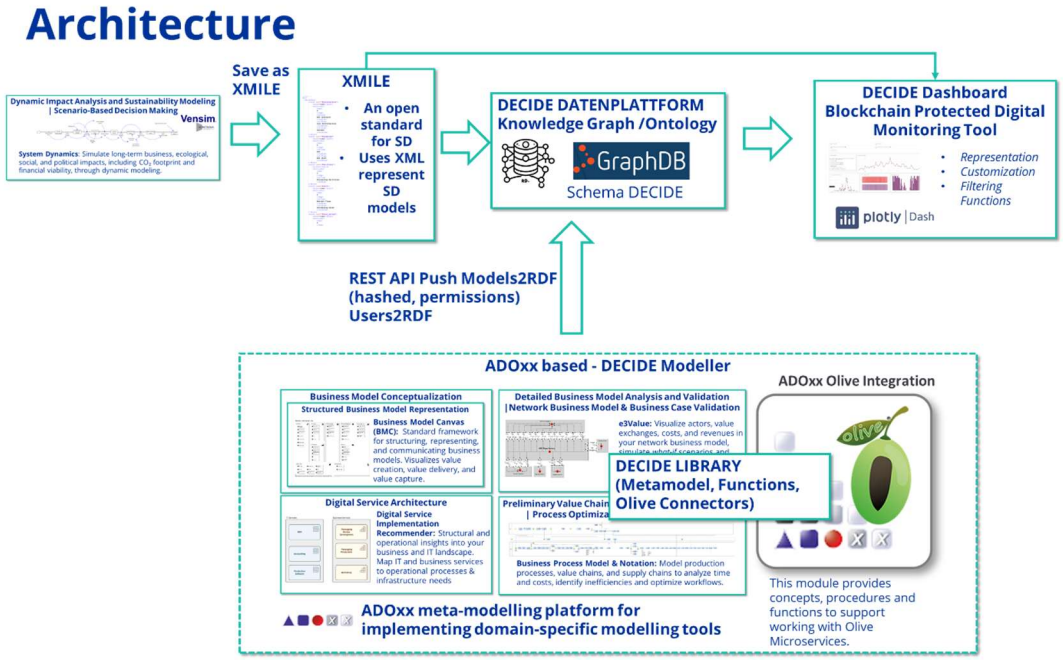


Figure 6: DECIDE Toolchain; Appendix 2 - DECIDE Toolchain.jpg

Potential and / or (Resource) Identification

The identification and analysis of value-creation potential from available resources, by-products or specific regional characteristics remains a major challenge for both established companies and new ventures, as discussed in Section 4. A key obstacle is the lack of transparency regarding untapped resource streams and proven circular business model solutions, combined with limited familiarity with CE principles, R-strategies and the diversity of CEBM configurations already implemented in different sectors and regions (Rizos et al., 2016; Kirchherr et al., 2018; Pieroni, McAloone and Pigosso, 2021). This phase aims to systematically uncover new market opportunities and value chains, whether based on bio-based side streams, industrial waste or other underutilised resources and to provide structured access to existing CEBM configurations as orientation for both new and existing business models. The two complementary tools supporting this phase are the Value Chain Generator (D.1.2.2) and the CEBM Catalogue (D.1.2.7).

The Value Chain Generator focuses on identifying circular value chains from waste and by-product streams, with a particular emphasis on the bioeconomy. A value chain is represented as a combination of feedstock, conversion technology, resulting outputs and potential target markets. The tool can be used either manually, by selecting and combining these elements, or in a guided mode. In a feedstock-driven mode, users start from a selected input material, such as brewers' spent grain from a brewery, and the tool proposes suitable conversion technologies, resulting outputs and possible offtake markets. For example, brewers' spent grain can be used as feedstock in an insect farming process, resulting in products such as protein meal, oil and organic fertiliser, which can then be linked to potential markets such as animal feed, aquaculture or agricultural applications. In a technology-driven mode, users start from a selected conversion technology and the tool suggests suitable feedstocks and potential target markets. Users can further constrain the generation by geography, technology readiness level and other case-specific criteria. Where structured or directly available data are missing, AI-supported search and estimation are used to identify relevant sources and to approximate missing information, such as indicative market sizes, price ranges or potential suppliers and customers within the selected region. These outputs provide an initial basis for assessing the viability of a proposed value chain. Beyond the initial identification of new CEBMs, the Value Chain Generator also supports the identification of optimisation and extension potentials for existing CEBMs, for example when alternative conversion technologies are applied to the same feedstock or when complementary value chains can be linked to an existing business model.

The CEBM Catalogue complements the Value Chain Generator by providing a structured, web-based repository of diverse circular business model examples across sectors. Each catalogue entry

describes a CEBM along a defined set of attributes: title, sector (for example textiles, packaging, smart city, food or batteries), addressed R-strategies as circular strategies (Lüdeke-Freund, Gold and Bocken, 2019), descriptive tags such as 3D-printing, e-waste, biomass or eco-design, a short summary, an abstract, the circular value chain (input feedstock, conversion technology and output products), the resulting circular economy impact (R-Strategies), the addressed Sustainable Development Goals, the place of operation (which is particularly relevant for legal and regulatory framing across jurisdictions such as the EU, the United States, Japan or China), the level of maturity (idea, prototype or implemented) and contact and reference links. The catalogue view consolidates all entries and provides filter options along sector, circular strategies, place of operation and predefined tags (e-waste, biomass or eco-design etc.), enabling targeted exploration based on user interest. This allows companies and regional catalysts to explore implemented CEBM configurations, recognise similar structures or material flows in their own context and initiate corresponding business model initiatives. Methodologically, the catalogue draws on the structured service catalogue approach proposed by Bozkurt et al. (2021), adapted to the circular economy domain.

Together, these two tools address the transparency and orientation gap identified in Section 4 by combining material-flow-oriented potential identification with structured, business-model-oriented case knowledge. Detailed descriptions of the Value Chain Generator and the CEBM Catalogue are provided in Deliverables D.1.2.2 and D.1.2.7.

Business Model Conceptualization

The objective of this phase is to develop a structured overview of value creation, value delivery, value capture and value proposition, typically using the Business Model Canvas (BMC). Building on insights from the Potential and Resource Identification phase, the BMC provides a standard framework for structuring and communicating business models. Two approaches are distinguished, depending on the available knowledge and the required level of detail. In the comprehensive format, a one-day Innovation Workshop, held online or offline, systematically develops a new business model. This workshop consists of two main phases: the Innovation Phase, which focuses on developing new business ideas, and the Transformation Phase, which addresses sustainable implementation. Within this framework, the emphasis is on the Innovation Phase. Alternatively, if the business idea and customer group are already well defined, a simplified workshop format can be used, which typically takes 2–3 hours. In both formats, a BMC is collaboratively created and discussed, integrating insights from previous phases. If a BPMN model exists, it can serve as the basis for the BMC; conversely, a newly developed BMC can inform the creation of a draft process model. The mapping between BMC and BPMN is described in the chapter Preliminary Value Chain and Supply Chain Structuring.

Structured Business Model Representation

The Business Model Canvas (BMC) (Osterwalder *et al.*, 2010) is a strategic management tool that provides a visual, one-page framework for describing, analysing, and designing business models. The BMC breaks down a business model into nine interconnected building blocks that illustrate how a business creates, delivers, and captures value. The nine components of BMC are: (1) Key partners, (2) Key activities, (3) Key Resources, (4) Value propositions, (5) Customer relationships, (6) Channels, (7) Customer segments, (8) Cost structure, and (9) Revenue streams. The BMC is visualized in Figure 7.

- **Key Partners:** External companies, suppliers, or third parties that the business collaborates with to create value, reduce risks, or optimize operations.
- **Key Activities:** The most important actions a company must perform to ensure the business model functions effectively and delivers value.
- **Key Resources**: The assets required to offer and deliver the value proposition, reach customers, and maintain business operations.
- **Value Proposition:** The core products and services that solve customer problems or satisfy customer needs.
- **Customer Relationships:** The types of relationships a company establishes with each customer segment to build loyalty and retention.
- **Channels:** The means by which a company delivers its value proposition to customers, including communication, distribution, and sales channels.
- **Customer Segments:** The distinct groups of people or organizations the business aims to serve.
- **Cost Structure:** The costs incurred while operating the business model.

- **Revenue Streams:** How the business generates income from its customer segments through the delivery of value.

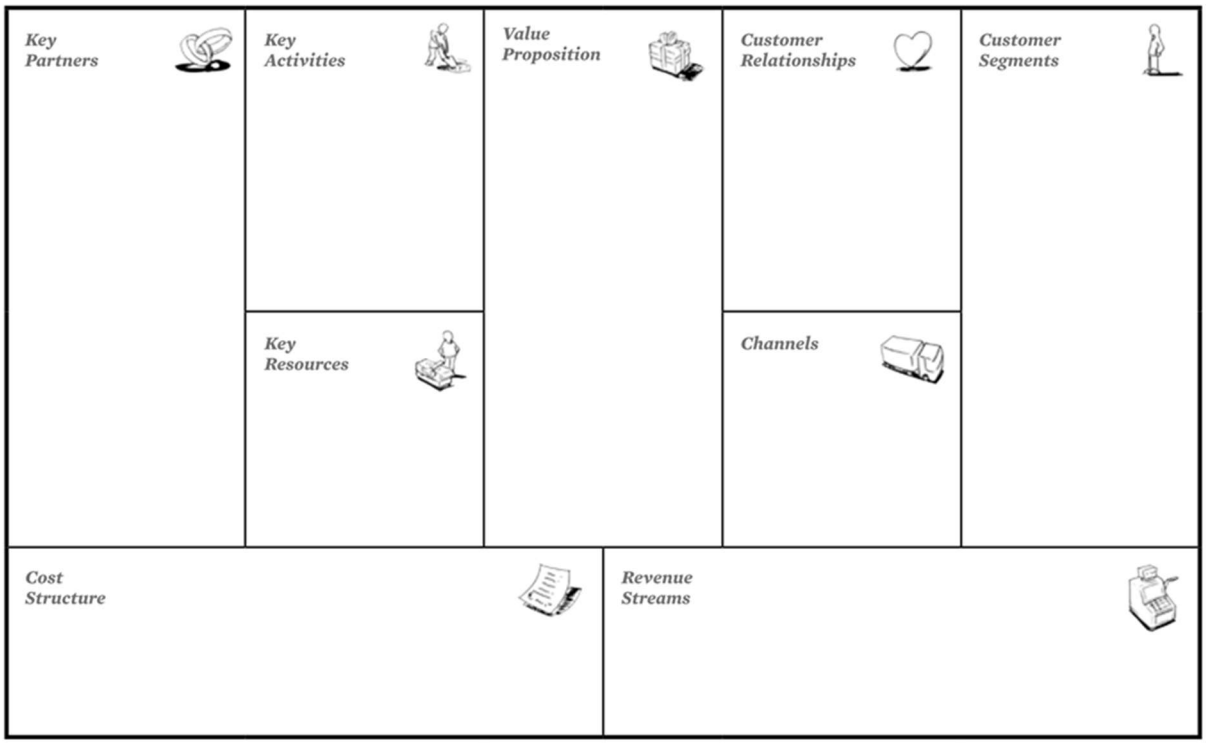


Figure 7: BMC

Osterwalder's definition of a business model highlights it as a conceptual tool comprising a set of elements and their interrelationships, capturing how a company creates, delivers, and captures value (Osterwalder, 2004). The structure of these relationships, both internally and with external partners, is a key aspect of any business model's architecture.

Business model Innovation workshop

For the systematic development of BM, we use the DIGITRANS (Figure 8) method (Digitrans, 2018) which was developed in an earlier Interreg project. The focus is on SMEs and is divided into two main phases: innovation and transformation. The innovation phase focuses on developing a new business idea, while the transformation phase deals with the sustainable implementation of the BM within the overall organization of the company. We have focused on the innovation phase, which is divided into the subphases of analysis and design. This takes place as a one-day workshop. In preparation, an online conference is held with the company wishing to develop a new BM. The methods used are not particularly complex and can be briefly explained to the participants. The team for the development of the new BM should consist of the management and the specialist employees of the departments addressed. The number of participants should

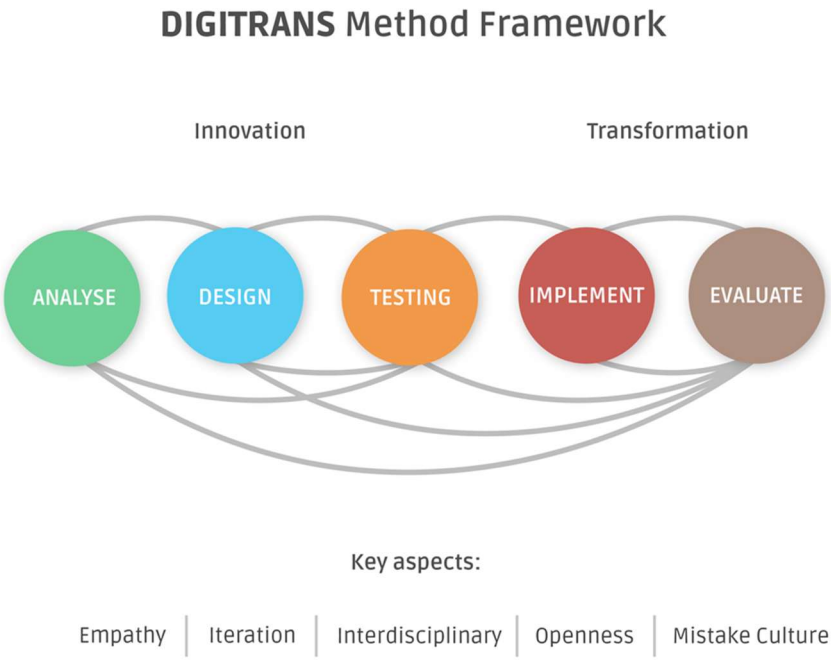


Figure 8: The DIGITRANS Method

not exceed ten. The analysis phase consists of the subphases insight phase and customer and value definition. Here, we analyse the company's environment and strategy to identify market trends, customer needs and competitors. Using a strategic map divided into four dimensions (technological and legal trends, competitors, customer trends and economic environment), we visualize the results of the analysis on a whiteboard. Participants can then contribute their perspectives and discuss each point. The current customers and partners are then identified in a stakeholder map. The customer- and value definition phase is about developing empathy for the customer and understanding their needs to develop a customer-centered value proposition (VP). The Value Proposition Canvas (Osterwalder *et al.*, 2014), which consists of two segments, is used for this purpose: The customer profile contains the customer's tasks, pains and benefits. The value map describes the characteristics of a BM-specific VP with the component's products or services, pain reliever and profit generators. The design phase is divided into idea generation and prototype development. In this phase, a new BM is designed that reflects the identified customer needs. To increase focus during the idea phase, the target group and the most important pains to be addressed in the solution are first summarized in one sentence. Solution ideas are then identified for the defined customer profile, the best ones are selected, and the focus is summarized in a slogan. Prototype development uses SAP Scenes (SAP, 2016) to visualize the customer journey and transfer the results to a BMC to present the conceptual BM.

Detailed Business Model Analysis and Validation

The objective of this phase is to provide a comprehensive understanding of Value Creation, Value Delivery, and Value Capture by refining the nine building blocks of the Business Model Canvas (BMC). While the BMC provides a high-level, strategic overview, e3Value modeling enables a more detailed and practical analysis by mapping value flows, operational processes, and infrastructure requirements. Transforming the BMC into an e3Value model (Network Business Model) enables the integration of concrete production workflows and resource needs, supporting a structured economic assessment including CAPEX/OPEX estimation.

This phase creates a holistic view of the business model by explicitly linking strategic goals with the operational and economic realities of implementation. By analyzing value-exchange relationships and simulating "What-if" scenarios, it is possible to assess not only revenue streams and cost structures but also the scalability and resilience of the business model under different market and operational conditions. This approach provides essential insights for optimizing the business model, identifying risks and opportunities, and ensuring that the proposed solutions are both economically viable and practically feasible.

E3Value

The e3Value method is a modelling approach designed to analyse and visualize value relationships within network business models. It enables the representation of value exchanges among actors who collaboratively create, exchange, and consume value, and serves as a tool to explore innovative business ideas and assess their economic feasibility. Key features of e3Value include visualizing value creation and exchange among all relevant actors (e.g., suppliers, business partners, customers) in a network business model. In addition, e3Value enables the simulation of business model profitability through “what-if” scenarios for different market conditions, while also facilitating analytical assessments of fairness and sustainability based on value distribution and impact indicators. The method makes responsibilities, value propositions, and interactions between actors transparent, supporting systematic analysis and evidence-based refinement of business models. It also enables mapping and refinement of operational workflows and infrastructure requirements based on the nine building blocks of the BMC, resulting in a more detailed and realistic assessment of value creation, delivery, and capture. e3Value is particularly valuable for evaluating the potential impact of new product launches, regulatory changes, or the entry of new market participants. Furthermore, it supports the identification of new service opportunities, areas for collaboration and trust-building, as well as potential inefficiencies and risks within a network business model.

Figure 10 illustrates the key concepts of the e3Value ontology: An actor is an independent economic entity, while a market segment groups similar actors. A value activity is a value-creating operation that brings operational transparency within an actor. Value ports enable the offering or consumption of value objects, and a value interface encapsulates the value exchange, ensuring two-way trading by enabling both the offering and receiving of value objects. Value exchanges connect two value ports to transfer value between actors, where value objects represent exchanged goods, services, or money. Scenarios are calculated by connecting value interfaces for the start (start stimulus) and end (stop stimulus) of a scenario, with AND/OR operators representing logical operations and enabling the representation of multiple business models within a single network business model.

e3Value supports NBM scenario-based business case calculations. By assigning market volume per customer segment, period length, prices, quantities and cost parameters, alternative scenarios can be compared in terms of revenue, cost and profit distribution across the network. This enables systematic what-if analyses (e.g., varying market uptake, price levels, cost structures, or product/service variants) and supports early validation of economic feasibility and sensitivity to key assumptions.

e3Value Metamodel: Structure and Key Variables

A metamodel is an abstract model that defines the structure, elements, relationships, and rules of a modeling language, specifying how valid models can be constructed and interpreted within a given domain. The e3Value metamodel provides a formal and structured framework for representing network business models (NBMs), capturing the essential elements and relationships that underpin value creation, delivery and capture across networks of actors.

At the core of the e3Value metamodel (Figure 9) is the Actor entity, which can represent either an elementary actor (such as a single organization) or a composite actor (such as a consortium). Actors can be grouped into Market Segments sharing common characteristics and a defined market volume. Each actor may have a range of associated financial variables, including profit, revenue, total costs, profit per period, revenue per period, and costs per period. Interaction between actors is facilitated through one or more Value Interfaces, which bundle all value exchanges relevant to a specific interaction scenario. Each value interface contains key variables such as price, number of items, total profit, total costs (fixed and variable), profit per period, and more—enabling detailed quantitative analysis of financial performance and sustainability. Value Offerings represent abstract groupings of products or services that are part of a value exchange. While not directly instantiated in models as concrete entities, they provide a conceptual structure for specifying what is being offered or requested. The value interface encapsulates these exchanges, pairing the delivery of a specific value with the corresponding counter-value (e.g., product for payment). Value Ports act as connection points for value offerings, indicating whether the actor offers or requests a particular value object, and establishing the direction of value flows. Value Objects themselves represent the economic entities exchanged (such as goods, services, money, or data) and are identified by their name attribute, which is referenced in value exchanges. The Value Exchange entity models the bilateral or multilateral transfer of value objects between actors via their respective value ports. The aggregation of multiple value exchanges is captured by Value

Transactions, representing the overall transactional flow within the network. Value Activities denote the specific operations performed by actors to create value, and these can be linked to both elementary and composite actors. To capture the dynamic and logical dependencies in value networks, the metamodel includes Events (such as start, end, AND, and OR events) and Dependency Paths. These elements enable modeling transition conditions, alternative business scenarios, and executing scenario-based simulations. This supports the analysis of alternative business cases, sensitivity analyses, and the evaluation of network effects. Overall, the e3Value metamodel enables detailed, transparent modeling of NBMs, supporting scenario-based analysis and evidence-based business model validation through the integration of structural, financial, and operational variables.

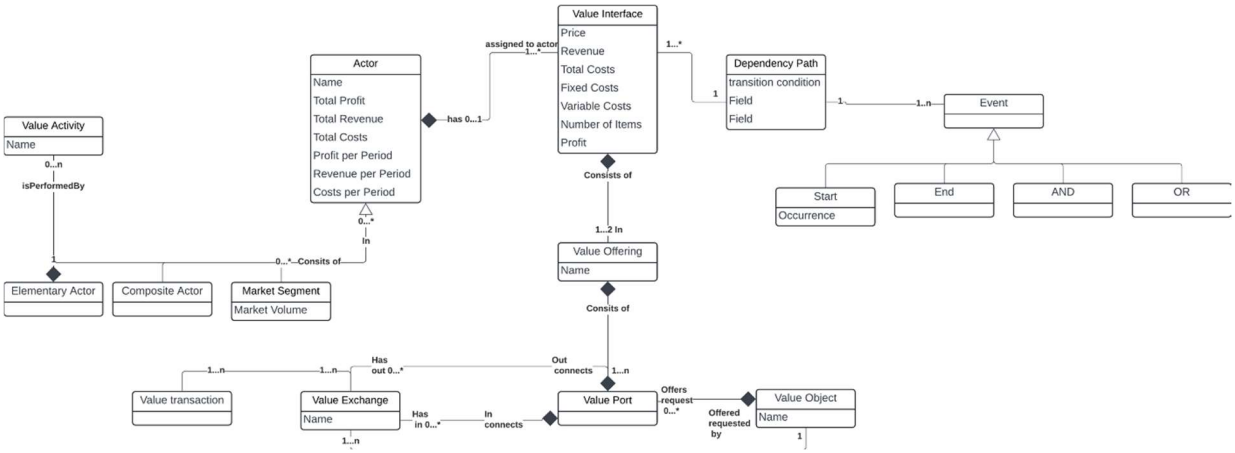


Figure 9: e3Value Metamodel

Mapping BMC to NBM

The objective of mapping the BMC to an NBM (e3Value) is to create a holistic and operationalized view of the business model, capturing both strategic intent and the underlying value exchanges, operational processes and infrastructure requirements. Although the BMC provides a high-level conceptual representation, it often remains ambiguous regarding the specific value exchanges between actors, the distribution of costs and revenues across the network, and the basis for early validation through what-if scenarios (Gordijn, Osterwalder and Pigneur (2005)). The translation into e3Value addresses these limitations by making value flows, financial parameters and actor dependencies explicit. This enables validation of the business model through dynamic simulations, enabling the assessment of economic viability, flexibility, and scalability under different scenarios.

Key steps and objectives

The mapping process requires each of the nine BMC building blocks to be translated into concrete value exchange relations within the e3Value model. This means that abstract BMC elements, such as a key partner or a revenue stream, must be operationalized as specific actors, value objects,

value interfaces, and quantified exchanges with prices and quantities. This translation forces modellers and stakeholders to make implicit assumptions explicit and to resolve ambiguities that the BMC format tolerates, such as unspecified cost allocations, missing actors, or vaguely defined value propositions. The resulting NBM therefore provides a significantly more precise and testable representation of the business model than the BMC alone. Key steps include: (i) refining the business model by using e3Value to link operational processes (e.g., production workflows) with infrastructure requirements (e.g., facilities and equipment), thereby supporting CAPEX/OPEX estimation and ensuring alignment between strategic goals and practical implementation; (ii) analysing value exchanges by mapping the flow of goods, services, and revenue among key actors to identify optimization opportunities and potential bottlenecks; and (iii) simulating economic feasibility through what-if scenarios that assess revenue streams, cost structures, scalability, and risks associated with changing market conditions.

In practice, the BMC-documented business model is transformed into an NBM, which is then modelled and simulated using a tool such as BMConfig (Fauser, Koppenhöfer and Hertweck, 2019). BMConfig was specifically designed to support the modelling and simulation of cross-organisational business models on the ADOxx platform, extending the standard e3Value notation with simulation capabilities for multiple business cases within a single model. The e3Value ontology addresses the problems identified, such as the complexity of the NBM, transparency in value exchange, simulation of profitability and requirements for the visualization of the NBM. This includes the representation of the value exchange relationships between the actors, the modelling of the elements of the NBM, including tangible and intangible value streams, processes, resources and the relationships across multiple actors, the calculation and representation of different BC and the display of multiple BMs and simulation results. In BMConfig, one or more business ideas are realized by a network of actors who jointly create, distribute and consume value within the framework of cross-organizational BMs. The method creates transparency in complex NBM, promotes innovative solutions and allows statements to be made about their profitability. In an initial literature review, we found that the e3V ontology has been used in various scientific articles on modelling value networks in the energy sector (Kartseva, Gordijn and Tan, 2009; Küller, Hertweck and Krcmar, 2015; Koppenhoefer, Fauser and Hertweck, 2018).

Figure 10 and Figure 11 show a mapping between the e3V and BMC. This builds on the work of Gordijn et al. (2005) and Caetano et al. (2017). Gordijn, the developer of the e3Value ontology, and Osterwalder and Pigneur (2002), the authors of the BMO and the BMC, compare the BMO and the e3Value ontology in Gordijn, Osterwalder and Pigneur (2005). Their analysis aimed to improve the integrated representation, design and analysis of business models by identifying similarities, differences and integration possibilities between the two ontologies. This should improve the representation, design and analysis of BM. Caetano et al. (2017) use the approach of Gordijn, Osterwalder and Pigneur (2005) and transfer it to the BMC. The two concepts of the BMC customer segment and key partner can be translated 1:1 into an e3Value model. Either actors or market segments can be used for modelling. The key activities concept is the central activities that a company must carry out to deliver a VP. This can be represented in e3Value by a value activity or by value exchanges with value objects. A key resource is represented as a value object in e3Value that is acquired from a key partner. The VP is the value that a company offers its customers. In e3Value, the VP is represented by a value interface and the corresponding value ports. The

customer relationships and channels are represented by value exchanges and value objects. Revenue streams and cost streams are linked to the value exchanges and value objects and are provided with prices and quantities. It should be noted that the mapping between BMC and e3Value is treated as a structured guideline rather than a formalized transformation rule. The required level of detail and the choice of mapping elements depend on the specific case, the available data and the modelling scope. The mapping between BMC and e3Value is not strictly unidirectional. While the typical workflow translates a BMC into an NBM, insights from e3Value modelling — such as missing actors, unclear value exchanges, or implausible cost structures — frequently lead to revisions of the BMC, resulting in an iterative refinement cycle between both representations.

To create and simulate a network business model in e3Value, the following inputs are required:

- Differentiation of customers into homogeneous segments
- Differentiation of the offered products/services
- Listing of all (relevant) actors: suppliers, service providers, etc.
- Mapping all value exchanges in the value chain (with price, quantity, and specification)
- Period of the simulation, e.g. 5 years
- Market volume

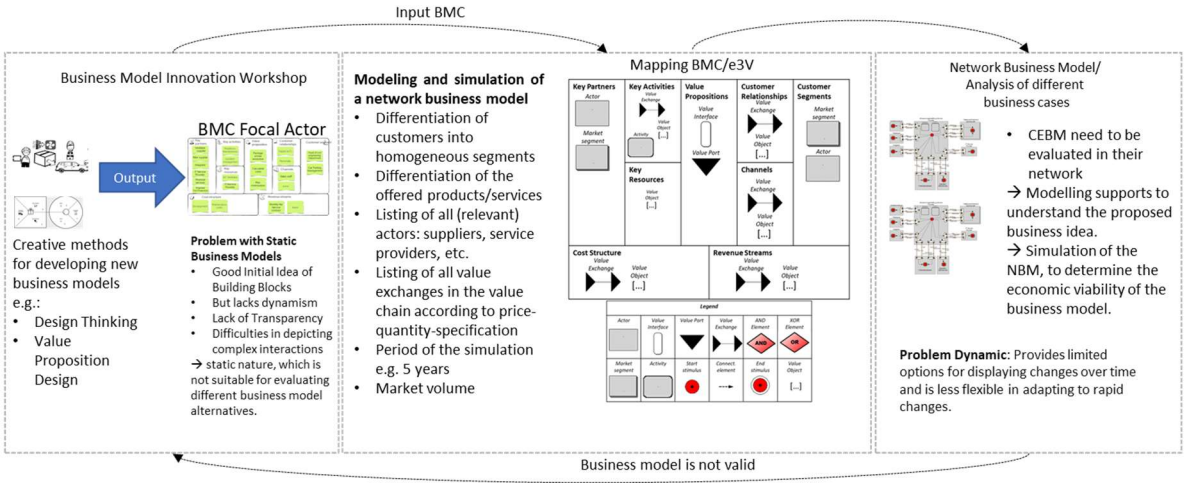


Figure 10: BMC to NBM; Appendix 4 - BMC to NBM.jpg

Preliminary Value Chain and Supply Chain Structuring

In this phase, the selected CEBM is modelled as a process model to develop a detailed understanding of the production, value and supply chains, including key operational and logistical activities, dependencies, required resources and involved actors. Through participatory graphical modelling workshops with relevant stakeholders, either existing processes are analysed or, in the case of a new CEBM, hypothetical processes are conceptualized. The aim is to establish a shared understanding of operational processes, identify potential challenges, and create a solid foundation for analysing costs, processing times, and resource requirements. When validating existing business models, BPMN is used to map actual business processes in detail, revealing how the business model operates in practice. This supports the identification of inefficiencies, risks, and opportunities for optimization. When developing new business models, BPMN serves as a tool to design and test process flows before implementation, enabling feasibility assessment and early identification of potential challenges

BPMN

The **Business Process Model and Notation (BPMN)** is a standardized graphical notation for visualizing business processes, maintained by the Object Management Group (OMG). It is used to document, analyse, and optimize business processes, enabling stakeholders to understand and improve the flow of activities within an organization. The creation of BPMN diagrams is useful for businesses as it facilitates better communication, enhances operational efficiency, identifies process bottlenecks, and supports continuous improvement initiatives by providing a common language for business process management. This visualization also supports identifying areas where waste occurs and opportunities for reusing, refurbishing, remanufacturing, recycling, or repurposing materials. By mapping the entire process, businesses can pinpoint inefficiencies and redesign their processes to enhance sustainability, support circularity, and align with circular-economy principles. A business process model consists of several key elements: (1) Flow Objects are the primary elements and include Events (which start, end, or alter the process flow), Activities (tasks or sub-processes), and Gateways (which control the flow paths by branching, forking, merging, or joining sequences). (2) Connecting Objects, such as Sequence Flows (indicating the order of activities), Message Flows (showing communication between participants), and Associations (linking artefacts to flow objects), connect these elements. (3) Swim lanes help organize the diagram by using Pools to represent major participants like organizations or departments, and Lanes to show roles or responsibilities within those participants. (4) Artefacts like Data Objects (showing data used or produced by activities), Groups (organizing related

activities), and Annotations (providing additional information) enhance the diagram's clarity and detail.

According to information systems literature, a participative modelling approach is recommended, where the close involvement of stakeholders during the modelling activity enables the merging of data collection and evaluation (Ssebuggwawo, Hoppenbrouwers and Proper, 2009; Prilla *et al.*, 2011; Riemer, Holler and Indulska, 2011). This methodology increases the quality and accuracy of the developed model by ensuring that all relevant actors contribute their perspectives and misunderstandings can be clarified directly during the modelling process. To accurately capture the production processes and the associated supply and value chains, modelling workshops are conducted. In these workshops, relevant stakeholders are actively involved in the modelling process by having their workflows, requirements, and perspectives modelled using BPMN (Business Process Model and Notation). This occurs alongside expert interviews, with process details transferred into the model in real time. BPMN models can represent both existing processes and hypothetical processes for novel CEBM concepts. In both cases, they provide an operational basis for refining the business model beyond a purely strategic description. BPMN models also support time and cost analyses of business processes. By mapping each activity, decision point, and interaction, organizations can estimate the duration and cost associated with individual process steps and the overall workflow. This enables identification of bottlenecks, resource-intensive operations, and cost drivers, supporting data-driven decisions on process optimization. For business models still in their design phase, the same logic applies on a projected basis, allowing early assessment of operational viability.

In the ADOxx-based implementation, time and cost parameters can be assigned directly to individual activities. Additionally, an organisational model can be linked to the process model, allowing hourly rates to be specified per performer role. When a role is assigned to a task, the associated labour cost is calculated proportionally based on the estimated task duration. This enables not only activity-level cost estimation but also capacity analysis based on working hours and the allocation of costs per person or role across the process.

Following the BMC analysis, the next step is to map its elements to the BPMN process model. This mapping ensures that the strategic insights from the BMC are translated into operational workflows.

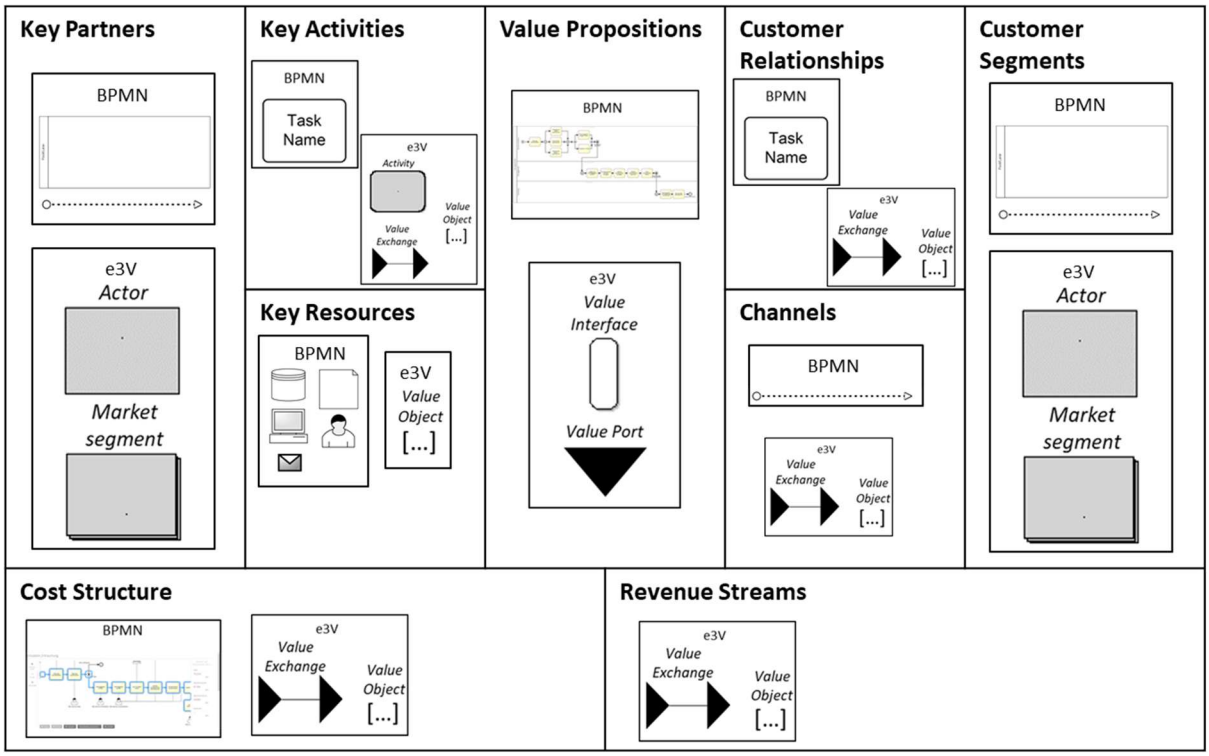


Figure 11: BPMN to BMC, BMC to e3Value; Appendix 5 - BPMN to BMC, BMC to e3Value.jpg

Mapping BMC and BPMN

The mapping between the BMC and BPMN bridges the gap between strategic business logic and operational process design. The mapping between BMC and BPMN is illustrated in Figure 11. Pools or Lanes in BPMN represent different actors involved in a business process, such as customer segments or key partners from the BMC. The value proposition, which defines the products and services that create value for specific customer segments, can be mapped to either the entire BPMN process or to specific activities or tasks delivering this value. Channels describing how a company communicates with and reaches its customer segments correspond to message flows in BPMN, illustrating how information, products, or services are exchanged between different pools or lanes. Customer relationships, representing the types of relationships a company establishes with its customer segments, can be depicted in BPMN through interaction events, gateways, and tasks that model various customer interactions and decision points throughout the process. Key resources in the BMC, representing the assets required for value delivery, can be mapped to pools, lanes, or artefacts in BPMN. Key activities are detailed as tasks within the process model. Cost structures, which outline all expenses associated with operating a business model, can be annotated in the process model or represented as data objects linked to specific tasks or activities, facilitating detailed process cost management and analysis. Revenue streams, however, cannot be directly represented in BPMN, as the notation focuses on the flow of activities rather than financial transactions. This mapping approach enables systematic translation of business model elements into operational workflows, ensuring that strategic insights from the BMC are operationalized and aligned with process execution.

Mapping BPMN to NBM

(Torres *et al.*, 2023) investigates the question of how to derive a BPMN model from an e3Value model and vice versa, highlighting the complementarity of both perspectives. BPMN focuses on the *how* of process execution, detailing tasks and activities within an organization, while e3Value focuses on the *what* and *why* of economic reciprocity and value exchange between actors. Integrating both supports analysis of how operational configurations affect value generation and distribution. By combining BPMN and e3Value, stakeholders can perform detailed analyses at both the process and value levels. This integration enables the identification of process inefficiencies and their economic impacts, providing a holistic approach to process improvement and value optimization. The combination of BPMN's process modelling and e3Value's value modelling supports better decision-making by providing insights into how process changes affect value creation and distribution. This dual perspective helps in evaluating the financial viability of different business scenarios and process adjustments. (Torres *et al.*, 2023) have developed guidelines for deriving e3Value models from BPMN models. These guidelines help translate operational processes into value exchanges, ensuring that the economic implications of process workflows are made explicit. This structured approach facilitates integration and enhances the usability of both models.

The e3Value ontology concepts used in this mapping are described in the "Detailed Business Model Analysis and Validation" section. The mapping between e3Value and BPMN, shown in Figure 11, aligns BPMN start and end events with e3Value consumer needs and boundary elements. BPMN pools represent participants in a process, corresponding to e3Value actors or market segments. BPMN lanes organize activities and map to e3Value value activities. BPMN activities and sub-processes correspond to e3Value value activities, while BPMN message flows align with e3Value value transfers, showing exchanges between actors. BPMN sequence flows indicate the order of activities and align with e3Value value transfers, leading to value interfaces and offerings, and mapping to e3Value dependency paths. BPMN AND gateways align with e3Value AND dependencies, and BPMN XOR gateways correspond to e3Value OR dependencies. BPMN OR gateways map to e3Value AND/OR dependencies, and BPMN loops correspond to e3Value cardinality dependencies. This mapping leverages BPMN's process-oriented approach for operational clarity, while e3Value provides a comprehensive view of value exchanges. This integration enables thorough analysis and simulation of business processes, aiding in the development of robust and sustainable business models. This approach follows the guidelines by da Silva Torres et al. (Torres *et al.*, 2023), emphasizing the complementary use of BPMN and e3Value. In our method, this mapping is treated as a structured guideline rather than a finalized standard. The relationship between e3Value and BPMN elements is rarely a strict one-to-one correspondence; the mapping serves to ensure consistency between business model logic and process design rather than to establish formal equivalences. The required level of granularity and the choice of mapping elements depend on case characteristics and modelling scope. Further refinement and validation are necessary to ensure that it consistently captures the relevant aspects of both process behaviour and value exchange structures across cases.

Dynamic Impact Analysis and Sustainability Modeling

This phase leverages System Dynamics to analyse and simulate the long-term ecological, economic and social impacts of business model prototypes developed in previous phases. Building on structural models such as BMC, e3Value, and BPMN, key elements and parameters are systematically transferred and integrated into the System Dynamics model. This integrated approach enables a comprehensive, quantitative assessment of business model innovations and their system-wide effects, revealing feedback loops, delays, and nonlinearities. It supports evidence-based decision-making and the development of robust, sustainable circular business models within the DECIDE project.

Introduction to System Dynamics

System Dynamics is a methodological approach for analysing and simulating complex, dynamic systems. Developed by Jay W. Forrester (Forrester, 1958)in the 1950s, the method aims to understand, visualize, and evaluate the long-term consequences of decisions by analysing the interactions and feedback within a system. Through simulation-based experimentation, the goal is to derive strategic actions and interventions based on model results, allowing decision-makers to influence a system in a desired direction (Forrester, 1958). System Dynamics is a domain-independent approach and can be applied to a wide range of problem contexts (Sterman, 2000). It is particularly useful for investigating complex relationships in economic, social, and environmental systems and is widely used in business management, resource planning, innovation, and sustainability research.

System Dynamics is closely associated with the Systems Thinking perspective and serves as a central instrument within its methodological toolkit. It uses simple graphical notations to model system structures and their behaviour over time. A fundamental principle of System Dynamics is that system behaviour does not emerge randomly but is largely determined by its underlying structure (Meadows, 1980; Sterman, 2000). This structure includes feedback loops, the arrangement of stocks and flows and time delays. To understand and influence a system's behaviour over time, these structural elements must be systematically analysed. On this basis, effective strategies and management interventions can be derived (Sterman, 2000). The System Dynamics approach is fundamentally based on three core concepts: feedback loops, stocks and flows (Sterman, 2000).

A system is defined as a group of interconnected elements. For the purpose of analysing system behaviour over time, it is useful to distinguish between open and closed feedback systems. We draw here on an example inspired by the company transentis website (Grasl, no date): An open system responds to input signals without its output affecting those inputs. A typical example is a light sensor that automatically opens a window blind at sunrise; the sunlight acts as input, but the opening of the blind does not influence the sunlight. A feedback system, by contrast, continuously monitors sunlight and dynamically adjusts the blind's position to optimize shading. While open systems may exhibit high detail complexity, even simple feedback systems often display significant dynamic complexity. System Dynamics is particularly well-suited to analysing such feedback-driven systems and supports the development of robust management and design strategies.

Complex systems consist of numerous interrelated elements that influence one another(Sterman, 2000). In System Dynamics, this mutual influence is referred to as feedback (Sterman, 2000). Feedback processes often lead to nonlinear and difficult-to-predict behaviour (Meadows, 1980; Sterman, 2000). Two main types of feedback loops can be distinguished (Sterman, 2000).:

- Reinforcing feedback loops (positive feedback). One example is the viral growth of an app: more users lead to greater visibility, which in turn attracts more users.
- Balancing feedback loops (negative feedback), by contrast, are stabilizing mechanisms that counteract changes. For instance, if a company's market share grows too rapidly, regulatory interventions may limit further expansion.

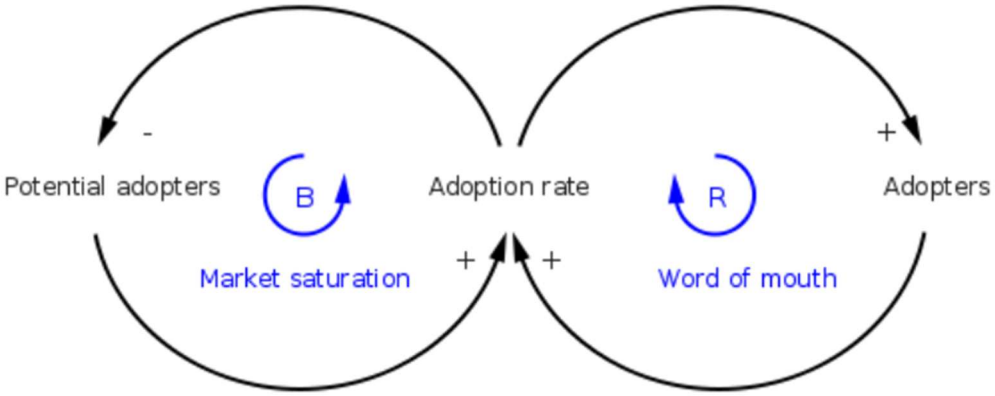


Figure 12: Reinforcing feedback loops and Balancing loop (Sterman, 2000)

To better understand such feedback structures, qualitative Causal Loop Diagrams (CLDs) are used. These consist of variables connected by directed arrows that indicate causal relationships, marked with positive (+) or negative (–) polarity (Sterman, 2000). Figure 12 illustrates an example of a reinforcing and a balancing loop. A practical example of a feedback loop in a business context is: the cost of consumables depends on production volume. These costs influence the product price, which, in turn, affects customer demand and, consequently, sales volume. If sales increase, the demand for consumables rises again, forming a reinforcing feedback loop. While CLDs are useful for visualizing causal relationships, they are not suitable for simulation, as they do not include quantitative information or time-based behaviour (Sterman, 2000). For that purpose, the structure

described in a CLD must be translated into a quantitative model using Stock and Flow Diagrams (SFDs). These include stocks, flows, and auxiliary variables, which are also referred to as converters.

Core Components of Stock and Flow Diagrams

Stocks represent accumulations or storage elements within a system. They collect resources over time, such as customers, inventory, energy, or capital. A stock's value at any point in time depends on the net effect of inflows and outflows up to that point (Sterman, 2000). Stocks are expressed as absolute quantities (e.g., number of customers, liters of whey, or euros in an account).

Flows describe the rate at which a stock changes. They either add to a stock (inflows) or reduce it (outflows) and are measured in units per period, such as customers per month, euros per day, or products per hour. For example, in a dairy processing plant, the ultrafiltration rate may indicate how many liters of whey are processed per hour. If this flow is too low, whey accumulates; if it exceeds downstream capacity, it can cause bottlenecks. Flows are therefore critical in determining a system's dynamics and efficiency (Sterman, 2000).

Variables | Converters | Auxiliary variables supplement the model with parameters, calculations or external inputs. They do not accumulate or transport units; rather, they influence how stocks and flows behave. Examples include:

- Computational rules (e.g., price = unit cost + margin)
- External factors (e.g., market price, temperature)
- Constants or coefficients (e.g., energy consumption per ton)

Unlike stocks or flows, variables serve to define model logic, unit conversions or control mechanisms. For example, the transport cost per kilometre influences where raw materials are processed, even though it does not directly affect production volume.

Connectors are directed arrows used in SFDs to show informational influence between elements, typically from a variable to a flow or from one variable to another. They do not transmit quantities but merely provide input for calculations. Connectors must never point directly into a stock, as stocks are only modified via flows.

Sources and Sinks represent flows that enter or leave the system boundary. A **source** supplies a flow to the system without being modelled itself (e.g., external demand). A **sink** represents an outflow that exits the model, such as waste or emissions. In diagrams, sources and sinks are commonly depicted as small cloud symbols.

The decision whether a variable is placed inside or outside the system boundary depends on the model scope. For example, if electricity prices are treated as external factors, they are modelled as exogenous inputs. If the model includes a combined heat and power unit that generates electricity when prices rise, thus influencing internal cost structures, the system boundary would be extended to include this mechanism and the electricity price becomes partially endogenous. In summary, System Dynamics enables the construction of simulation-based prototypes to analyze structural drivers of behavior over time and support strategic decision-making through dynamic experimentation. Figure 13 shows the graphical elements of stock-and-flow diagrams.

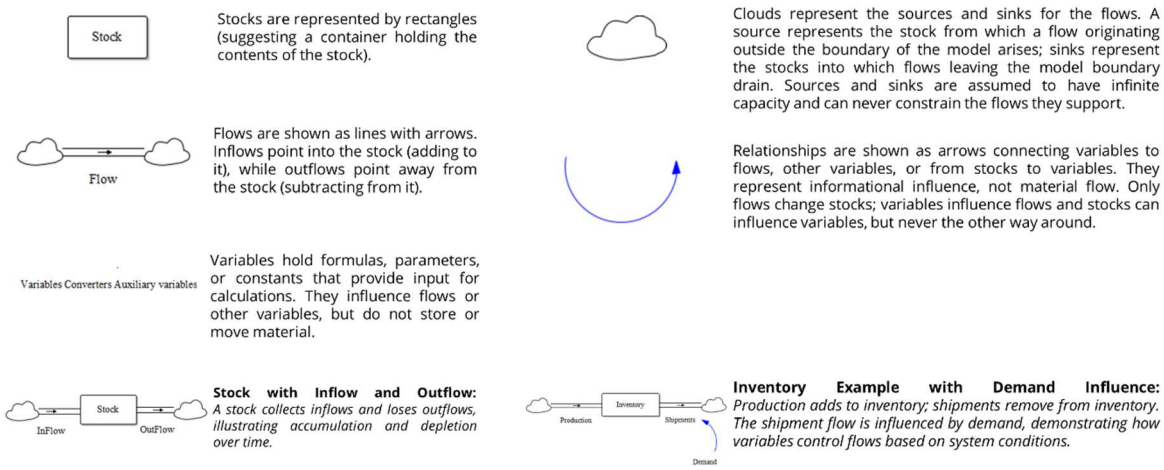


Figure 13: Stock and Flow Graphical Overview (based on Sterman, 2000)

System-Dynamics-Metamodel

A metamodel can be understood as a model of models, more precisely, as a model that defines the language for expressing a model (Object Management Group (OMG), 2019). It determines the concepts, rules, and relationships that may appear in valid models of a specific modelling language. In the Meta Object Facility (MOF) architecture, a metamodel operates at the M2 level and is itself defined by a meta-metamodel at the M3 level, following a recursive four-layer hierarchy.

Since a consistent conceptual structure is important for collaborative model development, selected metamodeling approaches were reviewed to identify a suitable reference structure for the present work. To identify relevant approaches to metamodeling in System Dynamics, we conducted a literature search using Google Scholar. This platform offers broad access to a wide range of scientific databases, enabling comprehensive coverage of relevant academic publications. We deliberately refrained from querying additional databases, as our goal was not an exhaustive bibliographic analysis but rather an overview of the field. We used the search term “System Dynamics Metamodel”, which returned 53 results. From these, we selected two key contributions that propose and formally describe concrete metamodels for System Dynamics.

The first approach, developed by (Sunkle *et al.*, 2014), presents a conceptual entity-relationship-based metamodel for System Dynamics. It defines core modelling constructs such as Stock, Flow, Converter, Cloud, InFlows, OutFlows, Module, along with a set of structural relationships (e.g., hasSource, hasTarget, Link types). The metamodel is designed to support structured what-if analyses in enterprise scenarios by providing a clearly defined and semantically rich modelling framework. The second approach, presented by (Burmester, Goeken and Burmester Matthias Goeken, 2008), introduces a graph-based metamodel grounded in the abstract syntax of a level/rate modelling language. It defines modelling constructs such as Level, Rate, Flow, Auxiliary, Constant, Source, and Sink, and connects them via named semantic relationships such as Precedes and Succeeds. The aim of their paper is to integrate Online Analytical Processing (OLAP) and SD on a linguistic level. Therefore, linguistic metamodels of the corresponding conceptual modelling languages are derived and related to each other, creating a translational relationship between the languages. These two approaches illustrate distinct but complementary strategies for formalizing System Dynamics: one with a semantic and behavioural focus, and the other with a structural and relational emphasis. Together, they demonstrate the versatility and applicability of metamodeling techniques for enhancing consistency, reusability and clarity in System Dynamics modelling.

In addition to the academic literature, we conducted an open web search on Google, which led us to identify a practitioner-oriented metamodel published by the company transentis (Grasel, no date). This metamodel is aimed at supporting SD modelling tasks and will serve as the primary reference structure for our own modelling approach. It is described in more detail in the following section. We adopt the transentis metamodel as it provides a minimalist yet functionally sufficient representation of stock-and-flow structures. This choice is not intended to claim theoretical superiority over alternative metamodels, but rather reflects its suitability for collaborative, comprehensible and sufficiently structured modelling within the DECIDE project. Its concise formulation of core concepts and their interrelationships enables clear and efficient knowledge transfer among project partners. While the other metamodels (Burmester, Goeken and Burmester

Matthias Goeken, 2008; Sunkle *et al.*, 2014) incorporate comparable elements, the model by Sunkle et al. (2014) offers a high level of detail. However, given the increased complexity, it does not offer additional analytical value for our application context. Accordingly, the transentis model is considered more appropriate for our purpose: the conceptual structuring and communication of system dynamics.

The standard structure of system dynamics models was first formalised in Jay Forrester's work Principles of Systems (1968). Most system dynamics modelling tools implement this standard to a great extent, although they do have their tool-specific variations. To address the need for uniform representation across diverse platforms, the XMILE format was developed as an XML-based standard for describing system dynamics models. The metamodel developed by transentis (Grasel, no date) offers a clear and compact representation of the core elements of System Dynamics, capturing their structure and interrelations in the form of a UML class diagram Figure 14. This model provides valuable insights into the general principles underlying System Dynamics and can be largely applied in tools such as Vensim or Stella. At the center of the metamodel are Stocks, which represent the system state at any given point in time. Stocks are accumulations and can only be changed through Flows; this unidirectional influence is visualized via the relationship's inflow and outflow. These relationships ensure that any modification to a stock must be mediated by a corresponding rate of change. Flows are specialized entities that represent rates, i.e., the quantity of change per unit of time. Flows connect to stocks as either sources or sinks and describe how the system's state evolves over time. Technically, flows are a subtype of Converters, as they also transform inputs into outputs, but with the additional constraint that they directly affect stocks. Converters represent all other types of functional transformations within the model. They serve to decompose complex relationships into interpretable elements. Unlike flows, converters cannot directly influence stocks; instead, they depend on stocks and can influence other converters or flows. This indirect influence captures feedback structures and system logic. A subset of converters includes Constants, which represent time-independent values or a constant function. An Initial Value, which defines the starting conditions of stocks. The Function class formalizes how converter outputs are calculated, often through mathematical expressions involving time-dependent or

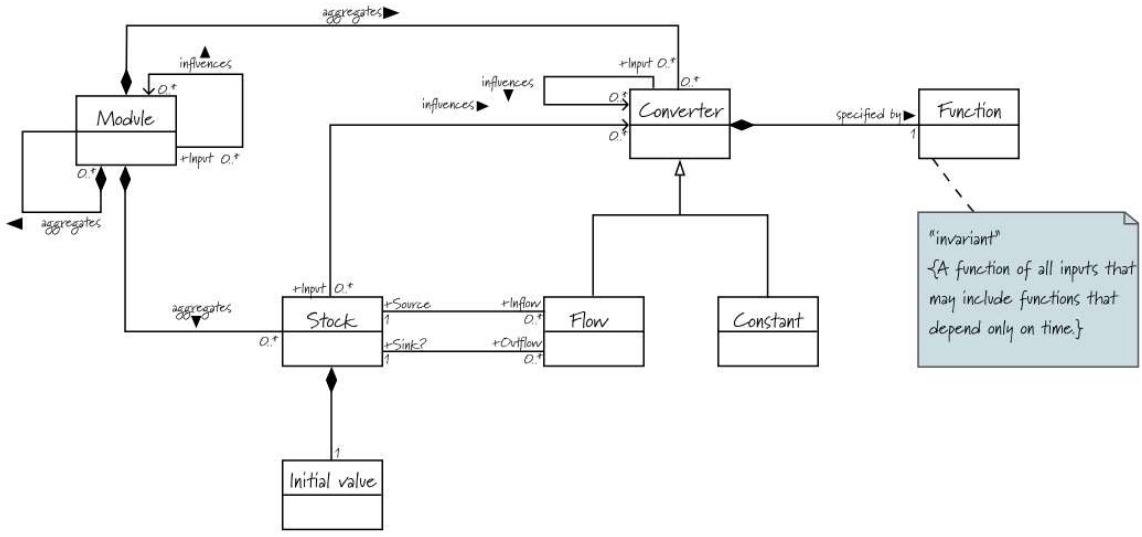


Figure 14: System Dynamics Metamodel (Grasel, no date)

static parameters. Modules are utilised for the aggregation of other model elements, thereby facilitating the establishment of levels of abstraction.

System Dynamics Simulation

System dynamics models provide a formal structure for simulating the behavior of complex systems over time. While causal loop diagrams (CLDs) depict qualitative feedback structures, they must be transformed into stock-and-flow diagrams (SFDs) to enable computer-based simulation. These diagrams form the foundation of a mathematical model composed of stocks, flows, and functional relationships, which can be implemented in simulation software such as Vensim or Stella to simulate system behavior. In these mathematical models, stocks and flows are represented by integral equations. Stocks accumulate over time and can be altered only by inflows and outflows, while converters are defined by functions of their inputs and/or time. Since such equations are generally not analytically solvable, the system's behavior is approximated using numerical integration methods. One widely used technique is Euler integration, named after the Swiss mathematician Leonhard Euler (1707–1783). The simulation time horizon is divided into discrete time steps if rates of change remain constant within each interval. The smaller the time step, the more precise the numerical approximation. In business applications, time steps typically represent days or weeks, which aligns well with the update cycles of common enterprise systems. It is important to emphasize that the goal of simulation is not mathematical precision, but rather the generation of plausible and insightful projections of future behavior based on structural assumptions.

The simulation process takes place in so-called "simulated time." It begins at time $t = 0$ and progresses in intervals defined by the parameter *dt* over a predefined time horizon (e.g., five years). In each step, the values of stocks are updated based on their inflows and outflows, while converters compute new output values according to their mathematical definitions. Initial values must be provided for all stocks and constants, and each converter requires a valid mathematical expression to determine its value. System dynamics simulations are deterministic: the future state of the system is entirely determined by the model structure, parameters, and initial values. This distinguishes system dynamics from stochastic or agent-based approaches that rely on random processes. Deterministic simulations are particularly well-suited for strategic decision-making, as they aim to systematically explore the consequences of structural interventions rather than represent variability or randomness (Dangerfield, 2014; Kunc, Morecroft and Brailsford, 2018).

In the context of business model innovation, system dynamics offers several advantages. First, it allows for abstract and structured representations of complex systems and supports stakeholders in analyzing the long-term consequences of strategic decisions (Sterman, 2000; Davis, Eisenhardt and Bingham, 2007). A business model can be viewed as such a complex system (Ksouri-Gerwien, 2024) . Second, it enables iterative learning through virtual experimentation to evaluate decisions in advance (Sterman, 2000), a practice that aligns well with experimental approaches in innovation management (Ksouri-Gerwien, 2024). Third, system dynamics is well established in strategic management research and has proven effective in modeling the interactions between corporate strategy and operational behavior (Cosenz and Noto, 2018). In this context, business models are also understood as operationalizations of corporate strategy.

In summary, system dynamics simulations transform structural models into dynamic experiments that reveal the temporal implications of managerial decisions. They offer a robust framework for evaluating alternative scenarios, validating assumptions, and supporting strategic interventions in complex and uncertain environments.

System Dynamics Modelling Method

In the DECIDE project, this modelling logic provides the general orientation for developing System Dynamics models based on the insights generated in the preceding business model, value network, and process modelling phases.

The development of valid and useful System Dynamics models requires a structured, iterative, and reflective modelling process. The goal is to develop a business model prototype calibrated based on available data. This prototype is then used to explore potential future scenarios and deepen the understanding of the business in question. The literature provides several established modelling procedures for System Dynamics. (Martinez-Moyano and Richardson, 2013) synthesized a six-phase modelling process, grounded in both empirical practice and existing methodological approaches, which has become recognized as a "best practice" in the field. This framework has also been adopted and enriched by (Ksouri-Gerwien, 2024), who incorporates additional sources such as (Vennix, 1999; Sterman, 2000; Wilkerson *et al.*, 2020). In this work, we follow the modified framework proposed by (Ksouri-Gerwien, 2024). Although the modelling process is often depicted as linear in the literature, it is inherently iterative in practice, with feedback loops between phases. The overall process is structured into six sequential phases: (i) Problem identification and definition, (ii) System conceptualization, (iii) Model formulation, (iv) Model testing and evaluation, (v) Model use, implementation, and dissemination, and (vi) Design of learning strategy/infrastructure. In the following section, we describe these phases in more detail:

Problem Identification and Definition

The objective of the first phase is to understand the problem at hand and to define the modelling objective (Sterman, 2000; Martinez-Moyano and Richardson, 2013). System Dynamics follows a problem-driven approach, "always model a problem. Never model a system" (Sterman, 2000). This involves collecting relevant data through interviews, observations, or documentation. A central task is the definition of model boundaries: "The art of model building is knowing what to cut out, and the purpose of the model acts as the logical knife" (Sterman, 2000). The creation of reference modes (i.e., "graphs over time") is particularly useful to represent past and potential future developments of key variables. These reference modes form the foundation for the system description and serve as a benchmark for model validation (Sterman, 2000).

System Conceptualization

In this phase, an initial dynamic hypothesis is developed, a hypothesis regarding the underlying causes of the observed problem behaviour (Sterman, 2000). The relevant variables and their causal relationships are identified and typically represented using Causal Loop Diagrams (CLDs)

(Martinez-Moyano and Richardson, 2013). The hypothesis is grounded in the mental models of stakeholders: "mental models represent the relationships and assumptions about a system held in a person's mind" (Ford, 2019). These implicit models are made explicit through interviews, structured questioning techniques (Sterman, 2000), or Group Model Building (GMB) workshops (Vennix, 1999; Wilkerson *et al.*, 2020). GMB allows multiple participants to jointly develop a dynamic hypothesis through guided discussion (Vennix, 1999; Ford, 2019). Modelling is typically conducted using CLDs. Modelling can be performed in a physical or digital context, utilising collaboration tools such as MIRO[1] (Wilkerson *et al.*, 2020).

Model Formulation

The qualitative system understanding is translated into a quantitative Stock-and-Flow Diagram (SFD) to enable simulation (Martinez-Moyano and Richardson, 2013). Relationships between variables are formalized into mathematical equations. A widely accepted principle in this phase is: "start small and simple; build toward complexity and completeness" (Martinez-Moyano and Richardson, 2013). Unit consistency and equation plausibility are critical throughout the model. The model should already be iteratively validated with stakeholders during this phase.

Model Testing and Evaluation

This phase focuses on evaluating the model's internal consistency and external validity. It includes both formal structure checks (e.g., units, stability of equations) and behavioural validation against empirical data or known system behaviour. Martinez-Moyano and Richardson (2013) outline various testing approaches, including behaviour tests, structure tests, and extreme condition tests. Model validation should be embedded continuously within the formulation process, "simulate early and often" (Martinez-Moyano and Richardson, 2013).

Model Use, Implementation and Dissemination

Once validated, the model is used to support planning and decision-making. Its applications range from simple parameter adjustments to structural scenario analyses (Sterman, 2000). Simulations are conducted for different environmental scenarios (e.g., best case, moderate case, worst case), using what-if analyses or sensitivity analyses (Martinez-Moyano and Richardson, 2013). Effective communication of results, through storytelling and visualizations, is key to ensuring insights are actionable and accessible to target audiences.

Design of Learning Strategy / Infrastructure

This final phase was deliberately added by Martinez-Moyano & Richardson (2013) to emphasize the importance of institutional learning. The goal is to anchor insights in participants' mental models, e.g., through interactive visualizations or serious games. Ksouri-Gerwien (2024) also

[1] https://miro.com/

highlights the strategic relevance of this phase for embedding long-term learning and systemic understanding within organizations.

Business Model Simulation with System Dynamics

Business models can be understood as complex systems that represent how an organization functions. System Dynamics (SD) provides a suitable approach to structurally model such systems and to analyse them through simulation. Several studies have implemented business models as SFDs in SD modelling tools (Abdelkafi and Täuscher, 2016; Cosenz and Noto, 2018; Ksouri-Gerwien, 2024). Research shows that SD is particularly well-suited for the dynamic modelling and subsequent validation of business models. Simulation experiments enable decision support by accounting for dynamic feedback effects. In many studies, the Business Model Canvas (BMC) serves as the structural foundation (Stadtlaender, Schoormann and Knackstedt, 2021). The nine building blocks of the BMC support the systematic organization of model elements such as stocks, flows, and variables, and support capturing the overall logic of a business model.

An advanced integration of BMC and SD was introduced by (Cosenz and Noto, 2018) with the Dynamic Business Model Canvas (DBMC). In this model, the business model is represented as an SFD across seven domains: (1) key partners, (2) strategic resources, (3) value proposition drivers, (4) key processes, (5) customer segments, (6) cost structure, and (7) revenue streams. (Cosenz and Bivona, 2021) use their approach to analyse the business model of an e-commerce platform (Giglio) and, for example, simulate the effects of different marketing strategies (e.g., customer acquisition, customer retention, email marketing) on business success. (Ksouri-Gerwien, 2024) points out that most existing works focus almost exclusively on financial parameters. Only a few contributions, such as (Cosenz, Rodrigues and Rosati, 2020) and (Abdelkafi and Täuscher, 2016), also integrate social and ecological dimensions, such as CO_2 emissions or charitable donations, into their modelling and evaluation. Moreover, (Ksouri-Gerwien, 2024) emphasizes that the field of quantitative business model simulation using System Dynamics is still in an early developmental phase. Many studies are highly application-oriented and exploratory and are often based on single case studies, which so far limit the generalizability and transferability of the results.

Within the DECIDE project, business models are not only simulated but also analysed with regard to their transferability across regions, sectors, and organizations. The approach of (Cosenz, Rodrigues and Rosati, 2020) serves as the methodological foundation for several key reasons:

- **Structuring framework for modelling:** The Dynamic Business Model Canvas provides a clear framework for modelling. This is particularly important in the DECIDE project, as numerous project partners are involved and different people contribute to model development. To ensure models are as homogeneous as possible, model variation is deliberately limited by using a standardized structural framework, in this case, the BMC. This not only enhances transparency but also facilitates comparison and benchmarking between different business models, regions, and sectors.

- **Consideration of environmental, social, and economic outcomes:** (Cosenz, Rodrigues and Rosati, 2020) extend their approach to explicitly include environmental, social, and economic outcomes. These three levels of impact are especially relevant from the perspective of a regional catalyst, as they go beyond purely economic benefits. In this work, the outcome dimensions are linked to the needs of companies and regional catalysts, particularly those parameters relevant for the transferability of circular economy business models.
- **Enabling knowledge exchange, capacity building, and benchmarking**: The standardized modelling framework supports structured knowledge exchange and facilitates the collaborative development, documentation, and reuse of models within the project consortium. At the same time, good practices can be identified and transferred to new contexts.
- **Integration dashboard (D1.2.5) and data platform (1.2.6):** A consistent framework is essential for integrating the modelling results into the central DECIDE data platform. Only by ensuring comparability and a clear model structure is it possible to make results interoperable and specifically usable for data analyses, dashboards, and further evaluations.

Despite these methodological advances, the transferability of successful CEBMs across regions, sectors, and organizations remains a significant challenge. Numerous factors contribute to this, including institutional, cultural, technological, and infrastructural differences. In addition, regional variations in resource availability, legal frameworks, network infrastructures, market conditions, and actor and cooperation structures must be considered. User acceptance, data availability, and the specific economic and social contexts also play an important role. Particularly for transnational and intersectoral applications, structured modelling and simulation approaches are needed that address both system dynamics and context dependency. Therefore, the DECIDE project not only pursues the development and simulation of circular business models but explicitly aims to enable their systematic transferability, scalability, and integration into various contexts.

Figure 15 illustrates the Dynamic Business Modeling for Sustainability Canvas (Cosenz, Rodrigues, and Rosati, 2020). This framework extends the classic Business Model Canvas by adapting its structure to better support System Dynamics modeling and simulation. Specifically, the BMC is reorganized to reflect key business model elements—including (1) key partners, (2) strategic resources, (3) value proposition drivers, (4) key processes, (5) customer segments, (6) cost structure, and (7) revenue streams—within a unified System Dynamics structure. The Dynamic Canvas explicitly maps the causal relationships and feedback loops between these components, enabling a holistic simulation of how business strategies, operational decisions, and external factors influence economic, social, and environmental outcomes over time.

Within the DECIDE project, this approach provides the methodological foundation for modeling and analyzing circular business models. Building on the insights gained from previously developed BMC, e3Value and BPMN models, we systematically translate relevant business model elements into System Dynamics, such as stocks, flows and variables. SD modelling starts with a simplified prototype and is refined iteratively by transferring key structures and parameters from earlier models, such as demand and customer base from the BMC, capacity constraints and cost/price logic from e3Value, and resource and process parameters from BPMN. These are parameterized

with available data and used to explore alternative scenarios assessing long-term behaviour and strategy implications. This integration supports simulation-based evaluation of various business model scenarios, allowing us to assess not only economic viability but also environmental and social impacts. The Dynamic Business Modeling Canvas thus facilitates both the systematic design and comparative analysis of sustainable business models, supporting evidence-based decision-making and knowledge transfer across regions and sectors.

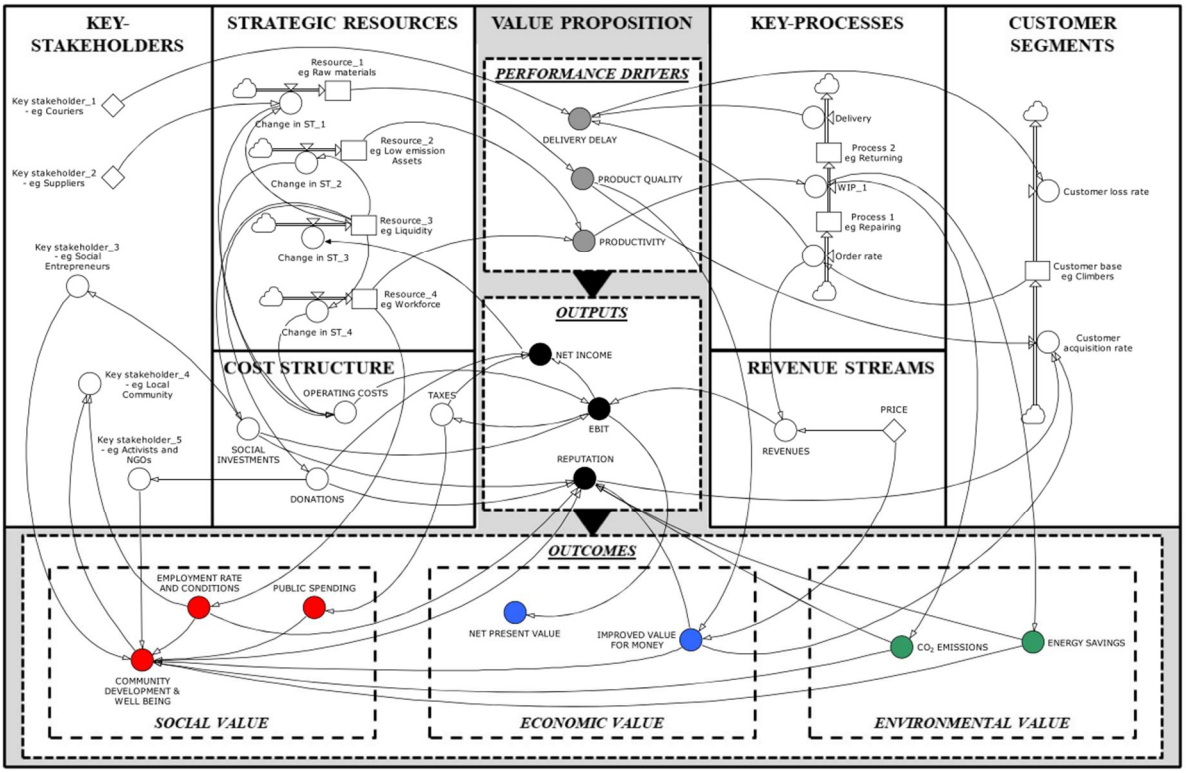


Figure 15: Dynamic Business Modelling for Sustainability Canvas

Comparison and implications

The BMC enables the representation of a business model at a higher level of abstraction and from a more strategic perspective (Caetano *et al.*, 2017). In contrast, e3Value enables modelling that is closer to the concrete configuration and economic operationalization of the business model. Transforming a BMC into an e3Value model requires additional information about the business model. It enables a more detailed analysis of the business model network and a quantitative assessment of its economic viability, including CAPEX/OPEX estimation. e3Value therefore focuses

on the value network by analysing actor constellations, value exchanges, business case calculations and the infrastructure requirements underlying the business model. By contrast, Business Process Model and Notation (BPMN) is better suited to a fine-grained representation of operational processes at the level of the focal organization. BPMN models are sequential and particularly useful for representing activities, responsibilities, resource flows, process times, and operational costs. However, due to its sequential logic, BPMN is less suited to combining operational processes and infrastructure design within one model, since investment, financing, or approval-related aspects often require additional events and modelling constructs that may reduce readability and increase complexity. System Dynamics complements these mainly static and structurally oriented representations by introducing a dynamic, simulation-based perspective. It captures feedback loops, time delays, accumulations, and non-linear relationships that cannot be adequately represented in BMC, e3Value, or BPMN. In doing so, it enables the exploration of long-term economic, social, and environmental developments under varying assumptions and scenarios.

The need for the combined application of business model tools and methods has been emphasized in prior research (D'Souza et al., 2018; Fruhwirth, Ropposch and Schindler, 2020). Fruhwirth et al. (2020) identifies three key requirements: (i) tools that support convergent thinking and decision-making, (ii) an overarching perspective that links specialized methods into a coherent toolbox, and (iii) software support that enables consistent representations across phases. Researchers and practitioners have criticized the static nature of many business model artefacts, as this constrains the systematic comparison of alternatives and the analysis of trade-offs between business model variants (Athanasopoulou and De Reuver, 2020). Static models do not capture temporal dynamics, feedback effects, or delays, which limits their usefulness for assessing the implications of business model variations under changing conditions. While the BMC supports strategic ideation and communication, e3Value enables the analysis of value exchanges and economic viability. BPMN provides insight into operational feasibility and process performance, whereas System Dynamics allows the dynamic assessment of long-term impacts.

Integrating BMC, e3Value, BPMN, and System Dynamics, therefore, supports addressing these limitations by combining strategic modelling, value network analysis, process modelling, and dynamic impact simulation within a multi-perspective toolkit for the development and analysis of sustainable circular business models. The integration of these modelling languages within the DECIDE Toolbox directly responds to several gaps identified in the literature: (i) methodological integration across structural, network, process, and dynamic perspectives; (ii) mechanisms for preserving and refining knowledge when switching between modelling languages; and (iii) the generation of decision-relevant evidence on economic, ecological and social impacts (Fruhwirth, Ropposch and Schindler, 2020; Fauser, Hertweck and Scheerer, 2024). This integrated approach increases transparency, supports innovation, and enables more comprehensive economic, operational, and sustainability assessments.

Table 4. Comparison of Modelling Languages				
Feature/Aspect	**Business Model Canvas (BMC)**	**Business Process Model and Notation (BPMN)**	**e3Value (e3V)**	**System Dynamics (SD)**
Strengths	Simple and intuitive framework for initial ideation; promotes stakeholder communication and shared understanding	Detailed process mapping that clarifies operational workflows and identifies inefficiencies and bottlenecks	Quantifies value exchanges across actors; enables scenario-based business case analysis and links value logic with infrastructure requirements	Captures feedback loops, delays, accumulations, and nonlinearities; enables long-term simulation of economic, social, environmental, and policy-related outcomes
Weaknesses	Static; lacks representation of dynamic interactions and detailed actor value exchanges; not suitable for in-depth quantitative analysis	Can be overly detailed and complex; not designed for business model visualization	Limited in capturing dynamic, time-dependent behaviour; requires a detailed understanding of value network structures and assumptions	Requires significant parameterization and data; high abstraction may obscure operational detail
Use Case	Initial business model ideation and structuring	Operational process modelling, resource allocation, and time/cost analysis	Detailed value network modelling, business case calculation, and economic scenario analysis	Long-term impact analysis, scenario exploration, and sustainability assessment
Typical Users	Business developers, managers, and workshop participants	Process analysts and operations managers	Business analysts and strategists	Strategy analysts, sustainability researchers, and business or policy decision-makers
Complexity Level	Low to medium	Medium to high	Medium	Medium to high
Focus	Strategic overview of value proposition, creation, delivery, and capture	Operational sequences, activities, resource flows, times and process costs	Value exchanges, economic viability, CAPEX/OPEX estimation, and infrastructure requirements	Dynamic behaviour, feedback structures, and long-term system impacts
Modeling Perspective	High-level and qualitative	Detailed, sequential, and activity-based	Network-oriented, quantitative, and scenario-based	Feedback-driven, temporal, and simulation-based
Primary Output	Business model canvas with nine building blocks	Process model with activities, roles, and time/cost annotations	Network business model with business case calculations, including CAPEX/OPEX estimation	Stock-and-flow model with simulation results over time
Temporal Perspective	Static snapshot	Sequential process perspective	Static structure with scenario variation	Dynamic over a defined time horizon

Capability Mapping and Implementation Planning

While the modelling approaches described before, BMC, e3Value, BPMN and System Dynamics improve transparency regarding business model logic, value exchanges, operational processes, and dynamic performance, they do not directly provide a consolidated, stakeholder-friendly abstraction of the organisational abilities and enabling technologies required to implement and operate a given CEBM configuration. In practice, companies often know what they want to offer, but lack clarity on what they need to be capable of to realise it (Küller, 2022). This gap between business model design and implementation planning is addressed by the Digital Service Implementation Recommender (DSIR) (D1.2.3). The Capability Mapping and Implementation Planning phase is not understood as a detailed IT system blueprint or software architecture. Instead, it provides a structured, capability-based perspective on implementation requirements, acting as a bridge between business model analysis and architectural realisation.

The DSIR builds on the concept of capabilities as defined in enterprise architecture theory (*ArchiMate® 3.2 Specification*, 2022): stable, technology-agnostic abstractions of what an organisation must be able to do, independent of how tasks are operationally performed. It distinguishes Business Capabilities (e.g., feedstock sourcing, quality governance, processing operations, offtake management) from enabling Technology/IT Capabilities (e.g., traceability, quality data capture, ERP). Methodologically, the DSIR extends the Network Business Model Architecture proposed by Küller (2022), who demonstrated how business model patterns can be linked to corresponding business and IT capabilities in the energy domain, and we transferred this logic to the circular economy.

To structure the capability analysis, the DSIR uses the six generic CEBM patterns consolidated by (Lüdeke-Freund, Gold and Bocken, 2019), repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, recycling, cascading and repurposing, and organic feedstock, as the primary organising logic. For each pattern, recurring implementation barriers, digital enablers, and capability candidates were identified through a systematic literature review and synthesised into a reusable capability catalogue (Lüdeke-Freund, Gold and Bocken, 2019). In application, a specific CEBM case is classified by pattern, and the catalogue is used to derive a case-specific capability profile, which is then represented as a Capability Map.

The primary inputs for this phase are the models developed in preceding phases, in particular the BMC, e3Value, and BPMN representations. The output is a Capability Map that consolidates business and technology capability requirements into a high-level view of what an organisation

must be able to do to implement the selected CEBM configuration. The phase serves three main purposes: first, it supports the identification of capability gaps between the intended business model and the existing organisational setup; second, it provides a structured basis for implementation planning by clarifying which organisational, digital, and infrastructural elements must be established or strengthened; and third, it facilitates communication between business, operations, and IT stakeholders by providing a shared discussion artefact at a high level of abstraction. Since the DECIDE Toolbox is modular, this phase can be revisited iteratively as the BMC, e3Value, or BPMN models are refined, ensuring that implementation requirements remain aligned with evolving business model assumptions.

The detailed development of the DSIR, including the capability catalogue, the literature review, and a demonstration using the whey training case, is documented in Deliverable D.1.2.3.

Data Platform and Monitoring Dashboard

While the preceding phases focus on the identification, development, validation and capability-oriented planning of CEBMs through complementary modelling perspectives, the resulting models and their analytical outputs need to be integrated and made accessible to stakeholders who are not directly involved in detailed modelling activities. This integration is provided by the DECIDE Data Platform (D.1.2.6) and the DECIDE Monitoring Dashboard (D.1.2.5), which together form the integration layer of the toolbox.

The DECIDE Data Platform provides the underlying semantic integration infrastructure. Model data from the ADOxx-based DECIDE Modelling Toolkit can be transformed into RDF/TRIG representations and pushed to the Data Platform through the upload function available via Model → Upload Models to Data Platform. During this process, the selected models are mapped against their corresponding metamodel descriptions and transformed into RDF triples according to the DECIDE-specific RDF transformation logic. The resulting triples are then written to the GraphDB repository. The upload process uses the RDF Transformation Service to perform the transformation and the Olive Microservice Controller to execute the corresponding operations on the GraphDB-based Data Platform. The required technical parameters are specified in the DECIDE-specific internal configuration file, which can be accessed via Extras → Edit Internal Configuration File. This configuration defines the Olive Microservice Controller endpoint, the Olive microservice used for GraphDB operations, the target Data Platform repository, the RDF Transformation Service endpoint, the metamodel file and graph URI, the RDF target format, the SPARQL update operations applied during the transformation process and the default base URI used for generated model resources. For BPMN and e3Value models, additional model-specific RDF properties can be maintained through Model → Model Attributes → RDF Properties. These properties allow users to add further model-related triples that are not directly covered by the respective modelling language, for example R-strategies, CEBM types or other case-specific information. These

additional RDF properties are stored in relation to the selected model and can complement the model-derived triples when the model is pushed to the Data Platform.

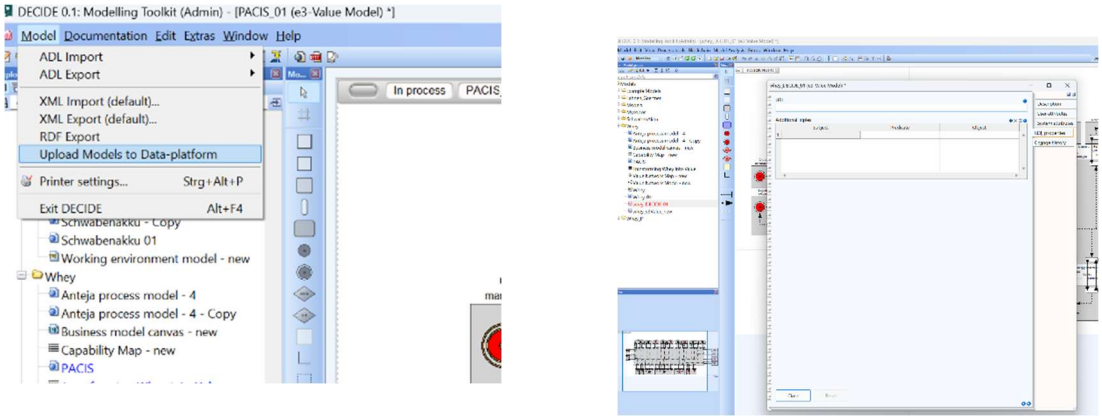


Figure 16: Upload function & Model-specific RDF properties in the DECIDE Modelling Toolkit

The most relevant parameters of the configuration file are summarised below:

- oliveMscEndpoint: Specifies the endpoint of the Olive Microservice Controller used by the modelling toolkit to access the DECIDE microservice infrastructure.
- oliveMicroserviceName: Defines the Olive microservice used for GraphDB-related operations, including RDF data updates, SPARQL queries and SPARQL update execution.
- dataPlatformRepositoryId: Specifies the target repository on the Data Platform to which the transformed model data is written.
- modelServiceEndpoint: Defines the endpoint of the RDF Transformation Service used to transform ADOxx model data into RDF/TRIG representations.
- metamodelFileUrl: Specifies the location of the DECIDE metamodel description used to map selected models against their corresponding metamodel before RDF transformation.
- metamodelGraphUri: Defines the named graph URI of the DECIDE metamodel within the metamodel RDF/TRIG file.
- modelSparqlUpdateUrl: Specifies the SPARQL update operations applied to the transformed model data before it is written to the Data Platform.
- modelDefaultBaseUri: Defines the default base URI used for generated RDF resources representing model elements.

In addition to the RDF-based data integration, the DECIDE Modelling Toolkit includes a blockchain-supported mechanism for model integrity verification. Within the Blockchain menu, a cryptographic hash can be generated for a selected model and stored in relation to this model. At a later point, the stored hash can be verified against the current model state. If the hash remains valid, this indicates that the model has not been modified since the hash was generated. The blockchain-supported functionality therefore contributes to traceability, tamper-evidence and integrity verification of model artefacts within the DECIDE tooling environment.

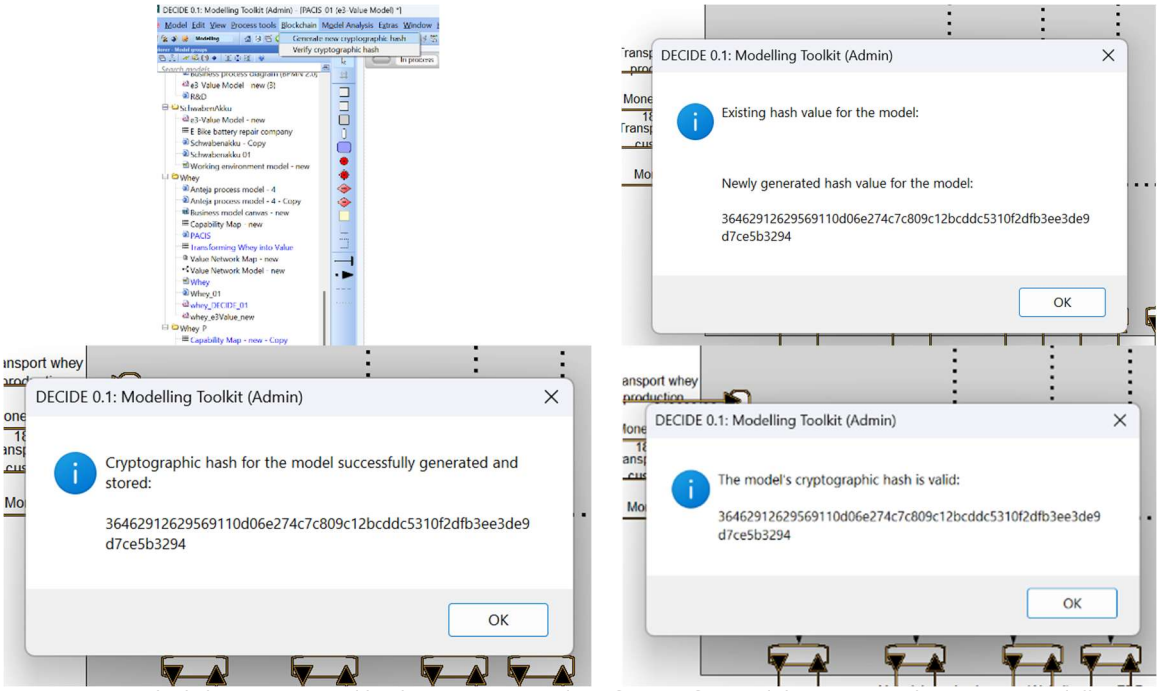


Figure 17: Blockchain-supported hash generation and verification for model integrity in the DECIDE Modelling Toolkit.

The DECIDE Monitoring Dashboard is implemented as a web-based application that consumes data from the Data Platform via SPARQL queries. It renders performance information for a selected CEBM along the three Triple Bottom Line dimensions of ecological, economic and social performance, and provides an aggregated view across all CEBMs when no specific business model is selected. The Dashboard combines indicators derived from the toolbox models with pilot-reported indicators delivered through a generic KPI extension schema. The current KPI catalogue comprises seven toolbox-derived indicators, including a Business Model Profile Card, an Actor Ecosystem Map, a Value Exchange Summary, a Revenue versus Cost Snapshot, a Circularity Penetration Score, a Waste Hotspots view and an Actor Consistency Check, and five pilot-reported indicators for CO_2 emission reduction, recycling rate, material reuse rate, circular revenue share and jobs created. A generic extension mechanism enables additional indicators to be added to any pilot case by writing triples to a dedicated named graph in the data platform, without modifications to the dashboard code.

By consolidating modelling outputs across the BMC, e3Value, BPMN and System Dynamics perspectives into accessible, stakeholder-oriented visualisations, the Monitoring Dashboard addresses the need for accessible interpretation of modelling results identified in Section 4 and supports decision-making by stakeholders who are not directly involved in detailed modelling activities. The detailed architecture and implementation of the Data Platform and the Monitoring Dashboard are documented in Deliverables D.1.2.6 and D.1.2.5.

E-Learning and Training Material

In addition to the methodological phases and software components, the DECIDE Toolbox includes structured e-learning and training material as a cross-cutting enabling component. Its purpose is to support the application of the Toolbox by project partners, companies and regional catalysts with different levels of prior knowledge in circular economy, business modelling and digital modelling tools. The material provides guidance on the purpose, required inputs, modelling steps, expected outputs and interpretation of results for the main Toolbox components.

The training material is implemented in a Moodle-based learning environment and follows a modular structure covering Circular Economy principles, the DECIDE Toolbox, the core modelling tools and practical case-based application. It combines presentations, video tutorials, handouts, exercises and example model files. The Whey case serves as a common, non-confidential training scenario that allows learners to follow the integrated modelling workflow across multiple Toolbox components.

This component does not constitute a separate modelling method. Rather, it supports the uptake, repeatability and transferability of the DECIDE methodology by reducing entry barriers, providing step-by-step guidance and enabling a shared understanding of the modelling process. The initial e-learning material is documented in Deliverable D.1.2.8, while its further development into a more interactive Digital Learning Concept is documented in Deliverable D.2.3.3.

Demonstrate Artefact

In the Demonstrate Artefact activity, the developed method is demonstrated on a case, thereby proving its feasibility (Johannesson and Perjons, 2014). The feasibility of the developed method is demonstrated through two pilot cases from the DECIDE project: the transformation of whey into high-value protein and lactose products (DanubeDairy) and the production of paper products from tomato stems (ICP). Both cases illustrate the end-to-end application of the DECIDE Toolbox, from business model conceptualization through value network analysis, process modelling, dynamic impact simulation to Capability Mapping and Implementation Planning.

Transforming Whey into Value

This business model was collaboratively developed by the project partners HSRT, Anteja and FOI as an initial prototype within the DECIDE Toolbox. The business model and relevant data were provided by Anteja. We further refined this case as a training case to be used in future Train-the-Trainer sessions or with students to illustrate the application of the various tools and methodologies.

Whey, a byproduct of cheese production, has historically been treated as waste, often discarded or used in low-value applications such as animal feed. Yet, whey is rich in valuable proteins, lactose, and nutrients that can be extracted and transformed into high-value products. These products, such as Whey Protein Concentrate (WPC80) and lactose, are in high demand across industries like food, fitness, and pharmaceuticals. In the Danube region, dairy production plays a vital role in the agricultural economy. However, the byproducts of cheese manufacturing, such as whey, remain largely underutilized (see D.1.2.2). While global markets for whey protein products, such as WPC80, are expanding, local production in Eastern Europe is limited. As a result, much of the whey is sold as low-value animal feed or simply discarded. We introduce DanubeDairy, a fictional small-to-medium-sized enterprise (SME) located in the heart of the Danube region. The company specializes in cheese production, generating significant volumes of whey as a byproduct. Currently, whey is sold as low-value animal feed. However, the management is exploring options to process it into high-value products such as WPC80 and lactose. This case study highlights the challenges and opportunities faced by SMEs like DanubeDairy. It demonstrates how circular economy principles

can be applied to transform waste streams into sustainable revenue sources. By leveraging various modelling tools, we will:

- Uncover the complexities of the whey-to-WPC80/lactose value chain and production processes.
- Identify opportunities for process optimization.
- Business model development and analysis.
- Evaluate the social, environmental and economic impacts of this business model.

DanubeDairy processes thousands of liters of milk daily, generating substantial amounts of whey as a byproduct of cheese production. The produced whey currently goes to waste. The company is exploring the feasibility of building a whey processing facility to capture emerging market opportunities and reduce waste.

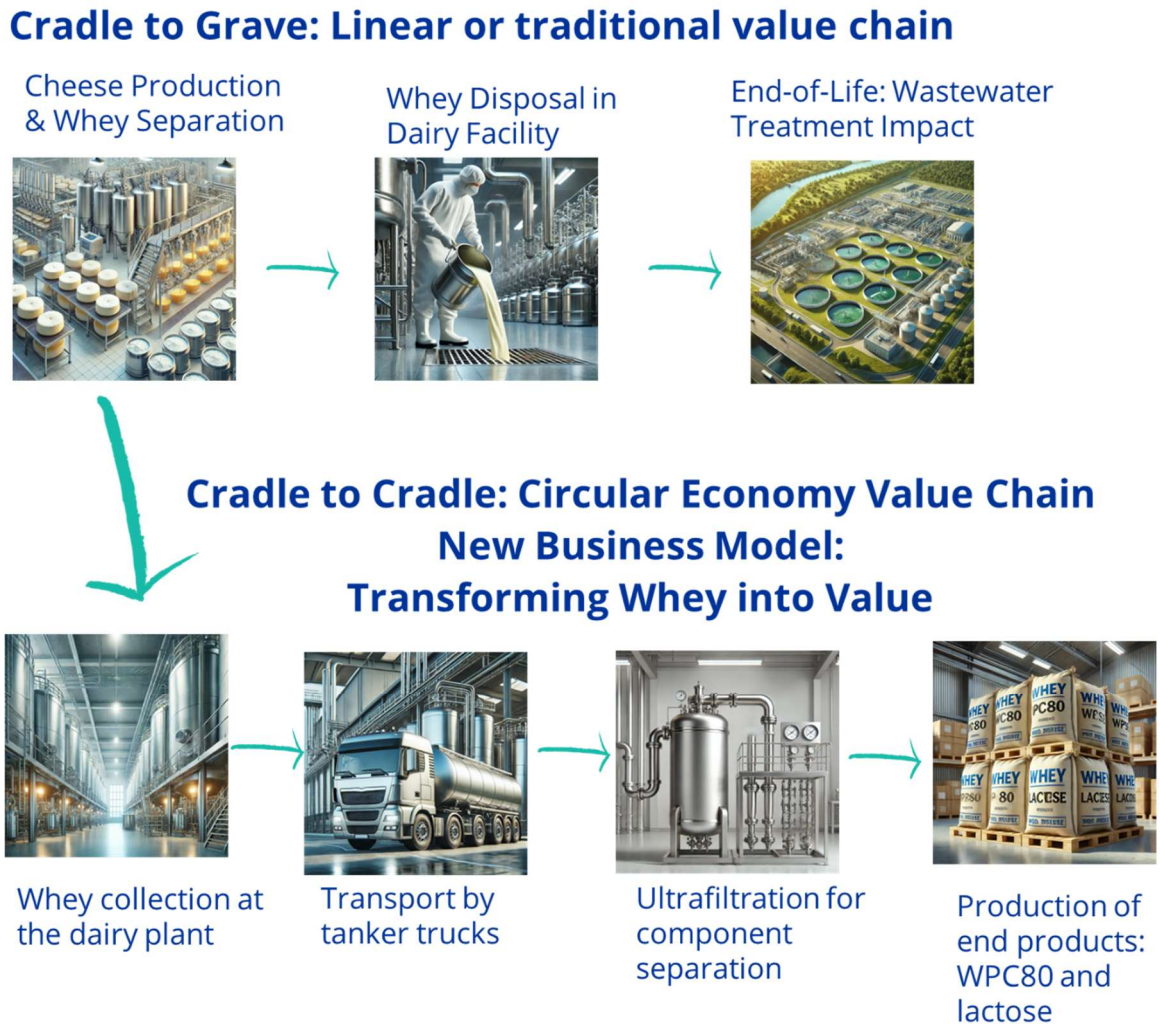


Figure 18: Whey cradle to grave to cradle to cradle

Figure 18 illustrates the transition from a linear value chain in which whey is disposed of as waste to a circular economy model that transforms whey into valuable products. This new approach can be classified as a *Cascading and Repurposing* business model type according to (Lüdeke-Freund, Gold and Bocken, 2019), in which materials are returned to the economic system through appropriate processes after their initial use. By applying the circular strategy of **Cascading and Repurposing**, whey is processed into high-value products such as WPC80 and lactose. This reduces waste, closes material loops, and creates new revenue streams, demonstrating how circular economy principles turn byproducts into valuable resources.

Business Model Conceptualization

The objective of this phase is to develop a structured overview of Value Creation, Value Delivery, Value Capture, and Value Proposition, presented in a Business Model Canvas (BMC). Based on the results of the Potential and (Resource) Identification phase and the use of the "Value Chain Generator" tool (see D.1.2.2), a BMC was developed. Since there was already a clear understanding of the business model to be analysed for this pilot case, we decided not to conduct an innovation workshop (see chapter "Design and Develop Artefact"). Instead, we conducted an online workshop



Figure 19: Whey BMC

to collaboratively create an initial BMC. Anteja contributed a consulting case from their work in Germany, assumed the role of the company during the workshop, and provided all relevant information required for the modelling process. Together, we discussed and elaborated on the individual building blocks of the BMC.

The BMC provides a high-level strategic overview of the business model idea. It leverages partnerships with dairy farmers, logistics providers and distributors to collect and process raw whey into high-value products for the food, fitness, and pharmaceutical industries. This approach ensures sustainability by turning waste into value, while also addressing the growing market demand for high-quality protein and lactose. The elements of this business model are summarized in the BMC (see Figure 19) and Table 5. This model highlights key aspects of Value Creation, Value Delivery, and Value Capture, providing an overview of the company's strategic goals:

- Value Creation: Transforming whey into high-value products like WPC80 and lactose.
- Value Delivery: Establishing efficient supply chains to deliver these products to the food, fitness, and pharmaceutical industries.
- Value Capture: Generating sustainable revenue streams through competitive pricing and strong customer relationships.

Table 5: BMC Whey

Building Block	Concrete Designation	Description
Key Partners	Dairy Farmers	Supply raw whey as a byproduct of cheese production.
	Logistics Providers	Transport whey from dairy farms to the processing facility.
	Technology Providers	Deliver specialized equipment for whey processing and separation.
	Distributors	Facilitate the sale of WPC80 and lactose to target industries.
Key Activities	Whey Collection	Organizing the transportation and storage of raw whey.
	Processing Operations	Separating whey into WPC80 and lactose using advanced filtration and drying techniques.
	Quality Assurance	Ensuring the final products meet food-grade standards.
	Marketing and Sales	Building relationships with customers in the food, fitness, and pharmaceutical industries.
Key Resources	Processing Facility	Equipped with filtration and drying technology.
	Specialized Staff	Skilled operators for production and quality control.
	Partnership Network	Connections to dairy farms and logistics providers.
Value Propositions	Sustainability	Turning waste into high-value products while minimizing resource wastage.
	High-Quality Protein	Supplying WPC80 for fitness and food markets.

	Resource Efficiency	Maximizing whey utilization through innovative processing.
Customer Relationships	B2B Partnerships	Long-term contracts with food manufacturers, supplement companies, and pharmaceutical firms.
	Customer Support	Providing technical and product support for customers.
Channels	Direct Sales	Selling to large manufacturers.
	Regional Distributors	Reaching smaller markets through local distributors.
	E-Commerce (optional)	Platform for smaller-scale sales, targeting niche markets.
Customer Segments	Food Industry	Manufacturers incorporate WPC80 in dairy or snack products.
	Fitness Industry	Companies producing protein supplements.
	Pharmaceutical Industry	Buyers of lactose for medicinal applications.
Cost Structure	Whey Collection Costs	Payments to dairy farmers and logistics providers.
	Processing Costs	Energy, equipment maintenance, and labor costs.
	Marketing and Distribution Costs	Advertising, sales efforts, and logistics.
Revenue Streams	Product Sales	Income from WPC80 and lactose sales.
	Sustainability Premium	Potential for higher prices for eco-friendly products.

While the BMC provides a high-level strategic overview, the specific value exchanges between actors and the distribution of costs and revenues across the network remain ambiguous. To address these limitations, the BMC is refined into an e3Value network business model in the next phase.

Detailed Business Model Analysis and Validation

This phase focuses on the detailed analysis and validation of the business model for processing whey into high-value products such as WPC80 and lactose. The e3Value ontology, implemented within the ADOxx tool, was used to develop the e3Value model. We identified key actors and value exchanges and assessed the economic feasibility of the proposed business model. Central to this approach is the mapping between the Business Model Canvas (BMC), BPMN, and e3Value, which enables the integration of strategic, operational, and value-oriented perspectives. This integration facilitates a coherent transfer of actors, processes, and value exchanges, resulting in a comprehensive assessment of Value Creation, Value Delivery, and Value Capture.

The development of the network business model for the whey case began with transferring the key partners and customer segments from the BMC into the e3Value model. Based on the mapping framework described in the “Design and Develop Artefact” section, the relevant actors, value exchanges, and value objects were systematically identified and modeled. Additional actors and relationships were refined through iterative discussions, leading to a representation of the business scenario. Products and services (WPC80, lactose) were specified, and customer segments (fitness, food, pharmaceutical industries) were differentiated according to their requirements. For each value exchange, details such as price per unit, quantity exchange, and product specifications were documented. The model also incorporated cost and price information for individual services to enable economic analysis. Simulation parameters, such as the simulation period, market volume, and sales volumes, were defined based on realistic business assumptions for the target region and market structure. Scenario analyses were conducted using BMConfig software, which allows flexible adjustment of key parameters and efficient evaluation of their effects on business

model outcomes. This approach provided a basis for evaluating the economic viability and adaptability of the business model under different scenarios.

The e3Value model for the whey valorisation case provides a comprehensive overview of all key actors, value exchanges, and monetary flows within the NBM to produce WPC80 and lactose as shown in Figure 20. At the core of the model is the "Whey Enterprise," which procures raw liquid whey from cheese manufacturers. The transaction is modelled as an exchange of 240.000 units

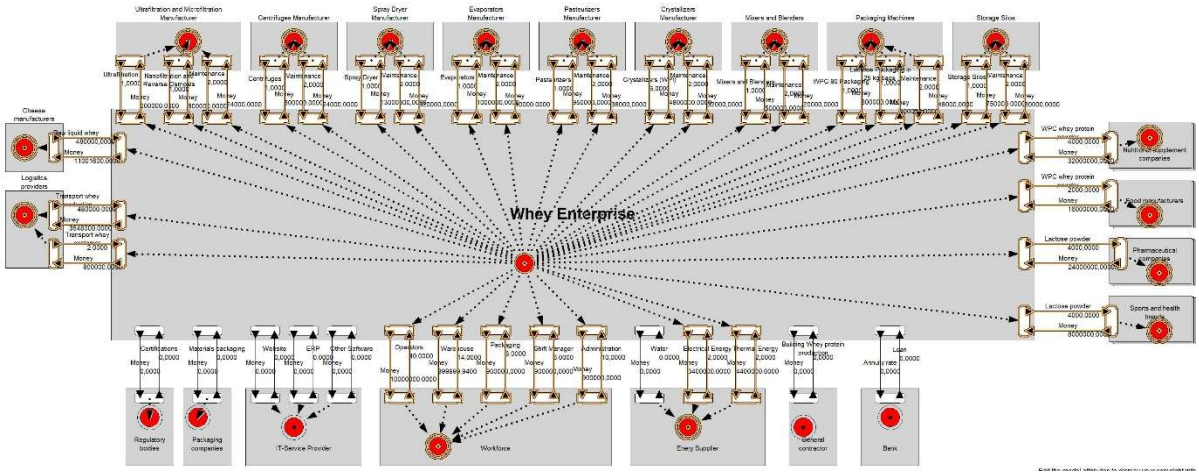


Figure 20: e3Value Whey; Appendix 7 e3value_whey.jpg

per period for €23 per unit, reflecting the primary material inflow and its associated costs. Logistics providers are responsible for transporting whey from suppliers to the processing site and from the plant to customers. This is represented in the model as two distinct value exchanges: one for whey collection and delivery (€7.60 per unit, 240.000 units per period) and one for final product distribution (€400000 for all shipments in one period). On the production side, the Whey Enterprise interacts with a variety of machinery manufacturers, including suppliers of ultrafiltration and microfiltration systems, centrifuges, spray dryers, evaporators, pasteurizers, crystallizers, mixers, blenders, packaging machines, and storage silos. Each of these exchanges is depicted as a one-time purchase (e.g., spray dryer: €13.000.000; pasteurizer: €950.000), alongside recurring annual maintenance fees. Workforce requirements are detailed in the model, with separate transactions for operators, warehouse staff, packaging staff, shift managers, and administration, each with defined annual compensation (e.g., 20 operators at €250.000 per year, 4 packaging staff at €112.500 each). The model also incorporates energy consumption, with annual payments for both electricity (€1.700.000) and thermal energy (€2.200.000), reflecting the high energy demands of industrial whey processing. On the output side, the Whey Enterprise sells its high-value products, WPC80 whey protein and lactose powder, to distinct customer segments. Nutritional supplement companies purchase 2.000 units of WPC80 per period at €8.000 per unit. Food manufacturers purchase 1.000 units of WPC80 per period at €8.000 per unit. Pharmaceutical companies and sports & health brands each purchase lactose powder in volumes of 1.000 and 2.000 units respectively, at €2.000 per unit. All monetary and value exchanges are represented in the e3Value model, enabling the analysis of value creation, delivery, and capture within the network. This

mapping supports the simulation and economic assessment of the business model, facilitating scenario analysis regarding market volume, price changes and infrastructure investment.

Preliminary Value Chain and Supply Chain Structuring

While the BMC provides a strategic overview of the proposed business model and the e3Value model captures actor-level value exchanges and supports economic feasibility assessment, neither perspective details the operational execution required to deliver WPC80 and lactose. The objective of this phase is therefore to develop an initial BPMN process model that maps the production, value and supply chains for both product streams at the operational level. This complements the strategic and value-network perspectives by making activities, dependencies, resources and time/cost drivers explicit and enables a feasibility assessment of the underlying processes. This model provides a structured view of the operational landscape, enabling informed decision-making about process optimization, resource allocation, and the overall feasibility of the new business model.

Following the BMC and e3Value model, the next step was to map its elements to the BPMN process model. This mapping ensures that the strategic insights from the BMC are translated into concrete operational workflows. For this purpose, we used the mapping approach previously described in the “Design and Develop Artefact” chapter. To accurately capture the production processes and the associated supply and value chains, a participatory modeling workshop was conducted. In these workshops, relevant stakeholders were actively involved in the modeling process, with their workflows, requirements, and perspectives directly incorporated into the BPMN model. This process was complemented by interviews, enabling real-time integration of process details into the model. Additionally, colleagues from the University of Maribor developed an Excel sheet to systematically collect data for business process simulation and to support process improvement. The colleagues from Anteja completed this Excel sheet and provided the necessary data. The resulting process model is depicted in Figure 21. The BPMN model was created using the DECIDE modeling environment, implemented in ADOxx. An overview of the collected data presented in Table 6, which provides details on the specific activities, gateways, and flows that form the initial whey processing model.

The BPMN process model for whey processing represents the workflow from whey collection to the delivery of WPC80 and lactose to the customer. The process starts when the dairy plant announces excess whey for pickup. A transport company is notified and is responsible for filling the cistern with whey at the dairy site. The filled cistern is then transported to the processing

facility. After arrival, the whey is stored in silos by warehouse workers and its quantity is measured. Subsequently, the whey is pasteurized, followed by a fat separation process. An expert in membrane separation performs ultrafiltration on the whey, resulting in two streams: approximately 70% of the total mass is directed to the lactose stream, while about 30% forms the WPC80 stream.

In the case of the WPC80 stream, the protein-rich concentrate obtained after ultrafiltration is initially collected. This is then pasteurised to ensure product safety and quality. The next step in the process is to dry the pasteurized protein solution, converting the liquid concentrate into a powder. The resulting protein granules are stored in silos until further processing. Once a specific threshold for WPC80 in the storage facility has been is reached, the product is then packaged in accordance with industry standards. The packaged product is loaded onto trucks and delivered to customers in the food, nutrition and pharmaceutical sectors.

For the lactose stream, the process continues with nanofiltration performed by membrane separation experts. After nanofiltration, the stream is split into two fractions: approximately 30% of the mass forms the lactose-rich concentrate, while the remaining 70% is collected as permeate, which primarily consists of water and dissolved small molecules. This permeate is treated as a byproduct and may be further utilized, for example, as input for a biogas plant or for other purposes, depending on the facility's setup. However, its subsequent use is not considered in this process model, as the process ends with permeate collection. Next, the lactose concentrate undergoes reverse osmosis to further increase its purity and is then collected in crystallization tanks. During crystallization, lactose forms solid crystals, which are separated from the liquid by centrifugation. The lactose crystals are then dried to remove residual moisture and ground to the desired particle size. Finally, the finished lactose product is packaged, loaded onto trucks, and transported to customers.

Simulation is a valuable tool for evaluating business process changes in a virtual environment, particularly when direct implementation would be costly or impractical. For the whey processing case, the BPMN process model was refined and adapted for simulation by defining relevant parameters, including process times, costs, and path probabilities. The required data, such as task durations, processing delays, material and transport costs, were transferred from the Excel sheet into the model Table 6. Using the DECIDE BPMN modelling environment, we were able to specify detailed time parameters for each activity: execution time (duration of the activity), waiting time (delay before start), resting time (delay after completion), and transport time (time to the next process step). This enabled a systematic analysis of process costs, throughput times, and potential bottlenecks under various scenarios. In a follow-up meeting, the simulation results were reviewed with stakeholders, providing a foundation for informed decision-making and targeted process optimization. While simulation is a powerful analytical tool, its results are based on abstract models and assumptions. It is important to: (i) Ensure input data and assumptions are accurate to achieve meaningful results. (ii) Interpret results cautiously, as they are not a direct 1:1 representation of reality. (iii) Validate simulation findings with practical trials or real-world data.

The total processing time for the entire workflow amounts to 79 hours, with overall costs of 4,517.00 € (WPC80 pathway) and 3,562.00 € (lactose pathway), respectively. To enable separate analysis of WPC80 and lactose production, the process was adapted accordingly: one simulation was conducted for the WPC80 pathway and another for lactose. For WPC80, the simulation resulted in a total processing time of 64 hours and costs of 4,517.00 €. For lactose, the respective processing time and costs were determined as 79 hours and 3,562.00 €. This differentiation allows for a more detailed assessment of the resource requirements and economic viability of each product stream. The process model provides a comprehensive and structured view of the operational workflow for whey valorization, covering activities from raw material intake to end-product delivery. This level of detail supports informed decisions regarding process improvements, cost management and business model feasibility.

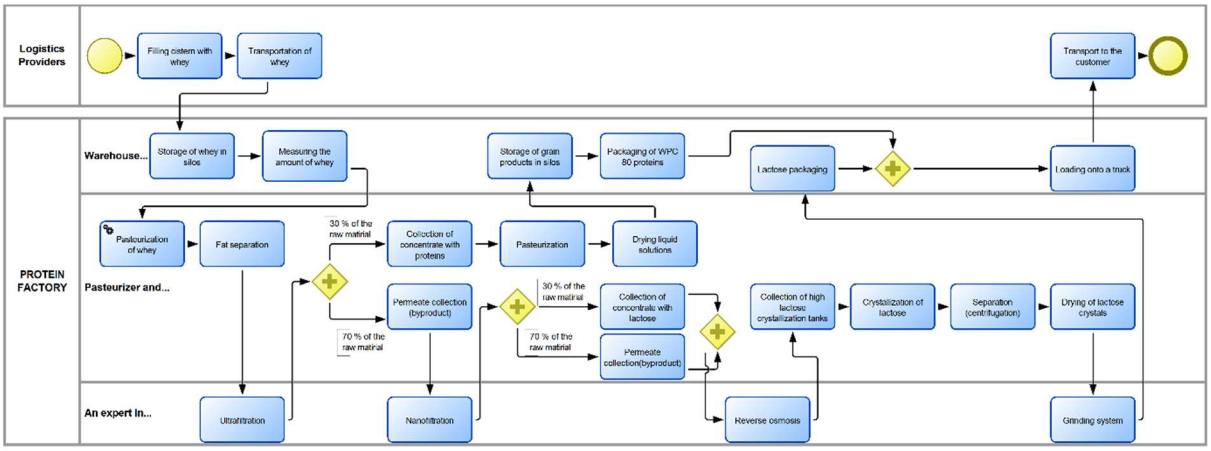


Figure 21: BPMN Whey; Appendix 6 - BPMN Whey.jpg

Table 6: Whey Data BPMN

Number of the activity	Number of the previous activity	Object type	Object	Performer (participant) of the activity	Execution Time	Waiting Time	Transportation Time	Costs
I.		Start Event (Message)	Excess whey is announced for pick-up	Transport company				
1.	-	Task	Filling the cistern with whey at the dairy site	Transport company	05:00:00	00:05:00		120,00€
2.	1.	Task	Transport whey to the processing location	Transport company	02:00:00	00:00:00		825,00€
3.	2.	Task	Store whey in silos at the processing site	Warehouse worker	05:00:00	00:00:00		80,00€
4.	3.	Task	Measure the amount of whey	Warehouse worker	00:05:00	00:05:00		8,00€
5.	4.	Task	Pasteurize whey	Pasteurizer and separator	00:37:00	00:05:00	00:22:00	125,00€
6.	5.	Task	Separate fat	Pasteurizer and separator	10:25:00	00:05:00	00:05:00	169,00€

7.	6.	Task	Ultrafiltrate	Expert in membrane separation	06:00:00	00:05:00	00:45:00	350,00€
8	7	Parallel Gateway	Lactose and WPC80					
8.1	8	Sub-sequent	Lactose					
8.2	8	Sub-sequent	WPC80					
9	8.1	Task	Collect permeate (byproduct)	Pasteurizer and separator	06:00:00	00:05:00	00:05:00	105,00€
10	8.2	Task	Collect concentrate with proteins	Pasteurizer and separator	01:15:00	00:05:00	00:22:00	67,50€
Production of WPC 80 proteins								
11	9	Task	Pasteurize	Pasteurizer and separator	00:37:00	00:05:00	00:22:00	115,00€
12	11	Task	Drying liquid solutions	Pasteurizer and separator	02:00:00	00:05:00	00:37:00	1.100,00€
13	12	Task	Store grain products in silos	Warehouse worker	03:00:00	00:05:00	00:05:00	30,00€
14	13	Task	Package WPC80 proteins	Warehouse worker	20:00:00	00:05:00	00:05:00	1177,50€
15	14 & 28	Exclusive Gateway	Lactose _WPC80_Closing					
16	15	Task	Load truck with product	Warehouse worker	00:45:00	00:45:00	00:00:00	75,00
17	16	Task	Transport product to customer	Transport company	03:30:00	00:00:00	00:00:00	275,00€
Lactose production								
18	10	Task	Nanofiltration	An expert in membrane separation	06:00:00	00:05:00	00:45:00	265,00€
19	18	Parallel Gateway	Lactose Collection					
19.1	19	Sub-sequent	Lactose					
19.2	19	Sub-sequent	Lactose Permeate					
20	19.2	Task	Collect permeate (byproduct)	Pasteurizer and separator	06:00:00	00:05:00	00:05:00	105,00
21	20	End Event	Products sold					
22	19.1	Task	Collect concentrate with lactose	Pasteurizer and separator	01:15:00	00:05:00	00:22:00	67,50€
23	22	Task	Reverse osmosis	An expert in membrane separation	09:00:00	00:05:00	00:05:00	75,00€
24	23	Task	Collect high lactose concentrate in crystallization tanks	Pasteurizer and separator	01:15:00	00:05:00	00:22:30	67,50€
25	24	Task	Crystallize lactose in tanks	Pasteurizer and separator	00:42:00	00:00:00	00:00:00	225,00€
26	25	Task	Separation (centrifugation)	Pasteurizer and separator	01:30:00	00:05:00	00:05:00	25,00€
27	26	Task	Dry lactose crystals	Pasteurizer and separator	03:00:00	00:05:00	00:05:00	80,00€
28	27	Task	Grinding system	Pasteurizer and separator	01:30:00	00:05:00	00:05:00	25,00€

29	28	Task	Package lactose	Warehouse worker	10:00:00	00:05:00	00:05:00	600,00€
Transport Lactose and Whey								
15	28 & 14	Parallel Gateway	Lactose _WPC80_Closing					
16	15	Task	Load onto truck	Warehouse worker	00:45:00	00:45:00	00:00:00	75,00€
17	16	Task	Transport to the customer	Transport company	03:30:00	00:05:00	00:00:00	275,00€

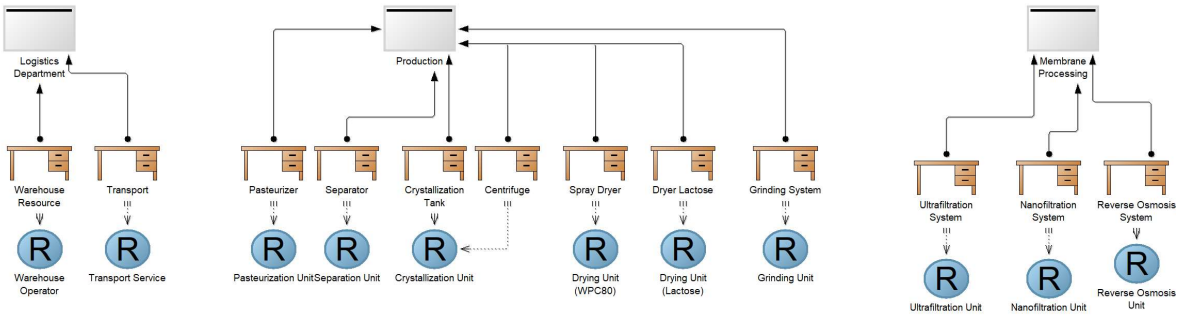


Figure 22: Organisational model defining resources for the BPMN-based process simulation

In addition to the graphical representation of the operational process logic, the BPMN model was enriched with organisational and resource-related information. For this purpose, resources such as operators, transport and production units were first defined in the organisational model, as shown in Figure 22. These resources can then be assigned to the corresponding BPMN activities within the process model. Each resource can be specified with parameters such as hourly wages, available working days and working hours per day. This makes it possible to simulate process execution based on resource availability and personnel costs. The resource-based specification extends the analytical potential and maintainability of the BPMN model. It enables the calculation of personnel cost distributions across process steps, the analysis of execution times and an initial assessment of resource utilisation and capacity constraints. The simulation outputs shown in Figure 23 illustrate two exemplary simulation outputs generated from the resource-enriched BPMN model: the distribution of personnel costs across process activities and the corresponding execution times based on the assigned resources. A further advantage is that changes to resource parameters, such as hourly wages or working time, can be maintained centrally in the organisational model. These changes are then reflected wherever the respective resource or performer is assigned to process activities. This improves consistency across the process model and reduces the effort required to update cost and time values.

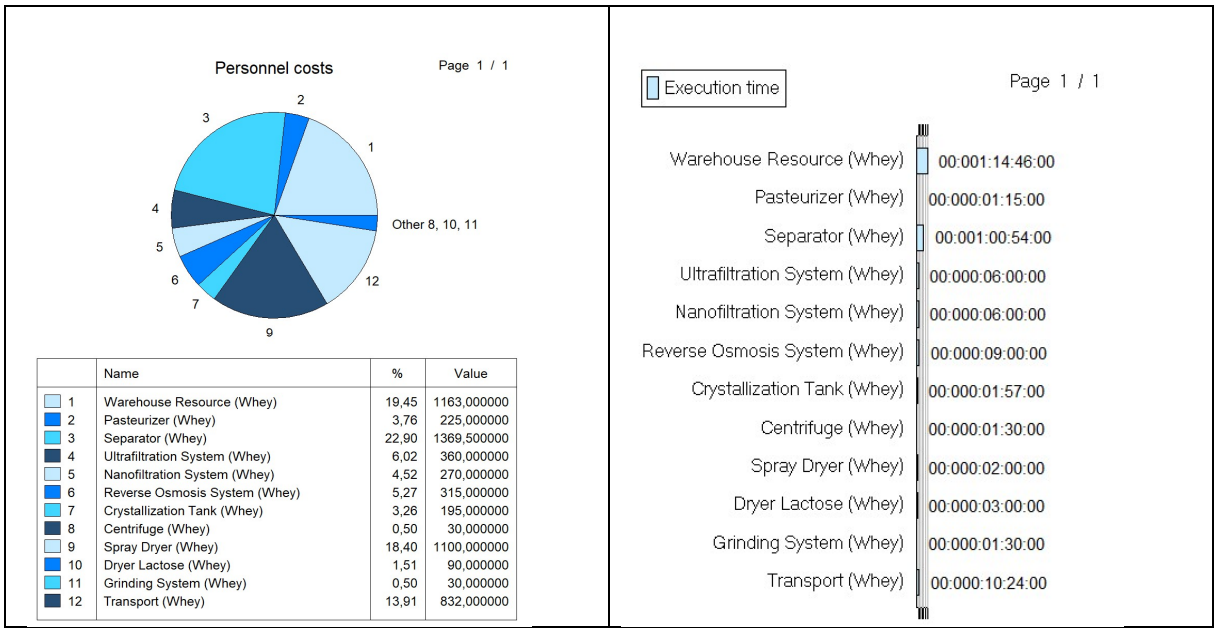


Figure 23: Resource-based BPMN simulation outputs

Building on the BMC, e3Value and BPMN models developed in the previous phases, the next phase translates these structural insights into a System Dynamics model for long-term impact assessment.

Dynamic Impact Analysis and Sustainability Modeling

In this phase, the Dynamic Business Modelling for Sustainability Canvas (DBMSC) (Cosenz, Rodrigues, and Rosati, 2020) is used to conduct a simulation-based analysis of the whey protein business model. By systematically translating key elements from the previously developed BMC, e3Value, and BPMN models into a System Dynamics framework, we move from static business modelling to dynamic business modelling, enabling the capture of feedback loops, temporal interactions, and scenario-based development. The objective is to provide an evidence-based assessment of the business model's economic, social and environmental impacts.

The System Dynamics (SD) model presented in this phase is not developed in isolation but is the result of a systematic transformation and integration of prior modelling efforts. Specifically, the Business Model Canvas (BMC) serves as the conceptual foundation, defining the key actors, resources, and value propositions that establish the model's structural boundaries. Building on this, the e3Value approach captures the essential economic logic and the flows of costs, revenues, goods and services between different actors. These financial relationships are mapped directly into SD variables and equations, ensuring consistency between static valuation and dynamic simulation. The BPMN model, in turn, provides a process-oriented perspective, detailing the operational steps involved in production, sales, and logistics. These workflows are translated into the SD framework as sequences of stocks, flows, and feedback loops, enabling the simulation of temporal interactions, bottlenecks, and process-driven dynamics. By synthesizing these distinct yet complementary modelling languages, the SD model offers a dynamic and integrative view of the business model, supporting the analysis of economic, environmental, and social impacts over time.

The developed SD model comprises a set of interconnected stocks, flows, and auxiliary variables, each corresponding to critical dimensions of the business model as mapped in the DBMSC, as shown in Figure 24. The stock *Whey_Intake* reflects the daily input of raw whey, directly linked to both supplier relations (key partners) and capacity constraints (Processing_Capacity). Inventories for WPC80 and Lactose capture the transformation of input resources into value-added products, regulated by process yields and market demand. Separate customer base stocks (*Customer_Base_WPC80*, *Customer_Base_Lactose*) are used to explicitly represent acquisition and churn for distinct product lines, incorporating market-driven conversion and attrition rates. Auxiliary variables such as *Acquisition_WPC80*, *Acquisition_Lactose*, and price-driven conversion factors, enable dynamic modeling of market responsiveness and sales effectiveness. Financial

performance is operationalized through a cumulative profit stock (*Cumulative_Profit*), with inflows determined by the daily profit rate (the difference between Revenue and Total_Costs). The model incorporates a granular representation of cost drivers, including *Energy_Cost*, *Personnel_Cost*, *Maintenance_Cost* and logistics expenses, enabling detailed economic analysis. Revenue streams are computed from actual sales volumes and product prices, thereby reflecting both operational performance and market positioning. The *Cumulative_Net_CO2_Saving* stock aggregates net greenhouse gas savings over time, benchmarking the environmental performance of WPC80 against conventional protein sources (chicken, beef, soy) while explicitly considering process-related emissions. The model further quantifies *Waste_Avoided*, representing the circularity benefits achieved by diverting whey from waste streams into productive use. Labor dynamics are modeled via the *Human_Resources* stock, which captures workforce scaling and attrition, and provides an explicit link to local job creation.

Simulation results provide an initial overview of key performance indicators for the first year of operation. The business model shows a rapid break-even and a profit in the simulation, with an accumulated profit of approximately €3.9 million after one year and an ROI of 1.67. The model further suggests creating about 8 full-time jobs and avoiding 29,120 tons of whey waste, with a resource efficiency of 0.51. However, these results are based on initial parameter assumptions and should be interpreted as preliminary. Further analysis and sensitivity checks are necessary to validate the findings and adjust the input data as required. Table 7 summarizes the main simulation outcomes.

Table 7: Simulation Results (after 1 year)

Parameter	Value*	Unit	Note
Return on Investment (ROI)	1.66655	–	Annualized ROI (Profit/Invested Capital)
Break-Even Point	222	days	Time until initial investment is recovered
Cumulative Profit (Year 1)	3.927.640	€	Total net profit after 365 days
Jobs Created (Year 1)	7.9	FTE	Full-time equivalents after one year
Waste Avoided	29,120	t(whey)	Whey processed instead of disposal per year
Invested Capital	23.700000	€	Initial investment required
Resource Efficiency	0.51		Output/Input ratio for whey valorization process

All values are based on the current model configuration and parameter assumptions for the first year of operation. Given the preliminary nature of these results, future work should focus on parameter refinement, model validation against empirical data, and the exploration of alternative scenarios to strengthen the findings.

While the previous phases established the strategic, value-oriented, operational and dynamic

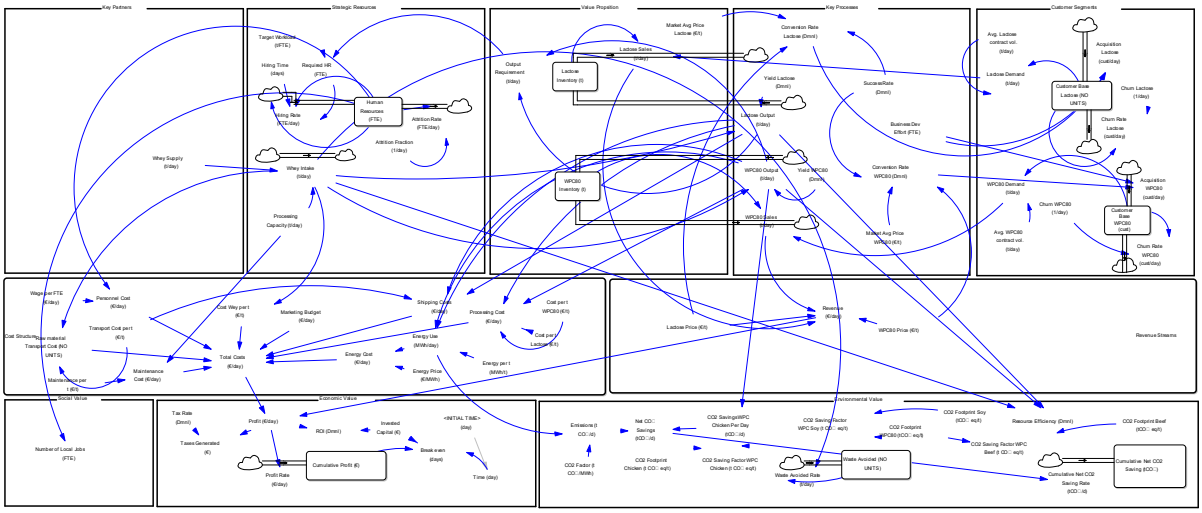


Figure 24: System Dynamics Modell Whey; Appendix 8 Whey_SD.png

perspectives on the whey business model, the implementation of the model also requires a clear understanding of the organisational capabilities needed to operate it. This is addressed in the next phase through the Digital Service Implementation Recommender (DSIR).

Capability Mapping and Implementation Planning

The previous phases established the strategic, value-oriented, operational and dynamic perspectives on the whey business model. To support the actual implementation and operation of the business model, these modelling outputs need to be linked to the organisational capabilities required to realise them. This is the purpose of the Digital Service Implementation Recommender (D.1.2.3), which is demonstrated in this section for the whey case.

While the BMC provides a high-level strategic snapshot of the whey business model, the DSIR demonstration requires an explicit link between the business model configuration and the implementation requirements that enable its operation. For this purpose, we operationalise the previously assigned Cascading and Repurposing pattern through a case-specific selection of CEBM design options proposed in the morphological box (see Figure 25) by Lüdeke-Freund, Gold and Bocken (2019). These design options structure the business model along the four dimensions value proposition, value delivery, value creation, and value capture and provide recurring circular-economy configuration choices within each dimension. In the whey case, the instantiated configuration is characterised by (i) using a biological byproduct stream as production input, (ii) relying on waste handling and processing as enabling services to convert the stream into marketable outputs, (iii) a predominantly B2B-oriented market logic, and (iv) transportation and logistics as a critical operational and economic requirement. Using the design-option view as the primary organising logic serves two purposes in the DSIR context. First, it keeps the capability discussion focused on the generic implementation logic of the selected CEBM pattern and avoids overloading the capability map with excessive case detail. Second, it supports reuse and comparability across cases: by mapping different cases to the same pattern-specific design options, recurring capability clusters can be identified and contrasted across multiple instantiations of Cascading and Repurposing. Based on this mapping, DSIR derives a case-specific subset of capability candidates from the developed CRBM capability catalogue (D.1.2.3).

The morphological box (see Figure 25) summarises the selected CRBM design options used to instantiate the whey case and serves as the direct basis for deriving the capability map. To avoid ambiguity, the pattern instantiation is described from the perspective of the whey-processing firm as the focal actor. The cheese producer remains an upstream feedstock provider (key partner/supplier) that generates and temporarily stores the whey stream and triggers its handover. The whey processor operates at the interface between upstream side-stream collection and downstream product distribution: it must organise the acquisition and governance of the whey stream (often referred to as “return flow” in circular patterns) and, in parallel, manage forward logistics and B2B delivery of WPC80 and lactose. Accordingly, “take-back/return flow” in this case

refers to organised collection and transfer of an industrial byproduct stream rather than consumer product returns.

BM Dimensions		CEBM design options								
Value proposition	Products	Repaired, refurbished, remanufactured, or recycled products	Reusable or recyclable products	Products based on recycled waste	Long-lasting products	Used products, components, materials, or waste as production inputs	Reusable or recyclable production inputs			
	Services	Facilitating collaboration	Take-back management	Customer education	Waste handling, processing	Product-/service-based functions	Maintenance, repair, control	Product-/service-based results	Upgrading	Auxiliary services
Value delivery	Target customers	Quality-conscious customers	Cost-conscious customers	Green customers	B2B customers	B2C suppliers	B2B suppliers	C2C suppliers		
	Value delivery processes	Connecting suppliers and customers	Providing access to a product's functionality	Providing (product-based) services and results	Providing used products, components, materials, or waste	Taking back used products, components, materials, or waste	Sharing products, components, materials, or waste			
Value creation	Partners and stakeholders	Suppliers	Manufacturers	Retailers	Service providers	Public institutions	Collectors of products, components, materials, waste	Others (e.g., researchers)		
	Value creation processes	Maintaining or repairing products, components	Refurbishing or remanufacturing products, components	Recycling of products, components, materials, waste	Upgrading or upcycling of products, components, materials, waste	Reselling products, components, materials, waste	Taking back or recapturing products, components, materials, waste	Winning back base materials	Using used products, components, materials, waste as input	Matching over- and under-capacities	Designing products, components, materials
Value capture	Revenues	Additional product revenues	Payments per unit of service	Payments for functions or results	Price premiums					
	Costs	Labor	Repair, maintenance, control	Waste handling, processing	Manufacturing	Resource inputs	Transportation, logistics	Supply risks		

Figure 25: Cascading and repurposing CEBM pattern (Lüdeke-Freund, Gold and Bocken, 2019)

Based on the morphological design options associated with the Cascading and Repurposing pattern, the whey case is instantiated along the dimensions value proposition, value delivery, value creation, and value capture. The value proposition is driven by upgrading a biological byproduct stream (liquid whey) into marketable, specification-defined ingredients (WPC80 and lactose), which requires robust waste handling and processing under food-grade conditions. In this industrial byproduct setting, the generic design option "take-back management" is interpreted as organised side-stream collection and feedstock governance (contracting, pickup coordination, hygiene requirements, and intake control), not as the return of sold products. Value delivery follows a predominantly B2B logic and combines upstream logistics from dairy sites with downstream distribution of WPC80 and lactose to industrial buyers, making transportation and handling a key cost driver. Value creation is realised through processing and upgrading operations that recover and concentrate valuable fractions (proteins and lactose) and create a multi-output production logic. Value capture is based on product sales, while costs are dominated by processing effort and logistics, consistent with the typical economics of cascading configurations.

The resulting capability map summarises the most relevant implementation requirements for operating the whey business model as an instantiation of the Cascading and Repurposing pattern. In line with DSIR's purpose, the map does not aim to be exhaustive. Instead, it highlights those capabilities that are (i) structurally required to run the model end-to-end and (ii) most sensitive to

the typical failure modes of byproduct-based configurations, namely supply uncertainty, input variability, contamination risk, compliance burden, and logistics-driven cost pressure.

On the business side, the map therefore prioritises capabilities that stabilise the upstream feedstock interface and the downstream offtake interface. Secondary Feedstock Access & Sourcing captures the ability to secure reliable whey availability in terms of volumes, timing and baseline quality, which is a prerequisite for capacity planning and stable operations. Closely related, Take-Back & Return Flow Management is included to represent the organised acquisition and governance of the whey stream (pickup coordination, SLAs, responsibilities and escalation rules), acknowledging that "return flow" in this case refers to an industrial byproduct stream rather than consumer product returns. To address the operational risk of heterogeneous or contaminated inputs and the strict requirements of food-grade outputs, Stream Sorting, Grading & Quality Assurance is included as a central capability for intake testing, classification and specification management. The core value creation is represented through Pre-Treatment & Processing Operations, which covers the ability to run the conversion chain reliably, manage yields and losses, and deliver consistent outputs (WPC80 and lactose). On the market side, Secondary Market Sales & Offtake Management reflects the capability to develop and manage B2B demand, customer-specific specifications, contracts and pricing, ensuring that production and offtake remain aligned, including contract administration, pricing, and order-to-cash activities such as invoicing and payment terms. Finally, Cost-to-Serve & Logistics Economics Control is included because transportation and handling costs are a dominant economic driver in liquid-stream models and must be actively managed to avoid "logistics dominance". Two cross-cutting capabilities complete the map: Compliance & Liability Management to handle product safety, documentation and liability across handovers, and Performance & Impact Management to steer operations and communicate selected circularity and sustainability indicators at a shared level of abstraction.

On the enabling side, the selected technology/IT capabilities reflect the need for transparency, auditability, and operational steering across the end-to-end chain. Traceability & Chain-of-Custody provides batch/lot-level tracking from intake to product delivery and supports both quality governance and compliance. Quality Data Capture & Analytics enables systematic intake testing, grading decisions and faster detection of deviations. ERP/MES/WMS Integration for Secondary Streams ensures that secondary inputs and multi-output production are treated as first-class operational objects in inventory, scheduling and lot management. Compliance Automation & Audit Trail supports documentation, certificates and reporting workflows required for audits. Operational Visibility Dashboards provide decision-relevant monitoring of volumes, yields, reject rates, costs and bottlenecks across sourcing, processing and distribution. Where sustainability KPIs are explicitly reported, Impact Accounting Tooling complements the steering layer by linking footprint indicators to volumes and production performance.

Together, these capabilities provide a concise but coherent capability profile for the whey case, enabling DSIR users to perform implementation planning and gap analysis without requiring detailed inspection of the underlying process, network and dynamic models.

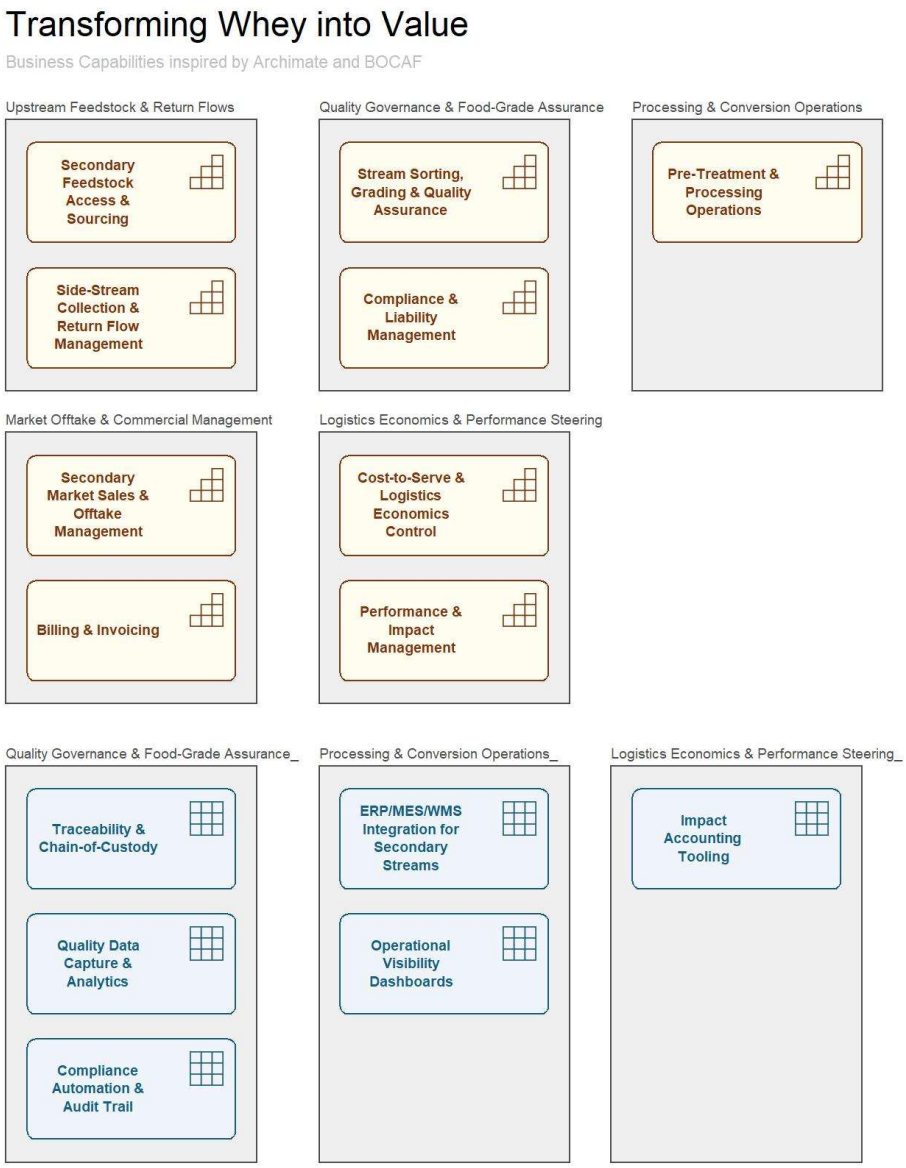


Figure 26: Capability Map Whey

Data Platform and Monitoring Dashboard

Within the DECIDE project, the consortium agreed on a consolidated set of eleven Key Performance Indicators that the Monitoring Dashboard renders for any Circular Economy Business Model stored in the DECIDE Data Platform. The catalogue is organised in two sections and distributed across the three Triple Bottom Line dimensions Ecological, Economic and Social. Section A contains six indicators that are derived automatically from the toolbox models (Business Model Canvas, e3Value, BPMN) and become available as soon as the case has been pushed into the data platform: the Business Model Profile Card, the Actor Ecosystem Map, the Value Exchange Summary, the Revenue vs Cost Snapshot, the Circularity Penetration Score and the Waste Hotspots & Opportunities view. Section B contains five pilot-reported indicators that are not derivable from the modelling artefacts and are therefore collected directly from the pilot owner: CO_2 Emission Reduction, Recycling Rate, Material Reuse Rate, Circular Revenue Share and Jobs Created.

The Section B indicators are integrated through a generic KPI extension schema stored in a dedicated named graph of the data platform. Each extension KPI requires only four properties (title, dimension, value and unit), which keeps the data collection burden low for pilot owners and allows the catalogue to be extended with additional indicators - including sector-specific or reporting-standard KPIs from established frameworks such as ESRS or GRI - without changes to the dashboard code. This design separates the methodological core of the toolbox from the pilot-specific reporting layer and makes the Monitoring Dashboard reusable across all eight pilot cases and beyond the project lifetime.

For the exemplary whey case, the dashboard combines the BMC structure of the enterprise, the e3Value flows between actors (cheese manufacturers, equipment manufacturers, logistics providers, workforce, energy supplier, nutritional supplement and food manufacturers, sports and health brands, pharmaceutical companies) and the BPMN process model of the. The full design, architecture, source code, KPI catalogue and SPARQL reference of the Monitoring Dashboard are documented in Deliverable D.1.2.5 Monitoring Dashboard.

Evaluate Artefact

Following Johannesson and Perjons (2021), the evaluation activity addresses the central DSR question of how well the developed artefact addresses the explicated problem and fulfils the defined requirements. In this deliverable, the evaluation focuses on the DECIDE Toolbox as an integrated methodological and software-supported artefact for the identification, development, validation, optimisation and implementation planning of CEBMs. The evaluation follows a naturalistic strategy: the artefact was applied, discussed and iteratively refined and evaluated within the DECIDE project context with method experts from universities, regional catalysts and SMEs across the Danube region. This diverse stakeholder constellation enables the assessment of the artefact both from a methodological perspective and with regard to its relevance, practical applicability and usability across different regional and organisational contexts. The Toolbox is thereby evaluated as a socio-technical artefact that combines methodological guidelines, software-supported tools, data integration and stakeholder-oriented visualisations. The evaluation comprises both formative and summative aspects. Throughout the project, feedback from Train-the-Trainer sessions, World Café discussions, DSIR capability workshops and pilot applications were collected and used to refine individual toolbox components, methodological mappings and supporting materials across subsequent design cycles. As the activities documented in this chapter were conducted toward the end of the project, they also consolidate summative evidence on the applicability of the toolbox in pilot cases and supporting components such as the Monitoring Dashboard, Data Platform and Digital Learning Concept.

The evaluation in this chapter consolidates the validation activities documented in detail in Deliverable D.1.2.9 and assesses the results with regard to the requirements defined in Table 3. It is structured along the three support gaps that guided the artefact design: transparency and orientation support, development and validation support, and implementation and capability support.

Evaluation Activities

The evaluation of the DECIDE Toolbox draws on several complementary validation activities that open different perspectives on the artefact. These include two Train-the-Trainer workshops with the DECIDE project consortium, a World Café format for structured reflection on the toolbox components, a DSIR capability workshop for the validation of the capability catalogue, the application of the toolbox in pilot cases across different sectors and regions of the Danube region, and dedicated validation activities for the CEBM Catalogue and the Value Chain Generator. The supporting components Data Platform, Monitoring Dashboard and Digital Learning Concept were additionally included in the evaluation. Together, these activities provide a broad evidence base for the assessment of the toolbox against the requirements defined in Table 3.

The two Train-the-Trainer workshops pursued different focal points. The first workshop took place in Târgu Mureș, Romania, and served primarily to familiarise the project partners with the DIGITRANS-based business model development logic and its extension within DECIDE. The participants worked through a compact workshop process from CE-oriented business model ideation via the Value Proposition Canvas and the Business Model Canvas to initial transitions into e3Value, BPMN and System Dynamics. The aim was to establish a shared methodological foundation and to test the transition from early business model ideas to more formal modelling perspectives.

The second workshop took place in Böblingen, Germany, and focused on the individual toolbox components and the development of methodological application expertise. The Whey training case from Chapter 7 served as the shared application reference. Prepared models for BMC, e3Value, BPMN and System Dynamics were provided that deliberately contained gaps and inconsistencies to stimulate cross-perspective comparison and refinement. Participants were asked to complete missing elements, perform basic analyses (break-even calculation in e3Value, time and cost analysis in BPMN, scenario simulation in System Dynamics) and interpret the resulting outputs. Tool experts were available for hands-on support. A total of 22 persons attended the two workshops, including representatives from SMEs, regional catalysts and university partner organisations.

The concluding World Café was conducted following the second workshop in Böblingen and provided structured group feedback in nine perspective-specific rounds. Four rounds addressed the central modelling perspectives (BMC, e3Value, BPMN and System Dynamics) and five rounds addressed the supporting components (CEBM Catalogue, Monitoring Dashboard and Data Platform, Pilot Impacts, Workshop Concept and Digital Learning Concept). Each table discussed three guiding questions: (i) What insights and value can be gained from the model, also with regard to the target groups? (ii) What insights are missing that are considered relevant for the target groups? (iii) What challenges occurred during modelling and how were they addressed? The questions were slightly adapted for the non-modelling components.

The DSIR capability workshop was held as part of a project partner meeting in Croatia and was conducted as a dedicated evaluation activity for the implementation and capability support of the toolbox. The project partners received a structured working document containing the full DSIR capability catalogue from Deliverable D.1.2.3 and were asked to (i) classify their pilot case according to the relevant CEBM pattern, R-strategy and design strategy, (ii) rate the relevance of each catalogue capability for their specific case using a three-step scale (++ very relevant, + relevant, 0 not relevant), (iii) document case-specific notes, renaming and adaptations for each capability and (iv) propose additional capabilities not yet contained in the catalogue. The workshop concluded with the same three reflection questions as the World Café, ensuring methodological consistency with the evaluation of the modelling perspectives.

The validation of the CEBM Catalogue was also conducted by the project partners at the partner meeting in Croatia. Individual catalogue entries were distributed among the partners in a workshop and reviewed using a structured validation form. The focus was on intelligibility,

completeness, consistency and practical usability of the case descriptions. The feedback concerned language improvements, consistency of company names, clarification of specific terms, the linkage to sectors and circular strategies, and the overall readability for international users.

The validation of the Value Chain Generator addressed the potential of the tool both for describing existing CEBM cases and for identifying new value creation potentials. Selected pilot cases were re-analysed to identify alternative circular economy strategies, possible valorisation pathways and additional business model opportunities. These results were discussed with the respective project partners and partly also with the participating companies.

Finally, the application of the toolbox in nine pilot cases from different regions and sectors of the Danube region complemented the workshop-based activities with a cross-sectoral validation under realistic application conditions. Table 8 provides an overview of the pilot cases. Different combinations of toolbox components were applied depending on data availability, company interest and maturity of the respective case.

Table 8: Pilot Cases

Region	**Pilot Case**
Germany	Sourcing Energy from Biomass
Slovenia	From Tomato Stems to Paper Products
Bulgaria	Surprise Boxes for Fighting Food Waste
Hungary	PLA Filaments to Replace Traditional Materials
Romania	Making Dehydrated Fruits and Veggies from Leftovers
Austria	Making Flags from Old Textiles
Croatia	Work Integration through Textile Waste Management
Moldova	Household-level Battery Recycling
Bosnia and Herzegovina	Products Made of Recycled or Biodegradable Materials

Evaluation of Transparency and Orientation Support

The evaluation activities show that the CEBM Catalogue (D.1.2.7) and the Value Chain Generator (D.1.2.2) address the transparency and orientation gap by providing structured, low-threshold access to CEBM case knowledge and value-chain-oriented knowledge. The World Café discussion on the CEBM Catalogue showed that the participants consider the central bundling of toolbox services, case examples and supporting materials valuable. Training materials, case examples and a clear overview of the available support were considered particularly relevant. At the same time, the participants identified functional improvement needs: better differentiation between service types, clearer user guidance, and stronger linkage with the other toolbox elements, particularly the Monitoring Dashboard. The discussion confirms the potential of the CEBM Catalogue as a low-threshold orientation offer for companies and regional actors, provided that it is designed in a user-oriented and practically navigable way. The complementary structured validation of the individual catalogue entries by the project partners led to concrete improvements with regard to intelligibility, completeness, consistency and readability of the case descriptions.

The validation of the Value Chain Generator showed that the tool not only describes existing CEBM cases but can also reveal new value creation potentials and extension opportunities for existing or planned business models. In the biomass-based pilot cases, the Value Chain Generator enabled the identification of alternative valorisation pathways, additional conversion technologies and potential offtake markets. Beyond the initial identification of new CEBMs, the Value Chain Generator thereby also opens a bridge back into the toolbox workflow: when an existing business model is to be extended through alternative conversion technologies or complemented through new offtake markets, the subsequent modelling perspectives (BMC, e3Value, BPMN, System Dynamics) need to be revisited to structure, validate and simulate the extended configuration.

The validation activities show at the same time that both components unfold their full benefit when embedded in the toolbox workflow. The orientation gained through the CEBM Catalogue and the Value Chain Generator becomes most actionable when it can be linked to the subsequent modelling activities. This result confirms the design decision to position both components as early-stage entry points into the integrated toolbox workflow rather than as isolated information systems. Overall, the evaluation activities provide evidence for the fulfilment of the requirement for low-threshold access to CEBM case and value-chain knowledge (R1) and identify concrete improvement potentials for the functional integration of both components into the overall workflow.

Evaluation of Development and Validation Support

The validation activities suggest that the four modelling perspectives contribute differently but complementarily to the development and validation of CEBMs. The findings indicate in particular that strategic, value-oriented, operational and dynamic perspectives address different requirements and build on each other within the integrated workflow.

The Business Model Canvas (BMC) was perceived in the World Café discussions and Train-the-Trainer sessions as an accessible and intuitive tool. Participants appreciated in particular the structured and easily comprehensible overview for communication, ideation and stakeholder discussions. At the same time, it became clear that the standard BMC reflects the specific requirements of circular business models only to a limited extent, particularly with regard to ecosystem relationships, circular strategies and quantitative value creation. These aspects are further specified by the subsequent modelling perspectives. The findings thus provide evidence for requirement R4 on systematic and customer-centric business model development support, and at the same time show the role of the BMC as an entry point and structuring reference element for the further modelling steps.

The e3Value perspective complements the BMC by making actor constellations, value flows and economic reciprocity explicit. Stakeholder feedback indicated that this perspective is particularly relevant for understanding network business models and provides a basis for discussing economic viability and alternative configurations. At the same time, it became apparent that the interpretation of e3Value outputs, particularly with regard to financial variables, scenario comparisons and the demarcation from dynamic developments, requires additional guidance. These hints are addressed through the Dashboard integration and training materials. The findings support requirements R2 on network business model modelling and visualisation, R3 on NBM modelling and calculation, R5 on viability and scenario analysis, and R6 on BM-to-business-case transformation.

The BPMN perspective was validated as particularly valuable for a detailed understanding of operational business processes. It made activities, responsibilities, handovers, throughput times, resources, capacities and cost drivers explicit. This was particularly relevant where business model assumptions depend on concrete operational workflows, logistics chains, production steps or resource availabilities. The resource-based BPMN simulation additionally enabled the linkage of organisational resources and roles with process activities, so that personnel costs, execution times and capacity-related assumptions can be consistently analysed. At the same time, BPMN was

perceived as comparatively demanding and therefore requires methodological guidance. These hints are addressed through training materials. The findings support requirement R7 on operational process detailing and feasibility assessment and additionally contribute to the parametrisation of subsequent dynamic analyses.

System Dynamics was evaluated as a complementary perspective for multidimensional and dynamic impact analysis. The method enabled the representation of feedback structures, time-dependent developments and scenario-based effects across economic, ecological and social dimensions. Participants emphasised the potential for understanding long-term implications and interdependencies, but also noted the need for careful parametrisation, facilitation and interpretation support. These concerns were addressed by using the Dynamic Business Model Canvas for Sustainability as a structuring template to focus the modelling process and to define relevant system boundaries, variables and impact dimensions. In addition, training material and prepared example models were provided to guide participants through the modelling logic, parameterisation and interpretation of simulation results. The findings support requirement R8 on multidimensional, dynamic impact evaluation.

During the practical application in the Train-the-Trainer setting, the participants used the cross-perspective mappings, particularly between BMC, e3Value and BPMN, to compare, complete and reconcile model artefacts. This supported the traceability of assumptions and the iterative refinement between perspectives. The findings thus provide evidence for requirement R9 on workflow-based methodological integration and the preservation of assumptions, parameters and traceability across modelling steps.

Beyond the modelling perspectives, the Monitoring Dashboard, supported by the Data Platform, addresses the requirement for accessible, cross-perspective result integration. The World Café round on the Dashboard showed that the participants consider a clear presentation of economic, ecological and social indicators, circular characteristics and ecosystem-related information for different target groups as central. A strong preference was expressed for interactive and intuitive functions such as filtering, sorting, visual storytelling and simple explanatory content. The Dashboard was overall regarded as a potentially high-value interface for translating modelling outputs into accessible and communicable formats, particularly for SMEs and regional development actors. The Triple-Bottom-Line view implemented in Deliverable D.1.2.5 with toolbox-derived and pilot-reported KPIs, together with the Data Platform described in D.1.2.6 as a semantic integration infrastructure, jointly address this requirement. The findings thereby support requirement R10 on accessible multi-perspective result integration.

Evaluation of Implementation and Capability Support

The DSIR capability workshops provided evidence for the relevance of capability-oriented implementation planning and complement the evaluation of the modelling perspectives with an implementation-oriented dimension. The application of the DSIR capability catalogue to pilot cases showed that stakeholders require support in the transition from business model and process insights to implementation-relevant capabilities. This confirms the problem explicated in Chapter 4 that modelling outputs alone do not automatically clarify which business and IT capabilities are required to implement and operate a CEBM.

The application of the DSIR capability catalogue is illustrated based on two cases from different sectors and CEBM patterns. The ICP case from Slovenia, which focuses on the transformation of tomato stems into paper products, was classified as a Cascading-and-Repurposing pattern with relevance for both biological and technical cycles. The participants identified Secondary Feedstock Access and Sourcing, Take-Back and Return Flow Management, Stream Sorting/Grading and Quality Assurance, Pre-Treatment and Processing Operations, Cascade Pathway Design, Industrial Symbiosis Orchestration, Secondary Market Sales and Offtake Management, Compliance and Liability Management as well as Operational Visibility Dashboards as highly relevant capabilities. In addition, they proposed three additional capabilities that are not yet contained in the catalogue: Biomass Stabilisation and Preservation Management, Foreign Material De-polymerisation and Washing and Fibre Degradation Predictive Modelling. These extensions reflect the specific operational challenges of agricultural by-product valorisation.

In contrast, the FoodOBox case from Bulgaria, a digital platform for redistributing unsold food, was used as a case that challenges a straightforward assignment to one of the existing DSIR catalogue patterns. As a working classification, it was related to Reuse and Redistribution, because edible surplus food is redirected to consumers before it becomes organic waste. However, the case also relates to food waste prevention and platform-based coordination and therefore cannot be fully captured by a material-flow-oriented interpretation of product reuse alone. This ambiguity was reflected in the workshop results, as participants considered capabilities linked to several R-strategies and catalogue patterns as relevant for the case. The participants identified Customer Access and Booking, Supplier–Customer Matching and Market Intermediation, Food Redistribution and Handling, Resale and Remarketing Execution, Partner and Collector Coordination, Marketplace and Transaction Platform as well as Performance and Sustainability Measurement as highly relevant capabilities. Several DSIR capabilities from different R-strategy and pattern contexts had to be reinterpreted to fit the context of food redistribution: capabilities originally conceived for

physical product reuse, resale or repair were adapted to edible surplus food, platform orchestration and time-sensitive coordination processes.

The reflection questions yielded two central findings across the participating cases. First, the case-based application of the DSIR catalogue made implementation requirements visible along upstream sourcing, downstream offtake and cross-cutting compliance, supporting structured discussions about capability priorities and gaps before detailed implementation work.

Second, the application of the catalogue revealed the need for case-specific adaptation and further refinement of the relationship between CEBM patterns, R-strategies and the corresponding capabilities. Several cases could not be assigned straightforwardly to a single dominant R-strategy or pattern. For example, the FoodOBox case combined food redistribution, food waste prevention and digital platform coordination, while other cases combined multiple R-strategies, biological and technical material flows, or different circular logics for inputs and outputs. This indicates that the current pattern-based structure of the catalogue provides a useful starting point, but that practical case application often requires interpretation, adaptation and the selection of capabilities across several R-strategy and pattern contexts. The workshops therefore also served as a mechanism for improving the catalogue: participants documented unclear classifications, adapted existing capabilities to their case context and proposed additional capabilities where relevant. Working approaches that emerged included assigning multiple relevant strategies to one case, distinguishing between input and output logic where appropriate, separating material-flow logic from platform coordination logic and treating the DSIR catalogue as a structured but evolving reference resource rather than as a fixed classification scheme.

Together, these findings provide evidence for requirements R11 and R12 and confirm the design of the DSIR capability catalogue as a structured but evolving reference resource for capability-oriented implementation planning. The catalogue offers a viable structured basis for identifying and mapping business and IT capabilities while accommodating case-specific adaptations and continuous content-level extension

Synthesis

Overall, the evaluation activities show that the DECIDE Toolbox addresses the three support gaps identified in Chapter 4 and provides evidence for the requirements defined in Table 3. The CEBM Catalogue and the Value Chain Generator support transparency and orientation by making case knowledge and value-chain-oriented knowledge accessible to companies and regional catalysts (R1). The combination of BMC, e3Value, BPMN and System Dynamics supports the development and validation of CEBMs from complementary perspectives. The BMC provides a structured entry point and structuring reference element (R4); e3Value addresses network business model modelling, calculation, viability analysis and BM-to-business-case transformation (R2, R3, R5, R6); BPMN supports operational process detailing and feasibility assessment (R7); and System Dynamics enables multidimensional, dynamic impact evaluation (R8). The cross-perspective

mappings between these modelling languages support workflow-based methodological integration (R9). The Monitoring Dashboard, supported by the Data Platform, addresses accessible multi-perspective result integration (R10). The DSIR capability catalogue and the capability map support the translation of modelling outputs into capability-oriented implementation requirements (R11) and the identification of capability gaps (R12). The capability catalogue should therefore be understood as a structured but evolving reference resource that accommodates case-specific adaptations and continuous content-level extension.

The supporting components reinforce the applicability and transferability of the toolbox. The Data Platform provides the semantic integration infrastructure for model-derived data and additional triples. The Monitoring Dashboard supports accessible interpretation of modelling outputs. The Digital Learning Concept and the training materials support consistent application by user groups with heterogeneous prior knowledge. These components do not replace the methodological core of the toolbox but improve its practical usability, repeatability and transferability across different regional and organisational contexts, contributing to the evaluation of the toolbox as a socio-technical artefact. The improvement potentials identified throughout the evaluation activities, including the further refinement of the relationship between CEBM patterns, R-strategies and capabilities, including platform-oriented cases patterns and the stronger functional integration between the CEBM Catalogue, modelling tools, Data Platform and Monitoring Dashboard, are future research.

Conclusion

This deliverable has addressed the research question of how an integrated toolbox can support the transparent identification, modelling, validation and implementation planning of Circular Economy Business Models (CEBMs) across regional, sectoral and organisational contexts. The starting point was the observation that companies and regional catalysts face three recurring support gaps in the development and implementation of CEBMs: a transparency and orientation gap, a development and validation gap, and an implementation and capability gap. Based on a Design Science Research approach following Johannesson and Perjons (2021), the DECIDE Toolbox was designed as a response to these three gaps, demonstrated through the Whey training case and evaluated through Train-the-Trainer workshops, World Café discussions, DSIR capability workshops, catalogue validations, Value Chain Generator applications and the application in nine pilot cases across the Danube region.

The DECIDE Toolbox is not a collection of individual methods or software components but a socio-technical artefact that combines methodological guidelines, digital tools, data integration, visualisations and learning support. The CEBM Catalogue and the Value Chain Generator provide low-threshold access to case knowledge and value creation potentials. The Business Model Canvas, e3Value, BPMN and System Dynamics cover the strategic, value-oriented, operational and dynamic dimensions of development and validation and are linked through cross-perspective mappings. The Monitoring Dashboard, supported by the Data Platform, translates modelling outputs into

accessible, stakeholder-oriented representations. The Digital Service Implementation Recommender extends the toolbox with a capability-oriented implementation perspective. The Digital Learning Concept and the training materials support consistent application by user groups with heterogeneous prior knowledge.

The evaluation indicates that the integrated workflow is perceived as practically useful, that the four modelling perspectives are complementary in addressing the representational gaps identified by participants and that decision-relevant evidence on economic, ecological and social outcomes can be produced prior to implementation when the workflow is supported by adequate facilitation and reference material. Beyond its methodological contribution, the artefact thereby offers practitioners a pragmatic path from early ideation to implementation-oriented validation of CEBMs. At the same time, the evaluation has revealed concrete development directions. The DSIR capability catalogue should be extended toward platform-oriented CEBM patterns, since the current pattern framework focuses on material-flow-oriented cycles and platform-based business models such as the FoodOBox case require substantial reinterpretation. The functional integration between the CEBM Catalogue, Value Chain Generator, modelling tools, Data Platform and Monitoring Dashboard should be strengthened to make the transition between early-stage orientation, modelling and result presentation more seamless. Future research should expand evaluation across diverse CEBM types and additional cases, strengthen uncertainty and sensitivity analysis in System Dynamics modelling and explore AI-supported approaches to cross-model handovers, including parameter extraction, consistency checks and traceability support. On the tool side, further formalising the mapping logic and providing more integrated analysis views within the ADOxx environment could improve usability for non-expert users.

With regard to transferability beyond the project, the toolbox provides a viable basis for continued application. The modelling components build on established platforms such as ADOxx, which continues to develop beyond the project lifetime, and Vensim for System Dynamics modelling. The CEBM Catalogue, the Value Chain Generator and the Monitoring Dashboard are maintained by project partners and remain available to interested users. The Digital Learning Concept and the training materials are designed to enable knowledge transfer beyond the project consortium. The project partners from the Danube region have acquired the methodological application expertise to apply the toolbox in their own consulting and training formats and to act as multipliers within their regional innovation ecosystems. Regional catalysts can use the toolbox to support SMEs in the structured identification, assessment and implementation of circular business models. Companies receive low-threshold entry points through the CEBM Catalogue and the Value Chain Generator and can, where needed, work with catalysts or project partners to engage with the more in-depth modelling and implementation perspectives.

In conclusion, this deliverable shows that the research question posed in the introduction is meaningfully addressed by the DECIDE Toolbox. An integrated, multi-perspective and socio-technically embedded toolbox can support the transparent identification, modelling, validation and implementation planning of CEBMs across regional, sectoral and organisational contexts when it is designed as a methodologically integrated workflow rather than a collection of isolated tools. The DECIDE Toolbox provides this foundation and is ready for continued application, extension and scaling beyond the project lifetime.

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