Design of a circular supply chain for electricity grid components

A Stedin case study

Y.J.P. (Yoeri) Martens MSc

Delft University of Technology

TU Delft

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by

Y.J.P. (Yoeri) Martens MSc

Master thesis of the master Transport, Infrastructure & Logistics
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Student number:	4670310	
Thesis committee:	Ir. M.W. (Marcel) Ludema	TU Delft (TPM), Daily supervisor
	Dr.ir. A.J. (Arjan) van Binsbergen	TU Delft (CiTG), Chair
	R. (Rick) Calame MSc	Stedin

Cover Image: Hans van Bergen

Preface

This thesis represents the end of my master's in Transport, Infrastructure and Logistics at the Delft University of Technology. Without the assistance of several people, this thesis would not have come to its current conclusion.

Firstly, I would like to thank my daily supervisor Ir. Marcel Ludema and my chair Dr. Ir. Arjan van Binsbergen for the valuable supervision they have given throughout the entire project. Their feedback, input in discussions and assistance during the many meetings we have had have proven very valuable in coming to the end-result that is this thesis report.

Secondly, I express my gratitude to my company thesis supervisor Rick Calame for all the interesting conversations we have had. You have continuously made sure to give me all of your time I needed, something I highly appreciated. Our discussions gave valuable direction and feedback to my project. Also, I would like to thank Stedin for facilitating this research and all my Stedin colleagues for providing so much useful information. This project was build on expert opinion and there is a long list of people that give their time as an expert. I would like to thank them all for their help.

Naturally, the support of those not directly involved can be equally significant. First I would like to thank Jeroen, who brought me in contact with Stedin to begin with. I am also grateful to my family for all their support during my thesis and six and a half preceding years of academic study. A special thank you goes out to my friend Jeroen, with whom I discussed the project more than almost anybody else and who peer reviewed this report. Last but not least, I want to express my gratitude to all my friends, too numerous to list by name, for their encouragement and support. You are all really appreciated.

Yoeri Martens
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Summary

The Netherlands has the ambition to be climate-neutral in 2050, while the current Dutch energy system is still very much dependent on fossil fuels. This means the Dutch economy needs to be electrified to switch to low- or zero-carbon solutions. As a result, it is expected that between 2019 and 2050, the electricity demand will rise by up to 263%. Providing the right infrastructure to transport this increased amount of electricity is made even more difficult by large fluctuations in the demand and supply of electricity. The electrification of our energy system requires a significant expansion of the electricity grid. This expansion means a higher need for electricity grid assets like cables and transformers, increasing raw material demand and CO_2-eq emissions.

In the current distribution grid, there are almost a hundred thousand transformer stations and three hundred thousand kilometers of cables. Depending on the electricity growth scenario, this will grow to over 150 thousand stations and four hundred thousand kilometers of cables in 2050. This not only means that new infrastructure has to be built but also that current grid infrastructure has to be replaced.

From 2025 onwards, Dutch DSOs (Distribution System Operators) are expected to invest over eight billion euros a year in the grid. This research is done as a case study for Stedin, one of the largest DSOs in the Netherlands, serving over two million customers with their electricity. For Stedin, this expansion challenge means an increase from 830 million in 2023 to an investment volume of 1.2 billion in 2026. This required a strategy shift of Stedin from operational excellence, which was focused on costs, to a 'Built, Exploit, Administer' strategy where the SC organisation focuses on 100% On-Time and In-Full (OTIF) availability of materials and an organisation-wide focus on the maximal contribution instead of costs. Endangering this effort, the International Energy Agency expects that the raw material demand for metals required in this electrification will surpass supply already in 2030.

Therefore, Stedin wants to implement a circular supply chain (CSC) to reduce primary, or virgin, material use and CO_2-eq emissions while increasing material availability by reusing assets and materials. Stedin has formulated the goals to reduce CO_2-eq emissions by 42% and virgin material use by 40% from 2021 to 2030, which is especially difficult given the rise in investment volume. Integrating the principles of the circular economy into the Stedin SC is expected to contribute to these targets.

This design project will help Stedin realise a consistent and complete CSC and offers direction for its implementation. Hence, the design objective formulated for this project is to design a semi-closed CSC for the redeployment and recycling of Stedin's electricity grid assets for 2030 from a high-level process orientation. There are already circular practices within the SC of Stedin but these are disregarded at first in the design process to give space to original thinking. Later, a current state analysis will help to make a connection between the new design and the existing activities in the implementation plan.

The first step is, through expert collaboration, to determine the most relevant asset classes that will be in the project's scope. This is done regarding SC and the sustainability impact generated by a CSC implementation. Stedin uses many asset types in the electricity grid, but not all classes are relevant to the design process. This is primarily when the expected reverse flows of an asset are relatively small, or the emissions and material use of the asset type are low. A workshop with stakeholders determined that cables and transformers for the various voltage levels are the most relevant.

For the cables, it is estimated that the reverse flow coming into the CSC in the year 2030 will be around *Redacted* thousand tons of material, mainly plastics, copper, and aluminum. Additionally, almost *Redacted* transformers are returned from the grid that year, representing nearly three thousand tons of material. This totals over *Redacted* million kilograms of assets that can be recycled or whose lifespan can be extended. This is around *Redacted* percent of the material demand for cables and transformers in 2030. Although the focus is on cables and transformers, one of the objectives is to make the CSC suitable for other asset types.

The design process is guided by three methods: the evolved double diamond method (EDD), the

SCOP method, and the CSC guiding framework. The SCOP method has a top-down approach, which is suitable for new supply chain design as one can move from an abstract starting concept to an increasing level of detail. The CSC guiding framework gives the concrete building blocks for CSC design, which the SCOP method lacks as it focuses more on overall SC design. As both methods lack guidance for the total overall design process, the EDD method is used to structure this process into a research and design part. These methods have not previously been used together in a design process.

The first part of the EDD is the research diamond, which is where the problem is discovered and defined. The main result of the first research diamond is the list of requirements that form the basis for what the design has to do and should be. The input for requirement generation includes Stedin's corporate, SC, and ESG strategies, the reviewed scientific and practitioner CSC literature, and further obtained general knowledge on Stedin operations and SC activities from internal documentation and expert consultation. Through a workshop, a group of internal experts validated these requirements to gain engagement with the design project, generate new ideas, and have approval to go to the design diamond.

After completing the research phase, the second diamond starts with the development of the CSC design. The SCOP method structures this at the macro, meso, and micro SC levels, where each level has more detail of the SC worked out. The first result of the design phase is thus a macro-level design that is taken one step further in a meso-level design. From the meso design, nine design decisions surfaced that form the beginning of the micro-level design, and tools are made to elaborate and evaluate the decision options. Finally, an implementation plan will combine these results into an actionable plan for Stedin.

The first use of the circular strategies from the 9R ladder is important in the macro-level structure. The 9R ladder is fundamental to the CSC design as this is the generally accepted list of circular strategies that can be used in a CSC. These strategies form a funnel through which the returned assets can go. Each strategy is abbreviated with the letter R and a number, where a higher number means it is a less circular strategy.

These strategies relevant to this project focus on the lifespan extension of the asset or the useful application of the materials in an asset. This means that in the macro design, these are the two main loops that are visualised together with the return flow of unused materials from the building site. A first separation is made in the lifespan extension loop in reuse (R3), repair/refurbish (R4/R5), remanufacturing (R6), and repurposing (R7). The second loop is concerned with the useful application of materials which includes the recycling (R8) and energy recovery (R9) of materials.

Also important in the macro design is the visualisation and focus on the partners involved and the information flows between them. Literature states that information exchange between partners in a CSC is extremely important as information and material flows are going both ways instead of the one-way stream in a traditional linear SC. This is why the forecast information flows are so clearly integrated into the macro design. New systems must be created for information exchange as both a forecasting system needs to be set up (and supporting data collection) and a support system for information exchange between partners internally and externally.

The next design structure level is the mesostructure, which is the most relevant for Stedin as this features a level of detail that is sufficiently coarse to sketch a clear picture but leaves the detailed steps for later. Stedin stated at the start of the project that they first require a more high-level design for the CSC, which can then be built on with more detail. This also means a deepening of the circular strategies of the 9R ladder. In the macro design, the reuse, remanufacturing, and repurposing were already separately shown, but in the meso design also, repair, refurbish, recycle, and recover have distinct activity blocks. This meso design offers the possibility for multiple closed-loop systems. The lifespan extension strategies result in renewed use of the assets in the Stedin value chain, but also the recycling of materials in new to-build assets is an example. Materials only leave the system for repurposing, recovery, and recycling of materials outside the value chain.

A difference is made between the general meso design and a separate design for the power transformers. Because of their weight and size, the assets are unsuitable for many transport movements. For this reason, having the assets sorted and tested at the construction site is preferable. This is possible because the construction site for high voltage is much bigger and often more remote, so it has much more free space than distribution transformers installed in urban areas. The rest of the design for power transformers is not different from the regular design, except that there is no return flow from unused assets because of their size.

Important in the execution of the design is the circularity funnel. The standard aim is to process an asset as high on the R ladder as possible, and policy has to be made to facilitate this. However, a Life Cycle Assessment needs to be done to ensure the chosen strategy is the most sustainable strategy and not just the highest strategy on the R ladder. Also, the necessity of making repeated forecasts for different time horizons of the reverse flow is already mentioned in the macro design but has to be elaborated on. An ICT system should facilitate the information exchange between CSC partners, and an extra system is needed for data collection, performance management, and forecasting. Also important is that all processing is safe and happens according to relevant laws and quality standards. Specifically for repurposing, it is important not to perform reconditioning activities, as this would be too commercial.

The next step in the design process is to focus on nine key remaining design decisions. The meso design will function as a backbone of the Stedin CSC, and these design decisions need to be made to make the next step to a microstructure design. Four decisions are related to the lifespan expansion loop, three to the material recovery loop, and two to transport and storage. There are two most important ones. The first is on the outsourcing decision for reconditioning activities, and several decisions are dependent on this choice (use of remanufactured parts, location of reconditioning, and distance of remanufacturing partner). The other is the creation of a mass-balance certification system for material recycling, which affects material recovery choices and cable stripping decisions. Most of these key decisions will not alter the structure of the mesostructure design but will deepen some of the activity blocks. For four decisions (location, recovery, stockpile, and distance), the design is slightly affected by the choices made.

Two frameworks are developed in this project to guide Stedin in structured decision-making: an elaboration framework and an evaluation framework. The elaboration framework has four parts and serves as a start for all nine decisions. These four parts are the choice elaboration, the decision impact, a description of the lacking information, and the decision-makers. The elaboration framework helps decision-makers to have a clear overview of the decision at hand, and subsequent decision-making can be done informally. The evaluation framework provides more formal support for the decision-making process.

For both decisions (outsourcing and mass-balance system), a MCDA method is chosen for evaluation, along with the pairwise comparison method for criteria weight determination and an expert-based scoring method for performance evaluation. Both decisions have important non-financial impacts that should be included in the evaluation, making techniques like a cost-benefit analysis unsuitable. A first set-up is provided for the methods for the two decisions. For the outsourcing decision, six criteria are selected: investments, price per asset, organisational complexity, supplier dependency, capacity and knowledge. As said, the stakeholders can weigh these criteria via the method of pairwise comparison. For the mass-balance decision, the criteria are: costs Stedin, price per asset, circularity, supply security, and bureaucracy.

The meso design and key decision list must be compared to Stedin's current state of circular activities. In the current state analysis, the process steps for the circular activities are mapped for MS & LS cables, HS cables, power transformers and distribution transformers. Each asset type has slightly different process steps that are followed. The lack of remanufacturing is the most important factor in comparing the as-is CSC with the to-be CSC in 2030. Recycling and redeployment of assets are already done, and the key decisions will especially help to build on those activities and make improvements. Remanufacturing of asset parts, however, is not facilitated, and capabilities for these activities have to be in- or outsourced. Also, there is no system in place to forecast information exchange with CSC partners, and there is no possibility of the direct reuse of recycled material in new assets.

There will also be interfaces between Stedin's CSC activities and current operations. However, these are less visible in the meso design as they mostly depend on the key decision choices. The biggest example of this is the insourcing of reconditioning activities, which would need to be embedded in existing logistical processes. For the construction site, the most important interface is on asset collection. Teams should be more aware of the possibilities of circularity and need to retrieve all decommissioned asses and handle them with care.

Implementation projects are identified from the backbone design and key decisions and later organised according to a complexity classification. In this classification, the most challenging project type are chaotic projects. However, there are no chaotic projects in the CSC 2030 vision implementation due to the lack of time pressure and stakeholder conflicts. There are six structured projects, three complicated projects, three complexicated projects and nine complex projects, totalling 20 projects for implementing the CSC. These projects vary from policy projects like the possibility of stockpiling new power transformers or creating a circularity strategy funnel with Asset Management to IT-related projects on forecasting and information exchange to the execution of logistical concepts for insourcing reconditioning or creating a DC for redeployment power transformers.

The implementation plan ends with a project planning and prioritisation of the projects. Four different time frames in the planning are chosen: 2024, 2025, 2026 & 2027 and 2028 - 20230. This reflects the need for some projects to be executed in the short-term, medium-term or long-term. The main focus of the last time frame until 2030 is mainly to expand the CSC beyond cables and transformers to other asset types. Within each planning category, the projects are prioritised based on their impact on the CSC creation goals and their importance in proceeding with other projects.

This implementation plan makes the design process results actionable for Stedin and helps realise the 2030 vision for the CSC. As said, Stedin already has existing circular practices, but this project helps create a consistent and more detailed CSC. The current state has organically grown, and this design provides additional process activities that are currently lacking, like remanufacturing, forecast information exchange with CSC partners, and reuse of recycled materials into new assets. Other improvements in the details of the CSC come from the nine key design decisions in which the elaboration and evaluation frameworks support decision-makers. When all projects are implemented, around *Redacted* million kilograms of cables and transformers can be circularly processed in 2030. This is around *Redacted* percent of the material demand for cables and transformers, which means that if all material is retrieved, the sustainability goals of Stedin on circularity can already be reached by implementing the CSC. Additional initiatives in asset design can even further increase the percentage of non-virgin material use.

The project discussion highlights several key points regarding reproducibility, limitations, and recommendations stemming from the research. A potential challenge is the replication of the results due to the extensive reliance on expert consultations, which are also not formally recorded. Other researchers could speak on the same topics with the same experts, but the results from these conversations should ideally be similar, but this cannot be guaranteed. Other examples of the limitations of heavy expert consultations are the problems of prior knowledge during the material scoping workshop and anchoring during the requirements validation.

Despite this limitation, deviations in outcomes are deemed unlikely to substantially alter the overall meso design due to the consistent application of circular strategies from the 9R ladder. Variations will especially occur in specific design decisions and requirement generation. Additionally, the reliability of the reverse flow estimation is questioned as it mainly relies on investment plans and DVO codes (indicating the type of work being done on a project) that have uncertainties in the data. Potential further research could look into improvements in forecasting methods using comprehensive data sources like GIS systems.

Furthermore, using a combination of the EDD, SCOP, and CSC guiding framework is important. While these frameworks provide structure and direction, gaps remain, particularly in offering designers more concrete design steps and helping in the actual creation of the design. Recommendations for further research include exploring gas assets, refining reverse flow estimation methods, and analyzing the performance of the CSC design on the design objectives of CO_2-eq emissions and circularity. Additionally, it would be interesting for more research to be done on using a MCDA in design component selection, which seems a novel approach and could raise problems in dependencies between component choices. Finally, the suggestion is given to seek inspiration from case studies in other sectors to enrich the CSC design process and potentially uncover overlooked design options.

Contents

Nomenclature

Abbreviations

Abbreviation	Definition
AHP	Analytic Hierarchy Process
AM	Asset Management
ASD	Acquisition, Sorting, Disposal
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CD	Customer-Driven
CDC	Central Distribution Center
CE	Circular Economy
CEA	Cost-Effectiveness Analysis
CL	Closed Loop
CSC	Circular Supply Chain
CSCD	Circular Supply Chain Design
DC	Distribution Center
DD	Double Diamond
DM	Decision Maker
DMS	Decision-Making Situation
DSO	Distribution System Operator
DT	Distribution Transformer
DVO	Service Renewal Agreement
EDD	Evolved Double Diamond
EEA	Economic-Effects Analysis
ESG	Environmental, Social, Governance
FTE	Full Time Equivelant
GD	Grid Driven
GDSS	Group Decision Support System
GIS	Geographic Information System
GPLK	Armoured Paper-Lead Cable
GWh	Gigawatt hours
HS	High Voltage
IT	Information Technology
IP	Implementation Plan
kV	Kilovolt
kVA	Kilovolt Ampere
LCA	Life Cycle Assessment
LS	Low Voltage
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
MS	Medium Voltage
OEM	Original Equipment Manufacturer
OL	Open Loop
OPEX	Operational Expenditure
OTIF	On-Time and In-Full
PM	Project Management
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
PT	Power Transformer

Abbreviation	Definition
RSC	Reverse Supply Chain
SAW	Simple Additive Weighting
SBTi	Science Based Targets initiative
SC	Supply Chain
SCBA	Social Cost-Benefit Analysis
SCC	Supply Chain Center
SCD	Supply Chain Design
SCOP	Supply Chain Outline Process
SHQ	Safety, Health, Quality
SMART	Simple Multi-Attribute Rating Technique
SPC	Socio-Political Complexity
STC	Structural Complexity
TOPSIS	Technique for Order Preference by Similarity to the Ideal Solution
TSO	Transmission System Operator
VM	Vendor Management
XLPE	Cross-Linked Poly Ethylene
ZP	Business Project

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1 Introduction

Energy systems are the foundation for the welfare and prosperity of a society. The way we live, travel, work, consume and produce are highly dependent on the energy systems in place and are currently largely dominated by fossil fuel-based systems. The Netherlands have the ambition to be climate neutral in 2050 and this requires a transition towards electrification of the Dutch energy system (Ministerie van Economische Zaken en Klimaat, 2023). The infrastructure for electricity transportation and distribution in the Netherlands is divided between one transmission system operator (TSO), Tennet, and several distribution system operators (DSO). This research is done for Stedin, one of the largest DSOs in the country delivering electricity to over 2.3 million connections (Stedin, 2023a). The energy transition is going faster than expected and is rapidly putting pressure on the electricity grid of Stedin. This has resulted in a shift in strategy from operational excellence to a focus on maximum contribution to grid expansion in a sustainable way. Next to billions in investments over the coming years into goals on expansion, Stedin has the ambition to reduce its CO2 emissions in 2030 with 42% compared to 2021 and to reduce the use of virgin materials by 40% in 2030 compared to current usage.

1.1. Industry challenge

The challenge of network expansion is something all DSOs in the Netherlands face. The industry organisation Netbeheer Nederland (2023a) calculated in their Integral Infrastructure Exploration 2030-2050 that electricity demand will rise by 126% to 263% between 2019 and 2050. The problems around electrification are made even more difficult because of the large fluctuations in demand and supply of renewable electricity. To facilitate the growth of electricity demand and supply, the expansion of the electricity network should happen at a two to three times higher pace than currently happening (Netbeheer Nederland, 2023a). That means the future grid will comprise 40% more cables, which is around 100 thousand kilometers of cable representing almost 70% of the total Dutch street length. Also, close to 50% more transformer stations, fifty thousand new ones, will be present in this new electricity network which will take around five square kilometers of above-ground space (Netbeheer Nederland, 2023a). Also, as the peak of the shift towards electrification and renewable electricity generation is expected to happen before 2040, almost 90% of the expansion should be completed by that time (Netbeheer Nederland, 2023b).

The expansion and fortification of the electricity grid will require a yearly investment volume of over eight billion euros by 2025 over the Dutch DSOs combined (Netbeheer Nederland, 2023b). After in increase of more than 20% compared to two years ago to 830 million euros, the total investment volume will rise further to 1.2 billion euros in 2026 of which close to a billion euro will be contributed to the electricity grid (Stedin, 2024). Despite the widespread felt urgency for the grid expansion, DSOs are not able to start all projects they would like to execute. Without feasibility constraints Stedin would like to increase the investment volume to over 1.5 billion euros (Stedin, 2024). This feasibility gap is also mentioned by the sector organisation Netbeheer Nederland (2023a). Both organisations mention the same bottlenecks in realising the expansion ambition; (technical) personnel, space, financing and material availability.

The material availability that is under strain is the reason for this research. Stedin already experiences delivery problems for materials like cables and transformers on the European market (Stedin, 2024). Also, the International Energy Agency notes that the demand for materials like copper, lithium, cobalt and nickel will surpass the total available supply in 2030 (Netbeheer Nederland, 2023a).

1.2. Stedin & circularity

To facilitate the 'Built, Exploit, Administer' strategy of Stedin, the supply chain (SC) organisation has as a main goal to be 100% On-Time and In-Full (OTIF) for materials. This demand-driven supply chain should result in a faster pace of building activities (Stedin, 2023b). Stedin has identified circularity as a means to enhance material availability while decreasing the related carbon footprint and material usage. The Ministerie van Infrastructuur en Waterstaat (2023) finds that a circular economy (CE) could contribute to fighting climate change, a cleaner environment, recovery of biodiversity and larger supply security of materials. These are goals that are firmly anchored into the strategy of Stedin and that is why Stedin wants to shift towards a supply chain based on circular economy principles. According to Stahel (2016), the circular economy "would turn goods that are at the end of their service life into resources for others, closing loops in industrial ecosystems and minimising waste. It would change economic logic because it replaces production with sufficiency: reuse what you can recycle what cannot be reused, repair what is broken, re-manufacture what cannot be repaired". These are concepts that need to be integrated into the Stedin SC to shift from a linear modal towards a circular one.

As Stedin wants to move more towards a circular supply chain it is important to define such a system. de Oliveira et al. (2019) state that a "Circular supply chain (CSC) is considered an umbrella term for the coordinated forward and reverse supply chains, to develop several reverse cycles such as reuse, repairing, reconditioning, re-manufacturing, or recycling which are integrated back into forward supply chains". Stedin has worked on their understanding of the current circular and sustainability practices within the Stedin SC and to define targets for 2030 in the past half year. Stedin is already processing a few million kilo's in metal and other types of waste streams as is shown in the current state analysis in Section 4.1. The majority of this flow is being recycled into new raw materials and the remainder is incinerate for energy or land-filled. Important is that the recycled raw materials are not entering the supply chain of Stedin again. At the end of 2022 a start has been made to build a redeployment program at Stedin where grid assets are reused or refurbished to be used again. This has resulted in the reuse of around 150 transformers and 25 grid stations and four million euro's in avoided procurement costs. This is however still a fraction of total material procurement costs. In Chapter 2 more will be explained on the Stedin operations and goals and in Chapter 4.1, the current state analysis will be discussed were next to the reverse flows the current processes for circularity are shown as well.

1.3. Design objective

It is seen in the current state analysis that a start has been made in including circular economy principles in Stedin's supply chain. However, a gap exists between formulated the sustainability objectives and the current practices. The current activities need to be expanded, professionalised and form a coherent whole. That is why Stedin wants a design for a 2030 vision of the CSC of the most important asset types. The main pillars of this design will still be the redeployment and recycling loops of Potting et al. (2017). Examples of areas for improvement are the inclusion of re-manufacturing by recycling parts and components and including the recycle flow into the Stedin supply chain. To address the needs of Stedin, the design objective of this thesis project is formulated as follows:

Designing the 2030 semi-closed-loop circular supply chain for the redeployment and recycling of cables and transformers from the electricity grid of Stedin from a high-level process orientation.

Some parts of this design objective require some further explanation. The first is time indication of 2030. The Stedin strategy works towards goals for 2030 both on the supply chain as well as sustainability. By designing the CSC for 2030 the design can be aligned with the strategic objectives. Second is 'semi closed-loop'. There are several types of CSCs that implement the principles of CE: reverse SC approaches, open-loop SC approaches and closed-loop SC approaches. The first, only focuses on the reverse flow, without any integration with the forward flow which is the case for open-loop and closed-loop systems. The difference between closed-loop and open-loop CSC is that in an open-loop system, third parties outside the own SC are involved while a closed-loop system keeps the reverse flow in SC (MahmoumGonbadi et al., 2021). In initial research on the operations of Stedin, it was stated that the CSC would involve both traditional suppliers inside the SC but also general waste disposal partners outside the SC and other reconditioning partners. Because the main aim of the CSC is not to connect the Stedin CSC with different supply chains, the term 'semi-closed-loop' is chosen to reflect the fact that while different partners outside the traditional SC are required, the focus is on the Stedin SC with Stedin centrally managing the system. Berlin et al. (2022) also state that most CSCs are not purely open or closed but a mix of both.

Next are 'redeployment' and 'recycling', which are the pillars of the CSC. Redeployment means the direct use of components, possibly after revision of the component. This can be the case for entire assets or parts of assets. The aim is not just to recycle grid components for basic materials and power but to close the loop and use recycled materials in Stedin's supply chain. This way, for example, cable materials won't be recycled as 'just' copper or aluminium but directly as input for suppliers. Lastly, 'process orientation' is mentioned because the design will be a conceptual process, not on the most detailed level of SC design. In the project, the SCOP methodology of Corominas et al. (2015) is used, which differentiates between the macro (highest level), meso and micro (most detailed level) structure designs. This project will focus on the macro and meso-level designs for the CSC.

This project's design end-product describes the supply chain process steps and how they interact. This means a visualisation, with an additional explanation, of how the end-of-use or end-of-life materials move through the circular supply chain. Also, prerequisites for the proper functioning of the CSC are described. For some process steps, important design decisions will be stated and explained, and an assessment framework will be provided to make these decisions at a later stage. The final implementation plan consists of these decisions that should be taken and other already determined implementation projects.

1.4. Research contribution

From the literature review in Chapter 3, it is found that there are no previous studies where a clear circular supply chain design method is formulated or a CSC for materials like Stedin's is designed. The contribution of this research is both societal, as it helps Stedin in introducing circular principles into their SC, and scientific as this project is a case study for several existing methods and a first combination of these methods.

Societal contribution

The goal of this research is to contribute to a sustainable way of electricity grid expansion. Organisations need to move away from a linear 'take, make, use, dispose' paradigm towards a circular way of operating where reuse of products and materials is central. Stedin has formulated goals both on CO_2-eq emission intensity reduction and to lower the use of virgin materials in the grid expansion. Integrating circular principles into the supply chain is an important instrument that can contribute to these goals while also enhancing material availability. Reusing, refurbishing, re-manufacturing and recycling of grid components will lead to a lower demand of primary materials but also reduces the need to energy intensive processing and transportation activities. An added benefit of these circular practices is that it creates an additional internal supply flow for components and increases material availability for suppliers. By designing the CSC in 2030, Stedin has a clear vision for where the SC and organisation needs to be to reach their goals. Because of the use of the evolved double diamond framework of the Design Council (n.d.-a), also leadership and engagement enablers will be included into the design next to the actual process steps for material flow. By adding an implementation plan to the design, the research results will become actionable and implementation more clear. The design can will be more likely to be successfully implemented because of this plan and the inclusion of enablers.

Scientific contribution

The scientific contribution of this research is mainly directed at the methods used. A combination of the Evolved Double Diamond (EDD) (Design Council, n.d.-a), SCOP method (Corominas et al., 2015) and the CSC guiding framework (Amir et al., 2023) is used. The EDD is relatively new, and in the literature, almost no papers are found that use the new version of the Double Diamond framework. The same is true for the SCOP method, while the authors have stated that applying the framework to real-world cases is needed to test the method's usefulness (Corominas et al., 2015). Also, Amir et al. (2023) have stated that more use cases for the framework are needed; seeing the recent publishing of the paper, it is not surprising that no further use cases are found. For all three used methods, more case studies that use the frameworks are needed.

Additionally, as far as has been found, it is the first time that the methods are combined. Corominas et al. (2015) state that their method needs a deepening relative to the actual design that the CSC guiding framework does bring with its building blocks. Vice versa, the CSC guiding framework lacks the top-down structure to address a design problem that the SCOP method brings. Lastly, the use of the MCDA in the selection of design components instead of design alternatives has not often been done before. This means a new context of application of the method that also needs additional research.

1.5. Report outline

In this section, the outline of this report is discussed. The project consists of seven activities that are used to fulfil the design objective. The first project activity is featured in Chapter 2, the background study. In this chapter, first, the context of the project is further detailed as it is done with the DSO Stedin. The business and ESG strategies are discussed as well as some general remarks on how Stedin operates. The second part discusses this material scoping for the rest of the project. The methodologies used in this project are discussed in Chapter 3. The project activities organise the chapter, so each activity discusses which methods are contemplated and how the final methods are used. The first section is a literature study is done to understand better circularity and what it means for supply chains, as well as to research a suitable CSC design method.

Next, the current state of the circular processes for each of the four selected asset types is discussed in the first part of Chapter 4. This analysis is done in the first part of the project but is mainly used for the implementation plan. The results of the 2030 reverse flow estimation are given in the second part of Chapter 4. These estimations can be used to dimension the design process and give Stedin input for a more detailed design later on. In Chapter 5, the objective of the design is stated more elaborately, and the process and results of generating the requirements are discussed. The developed macro and meso designs are discussed in Chapter 6. Here, the results of the design process are shown and elaborated.

In Chapter 7, the key decisions that need to be taken concerning the CSC design are discussed. This is a list of important decisions and their trade-offs that Stedin must make when implementing the design. Additionally, the framework is given to evaluate the two most important decisions. The current state analysis of the 'as-is' situation is combined with the CSC design and decision list to develop an implementation plan in Chapter 8. In Chapter 9 the report ends with the conclusion of the project and the discussion with the generalisation of the findings, the methodological limitations and suggestions for further research.

2 Background Study

The start of the project is a background study to dive into the project context and to determine the materials in the project scope. The project is done with the DSO Stedin, so a section is included in the background study on Stedin to give the project context. Second, the material scope has to be determined to include the most relevant asset types. But first, in Section 2.1, the methodology for the background study is discussed.

2.1. Approach background study

In this section, the approach for the background study is discussed. First, the methods for the project context of Stedin are shortly discussed. Second, the considerations and choice of the methodology for the scope determination are explained.

2.1.1. Method project context

The background study starts with the project context which is the DSO Stedin. The information for this analysis is obtained from internal and external sources on the corporate strategy (Stedin, 2023a), material supply chain strategy (Stedin, 2023b), the investment plan of 2024 (Stedin, 2024) and the ESG strategy (Stedin Groep, 2023). Furthermore, a lot of informal conversations have been held with various experts within Stedin to obtain more information into the priorities and workings of the company. These experts were mostly a SC expert (personal communication, n.d.), external sustainability expert (personal communication, n.d.), two redeployment experts (personal communication, n.d.) and a sustainability expert (personal communication, n.d.). A broad range of other experts have been consulted throughout the project who contributed to a better understanding of the context.

2.1.2. Method determination material scope

Because Stedin uses a large number of assets, it was important to select the most relevant materials included in the project's scope. By scoping the list of assets, more focus can be given to the design of these selected assets instead of many shallowly contemplated designs. The first step in this process is to make an initial selection of the most important asset categories for Stedin.

MCDA for scoping and prioritisation

Several methods are developed to evaluate and prioritise different alternatives in a decision-making situation (DMS) (Guitouni & Martel, 1998). The most frequently used methods are tools like the cost-effectiveness analysis (CEA), economic-effects analysis (EEA), cost-benefit analysis (CBA), the social cost-benefit analysis (SCBA) and multi-criteria decision analysis (MCDA) (Macharis et al., 2009). The most important difference between the first three techniques and the latter two is the inclusion of non-economic aspects in the evaluation. For techniques like CEA or CBA, it is difficult to capture the full range of impacts from a policy of project (Browne & Ryan, 2011). However, also in a SCBA, it remains challenging to achieve a monetary evaluation of social criteria (Tudela et al., 2006) or effects remain too uncertain in analysis (Lake & Ferreira, 2002). In those instances, the externalities and intangible benefits of a project are not fully captured in the analysis and justification of the project from a social point of view becomes difficult (Macharis et al., 2009). The MCDA provides possibilities for evaluating several alternative projects on both quantitative and qualitative criteria (Vincke, 1992). MCDA methods most often have six steps or stages: (1) the scope of the DMS is defined; (2) different alternatives and criteria are defined; (3) the criteria are prioritized with different weights; (4) the alternatives are evaluated based on the criteria; (5) the evaluation is performed; (6) decision-makers make the final decision (Lahdelma et al., 2000; Salo & Hämäläinen, 2010).

An initial attempt was made to evaluate, prioritise and select the most relevant asset classes with a multi-criteria decision analysis (MCDA). Based on purchasing data, CO_2-eq emission data, and expert consultation (sustainability expert, personal communication, n.d.), a first selection of the 12 most important asset classes was made. These 12 asset categories have the highest spending and emissions and the expert stated their importance. The latter was especially the case for high-voltage asset classes for which no data was available. In the next step, several criteria were drawn up in collaboration with an SC expert (personal communication, n.d.). However, in the data collection process to evaluate the criteria, it was concluded that the right data was lacking to evaluate the criteria quantitatively. For this reason, it was decided that a qualitative workshop based on an impact framework would be organized to evaluate the asset classes.

Qualitative workshop
A workshop is a research method most closely related to action-oriented research methods like focus groups, action research and participatory design (Storvang et al., 2018). The main objective of a workshop can be to create a new output or to evaluate a topic of interest like a product, process or tool (Thoring et al., 2020). A workshop is defined as: 'A group of people are put together at an agreed time to work intensively with a particular set of problems. The workshop is thoroughly planned, and plenty of time is allocated. Thereby, a more focused concentration is achieved than holding a general meeting' (Storvang et al., 2018). There are three different roles in a facilitated workshop: researcher, facilitator and participant. The participants can be experts or other stakeholders related to the DMS. There are several key aspects to planning a facilitated workshop. First, it is important to see if the relevant participants are involved in the workshop and what briefing they need. Next, the social process has to be determined. This has to do with what the participants will be doing in the workshop, how the knowledge is exchanged, and what the rules for communication will be. Last are the technical considerations. This has to do with the time and place of the workshop, what setting is appropriate to succeed in the workshop, and what media will be used (Storvang et al., 2018).

The workshop was hosted online (08-03-2024) using Miro to let the participants collaborate and directly log the results. The participants were experts selected from different disciplines to include a broad knowledge base. These experts were a sustainability expert, a logistics expert and a procurement expert. This group of experts possesses knowledge of asset characteristics, sustainability, circularity, logistics, and vendor management. The long list was also discussed with two more experts to prepare the workshop better. These experts were a external sustainability expert (personal communication, 7-03-2024) and an expert in redeployment (personal communication, 29-02-2024). The set-up of the workshop itself was discussed with an expert in the field of creative workshops (personal communication, 21-02-2024).

The final workshop set-up consisted of several parts. First, the participants received documentation in preparation for the workshop. This documentation was a PowerPoint where the reason for the workshop was explained, the set-up of the workshop, the long list of asset classes, purchasing and sustainability data, and an agenda of the workshop. This preparation was meant to give participants a common baseline knowledge of the asset classes and make the workshop more efficient. Figure 2.1 shows the framework used in the workshop. The participants are asked to evaluate the asset group based on the impact that a CSC for that asset group will have on the supply chain and sustainability. For SC, this means that a CSC can have a positive impact on, for example, material availability, shorter lead times, more reliable supply, and, for sustainability, the effect on CO_2-eq emissions and (virgin) material use. In the first part of the workshop, these axes are discussed with the participants to get a common baseline on what everybody thinks the axis means and why an asset class would score high on an impact axis. The workshop expert suggested this to reduce confusion about how to score the asset classes later.

The next part of the workshop was for participants to take 15 minutes to fill in the framework. Each participant had their own framework in Miro and was expected to only look at their framework during this workshop stage. They got online post-its corresponding to each asset class that could be placed somewhere in the impact/impact matrix. Figure 2.1 shows an example of the starting set-up. After this, the results were copied to a common framework to see differences in the individual results. These results were then discussed per asset class, and the participants placed a post-it for that asset class on a final common framework. This way, the final results were obtained, which will be discussed in Chapter 2.3. The highest-scoring asset classes in the upper right quadrant were selected for further continuation in the project.

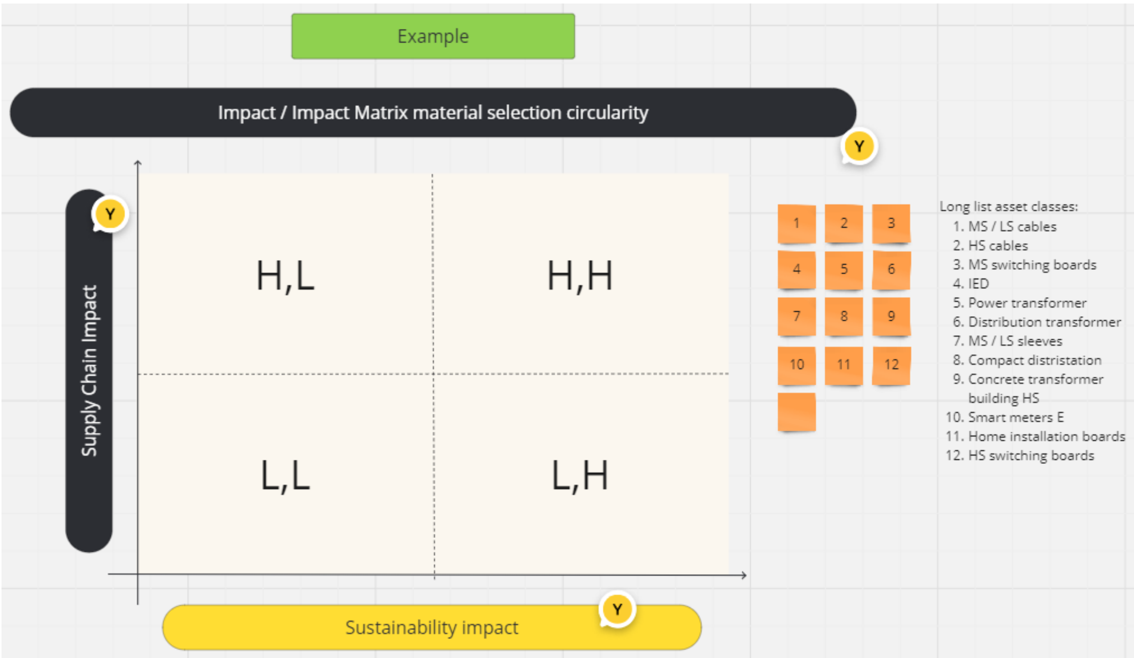


Figure 2.1: Impact framework used for scoping workshop

2.2. Project context: Stedin

2.2.1. Company structure

Stedin is an organisation of over 5,500 employees, mainly active in the Dutch provinces of Zeeland, South Holland and Utrecht. The overview of the service area of Stedin can be seen in Figure 2.2. This research was done at the supply chain department of Stedin, which has approximately 200 to 250 employees and is divided into three different main departments. These departments are vendor management (procurement, supplier relations, performance), logistics (CDC, logistic services) and services (offices, equipment). A fourth department is the Supply Chain Center (SCC), the centralised improvement capacity of the entire SC department, consisting of business consultants, analysts, and project leaders. The SCC will conduct the research into Stedin's circular supply chain in 2030. From a larger organisational perspective, SC is on a board level the responsibility of the Chief Financial Officer. The SC Director leads the department and is supported in this role by the four managers of the previously described departments (Stedin, n.d.).

On a board level, Stedin has three other members responsible for around six departments. Although Stedin is structured into 25 departments, operationally, the focus is on the value chains within Stedin. These are Consumer, Maintenance, Business Project and Business Complex. All these chains work on the electricity and gas grid but have their own type of work within these grids. The first two chains are clear by their description, but the latter two need more clarification. Business Project is generally responsible for building the grid at a low and medium voltage level within Stedin's service area. Business Complex is doing the high voltage project within the Stedin service area. These are often transmission stations where the transmission grid of the TSO Tennet is connected with the distribution grid of the

Figure 2.2: Overview map of service areas DSOs Netherlands (Energievergelijk, 2024)

DSO Stedin. A fifth chain that is being integrated into the others is DNWG, the DSO from Zeeland that became part of Stedin. This organisation performs the same operations as the other four chains but still has separate processes.

The SC department of Stedin needs to facilitate these chains in their operations. This means that SC is organised, next to its four departments, into three value streams: materials, contractors and services. This means that the organisation is focused on procuring and delivering the required materials to the sites, ensuring contractor capacity and that the work environment for all employees is functioning correctly. The latter means a responsibility over the offices, distribution centres, mobility, equipment and gear (Stedin, 2023b).

2.2.2. Company strategy

In 2022, Stedin released its 2023-2027 mission, vision and strategy. This new strategy is focused on solving the challenges of the energy transition that Stedin, as a DSO, needs to facilitate. The new vision incorporates this necessity: 'Enabling the energy transition by building faster, optimally exploiting and administrating the grids'. This vision holds the three main priorities of the strategy: build, exploit, and administer. The building is focused on putting more cables, transformers and other components in the grid. This can be new traces, fortifying the current grid or replacing old grid parts. In case old grids are fortified, a reverse flow of decommissioned materials will be generated. In Section 4.2 estimations are given for this potential reverse flow. The exploiting is focused on making optimal use of the grid that is already in place. Lastly, administer is focused on guaranteeing the grid performance (Stedin, 2023a).

2.2.3. ESG strategy

One of the other priorities in the new strategy is sustainability. Stedin has the conviction that the grid's expansion has to happen sustainably and that it cannot be the case that a company central to the sustainability ambitions of the Netherlands is not conducting their own operations sustainably. The group ESG (Environment, Social, Governance) strategy is the elaboration of that conviction. Next to the goals of being a good employer (Social) and company ethics, integrity, and sound management (Governance), there are sustainability goals on CO_2-eq emission reduction, circularity, and biodiversity.

On CO_2-eq emission reduction, the goal is a reduction of 42% compared to 2030 to 2021, which is in line with the Paris Agreement based on the Science Based Targets initiative (SBTi). For the offices, mobility and aggregates, this means a 100% reduction in CO_2-eq emissions. For procurement in scope 3, the goal is a 42% of CO_2-eq intensity reduction based on the emissions per euro spent. Materials are a difficult theme in this KPI and have a 2030 target of 12% emissions reduction for primary materials and 30% reduction for other materials (see Subsection 2.2.5 for an explanation on material types).

For this design project, the circularity targets are the most important. The main KPI is a 40% reduction of primary or virgin material use. This target is currently not based on the total material volume but on the ratio between virgin and non-virgin material. Further sub-target settings are happening during this research period and, therefore, are not definitive yet. They will focus on enlarging the share of redeployed assets (parts), increasing the amount of recycled materials in the Stedin SC, and reducing the residual product share in the recycling process. Lastly, the target for biodiversity is to have a net-positive impact on Stedin's supply chain in 2030. This is the least developed topic within the sustainability ambitions but will be connected to material use. Therefore, reducing virgin material use with circular strategies will also contribute to biodiversity and, of course, to CO_2-eq emission reduction (Stedin Groep, 2023).

2.2.4. SC objectives

Stedin's corporate strategy is translated towards the SC department through the three value streams of SC. To facilitate the 'build, exploit, administer' strategy, the SC organisation focuses on 100% On-Time and In-Full (OTIF) on material delivery, 100% available contractor capacity and 100% functioning work environment. The CSC design will contribute mainly to the 100% OTIF goal on material availability. Here, the top KPIs are forecast accuracy, optimal use of supplier contracts, supplier performance, logistics ability and logistics reliability (Stedin, 2023b).

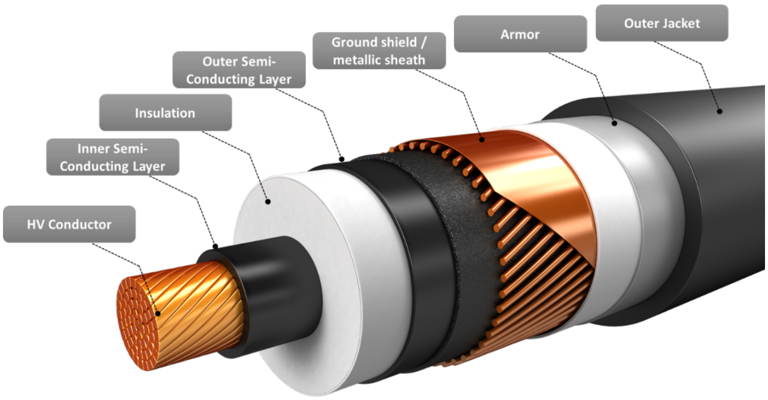
For the sustainability goals of Stedin, the SC organisation is one of the most important departments within Stedin as almost all emissions, material use and biodiversity impact are created by the activities of this department. This is the case as SC is responsible for the procurement of materials, organising offices and mobility, and reverse logistics. The Asset Management department is also important as it sets the standard for which assets are needed. This department must design more sustainable and circular asset configurations, but SC is responsible for further execution. SC's logistics team will be executing the CSC design and is already responsible for the redeployment and recycling that is currently happening.

2.2.5. Electricity grid components

Last year, the SC organisation of Stedin used around 4000 product types with material group codes, and even more are used outside this system. The assets are divided into three categories: primary, secondary, and tertiary. Primary assets are used in the primary installations of distributing power to the end-consumer and are asset types like cables, transformers and switching boards. Secondary assets are used to secure, control, and monitor the previously mentioned primary installations and assets like control systems and smart meters. Tertiary assets are the housing of the combination of primary installations and secondary assets. These are mainly concrete (prefabricated) transformer buildings.

A few large product groups are important in the build-up of the electricity distribution network and will feature in this research. This section will explain more about some of the most important assets used in the grid and section 2.3.1 gives a short explanation for each asset included in the asset long list before scoping. First of all are the cables used in the transmission and distribution of electricity, of which several types are used. The cable composition is somewhat different for low-voltage and medium-voltage cables, but overall, two types of cables are used in the Dutch grid. The first is GPLK (Armoured Paper-Lead Cable), in which impregnated paper is used for isolation. The second is XLPE (Cross-Linked Poly-Ethylene), which uses plastic isolation. In the past, the GPLK was mostly used in the networks, but currently, all low, medium, and high voltage cables are XLPE cables with an aluminium core and copper shield. In Figure 2.3a, an example is given of a cable cross section with the various cable parts identified. Cables come in limited length, and sleeves are used to connect the ends of two cables to form one continuous network. On average, by weight, the aluminium is almost one-third of the cable, copper is 17%, the outside PE mantel is 12%, and 36% is the XPLE isolation (sustainable procurement expert, personal communication, n.d).

One of the most important components in the grid is the transformers. A transformer is used to convert the voltage from the (ultra) high voltage network (110 and 150 kV for high voltage and 220 and 380 kV for ultra-high voltage) to medium voltage (3 and 23 kV) or from medium voltage to low voltage (0.4 kV). In Stedin, the term distribution transformer is used for assets that transform from medium to low voltage, and power transformers are used for assets that transform from high to medium voltage. In Figure 2.3b, an example of a distribution transformer is given. Power transformers are used to transform from high to medium voltage. On average, by weight, the steel is almost 50%, the transformer oil is around 14% and aluminium 15%. Power transformers are similar to a distribution transformer shown below, but can be up to a fifty-fold in weight. The copper wires are one of the most important functional parts of the transformer, but by weight, they are less than 1% (sustainable procurement expert, personal communication, n.d). The manufacturing and extraction of virgin materials for transformers and cables are responsible for more than half of all the CO_2-eq emissions and virgin material use of Stedin. Therefore, circular strategies are very important when applied to these asset types as it helps to reduce emissions and material use significantly.



(a) Cable cross section (Alahmad, 2023)

(b) Distribution transformer (LV Trading, 2024)

Figure 2.3: Example of assets from electricity grid

Another important component type is switching boards, which is used to change network configurations in different types of network stations. In Stedin, a division is made between medium and high-voltage switching boards to separate internal workflows. However, in practice, these assets are often the same type and are technologically the same.

As secondary assets, circuit breakers are used to regulate normal operating currents and switch off overloads and short-circuit currents. Also, insulators are used to reduce short-circuit currents, and electronic safety equipment is deployed to monitor the safety and operations of the grid (Phase to Phase, 2011). For Stedin, examples of other secondary assets are IEDs and smart meters.

As mentioned, the tertiary assets house the primary and secondary assets. In practice, these can be prefabricated compact distristations or separate transformer buildings. For compact stations, all the primary installations are already built into the concrete housing and can be directly installed at the construction site. For more complex situations or high-voltage projects, separate concrete buildings are constructed where all the assets are placed. The concrete from the tertiary assets accounts for almost half of all CO_2-eq emissions and virgin material Stedin uses.

2.3. Determination materials in project scope

This chapter discusses the results of the material scoping project activity. Section 2.3.1 shows the long list of the different asset classes, and the following two sections discuss the individual and final results from the workshop. This leads to a conclusion on which assets are included in the project's scope.

2.3.1. Long list asset types

The different type of assets are discussed in the background study in subsection 2.2.5. For the initial selection of the long list, purchasing data with an article number was used to assess the importance of assets. This was the purchasing data from 2023 in euros spent, and an analyst already made a ranking. The same analyst also calculated the CO_2-eq emissions based on DEFRA factors, resulting in a ranking for emissions. Asset classes without an article number were also discussed with an expert to evaluate their importance in terms of volume, costs, material use and emissions. These asset types are for the high-voltage projects for Stedin. The resulting list can be found below.

1. MS/LS cables: used in medium and low voltage projects. Have the same type of materials and SC so taken together
2. HS cables: used in the high voltage projects
3. MS switching boards: used to configure the network at a grid station and to handle short-circuiting voltages
4. IED: electronic devices used in security and control of transmission grid stations
5. Power transformer: used to covert currents from transmission to distribution voltages
6. Distribution transformer: used to covert currents from medium to low voltages in grid stations
7. MS / LS sleeves: used to connect different cable parts in medium and low-voltage projects
8. Compact distristation: standardized concrete housing for distribution grid stations
9. HS building: the concrete building used to house high voltage equipment at grid stations
10. Smart meters E: measuring and communicating data on electricity consumption by households
11. House installation boards: used to guide cables into the home and install the smart meter on
12. HS switching boards: same as for medium voltage but used at different locations

2.3.2. Individual results workshop participants

After a discussion in the workshop about what the SC and sustainability impact axis mean, the participants placed the different asset classes into the framework. The individual results are below in Figure 2.4. As can be seen, the pattern of the individual results is quite different for the participants. On the upper left, the sustainability manager placed the assets scattered throughout the framework. For this expert, the highest scoring classes were the MS/LS cables, power transformers, MS switching boards, distribution transformers, and HS switching boards. The placement of the logistics expert was mostly low on SC impact and medium on sustainability, except for four classes, which scored in the upper right quadrant. These classes are the MS/LS cables, distribution transformers, MS/LS sleeves, and smart meters E. The vendor management expert places all classes very concentrated in the high middle part of the framework, with MS/LS and HS cables scoring the highest on the combined axes. In the discussion later, it was found that this expert misunderstood the SC impact axis, which, in hindsight, meant that he would have placed some classes lower on SC impact.

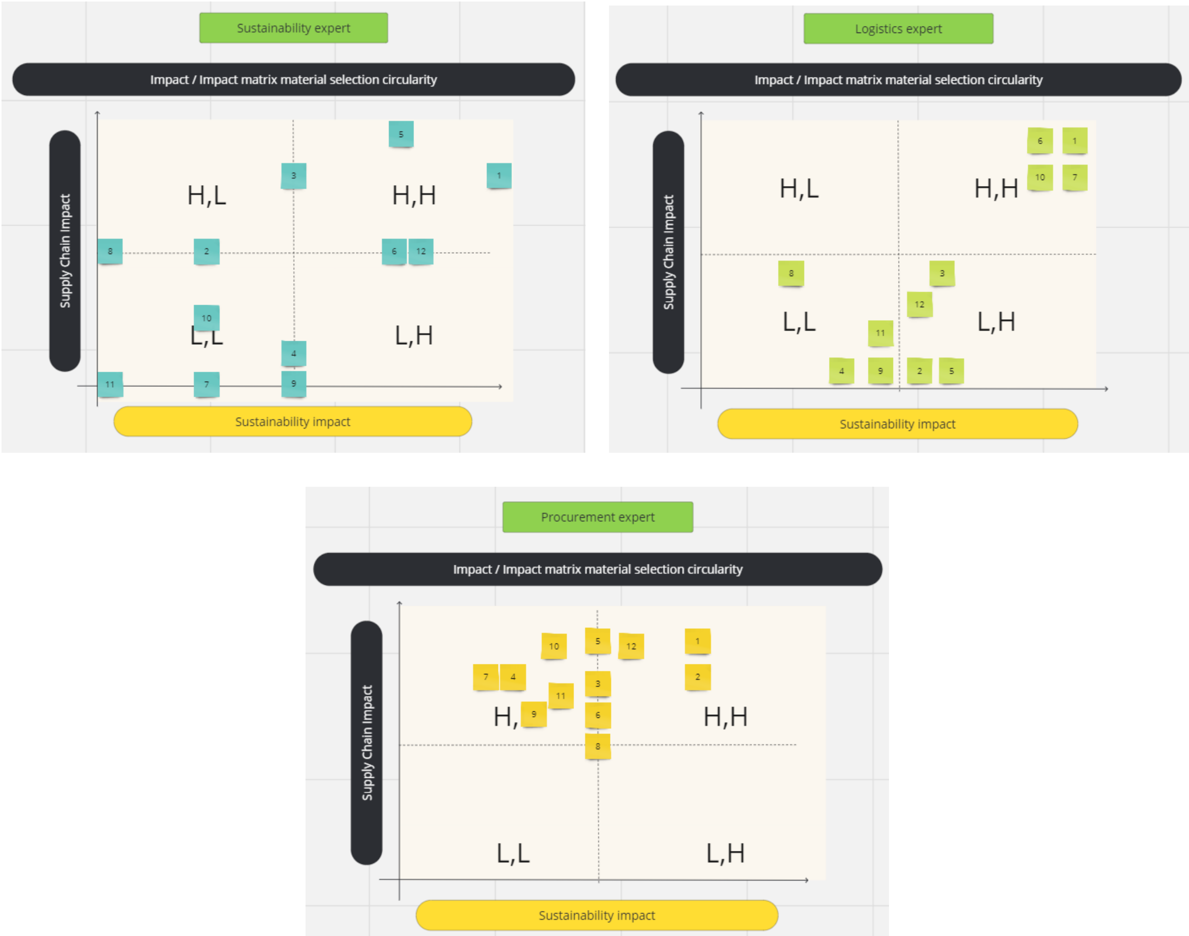


Figure 2.4: Individual results scoping workshop

2.3.3. Final results scoping workshop

After the individual ranking of the asset classes, all these results are copied and placed over each other in a combined version of the framework. This framework can be found in Appendix A. This figure was discussed class by class, and at the end of the discussion on an asset class, a post-it was placed in the final framework, which can be found in Figure 2.5. On the first asset class, the MS/LS cables, there was the most agreement as all experts placed this asset in the upper right corner of the framework, so it was also placed here in the final framework. The HS cables were scored fairly differently across the experts, but the discussion concluded that they are much less important than the MS/LS variant. However, they should still score well on both SC and sustainability impact. The MS switching boards scored high on SC impact and similar on sustainability. However, after discussions, it was decided that this is overstated, as circularity would not help much with this class's SC issues. Therefore, it ended up right at the center of the framework. The same holds for the IEDs.

All participants agreed that both transformers should be placed on the high side of the sustainability impact axis. There was a very large spread of SC impact for the power transformers. The logistics expert scored it very low, but the distribution transformer scored the highest of all classes. After deliberation between the participants, they all agreed that both transformer types should score high on both axes but that the distribution transformers were more important because of the volume of this class. The sleeves were somewhat misjudged regarding recyclability and the possibility of reuse or refurbishment. Because it is also a very small flow in terms of weight, they were rated as the least important in the final results. The compact distristation scored quite similar on SC impact, but on sustainability, the expert in this field argued that the volume of concrete was not that high for these units. On the HS concrete structures, the experts agreed that they have a high sustainability footprint, but that circularity would only add a little in terms of CO_2-eq reduction, and that is also not a scarce material. For that reason, it scored pretty high on sustainability but the minimum on SC.

There was some discussion on how to score smart meters in the final framework. This class has a high volume but is low in weight. Also, in the end, the experts felt that circularity would not generate that much impact as many meters come back too damaged or are very old. Because part of the flow could be refurbished and the rest recycled, it scored in the upper right corner of the lower left quadrant. The vendor management specialist scored high on SC impact for house installation boards. However, after discussion, it was decided that these assets do not lend themselves to reuse and are relatively low in material weight volume. Finally, the HS switching boards scored quite high on sustainability impact, and for the SC impact, they decided to triangulate and put it above the MS variant.

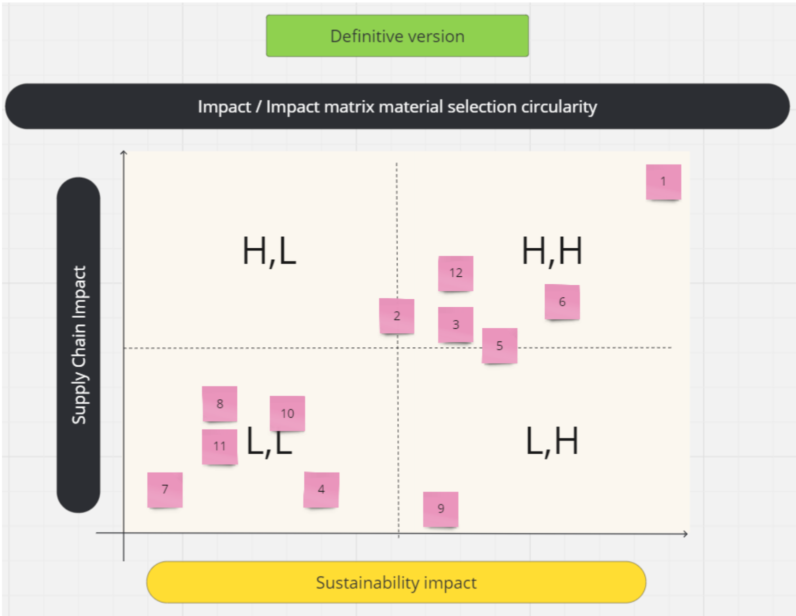


Figure 2.5: Final result scoping workshop

2.3.4. Conclusion material scoping

In the final framework, both the HS and MS/LS versions of cables, transformers, and switching boards scored in the upper right quadrant. For these six asset classes, the experts thus evaluated that the impact would be the highest if a CSC was designed for that asset class. For the final scoping of the materials, it was decided to drop the switching boards, although they scored well. This is because switching boards contain the highly polluting SF6 gas. This gas is much more potent for global warming and is not allowed to be used in newly installed assets by 2027, and after 2035, reused or refurbished assets can not be used (Redeployment expert, personal communication, 12-03-2024). Stedin has the ambition to phase out SF6 containing installations between 2030 and 2035 but preferably earlier (Stedin Groep, 2023). This information was not yet known during the workshop so it changed the results. As the asset cannot be redeployed, the circular and SC impact is dramatically reduced. The SF6 issue is unique to this asset type and is therefore not an additional criterion, but a restriction that was not yet taken into account. As switching boards also do not have a very high flow in terms of weight volume, it was concluded that we should focus on cables and transformers.

3 Thesis Project Methodology

This chapter explains the different methods used in the research to satisfy the project objective. The chapter starts with a literature review on circularity, circular SCs, and CSC design methods. Other methods discussed are workshops, data analysis, interviews, and the application of design methods found in the literature reviews (Evolved Double Diamond, SCOP, CSC Guiding Framework). The different project activities are already briefly mentioned in the Introduction in Chapter 1, but they will be explained in more detail here.

In Table 3.1, an overview of the seven different project activities is given accompanied with the methods used for that activity and the chapters in which the activity is performed. As the methodology for the literature review is already discussed in Section 2.1, it is omitted in this chapter. The chapter is structured in sections for each of the project activities. Each section has a description on which methods are contemplated and how the final methods are used.

Table 3.1: Overview of all project activities and methods

Project activities	Methods	CH.
Determining the materials from the electricity grid with the highest potential for redeployment and high-grade recycling.	Qualitative and quantitative analysis, workshop	2
Finding suitable methodologies and frameworks for the design of a circular supply chain.	Literature review	3
Give a rough estimation of the future material reverse flow for the selected materials.	Data analysis (Excel)	4
Generation of requirements for the design of the circular supply chain.	Validation session & workshop, Stedin strategy	5
Development of design scenarios for the circular supply chain.	SCOP, CSC Guiding Framework, EDD	6, 7
Develop framework for evaluation important design decisions.	MCDA, workshop	7
Formulation of an action plan to implement the circular supply chain.	Qualitative analysis	4, 8

3.1. Literature study circularity and CSC design

The first project activity is to find a suitable methodology for the design of Stedin's circular supply chain. First, the methodology of the literature review is discussed. As it is important for the methodology selection and further design activities, the literature review starts with exploring the concepts of the circular economy and the circular supply chain (CSC). After this, more attention is given to the concept of (circular) supply chain design, including supply chain design, circular supply chain design, and the double diamond method. This literature review functions as a way to complete the first project activity and understand the current state of knowledge on CSCs and (C)SC design.

3.1.1. Literature review methodology

A literature review was conducted to determine the state of the art in circular supply chains and supply chain design. A search plan, described below, was used to locate the relevant literature.

Step 1 was to search in ScienceDirect for two generic search term combinations: (Supply Chain) AND (Design) and (Supply Chain) AND (Circular). This query generates a large volume of literature that is not ready to be efficiently sieved through.

Step 2 is to compose search criteria to refine the original ScienceDirect query to be more specific and relevant. These search criteria are in Table 3.2. In the keyword section, the different keywords used are described per concept. In the truncation part of the table, only the concepts are stated, but the keywords within the concepts are used. The numbering in the table is used to show which additional criteria were used for which truncation.

Step 3 is to go through the refined result list and select papers based on the perceived relevance of their title. This short-list is further analyzed based on the abstracts of the papers. This is done both for the concepts of supply chain design and circular supply chain.

Step 4 is to apply the common 'forward snowballing' and 'backward snowballing' search techniques, using relevant papers' citations and cited papers. This is done both for the concept of supply chain design and circular supply chain.

Step 5 is to collect all these papers in Mendeley to have an overview of all relevant papers ready for analysis. In Mendeley, the papers are categorized per concept and annotated to mark important concepts.

Step 6a is for the circularity theme to also include literature from practice, like the Ellen MacArthur Foundation and Gartner. These articles provide a more practical addition to the scientific literature and are partly used for circular supply chain concepts and best practices in design. Search terms here are combinations of (Supply Chain), (Circular), (Circularity), and (Best Practices).

Step 6b is for the design theme of the literature review. As will be described later in this chapter, the literature for (circular) supply chain design provided insufficient guidance for the design of the Stedin supply chain. Therefore, a search was also done into the Double Diamond method by Design Council (n.d.-b). This general design method can help in the practical design exercise. Search criteria for the Double Diamond and Evolved Double Diamond method are also given in Table 3.2

Table 3.2: Search criteria used to generate a list of literature on ScienceDirect

Concept groups	Supply chain; Circular ; Design; Double Diamond
Keywords	Supply Chain: supply chain, logistics Circular: circular, circularity, closed-loop, LCA Design: design, configuration Double Diamond: double diamond, evolved double diamond, framework for innovation, method
Truncation	1. (Supply Chain) AND (Circular) 2. (Supply chain) AND (Design) 2. (Supply Chain) AND (Circular) AND (Design) 3. (Supply Chain) AND (Double Diamond) 3. (Design) AND (Double Diamond) 3. (Double Diamond)
Additional criteria	All the searches are both done with and without these search criteria 1. LIMIT-TO (PUBYEAR , >2010) 2. LIMIT-TO (PUBYEAR , >1990) 2. LIMIT-TO (ARTICLE TYPE, review)

3.1.2. Circular Economy & Circular Supply Chain

In this section, first, the general concept and importance of the circular economy is explained. In the second part, the integration of circularity principles into the SC are discussed.

The Circular Economy

On an annual basis, around 100 billion tonnes of materials enter the worldwide economy (Ellen MacArthur Foundation, 2023). Worldwide consumption of goods has been on the rise, and the traditional linear "take-make-consume-dispose" way of working in the economy is depleting the planet's resources (Masi et al., 2017). To reverse this trend and move towards a more sustainable economy, researchers, practitioners, and policymakers are looking increasingly towards the circular economy (CE) as a potential solution (Amir et al., 2023). The Dutch government sees the circular economy as an important means to improve sustainability in the country and bring the economy's use of resources within planetary bounds. For this reason, the country wants to be fully circular in 2050 (Ministerie van Infrastructuur en Waterstaat, 2023). Introducing the principles of circularity into businesses can also offer a significant competitive advantage. Gunasekara et al. (2023) state that companies that introduced CE-related initiatives outperform competitors in revenue growth by 6% to 50%.

Many authors give definitions of CE that all involve closing the material loop and eliminating waste in its core. One given by Hobson (2015) states that "[The CE is] an industrial system that is restorative or regenerative by intention and design... [and] aims for the elimination of waste through superior design of materials, products, systems and business models". In addition to this, Stahel (2016) state that the circular economy "would turn goods that are at the end of their service life into resources for others, closing loops in industrial ecosystems and minimizing waste. It would change economic logic because it replaces production with sufficiency: reuse what you can, recycle what cannot be reused, repair what is broken, re-manufacture what cannot be repaired".

Three main principles arise from the definitions of CE. Those are eliminating waste and pollution, circulating products and materials at their highest value, and regenerating nature (Ellen MacArthur Foundation, 2023). In this way, economies can decouple their emissions and material use from the economic output created; in other words, they create more output with less input. It is estimated that this will not only help to make the economy more sustainable but also result in 4.5 trillion dollars in additional economic growth (Dull et al., 2023). Michelotti (2021) states that important barriers to implementing the concepts of CE are the lock-in of raw materials at a design stage, the growing need for End-of-Life (EoL) material management, and lack of selection criteria in setting up circular partnerships.

Circular Supply Chains

From the literature, it is found that innovation in SCs to include the principles of CE is needed to realize its potential (Angelis et al., 2018; Masi et al., 2017). Several definitions and types of circular supply chains (CSC) can be bound in the literature. de Oliveira et al. (2019) state that a "circular supply chain (CSC) is considered an umbrella term for the coordinated forward and reverse supply chains, to develop several reverse cycles such as reuse, repairing, reconditioning, re-manufacturing, or recycling which is integrated back into forward supply chains." To clarify that definition, reverse supply chains or reverse logistics is defined as "a series of activities that are required in order to retrieve a used product from a customer and either dispose of it or reuse it" (Nasir et al., 2017). The definition of de Oliveira et al. (2019) mentions a list of reverse cycles, which is commonly referred to as an 'R-list'. These 'R-lists' started the so-called 'Ladder of Lansink', which is based on the Dutch regulations of 1979 on waste treatment methods (Potting et al., 2017).

The first 'R-list' was based on reuse, reduce and recycle. Later, this was expanded to a more commonly used 9R strategy ladder (Potting et al., 2017). The first strategies in this ladder are around smarter product use and manufacturing with refuse (R0), rethink (R1), and reduce (R2). The second set of strategies is based on prolonging the lifespan and using products and parts. Strategies for this are reuse (R3), repair (R4), refurbish (R5), re-manufacture (R6) and re-purpose (R7). The lowest part of the ladder, the closest to the linear economy, is concerned with the useful application of materials after the first R-strategies are used. The two options here are recycle (R8) and recover (R9) (Potting et al., 2017). In Figure 3.1, an overview of the strategies from the 9R ladder is given.

It is necessary to note that although the R ladders have a hierarchy in them, it does not by definition mean that one should choose a 'higher strategy' in every situation. A life cycle assessment (LCA)

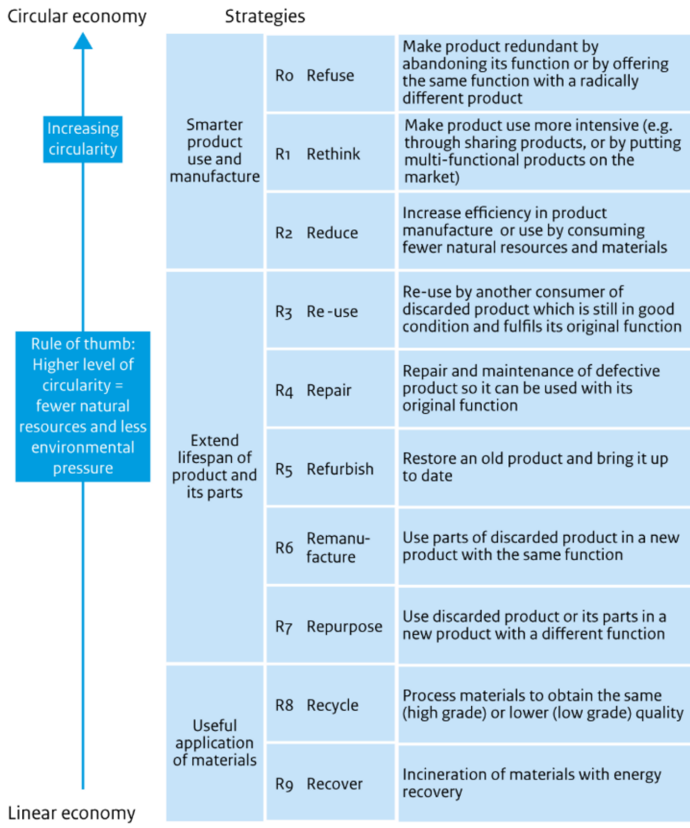


Figure 3.1: Overview of the 9R ladder of Potting et al. (2017)

can for example be done to assess the environmental impact and resources used over the life cycle of a product (Finnveden et al., 2009). By doing an LCA on the different circular strategies, it can be evaluated which strategy leads to the best environmental result for each strategy.

Of course, even more, elaborate versions of the R-ladder exist, which are usually just subdivisions of the before-mentioned strategies (MahmoumGonbadi et al., 2021). Another very often used version of the R-ladder by practitioners is the Butterfly diagram by the Ellen MacArthur Foundation (2023). This model defines two cycles: a technical cycle for materials like metals and plastics for which the R-ladder can be directly applied and a biological cycle. In the latter, cascading of materials (an example of which in the garment industry is given by (Angelis et al., 2018)) and regeneration are much more prominent than in traditional R-ladders. Another commonly found framework in a practical context is the ReSOLVE framework (Gunasekara et al., 2023) where Regenerate, share, optimize, loop, virtualize, and exchange are the main strategies. Most of these strategies can be matched to a strategy from the 9R framework. Virtualize is a noticeable variant of the rethink strategy where the same utility for the user is delivered in a virtual instead of a physical way.

Important when discussing sustainability in SCs are the different types of sustainable SCs. The reverse logistics or a reverse SC (RSC) type is explained earlier in the section. Another type often mentioned is the green SC, which focuses on reducing environmental impact (Batista et al., 2018). However, fitting to the R-list strategies are the terms circular, closed-loop (CL), and open-loop (OL) SC (González-Sánchez et al., 2020). The circular supply chain (CSC) is actually the overarching term for the CL and OL SCs (Gunasekara et al., 2023). The difference between a CSC and a RSC is that the CSC also includes the forward flow of products and how to integrate the reverse flow into the forward flow. In an OLSC, third parties are responsible for the reverse flow, which can be inside or outside the traditional value chain. In a CLSC, the flows remain in the traditional value chain and are centrally managed by one of the organizations in that chain (Gunasekara et al., 2023; MahmoumGonbadi et al., 2021). Berlin et al. (2022) states that CSCs are usually neither CLSCs nor OLSCs but show characteristics of both.

Whether an SC is open or closed-loop is not relevant to the design of the Stedin CSC. Most important for the understanding of CSCs are the strategies of the 9R ladder of Potting et al. (2017). Other models only repackage the strategies of this framework into a different visualisation. The 9R ladder is the core of a CSC as these are all the options a designer can use to integrate the principles of the circular economy in their operations.

3.1.3. Design methods

In the first part of this section, the general SC design methods are discussed to determine whether there are methods that are useful in the Stedin case study. Next, circular SC design methods are investigated. These various methods are investigated to develop a suitable design methodology for this project. The advantages and disadvantages of these methods are discussed, and at the end of the chapter, the conclusion is made on which method or combination is the most useful.

Supply Chain Design

There are some frameworks on SC management, like the SCOR model (Vegter et al., 2020) or the Global Supply Chain Forum framework (Lambert et al., 2005). However, they focus on the specific SC management processes and how to describe or analyse them. Most papers on the topic of supply chain design (SCD) focus on formulating mathematical models to optimize specific parts of a supply chain (Corominas et al., 2015). Examples of these types of articles are Beamon (1998), focused on multi-stage SC modeling, Goetschalckx et al. (2002) on strategic and tactical design algorithms, and Garcia and You (2015) on enterprise-wide optimization in SCD.

The papers concerned with SCD methodology can be categorized into two groups: methods based on typologies and those on a succession of stages. Typology-based methods look at the type of products and corresponding SC types. The first of such methodologies is the one proposed by Fisher (1997), which differentiates between physically efficient and market response SCs, which are matched to functional and innovative products. Another example is the two-dimensional method of Vonderembse et al. (2006) where the product type (standard, innovative, hybrid) is matched with the product life cycle (introduction, growth, maturity, decline) to recommend either a lean SC, an agile SC or a hybrid version. Christopher and Towill (2001) comes with a three-dimensional method where the type of product (standard or special), demand (volatile or stable), and lead times (short or long) are used to come to a lean, innovative agile, or top-up agile SC. However, Calleja et al. (2018) find that an approach based on typology can not be properly used to design a supply chain.

The other type of SCD method is based on stages one can go through in the design. A lot of stage-based models still focus on mathematical optimization or modeling. The first paper that introduces a stage-based model is by Lakhal et al. (1999), which is based on activity graphs. It focuses on which resources, methods, and activities are necessary to deliver a consumer product. However, it does not give handles on configuration or filtering through design options. Vila et al. (2006) defines five stages in the design process, but these stages mainly build towards the constitutions of the mathematical model itself and are less useful for general design. Another stage-based model is by Reiner and Trcka (2004), which goes through various design stages but is based on simulation models.

Two more practical models for this design research are the frameworks of Chandra and Grabis (2016) and Corominas et al. (2015). The former method has eight steps and starts with aligning the SC strategy with the goal of the design exercise. Afterward, it goes through the steps of conceptual design, experimental planning, pre-selection of designs, modeling, decision-making, implementation, and monitoring. The modeling can be qualitative and quantitative, but the planning aspect is less relevant for the Stedin case as this is mostly aimed at optimisation. This can be important at later stages when the design of the SC gets more detailed, i.e. exact warehouse location or size, or when the SC is more matured.

The Supply Chain Outline Process (SCOP) method has five different design stages, which become more detailed and end in the decision of the SC configuration. The method explicitly takes reverse logistics into account from the start of the design and has a top-down approach suitable for process-orientated design. It starts with the definition of the SC Object, environment, and objectives and then moves through different SC structures. It starts with a broad definition of the SC macrostructure (large activity blocks), goes to the mesostructure (more detailed activity blocks and their relations), and ends at the microstructure where specific SC assets and configurations can be designed based on mathematical modeling. The final step is the selection of the SC configuration.

There are no exact boundaries between the three structure levels. Corominas et al. (2015) works with certain graph conventions that visualise the SC. In these conventions, the core is to move from a large block like ’procurement-production-distribution’ in the macrostructure to just a ’procurement’ block in the meso level where there are several possibilities for procurement. In the micro-level structure, the exact details of these blocks, such as location, ownership, and capacity, are further specified. These exact graph conventions are not used in this project because even in the meso structure the choice options are already too detailed.

Although this method offers a way to structure the design of the SC from general to more detailed levels, it does not offer a way to create the design for each level. There is a sequence of steps in terms of granularity, but there is no concrete assistance in the SC design process. This is also seen as a main gap by the authors as they state that the method needs a deepening relative to design decisions and elaboration on options.

Circular Supply Chain Design

The SCOP method already takes reverse logistics as a possible SC process into account from the start. In practical literature, it is also stated that including a vision for the RSC and incorporating reverse flow into the SC planning is important for SCD (Rainier et al., 2022). A start to include more circular thought into SCD is the 9R ladder by Potting et al. (2017). These different strategies are recognized all over the world as the potential loops one can include in the design. However, it is not a clear method for creating a CSC design (CSCD). The same is the case for the Butterfly Diagram or the ReSOLVE framework. These frameworks come up a lot in practical literature on CSCD but are not an actual method (Ellen MacArthur Foundation, 2023; Gunasekara et al., 2023). Another tool that has already been mentioned is the SCOR model. An updated version has been released where the CE principles are integrated. However, the SCOR offers more SCM or SC analysis tools for the CSC than the general SC design.

Despite the importance and interest in CE and CSCs, there are few frameworks for the design or implementation, and research on CSCs is fragmented (Amir et al., 2023; González-Sánchez et al., 2020). Ellen MacArthur Foundation (2016) created a framework around the implementation of RSCs. This framework is a typology-based one with three different archetypes: low-value extended producer responsibility, service parts logistics, and advanced industrial parts. For each archetype, several handles are given: requirements, a prototypical reverse logistics solution, key success factors, some statements on network design, incentives for returns, and recovery capabilities. Two problems arise with this framework. The first is that the archetypes do not capture all large product categories that Stedin uses. For example, cables are not a product type that fits the archetypes’ descriptions. The second observation is that the different elements of the frameworks are more advice in implementation than a design method.

Amir et al. (2023) observed that there are no overall frameworks for CSC design, and therefore, they created their own CSC guiding framework for OEMs, which has four main constituents and is shown in Figure 3.2. The first building block is the systemic approach shown in the top of the figure, which can be integrated or holistic. The integrated approach focuses more on the activities’ processes and inter- intra-organizational integration. The holistic approach is more oriented towards the whole of the business model, product design, and processes. The second identifies the main drivers towards CSC implementation, such as business, environment, circularity, and policy.

The third is the various levels of decision-making on the right of the figure, with choices on strategic, tactical, and operational levels. The levels of decision-making, strategic, tactical, and operational, resemble the three levels defined in the SCOP method: macro, meso, and micro. A difference is that there are levels of decision-making in the CSC guiding framework, and in the SCOP, there are levels of SC structure. One is about processes and strategy, the other about physical details.

Lastly, the mechanisms for implementing CE principles are recovery strategy, distribution and collection, and network management. In addition to these framework building blocks, they state that it is important to look at stakeholder involvement aspects such as roles and relationships, ownership and sharing, incentives, and disincentives. The framework tries to cover a systematic approach to the design process and provides strategies or mechanisms for implementation.

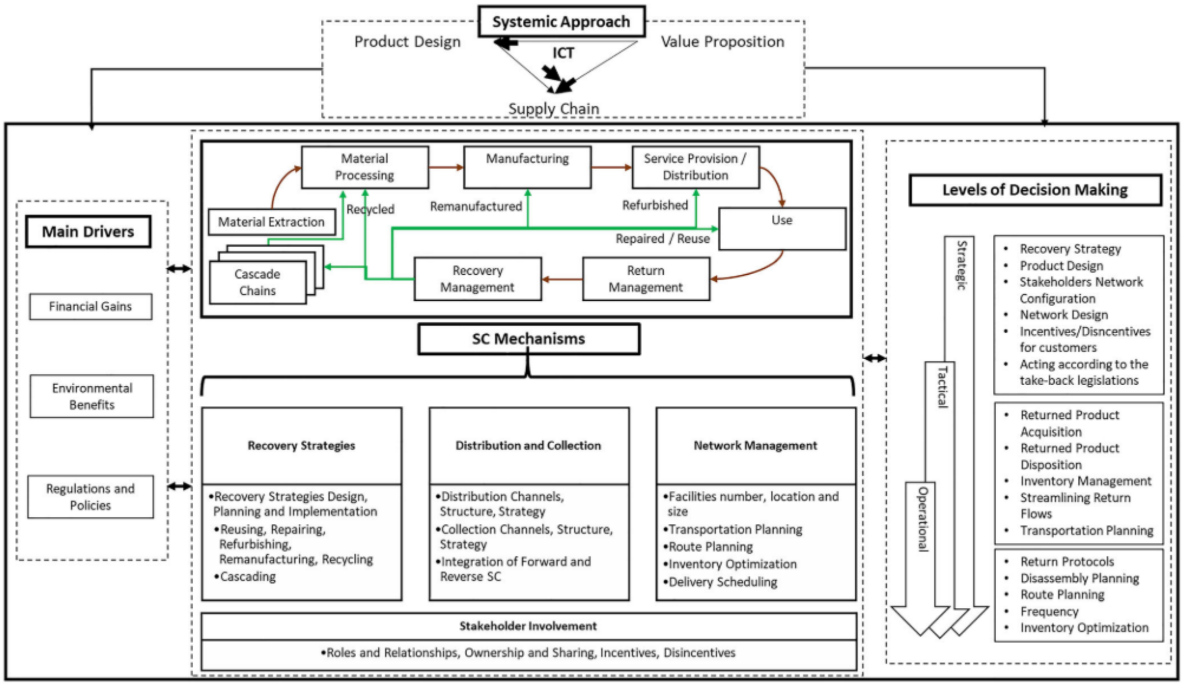


Figure 3.2: Overview of the building blocks of the CSC guiding framework by Amir et al. (2023)

Angelis et al. (2018) state that there is still very little information on the actual implementation of CSCs by businesses. From practical and scientific literature, some main points of focus in the design of CSCs can be found. Ellen MacArthur Foundation (2023) give a framework with nine focus areas for practitioners to focus on regarding CSCs. The people and structure, network design, supplier engagement, and data and quality focus areas are most relevant for this project. It is important that silos within SC departments are broken down as CSCs require more cooperation than traditional linear ones, with internal and external partners (Michelotti, 2021). Research found that a lack of internal cooperation, proper structure, top management support, SC member coordination and collaboration, and expertise are related to the failure of CSC implementation (Lahane et al., 2020). Important in this regard is also the forecasting of the reverse flow to inform internal and external stakeholders (Circular Supply Chain Network, 2023; Gunasekara et al., 2023). A way to solidify circular knowledge in an organization is to use a center of expertise on circularity and to create roles dedicated to circularity.

Evolved Double Diamond

Frameworks like SCOP (Corominas et al., 2015) or the CSC framework by Amir et al. (2023) give general guidance on the SC and CSC design steps but do not support the actual design process. Therefore, a more generic design method is required to augment the SC design frameworks. A well-established method based on design thinking is the Double Diamond (DD) method by Design Council (n.d.-b). It was created in 2003-4 and serves as a general and visual aid in all types of design projects (Design Council, 2007). The framework comprises four design phases over two diamonds: discover and define the first diamond and develop and deliver in the second. In the first diamond, the discover phase is a diverging part where the idea for what must be designed is established. The context of the challenge is explored, and the user's goals, needs, and motivations are discovered. Tools like market research, user research, and interviews can be used to collect data. This broad exploration needs to converge in the define phase. In the collected data, patterns are sought, and insights are gathered from the prior research. The end result of this first diamond is a clear understanding of what needs to be designed, what the requirements are for the new product or system, and what will be important in the value of the design (Design Council, 2007; Gustafsson, 2019).

In the second diamond, the development and testing of the design are happening. This stage involves a lot of creativity to generate design options for viable alternatives. The data and insights from the first diamond are input for this process. This is all part of the diverging part of the diamond, as a wide array of solutions need to be examined. The designs are also tested to evaluate whether they function as required and to iterate on the alternatives, leading to improved designs. In the last part of the DD framework, the process converges again towards a final solution and implementation plan. The different design alternatives are evaluated for their merits and can be further improved based on findings from the evaluation. Also, the final implementation of the design should be considered, and a product or system can be taken into use (Raposo et al., 2022).

The DD diagram makes the design process visual and assists in the cooperation of designers and other stakeholders in the design problem. Also, a design team can use the diagram to assess the project status. Every designer can modify the diagram to suit the uniqueness of their project, but it will always give guidance in the key design phases. There is, however, critique on the diagram for it being too linear and not including iterations more viable. Some designers add more diamonds to showcase that the design process has more phases than the four standard ones (Raposo et al., 2022). The Design Council updated the DD diagram to come up with the evolved double diamond or the framework for innovation which is shown in Figure 3.3. This is an expansion of the original diagram that includes the iterative characteristics of a design project more intrinsically. Four design principles are central to the philosophy of the new framework. These are to put people first, communicate visually and inclusively, collaborate and co-create, and iterate a lot. The new framework also introduces two organizational aspects of the design process: leadership and engagement. Leadership is about creating a design project's conditions and culture for innovation. This also includes providing the right skills and mindset during a project. Engagement is about building relationships with stakeholders and informing them of meaningful progress (Design Council, n.d.-a). Although this updated version of the diagram was introduced a few years ago, almost no literature mentions or uses the evolved double diamond (EDD) method. The only paper that was found that mentions the EDD is by Pyykkö et al. (2021).

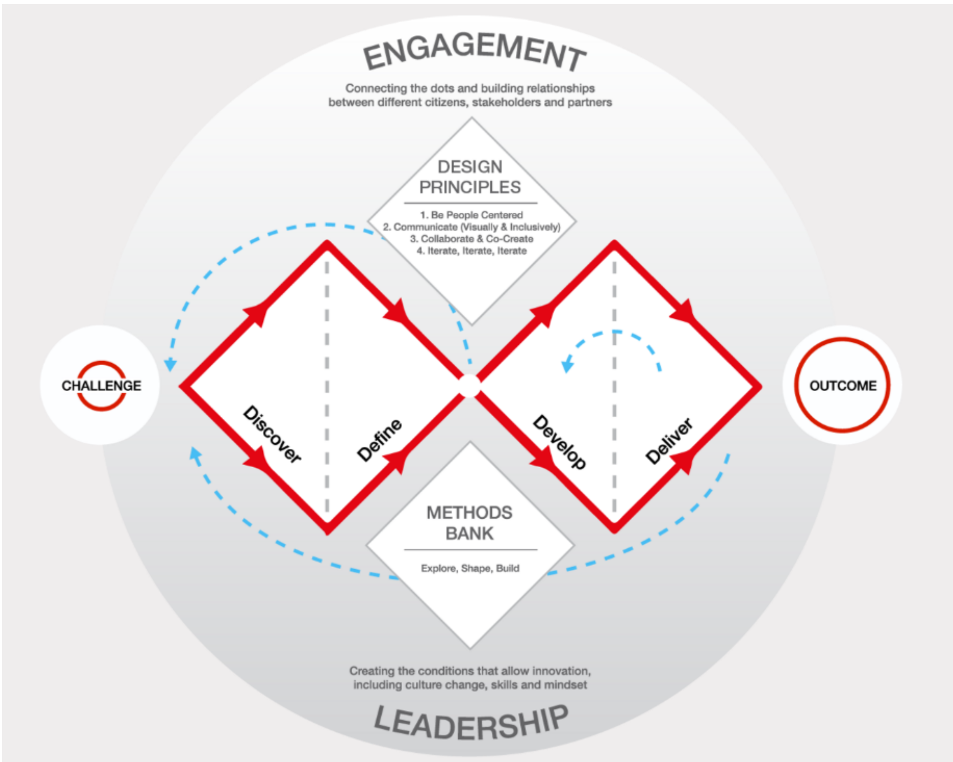


Figure 3.3: Evolved Double Diamond framework (Design Council, n.d.-a)

3.1.4. Conclusion literature review

After this background study, the project context and the concepts of the circular economy and circular supply chains are clear, and the project's design phase can start. The first project activity shown in Chapter 1 is to find a suitable methodology for the design of a circular supply chain. The SCOP method by Corominas et al. (2015) provides a top-down approach and gives a sequence of steps in granularity but lacks concrete assistance in the design process and focus on circularity. The framework by Amir et al. (2023) does give several building blocks for the CSC design. A combination of the two frameworks would combine some of their favorable traits. Using the SCOPs top-down approach, a designer can move from object and objective definition to ever-increasing detail of the design. This is important for Stedin as the objective at this time is not to optimize specific SC characteristics but to design the process steps on a higher level. The CSC guiding framework concentrates on CSCs and offers the building blocks in the design of the CSC. The focus of this framework is also on process design and does not include a mathematical model, which is required in the fourth step of the SCOP.

Although a combination of these two models offers guidance in moving through the level of detail and provides building blocks for CSC design, it offers less help in the actual design process. The evolved double diamond diagram is a method that can fill this gap. The SCOP method and CSC guidance framework are helpful in the develop phase of the EDD, but a design process requires a research phase as input for the development of alternatives. The EDD helps formulate the entire design process while also contemplating the leadership and engagement required to execute the design process and implement the results successfully.

The EDD is relatively new, and in the literature review, almost no papers are found that use the new version of the Double Diamond framework. The same is true for the SCOP method, while the authors have stated that applying the framework to real-world cases is needed to test the method's usefulness (Corominas et al., 2015). Also, Amir et al. (2023) have stated that more use cases for the framework are needed. So for all three methods, there is a research gap as more case studies that use the frameworks are needed. Additionally, as far as has been found, it is the first time that the methods are combined. Corominas et al. (2015) state that their method needs a deepening relative to the actual design that the CSC guiding framework does bring with its building blocks. Vice versa, the CSC guiding framework lacks the top-down structure to address a design problem that the SCOP method brings. Therefore, this combination of method enriches them both.

3.2. Current state analysis: expert consultation

The current state analysis is done during the discover diamond of the EDD and is used for the implementation plan. It is based on a large volume of informal conversations with a broad range of experts. Conversations with an outside sustainability expert (personal communication, n.d.) and SC expert (personal communication, n.d.) led to a first understanding of the circularity activities at Stedin. The initial in-depth base for the process diagrams is made for redeployment in the program Blue Dolfin and recycling by the responsible manager. The processes for redeployment in Blue Dolfin and further understanding of the processes are obtained from two redeployment experts (personal communication, n.d.) and a logistics expert (personal communication, n.d.). For an understanding of the recycling process, a internal recycling expert (personal communication, n.d.) and external recycling expert (personal communication, 28-02-2024) are consulted. Further refinement for the specific processes around power transformers was discussed with an asset expert (personal communication, n.d.). The Miro application is used to visualise the current state diagrams.

3.3. Reverse flow estimation: Data analysis

Simultaneously with the scoping activities, the preparation for the reverse flow estimation was done. There is a need for reverse flow estimation to dimension the designs, and the results were used for the final decision in scoping. For the design process, it helps to know if a reverse flow will be 1000 units or ten and if these units represent millions of kilograms of material or just 100 tons. In an ideal scenario, there would already be information available on which assets will leave the grid in 2030 to determine the exact flow of the selected assets. However, it is unclear to Stedin what the exact assets are in the grid and when they will be decommissioned. Therefore, it was necessary to shift the focus towards a more indirect method to provide an estimate for the reverse flow.

Determining the estimation method was done with an data expert (personal communication, n.d.), and the data collection was done by this expert and another external data expert (personal communication, n.d.). Initially a method was investigated were estimations would be based on GIS data (Geographic Information System). In this method it would be required to know the expected decommission date for each asset but this turned out to be data that is not available. Another idea was to use historic data from the waste processor to predict future flows. However, this data was not useful as there were too many one-time factors influencing the long term trends. The final method was based on estimating how many assets per class will be put into the grid in 2030. These estimations were already generated from investment plans for internal purchasing decisions by the data analyst and stated both investment volume and quantities per asset class. The most important assumption in the estimation method is that for part of the assets that will be put into the grid, there will also be old assets that are decommissioned and should be processed. However, not every project will feature decommissioning because of the significant expansion challenge facing Stedin. This made it very important to obtain data on how often this happened.

Every project at Stedin has certain DVO codes that indicate what activities are carried out in a project. There is a DVO code ’remove’ that indicates that old assets are removed from the grid for a certain project. The data consulted generated a list of the last 110 thousand projects that are either already completed or still in an earlier stage. This earlier stage can be that they are currently doing physical work, handling the final financial details, or that it has only just been created. A data analysis was done on these projects to determine two different percentages. Stedin splits projects into either ’customer-driven’ or ’grid-driven’ projects, indicating whether the project is being done because of a specific customer request, can be a new connection or fortification, or because Stedin sees a (future) need from a grid perspective. The data analyst already gave the ratio between these workflows. Because the expectation was that these project flows would have different characteristics, removal percentages were needed for both. The analysis of the data was done in Excel based on the indication of whether a project has a removal DVO-code. The obtained percentages for each workflow were validated afterwards with internal experts.

The expected reverse flow was estimated based on the quantity data for 2030, the split between customer and grid-driven projects, and the percentage of the projects with the removal DVO codes. This is done by multiplying the quantity for an asset class by the share of workflow times the removal percentage of that workflow. This way, the reverse flow in several assets, or the total length of cables, is obtained in the case of cables. To translate this to weight volumes, weight data per unit of that asset was required. This data was obtained from existing material passports, technical product fact sheets, and data from product experts in asset management. For each selected asset class, the weight per unit is based on multiple suppliers and is taken as an average or weighted average depending on the most suitable. For cables, power transformers, and MS switching boards, averages were taken; for distribution transformers and HS switching boards, weighted averages were used based on the expected 2030 quantities per type of asset. To estimate the reverse flow in kilograms, that weight per unit is multiplied by the reverse flow in quantity. The results of these steps are discussed in the second part of Chapter 4.

3.4. Requirements generation: Brainstorm, interviews & workshop

To set the boundaries and preferences for the design, requirements have to be determined. These requirements give guidance in the design process in what the CSC should look like and should be able to do. The generation of requirements is split into three stages: a first individual brainstorm, an initial validation session, and a final requirements workshop.

Brainstorm

The literature and Stedin strategy are important in the first stage of the requirements generation where a brainstorm resulted in a mind map of requirements. The scientific and practical literature indicate general circular strategies and focus points in CSC design that can be used as input to generate requirements. Stedin has also formulated a general corporate strategy, an ESG strategy, and an SC strategy for materials. These strategies contain goals and ambitions that function as input for the requirements. This is combined with a generally obtained understanding of Stedin’s operations. Bahill and Dean (2009) is used to understand better how requirements should be formulated and which types of requirements a system can have. In an individual brainstorm by the author, a first set of requirements is generated. The requirement generation is split up between five different themes. This is done to assist in the generation process and make the requirements more well-organized later on. In this stage, the requirements are split up into constraints and objectives, or as Bahill and Dean (2009) calls them, mandatory and trade-off requirements. This initial requirements list was formalized and divided between functional and non-functional requirements (van Binsbergen, 2021).

Validation: interviews or workshop
After the initial generation of requirements, they need to be validated by stakeholders. There are various methods as the already discussed workshop or interview techniques like the Q-method and Delphi methods. The advantage of the interview method is that not all stakeholders have to be in the same place at the same time to elicit feedback. The Q-method interviews are used to investigate the perspectives of the different participants. The participants need to rank and sort a series of statements to determine the most important. In this method, stakeholders do not interact to reach a consensus (Shinebourne, 2009). In the Delphi method, there is an implicit interaction between the participants. This method features different rounds of interviews or questionnaires to come to a consensus. The disadvantage of this is that it requires more time in the research process and from the researcher and participants themselves, as more rounds are needed (Beiderbeck et al., 2021).

A workshop format has been chosen for the initial and final validation. This is done because it is important to Stedin that the system requirements are discussed by multiple stakeholders in a way they can interact and understand what they find important. The Q-method does not have this cooperation, and the Delphi method works towards consensus for the requirements set. At the same time, different stakeholders may have different system requirements.

In the first validation round two experts are selected to These are experts in strategy and organization (personal communication, 14-03-2024) and SC and IT (personal communication, 14-03-2024). In a review session, the experts looked at the generated requirements' relevance, whether the requirement type was correct (constraint/objective & functional/non-functional), and if requirements were missing. The themes and possible rearrangement of requirements over the themes were also under review. The experts received the first version of the requirements in advance, and during the review, the list was discussed theme by theme. The result of the expert review was feedback for a second version that could be incorporated.

The last stage of the generation was an online workshop of an hour (21-03-2024) with a larger group of experts to finalize the requirements list. These experts were the two experts from the validation session augmented with the Director of Supply Chain (M. Baars), the Sustainability Manager of Asset Management (T. Wubbels), and the Manager of Logistic Services (R. van der Spoel). This group overlaps with the workshop on the scoping of materials but is more oriented towards strategy and process knowledge. During the workshop, the experts went through the second version of the requirements theme by theme to give feedback on whether requirements should be removed from the list, if they were lacking, or if they should change from constraint to objective or vice versa. Before the workshop, the experts received documentation explaining the different requirement types and the list. The feedback from this workshop was incorporated to form the final version of the requirements list, which is discussed in Chapter 5.

3.5. Design methodology: EDD, SCOP, CSC framework

The development method for the designs results from the literature review's conclusion in Section 3.1.4. The Evolved Double Diamond method is the basis for the overall process, as already stated in the introduction of this chapter and visualized in Figure 3.4. This method consists of two diamonds: the research and design diamonds. Each diamond is again divided into two phases: the discover and define phases in the first diamond and the develop and deliver phases in the second diamond. In the figure, all the important activities for the design processes are placed in the different phases and the leadership and engagement aspects are included. More information on the use of the EDD, SCOP and CSC guiding framework follows below.

The EDD, as shown in Figure 3.3, also shows two more aspects: the 'design principles' and 'methods bank'. The design principles are considered in the design process but are less visible in the adjusted figure. The entire project relies heavily on expert input and is thus very people-centered, and collaboration and co-creation are facilitated in several workshops and feedback moments. All the results in the design process are graphically presented, and feedback from the collaboration sessions provides opportunities for iteration. The methods bank is not used because the framework's creators have not shared specific techniques for this, and the CSC guiding framework and SCOP method have already been used as design methods.

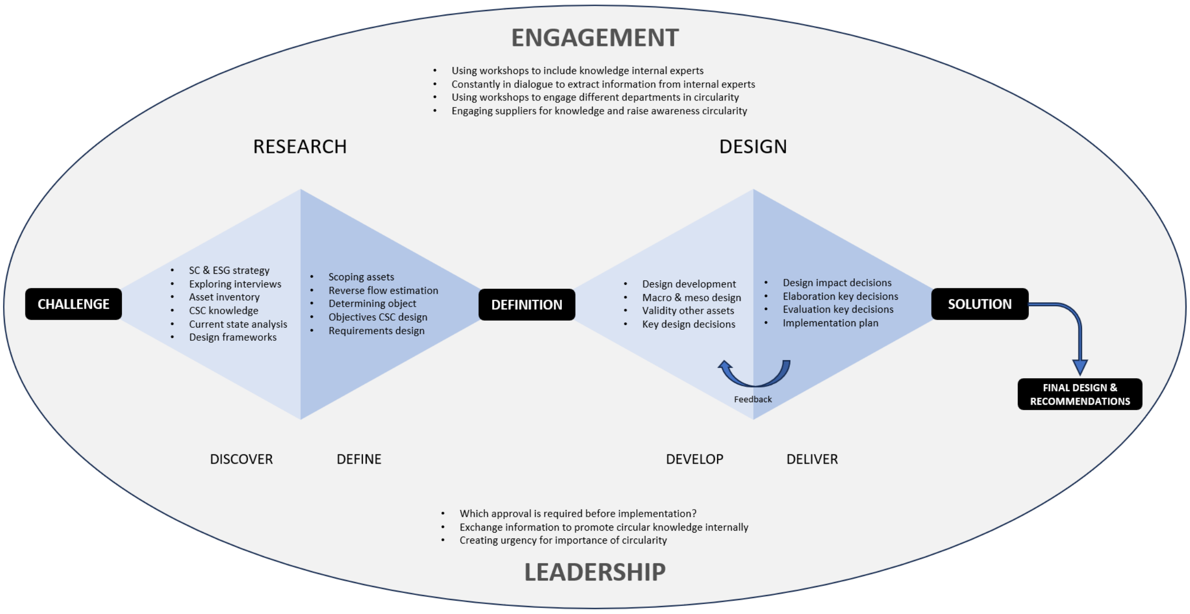


Figure 3.4: Evolved Double Diamond diagram adjusted for project

This framework is combined with the SCOP method, where five phases are defined:

1. SC object, environment, and objectives
2. Definition of SC macrostructure: Identification of activity blocks and the relation between them
3. Definition of SC mesostructure: Options for each SC activity or group of activities
4. Definition of SC microstructure: Transportation, sources of demand, facilities
5. Choose SC configuration

Design frameworks
In the discover section of the EDD, a first knowledge basis is built up that offers input for the define phase. Activities in the discovery phase include familiarising with Stedin, SC, and ESG strategy, getting to know the organization, reviewing the literature on CSC, gathering data on asset types, volumes, and emissions, and conducting a current state analysis. Although the EDD seems linear, this is not the case. Iteration is an important foundation of the EDD, so parts of the activities in earlier phases of the EDD can be revisited at later moments. This is, for example, the case for the current state analysis, which is part of the knowledge build-up on Stedin but could be refined later. The first stage of the SCOP method is part of the defined stage of the EDD. Here, the asses are scoped, as described in Section 2.1.2, and the reverse flows are estimated, as described in Section 3.3. Also, the SC object and objectives are synthesized into a design brief, shown in Section 5.1. This leads to the generation of the design requirements at the nexus of the define and develop phase. The design brief and the requirements, combined in Chapter 5, define the design problem.

The SCOP method's second, third, and fourth steps are within the development phase. The advantage of combining these SCOP steps in this development phase is that it structures the development of the designs. It forces a top-down approach suitable for a greenfield SC design like this project. The microstructure will be less relevant for this design project as this is a level of detail that Stedin is less interested in at this moment. Therefore, the focus will be on the macro and meso levels. At the macro level, the design could be for many companies, focusing on including all the high-level activity blocks. In the case of a CSC, this relates a lot to the 9R ladder of Potting et al. (2017). On the meso level, the CSC guiding framework of Amir et al. (2023) is used to help design this more detailed mesostructure. This framework consists of several building blocks, a systemic approach, main drivers, level of decision-makers, and mechanisms. The main drivers are part of the first step in the SCOP method, but the other building blocks help in the design process.

Design development
The development of the designs is based on the frameworks described above. The start is on a macro level to design the general contours of the to-be process. The basis for this, and therefore also the later design, is the 9R ladder, as this framework describes the different strategies that can be used for the circular processing of assets. The design visualisations are made in the Miro application, which gives tooling to visualise the process, collaborate with stakeholders on the design, and quickly adapt it. The macro design was validated by two experts (Logistics expert, personal communication, n.d.)(SC expert, personal communication, n.d.). In the validation sessions, the design was discussed on feasibility and completeness of the process.

The meso design structure was developed from the macro design. This level is more detailed and Stedin-specific, so the design requirements are very important in this stage. The macro-level activity blocks needed to be expanded into separate processes. During the design of the meso-level structure, the CSC guiding framework, 9R ladder and other information on CSCs collected in the literature review are used as input or inspiration and tested against the requirements. This is again validated by a logistics expert (personal communication, 03-04-3024) to see if the process is still feasible and if steps should change. This validated design, a process diagram augmented by a list of design characteristics that can not be seen from the diagram, is the final step in the process design. The following stages are the key design decisions that arise from the design process and the implementation plan.

Contextual aspects: leadership & engagement
The EDD also introduces two cultural elements that are an augmentation compared to the traditional DD method: engagement and leadership. These are two elements that influence the success of the design process and the implementation of the design. Stakeholders are engaged to create a commitment to the result and to receive valuable input. Several workshops, sessions, and interviews are done with a large group of stakeholders to achieve these goals. The Stedin stakeholders are both within several teams in the supply chain department, as well as technical experts from the asset management department. Additionally, suppliers are contacted to with the same goals in mind. From a leadership perspective these interactions are also valuable to create urgency for the overall theme of circularity.

This research focuses on the circular supply chain, which interacts with circular product design and circular purchasing. By bringing circularity more under the attention of stakeholders, the other topics within circularity will hopefully also become more top in mind. Adjacent to this is the knowledge transfer between stakeholders on circularity. Because this research requires a broad range of perspectives, the author is also able to provide stakeholders with knowledge of other stakeholders. Finally, it is important to remember which approval is needed for the different stages in the design process. For this reason, for example, the SC director was included in the finalization of the requirements. This creates a go/no-go moment regarding the important principles of design.

3.6. Key design decisions & implementation plan

Key design decisions
After the design development, the delivery phase is the last part of the EDD. After multiple iterations in the development phase, there is a final design backbone and a list of several important design decisions, which is expert validated, that have to be taken to implement the design. A decision elaboration and evaluation framework is needed to evaluate these important decisions. Before creating the elaboration framework, a small literature review is done on business decision-making frameworks or required information. The created elaboration framework is primarily based on expert input and validation.

Based on the created elaboration framework, the nine key decisions are discussed. The input for this elaboration comes from all the interviews, sessions, workshops, and literature from the project. This information is combined with critical thinking to go to the elaborations. The impact of all decision choices on the design is analysed to test whether the meso design holds even with the key decisions taken. From this, a few design alterations are shown for the cases where choices affect small parts of the design. The literature from Section 2.1.2 is used and built on to expand on the elaboration framework with the evaluation framework. The literature is combined with the decision descriptions to choose the appropriate evaluation technique for the two most important decisions.

Implementation plan
Also, part of the last EDD phase and SCOP step is the delivery or implementation of the design. This implementation plan is based on the designs presented in Chapter 6, the key decisions from Chapter 7, and the interfaces of the 2030 designs with the current state from Chapter 4. The identified projects are categorised by the method of Ika et al. (2021), which offers support later on when the projects are executed. Finally, project planning is made based on the estimated importance of the projects, which is validated by a SC expert (personal communication, 29-04-2024).

4

Current state & future reverse flow

This chapter is a combination of the current state analysis of the situation in 2024 and an estimation of the 2030 reverse flow. In the first part, Section 4.1, the circular practices are mapped as they exist overall and for specific assets. This section also includes data on the current circular processed flow. In the second part of the chapter, Section 4.2, the reverse flow for 2030 is estimated.

4.1. Current state analysis 2024

For the later implementation of the designs that will be developed, it is important to analyse the as-is situation around the redeployment and recycling in 2024 of the assets scoped in Section 2.3. As explained in the methodology, several experts were consulted to create and validate this current state analysis and is partly a result of the conversations held for the background study. Although this current state is known before the development of the 2030 design, it is explicitly tried not to take the current state into account in the design process. The desire of Stedin is to approach the 2030 design from a 'new' or 'fresh' perspective disregarding the current situation. However, the current state will play a role in the implementation plan in Chapter 8 and will always, at least unconsciously, offer inspiration for the 2030 design.

Figure 4.1 shows the overall current state, which is mainly geared to the ZP (Business Project or medium and low voltage) chain. This figure, and the other current state figures in this chapter, are on the meso level of the SCOP method. This ensures that the current state of the circular practices can be best compared to the meso-level design that is made in Chapter 6.

The processes for all cable types and the distribution transformers are captured in this overall figure. The process for the power transformers is quite similar, with some small deviations. Next, later in this chapter, a separate current state diagram for each asset type in the scope is shown and discussed. The main processing paths for assets are to the right in the diagram, which is the redeployment loop, or the the bottom, which is the recycling loop. These are the two main strategies that are used in circular processing.

Below in Table 4.1, the current state for the reverse flows is shown. A disclaimer has to be given on the accuracy of the data. The recycle partner only reports on 'cables' or 'transformers' which means that no distinction can be made between asset types. The redeployment data has not been recorded in a structured way in 2023 and before so actual data can deviate from these numbers.

Table 4.1: Current state reverse flow 2023

<table>
<tr><th>Asset</th><th>Recycled</th><th>Redeployed</th></tr>
<tr><td>MS / LS cables</td><td rowspan="2">Redacted kg</td><td>Redacted m</td></tr>
<tr><td>HS cables</td><td>Redacted m</td></tr>
<tr><td>Distribution transformer</td><td rowspan="2">Redacted units</td><td>Redacted units</td></tr>
<tr><td>Power transformer</td><td>Redacted units</td></tr>
</table>

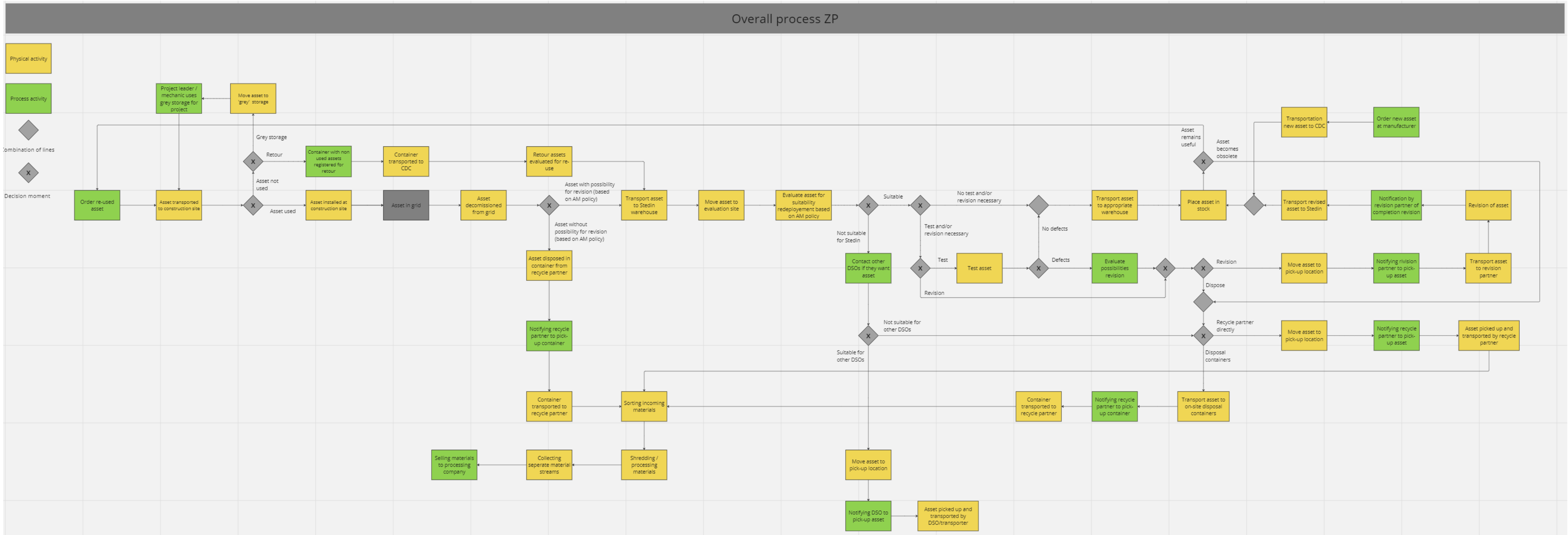


Figure 4.1: Overall process diagram current state

4.1.1. MS & LS cables

The current state diagrams contain both physical activities (yellow) and process activities (green), as can be seen in the diagram of MS and LS cables in Figure 4.2. Two decision moments can be seen: whether a new asset is used or not at the construction site, and, if it is not used, whether the cables will go back to the central distribution centre (CDC) or end up in a 'grey' storage site of the project leader or mechanic. This is not a process that should happen, but from interviews, it was found that this does happen in practice. Therefore, there is a loop shown where a cable is used at a later date by a project leader without ordering it from the CDC. The standard loop for cables is that a new cable is ordered from the manufacturer, placed in stock and then transported to the construction site.

If the cable is used in the grid, it will come out of the ground when the asset is at end-of-use (EoU). At this point, the cables are disposed of in containers from the recycling partner at the construction site, which is picked up after notifying that partner. Then, the cables enter the recycle loop, where the recycle partners sort and shred or process the cables to sell the different material streams. There is no re-use of the cable as this is technically not possible (sustainability expert, personal communication, n.d.).

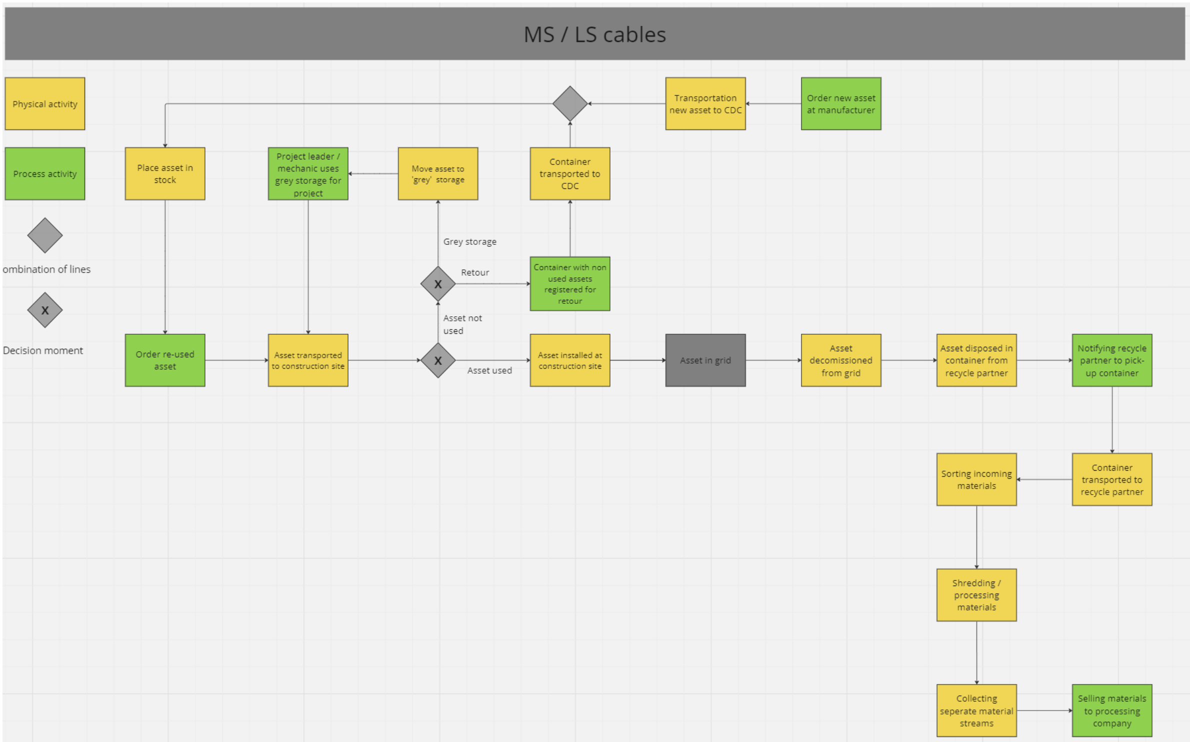


Figure 4.2: Process diagram current state MS/LS cables

4.1.2. HS cables

Most of the HS cables have the same composition as LS and MS cables and approximately the same process diagram, as seen in Figure 4.3. There is one important difference: the reuse of cable parts from the old oil pressure cables. When an asset is decommissioned from the grid, there is now a choice that needs to be made. Does the asset go into the recycling loop, which is the same as described in the previous section, or will it be reused. If an asset part, in this case, part of a cable, is reused, it is handled by an external partner. This partner will also use the asset part at the construction site if needed.

4.1.3. Distribution transformers

The current state process diagram of the distribution transformers can be seen in Figure 4.4. There are quite some steps that are similar to cable diagrams, although they will have different starting or end-points. Just like cables, after the delivery of the asset at the construction site, it can be that the

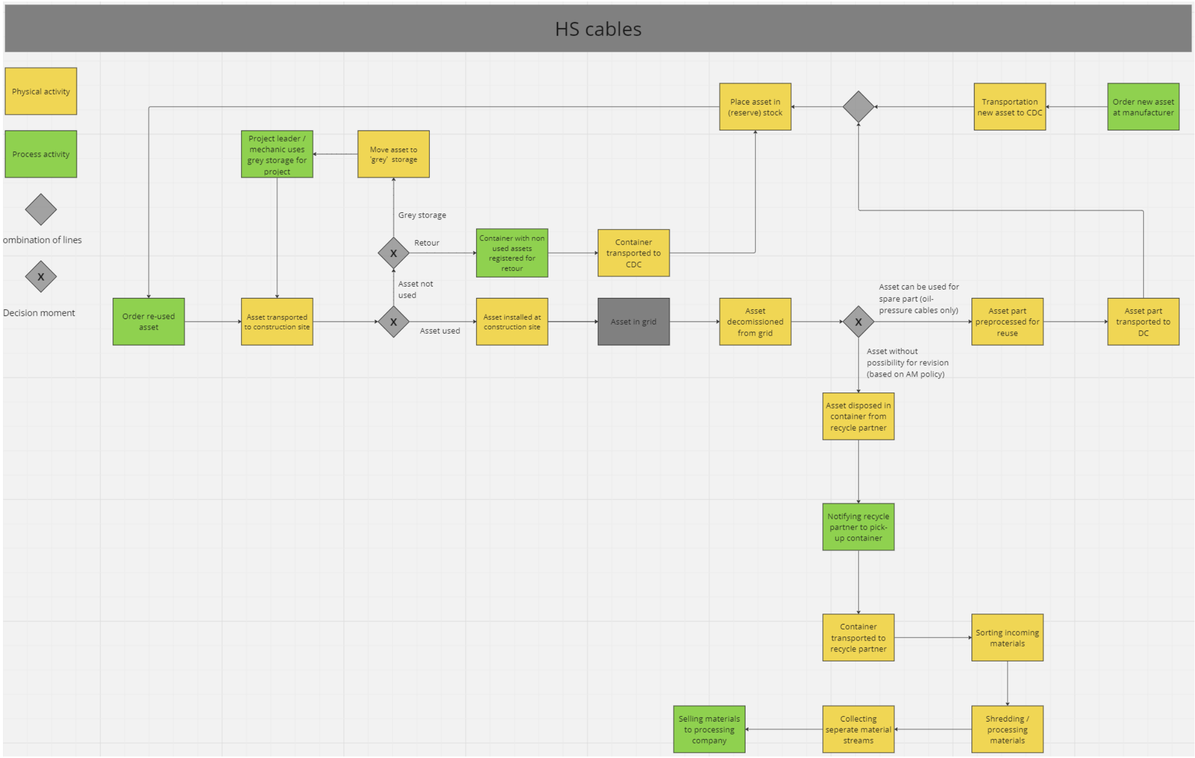


Figure 4.3: Process diagram current state HS cables

asset is not used in the end. This is not often the case for distribution transformers, but it can happen. Then, the same steps will be taken for grey storage or reverse flow. The difference is that the assets are transported to the Stedin CDC instead of the containers used for cables.

After transportation, the asset is evaluated for suitability for redeployment based on guidelines from the asset management (AM) department. If they are not suited for Stedin, other DSOs are sometimes contacted if they have an interest in the asset. If this is the case, the asset will be picked up by the DSO or a partner of the DSO at the pick-up location. If it is not suitable for another DSO as well, it moves into the recycling loop. Most of the time, the complete asset will be picked up by the recycling partner and transported, sorted and processed by them, just like with the cables. The actual process is more complex for transformers due to oil isolation. In rare cases, parts of the asset need to be disposed of, which is done by the waste containers at the CDC. These containers are picked up like the containers full of cables at the construction site and processed accordingly.

If the asset can be reused based on AM policy, the next decision moment comes. If the evaluation finds that the asset is functioning well, it can be directly transported to the right warehouse facility and placed in stock. If further testing or revision seems necessary, it moves to another decision moment. Some assets clearly need some kind of revision, and this process can be started. Others are tested for defects. If no defect requires revision, it can be directly placed in stock. If defects are found, it arrives in the revision process with an evaluation of the required work. After testing, it can also be decided that the asset can not be reconditioned and enters the previously described recycle loop.

An external partner revises the distribution transformers. If a revision is required, the asset is transferred to a pick-up area and transported by the revision partner. After revision of the asset, Stedin is notified and receives back the asset, after which it is placed in stock just like other newly manufactured assets. There is a policy that dictates that revised assets need to be used first in construction to stimulate redeployment. It can be the case that an asset becomes obsolete, and in that case, the asset enters the recycle loop.

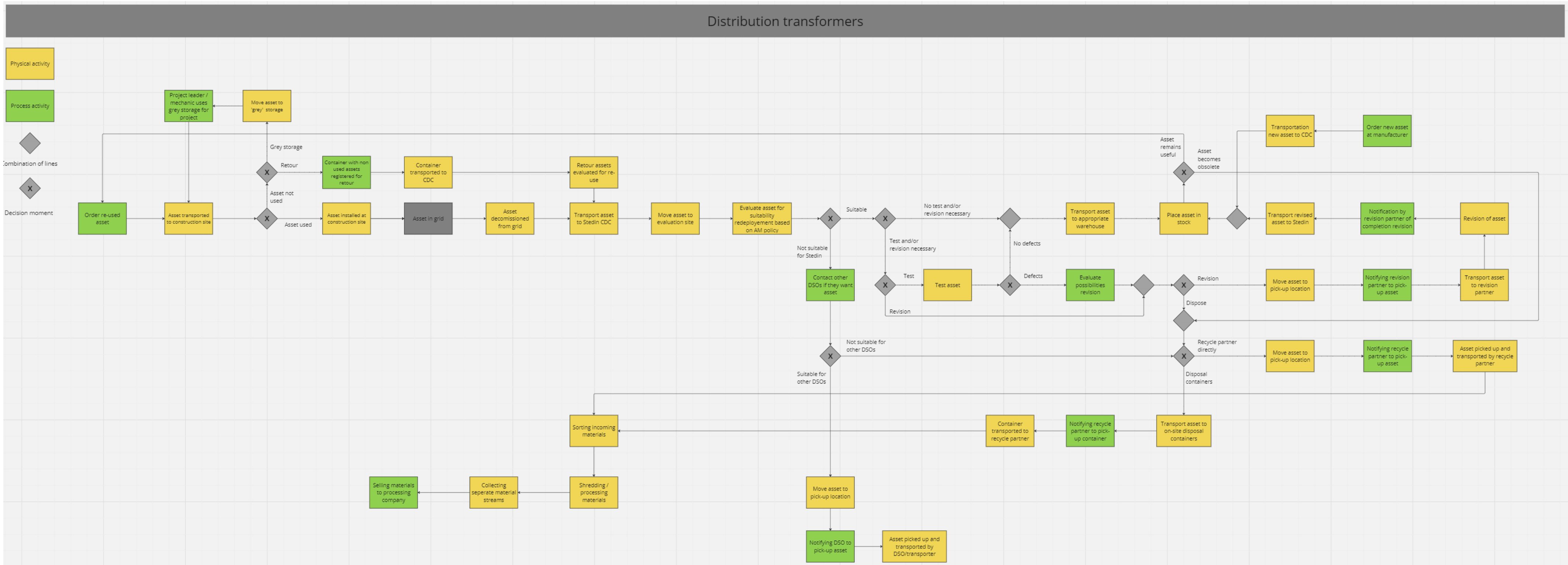


Figure 4.4: Process diagram current state distribution transformers

4.1.4. Power transformers

Again, as can be seen in Figure 4.5, there are similarities in the process diagram of power transformers. The differences come from the fact that these transformers are significantly heavier than distribution transformers and require different handling. In contrast to the other assets, it is never the case that an asset is not used. These assets are very specific and are normally ordered for specific projects. The asset is evaluated for the possibility of reuse on the former construction site. If the asset cannot be reused based on AM policy, it is picked up, dismantled and recycled by partners. This can also be the case if there is no demand for that transformer. In the current process, power transformers are only reused if there is a new construction site where it is required.

If there is demand and the asset is suitable, a new type of decision is made. The asset can be revised on-site if minor reconditioning is needed. In this case, after work on site is done, the asset can be transported to the new site. In contrast to the former demand remark, some assets are stored for emergencies. As these assets have long delivery times, an emergency stock is used. However, this is only the case if there is a demand for a new asset in emergency storage. If too much work needs to be done on the asset, a partner picks up the asset and revises the site. After this, it can be directly used at the new construction site or in emergency storage.

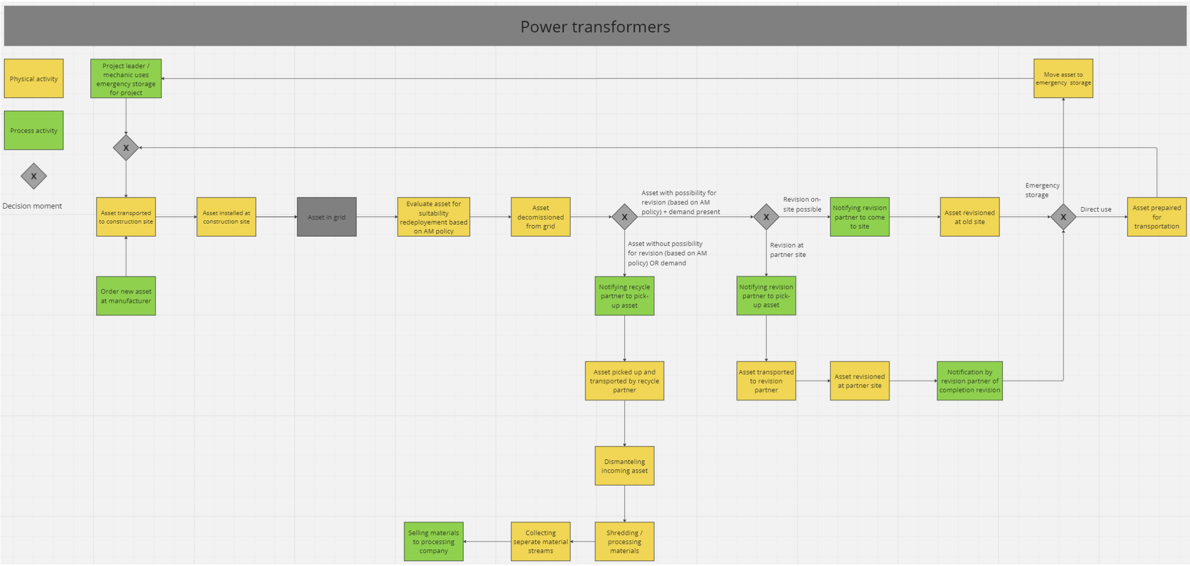


Figure 4.5: Process diagram current state power transformers

4.2. Estimated asset reverse flow 2030

In the previous section, the current reverse flow of assets in 2023 is shown. In this chapter, the results of the reverse flow estimation for 2030 are discussed. An estimation of the reverse flow gives the possibility to dimension the design if necessary and to prepare the organisation on the scale of the flow at a later stage. In the first part of the Chapter, Section 4.2.1, the initial data collection required for the estimation is treated. Section 4.2.2 shows the calculation of the variables for transforming the initial data towards reverse flows. Finally, in Section 4.2.3, the estimations of the reverse flows are discussed.

4.2.1. Data collection volume 2030

The starting point for estimating the reverse flows is the forecasts resulting from Stedin's investment plans for 2030. These forecasts are on the asset class level and state the expected volumes of a class to put in the grid in 2030. A data consultant of Stedin determines them based on three methods. The MS/LS cables, distribution transformers, and MS switching boards are done by method A, HS cables and HS switching board with method B, and the power transformers with method C. Method A's forecast is based on historical figures of materials put into the grid that are scaled based on the Strategic Investment Plan for 2030. In method B, the forecast is based on long-term programs within the high-voltage unit of Stedin, which forecasts programs for more extended periods. In method C, the data is based on an expected demand by the high-voltage organization used in a tender.

Below in Table 4.2, the forecast for the six highest-scoring asset classes in the scoping exercise is shown. Although it was said in the previous scoping chapter that switching boards are not in scope, they are still included here. This is because part of the decision to leave these asset classes out of scope is based on the low estimated reverse flows shown at this chapter's end. In the forecast data, it can be seen that there are large differences in quantities. This is because of the type of use of the asset. The high-voltage assets are often much lower in volume but heavier per unit. The average weight per unit of an asset class is shown in the last column of Table 4.2. The quantity of assets in 2030 can be regarded as the forward flow estimation for 2030. For the design, the forward flow is less relevant because this flow is done based on the existing forward logistics processes. These average weights are based on material passports or data sheets Stedin received from the suppliers. Depending on the information available, more or less material types are included in the averages.

Many material passports are available for MS/LS cables, so the average weight is based on 22 different types. As the purchasing data of 2023, used in the scoping workshop, it is found that the division between MS and LS cables is approximately 50/50; this was also used in the calculation of the average. For HS cables, 9 data sheets are used to calculate the average. Ten material passports are used in the calculation for the distribution transformers. A weighted average between the different types (in kVA) is taken to obtain a more realistic outcome than a regular average. For power transformers, the regular average is taken because the four different fact sheets obtained were for across the possible spectrum, and the expected use in 2030 is also spread over this spectrum. For MS switching boards, a regular average is taken because only two passports were available. A weighted average was used for the three types of HS switching boards because more exact forecasts are also available.

Table 4.2: Estimations from investment plans 2030 and average weights asset classes

Product	Investment volume 2030	Quantity assets 2030	Unit	Average weight (kg/unit)
MS/LS cables	€ Redacted	Redacted	m	Redacted
HS cables	€ Redacted	Redacted	m	Redacted
Distribution transformers	€ Redacted	Redacted	pieces	Redacted
Power transformers	€ Redacted	Redacted	pieces	Redacted
MS switching board	€ Redacted	Redacted	pieces	Redacted
HS switching board	€ Redacted	Redacted	pieces	Redacted

4.2.2. Determining estimation variables

The central assumption in estimating the reverse flow is that projects' removal percentages will remain stable until 2030. This is because the project portfolio division is not expected to change significantly until 2030. It can be that the percentage will rise due to initiatives stimulating a higher asset retrieval rate but this is mentioned as a project in the implementation plan.

So, if the project removal percentage is known, it can be combined with the forecasts on asset placement to come to a reverse flow in 2030 of assets being decommissioned from the grid. The DVO codes (Service Provision Agreement) on projects are used to obtain these percentages. Every project from Stedin has one or multiple DVO codes indicating what type of service the contractors have to perform. One type of DVO code is removing assets during a project. So, every project with a removal DVO code will have a reverse flow of assets from the construction site. A limitation is that project leaders must always put the right codes in the system. The expert who delivered the data of all the projects and whether they have a removal DVO code indicated that this is a lower limit estimation because he expects that the removal code is not always put on the project when needed. The code can also be put multiple times on a project because the removal was done four times. For example, the data was processed to indicate whether a project had a removal code.

There are two important workflows in Stedin's projects: customer-driven (CD) and grid-driven (GD). In CD projects, the initiative is taken by a customer, and in GD by Stedin. The experts consulted in this activity expected that the percentages would be different for the two workflows as the dynamics of the flows are different. For this reason, two separate percentages are determined, and the division between the two workflows is used in the calculation of the reverse flows. The initial data set contained almost *Redacted* projects from 2018 to projects expected in the future. Removal of gas-related projects gave a list of *Redacted* projects, *Redacted* CD, and *Redacted* GD, with a removal percentage of *Redacted* A percentage on a project basis is inaccurate as it does not say anything about the project size. No data was available on a project basis, but each project belongs to a program, and forecasts (or realizations) for these programs are available. By combining the percentage of projects per program with a removal code and the program investment, a removal percentage can be calculated based on investments where removals are done. This results in a percentage of *Redacted*.

In consultation with the experts, it was decided only to include projects already totally finalized or at least financially (the second last project status in the funnel). These project phases will most likely contain reliable data as all are concluded and administratively finalized. For GD, this resulted in a list of *Redacted* projects with a removal percentage of *Redacted*, which the experts found realistic. For CD, all projects were considered to be at least in the execution phase. Analyzing these remaining project phases and removal percentages resulted in surprising results. The finalized projects had extremely low percentages, but the remaining phases had much higher percentages. It was chosen to remove the completed projects from the final calculations as they appear to have had a different way of working than currently used. For CD, the program related to the internal value stream customer is removed on the advice of a business control expert (personal communication, 15-03-2024). Projects from this program are at consumers' homes and have much less often a reverse flow. Table 4.3 shows the final results for the variables. It can be seen that CD and GD indeed have different removal percentages and that GD is about *Redacted* of the investment volume.

Table 4.3: Input variables calculation reverse flow

General	
Material costs 2030 customer-driven (CD)	€ Redacted
Material costs 2030 grid driven (GD)	€ Redacted
Share material costs CD	Redacted%
Share material costs GD	Redacted%
% investments CD with DVO removal	Redacted%
% investments GD with DVO removal	Redacted%

4.2.3. Estimation results

The data from the previous two sections is combined to determine the final estimation of reverse flows in 2030. First, the reverse flow in quantity is determined, as is the volume in units of the asset. This is done by multiplying the forecast for 2030 from Table 4.2 by the share of the material costs per workflow times the removal percentage for that workflow. The total results show the quantity of each asset class expected to come from the grid in 2030. This is always a lower quantity than the original 2030 input forecast, as only a part of these projects is expected to have a reverse flow. Next, the average weight from Table 4.2 is multiplied by the previously obtained quantity estimate to find the reverse flow in kilograms.

For cables, it can be seen in the results that the expected reverse flow in meters of MS/LS is more than a factor of ten higher than HS. However, this difference shrinks to just over three on a weight basis. The same can be seen for transformers, where, on a quantity basis, around *Redacted* times more distribution transformers come back than power transformers. However, on a weight basis, this shrinks to a factor of three again. For MS and HS switching boards, this difference is much less the case as there is a large overlap in actual asset types in both classes. The difference in the forecast between MS and HS is made on an internal value stream basis, so low and medium voltage or high voltage, but the equipment itself can be precisely the same. Only one type of switching board is specific to the HS class, so the average weight for this class is slightly higher.

Overall, the MS/LS cables are the largest reverse flow in weight, followed by distribution transformers and HS cables. Both the switching board classes have the lowest flows on a weight basis and can not be reused because of legislation. Because it is not a large flow and the type of material is less valuable, these classes are less relevant for recycling and thus excluded from the scope. Although HS cables have a higher per-unit weight than MS/LS, the composition and the way of processing are quite similar. On the other hand, distribution and power transformers' differences in quantity are so significant that the processes for processing both classes will be somewhat different. The composition in terms of materials and structure are similar, so there is less difference.

The investment volume in 2030 is expected to be the largest in Stedin's current twenty-year forecast window. This means that in the period between 2028 and 2033, the investment volume will be within a 10% margin of the volumes shown in Table 4.2. In the years after this window, the investment volume will step-by-step decrease, which means there are fewer projects where end-of-use assets will create a reverse flow. In the stated window, the reverse flow will be similar to the 2030 results. However, this will decrease, especially after 2035, when the investment volume is expected to decrease more rapidly. The estimated reverse flow is approximately *Redacted* percent of the material demand for these assets.

Table 4.4: Results reverse flow calculations

Product	**Reverse flow 2030 quantity**	**Reverse flow 2030 weight (kg)**
MS/LS cables	Redacted	Redacted
HS cables	Redacted	Redacted
Distribution transformers	Redacted	Redacted
Power transformers	Redacted	Redacted
MS switching board	Redacted	Redacted
HS switching board	Redacted	Redacted

5

SC object, project objectives & requirements

This section discusses the result of the first stage of the SCOP method and the requirements. In the first step of the SCOP method, the supply chain object, environment, and objectives must be described. This is the first design brief and forces the design team to consider what it is exactly designing, what environmental factors influence the design object (so the CSC), and with which objectives the design project is done. In the section on this step, the description of these topics is given. This design brief is the first starting point for generating design requirements. The requirements should be based on the SC object and objectives, and the environment in which the object is designed should be considered. In Section 5.2, the results of the requirements generation process are shown.

5.1. SC object, environment & objectives

The main goal of Stedin's supply chain is to facilitate on-site grid construction, whether maintenance-related, for the reconstruction or fortification of current infrastructure tracks or new connections. The three value streams required to fulfill the goal of the SC are equipment and tools, contractor capacity, and construction materials.

In this design of the new 2030 circular supply chain of Stedin, the SC object is concerned with the value stream construction materials. More specifically, the SC object for the whole SC is the delivery of cable and transformers on the construction site. Like most companies, the focus of the current Stedin SC is linear: how to get materials on time and on-site in full. This is predominantly the material flow from the CDC or RDCs of Stedin towards projects or contractor locations.

Now, the way of working needs to become more circular, which also changes the object of the SC. The focus is not solely on delivering components on-site but also on reverse logistics and processing end-of-use or end-of-life materials. This reverse flow is directed from the building sites across the service area towards locations for the circular processing of the assets. As the focus of this project is the design of the CSC, the SC object becomes the collection, sorting, and disposal of cables, transformers, and switching boards and their integration into the forward supply chain.

An important influencer from the external environment on the Stedin SC is the need to facilitate the energy transition towards a zero- or low-carbon energy system. This ambition has resulted in a rapid increase in the volume and variability of electricity generation and consumption. As a result, the electricity grid in the service region of Stedin needs to be heavily expanded, which means a significant increase in material demand. Because grid expansion has also become more crucial to the country's ambitions, the reliability of the material supply will grow in importance. Along with the general challenge for the SC to facilitate the grid expansion, the public, government, and sector expect this to be done sustainably. Important goals are the reduction of CO_2-eq emissions and primary material consumption. This also influences the role of the SC. The purpose of circularity and reverse logistics is not monetary but aimed at sustainability and facilitating material availability.

The main goal of the new SC design is to contribute to the priorities in Stedin's corporate (ESG) strategy. From the ESG strategy, the most important ones are reducing CO_2-eq emissions and primary material consumption. The CO_2-eq emissions in 2030 need to be reduced by 42% compared to 2021, which aligns with the Paris Agreement. The goal of primary materials is to reduce consumption in 2030 by 40% compared to 2022. These two goals are, of course, related to each other. A reduction in virgin material usage will have a direct effect on CO_2-eq emissions of the SC. The general Stedin SC goal is 100% OTIF (on time and in full) for materials, which is also what the rest of the SC is evaluated and managed on. The total investment volume of Stedin has to grow from over 800 million euros in 2023 to over 1.8 billion euros in 2030. A circular SC can contribute to this goal by creating an additional in-house supply flow to ensure material availability is not an investment bottleneck.

5.2. Requirements generation

In this section, the results of the design requirements generation are presented. Three different generation and validation methods have been used, and each result is presented in a separate sub-subsection. The first method was individual brainstorming, the second was an expert validation session, and the last was an expert workshop.

5.2.1. Results individual brainstorm: version one

The researcher does an individual brainstorm to generate the initial set of requirements. This brainstorming session was based on the general corporate, ESG, and SC strategies for Stedin's materials. This is augmented by information from scientific and practitioner literature and build-up knowledge on the operations of Stedin. The visual mind map resulting from the brainstorming session can be found in Appendix B in Figure B.1. This mind map was converted to an initial, properly written version of the requirement list. This list is divided into five themes (logistics, organizational, data/systems, ESG & strategy, and business case) and the type of requirement (constraint / objective & functional / non-functional). From the brainstorm came 27 different constraints and 26 different objectives. This first version of the requirements can be found in Appendix C.

5.2.2. Results expert validation session: version two

The first version of the requirement list was validated in an expert session with two participants. In this session, the participants gave feedback on all aspects of the list. Two structural changes were made to the list based on the feedback. The first is the adjustment of the themes with logistics changing to supply chain and ESG & strategy to just ESG. Part of the SC strategy-related requirements moved to the supply chain theme. The second is that instead of first showing all the constraints per theme and then all the objectives, the constraints and objectives are grouped per theme. The experts found this way of presenting more clearly.

Additionally, feedback was requested on whether requirements were missing, should be rejected, or the classification was wrong. The most important feedback in the supply chain theme was that not all the basic process steps were represented in the requirements. Therefore, several new functional constraints were added to this theme. Also, as already said, the theme had more non-functional constraints and objectives due to the addition of the SC-related strategy-themed requirements. For the organizational theme, the most important change is the removal of objectives ten and eleven from Section C.2. The expert thought these requirements would steer too much towards the existing organizational structure. Stedin explicitly intends that the 2030 design developed in this research is independent of the current state. For data and systems, the most relevant change is the addition of a non-functional constraint on the data type in the forecast. Some requirements were transferred to the SC theme in the ESG theme. However, a functional constraint on zero-emission transportation was also moved from the prior logistics theme to the new ESG theme. Regarding the business case theme, the experts had no feedback. The complete second version of the requirements list can be found in Appendix D.

5.2.3. Results expert workshop: final version

The second version of the requirement list was again validated and reviewed in an expert workshop. Five experts participated in this workshop, also from outside the SC organisation of Stedin. In addition to earlier expert consultations, the Director of Supply Chain also participated in ensuring that the requirements met the objectives of the executive board. The same type of feedback as in the expert validation session was solicited; this time, however, also from new perspectives.

Experts in the workshop validated almost all requirements from the second version. Most feedback was on reminders of what they felt was important, but these comments were mostly background to the requirements. An important change was the addition of SC objective four, which focused on the quality of the input next to the output in objective five. Also, a topic of discussion was the re-purposing or reuse by third parties like other DSOs or commercial entities. By regulation, Stedin cannot perform commercial activities outside of grid management. So it is important, as stated in organizational constraint eight, that this re-purposing or reuse does not become a commercial activity on its own. Stedin can not perform too much work on these assets before passing them on. As Stedin can also receive assets from other DSOs, these exchanges also require an information flow between the DSOs on supply and demand, which is stated in data objective two. The last large change is removing the objective of understanding the design for lower-level employees. It was stated in the workshop that it is important that managers executing the design understand it, and it is their responsibility to make it clear to the employees.

Below, the final requirements list is given. As said, this list is validated in the workshop and has received approval from the most important stakeholders. Behind each requirement it is indicated from which source the requirement is derived. It can be from scientific or practical literature (LIT), from the Stedin strategy (STRGY), from conversations with Stedin stakeholders (STEDIN) or by the the author (AUTH).

Supply Chain
Constraints
Functional: The system should be able to...

1. retrieve all assets decommissioned from the grid for processing (STEDIN)
2. collect unused asset returns from the construction site for processing. (STEDIN)
3. assess all assets coming from the construction site for circular processing. (STEDIN)
4. process circularly all assets coming from the construction site. (AUTH)

Non-functional: The system must operate such that...

5. assets are always handled safely. (AUTH)
6. assets are always handled with care to maintain quality. (AUTH)
7. the processes for recycling and reuse of materials comply with relevant laws and regulations. (AUTH)
8. assets that are redeployed meet the quality requirements from Asset Management. (STEDIN)
9. the design enables that 100% of materials prepared for redeployment can be redeployed. (STRGY)
10. the design enables that 100% of materials ordered for redeployment can be delivered on time. (STRGY)
11. the design enables that 100% of the redeployment needs that had been calculated can be present. (STRGY)

Objectives
Functional: The system should be able to...

1. protect materials for quality preservation, in the case storage is required. (AUTH)

Non-functional: The system must operate such that...

2. recycling and reuse processes are done with a LTIR and RIF of zero. (STRGY)
3. reuse assets have the shortest possible lead time. (AUTH)
4. materials that are recycled are processed in the highest possible quality. (LIT)
5. the output of a recycling process is of as high quality as possible. (LIT)

6. the transport distances between CSC partners are as low as possible. (STEDIN)

Organisational
Conditions environment

1. Sufficient circular knowledge/skills are available in the organization to implement the design. (LIT)
2. Sufficient circular knowledge/skills are available in the organization to adjust the design even during implementation. (AUTH)
3. Within Stedin, the new processes for the CSC are known. (LIT)
4. The circular SC processes are known to contractors and CSC partners. (LIT)

Constraints
Functional: The system should be able to...

1. make sure hat no more assets are prepared for redeployment than Stedin or the market demands. (STEDIN)

Non-functional: The system must operate such that...

2. the design enables partners in the CSC to always return materials 100% on time. (STRGY)
3. the design is technically feasible. (AUTH)
4. the design should be implementable in the period up to 2030. (STEDIN)
5. offering assets for re-purposing or reuse by third parties can not become a functioning commercial activity. (STEDIN)

Objectives
Non-functional: The system must operate such that...

1. partners in the CSC are working as sustainably as possible. (AUTH)
2. recycled materials are used within the Stedin value chain as much as possible. (AUTH)

Data / systems
Conditions environment

1. Data is collected for the monitoring of the circular processes. (LIT)

Constraints
Functional: The system should be able to...

1. make regular forecasts of the reverse flow. (LIT)
2. monitor the performance of the CSC on pre-set KPIs. (LIT)
3. exchange forecast data with CSC partners. (LIT)
4. exchange forecast data with the Stedin procurement department. (AUTH)

Non-functional: The system must operate such that...

5. the minimum exchanged forecast data are the asset types, the expected volumes in numbers, and weights (STEDIN)

Objectives
Non-functional: The system must operate such that...

1. the reverse flow forecast is 100% accurate. (STRGY)
2. supply and demand of assets by other DSOs is monitored. (STEDIN)
3. forecast data for internal and external stakeholders is available as soon as possible. (AUTH)
4. the CSC process is as uniform as possible for the different asset groups. (STEDIN)
5. the CSC process is easy to implement in parts. (AUTH)

ESG
Constraints
Functional: The system should be able to...

1. do transportation within the SC with zero emissions. (STRGY)

Non-functional: The system must operate such that...

2. the design enables that the CO_2-eq intensity of materials can decrease by 40%. (STRGY)
3. the design enables that the CO_2-eq emissions from primary materials can decrease by 12%. (STRGY)
4. the design enables that the CO_2-eq emissions from other materials can decrease by 30%. (STRGY)
5. the design enables that the primary material use intensity can decrease by 40%. (STRGY)
6. more than 7% of the residual stream is used as raw material in the Stedin SC. (STRGY)

Objectives
Non-functional: The system must operate such that...

1. the design enables that the CO_2-eq intensity of materials can decrease as much as possible. (STRGY)
2. the design enables that the CO_2-eq emissions from primary materials can decrease as much as possible. (STRGY)
3. the design enables that the CO_2-eq emissions from other materials can decrease as much as possible. (STRGY)
4. the primary material use intensity decreases as much as possible as the reverse flow allows. (STRGY)
5. as much of the residual stream as possible is used as raw material for new Stedin assets. (AUTH)
6. assets are processed as high as possible on the R ladder. (LIT)
7. the portion of the residual stream disposed of as residue is as low as possible. (STRGY)

Business case
Constraints
Non-functional: The system must operate such that...

1. any costs for the new system should be able to be financed. (AUTH)
2. there should be sufficient incentives for CSC partners to participate in the CSC. (LIT)
3. in the business case, the benefits outweigh the required Stedin investment in the new CSCs. (STEDIN)

Objectives
Non-functional: The system must operate such that...

1. the additional cost of a redeployed asset compared to a new asset is as low as possible. (AUTH)

6

Developed CSC designs

This chapter discusses the developed macro and meso structure designs. The first part explains the development process based on the selected literature. The next two sections present the macro and meso designs for the different asset types. The last section tests whether the design, which was developed with cables and transformers in mind, is also applicable to other types of assets.

6.1. Pre-development steps

The methodology for the overall design process is based on the evolved double diamond. The earlier chapters were part of the first diamond, the research diamond with the discover and define phases. In the previous chapter, the design requirements are presented. These requirements and the design objectives form the definition of the design problem, and this chapter builds on that. The first phase of the second design diamond is the develop phase. Here, the different designs are developed, which can be delivered in the last EDD phase.

The development of the CSC design is based on the frameworks by Corominas et al. (2015) and Amir et al. (2023). The first step in the SCOP framework is to define the design's object, environment and objectives, which are already discussed in Section 5.1. The objectives in the SCOP are similar to the main drivers in the CSC guiding framework. The main drivers in this project are environmental, to reduce CO_2-eq emissions, and circularity, to reduce virgin material use. The profit driver is less relevant because Stedin is not a commercial enterprise. However, there is a need to contain costs associated with the CSC implementation as stated in the business case requirements. The policy driver plays a role in the background as Stedin has to report much more under the new CSRD (Corporate Sustainability Reporting Directive) by the European Union. This visibility of ESG performance and efforts is an additional stimulus for Stedin's wish to design a CSC.

After these first steps of the design frameworks, phases two and three of the SCOP are the macro and meso structure designs. The macro design is on a very granular process level with less detail, and the meso design deepens this macro design. Both the designs are mostly based on the 9R strategies of Potting et al. (2017). This R ladder is a commonly accepted list of circular strategies and forms a basis for CSC design. The CSC guiding framework also takes into account these strategies but is more helpful on the meso level as more details are required here.

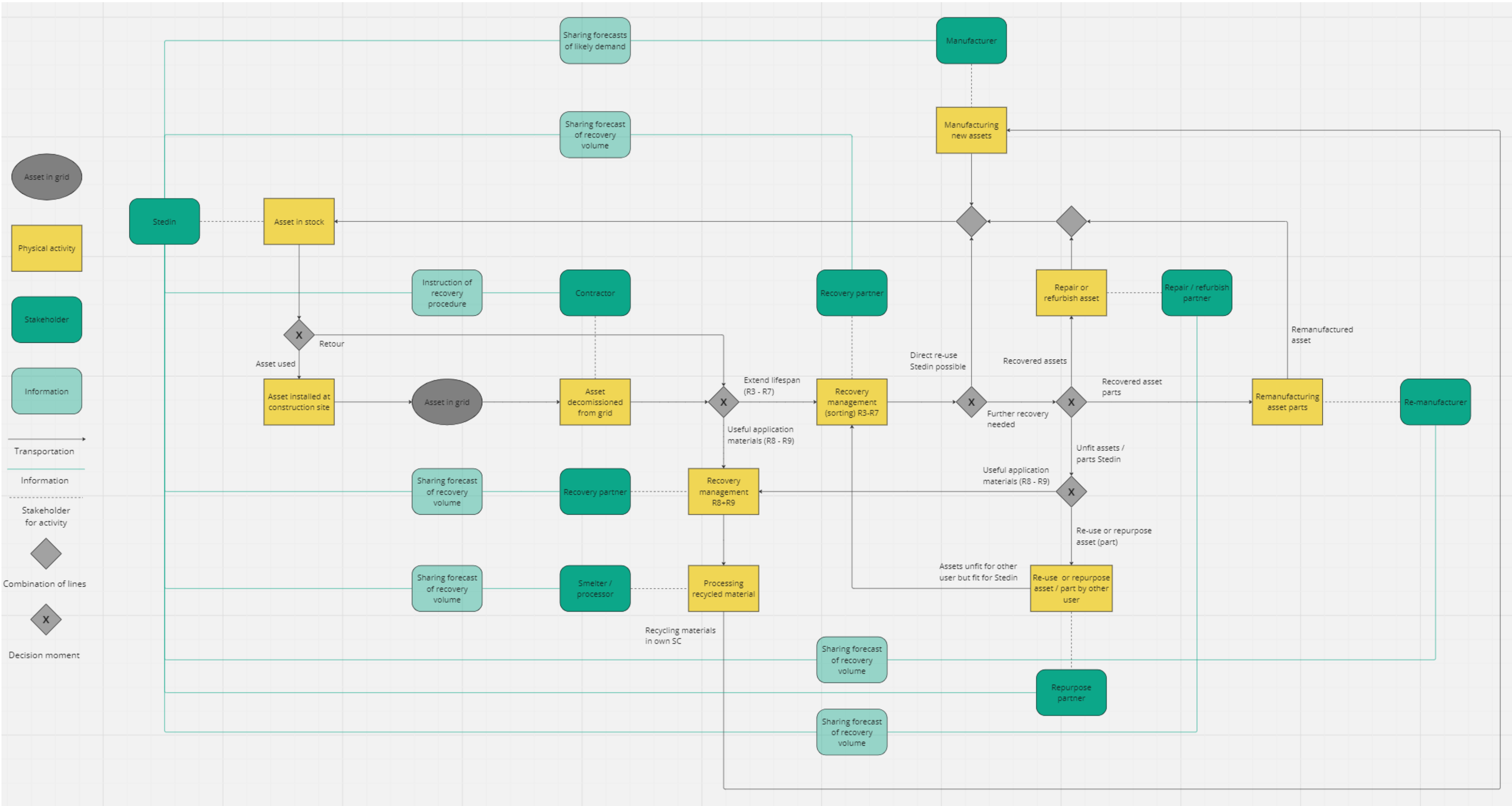


Figure 6.1: Design macro structure diagram with the legend on left side

6.2. Results macro structure design

As said, the macro design, as shown in Figure 6.1, is based on the 9R circular strategies of Potting et al. (2017). This is the second step in the SCOP method, which aims to identify the main activity blocks and the relationships between them. Broadly speaking, there are two main paths an asset can take to be circularly processed: useful application of materials (R8 - R9) and the extension of the lifespan of the asset (R3 - R7). In principle, the higher an asset is processed on the R ladder, the more sustainable it is. This is because the loop is often shorter, fewer new materials or labour are needed, and fewer transportation movements are required. The third loop is the return loop. This is a version of reuse (R3) where the asset is transported to the construction site but is, in the end, not used. Although this loop is pure waste, it has to be accommodated in the design as, from conversations within Stedin, it was made clear that perfect ordering by the project leaders is not feasible. As these assets can deteriorate at the construction site, they enter the process at the same point as decommissioned assets, as both material recovery and lifespan extension can be needed.

The figure shows the macro design of the physical process, information flows, and stakeholders. Several academic and practical literature articles, like Circular Supply Chain Network (2023) and Gunasekara et al. (2023), stress the importance of information exchange between stakeholders in a CSC. This is because two-way information and material flows are created and the reverse flow can also be challenging to predict. This is in contrast to a linear SC where information and materials are only flowing in one direction. The complexity of flows in a CSC is visualised in Figure 6.2. Therefore, the internal stakeholders (vendor management, VM) and external stakeholders (CSC partners) must receive frequent forecasts on how much assets or material is expected to be processed. This way, the CSC partners can anticipate the reverse flow of their production planning, and VM can integrate it into their procurement planning.

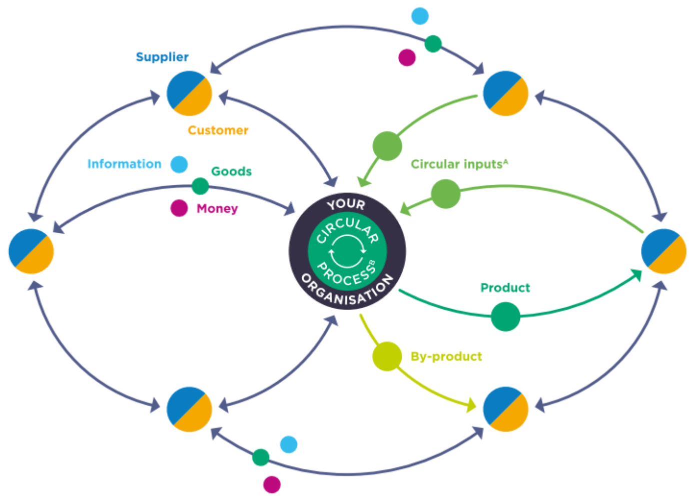


Figure 6.2: Visualisation of circular information and material flows (Ellen MacArthur Foundation, 2023)

Therefore, every physical process step is accompanied by the relevant stakeholders, and all stakeholders exchange information with Stedin and vice versa. It is important that this forecast information exchange is included from the start and is enabled by technology, as stressed by the CSC guiding framework. The meso design diagram does not feature the stakeholders and information flows as the concept remains the same more detailed process activities and to make the designs better understandable. The ICT development will be one of the projects in the implementation plan in Chapter 8.

The physical process for the CSC starts at the grey box where the asset is placed in the grid. After decommissioning, the decision has to be made whether the asset will go through the useful application of the materials loop (R8 - R9) or the lifespan extension loop (R3 - R7). In the material application loop, the first step is recovery management. This activity block is about both the collection and processing of the assets for either recycling (R8) or recovery (R9) by a recovery partner. The processing of the resulting material flows can be done by a smelter or processor that can process the separate material streams into useful end products. After recycling, the materials could be reused to manufacture new assets for Stedin.

The lifespan extension loop figures more decision moments to select the proper circular strategy. In this loop, recovery management must sort and prepare the assets for further processing. Afterwards, the assets are filtered by their condition and required work. Some assets can directly be reused (R3) and brought to stock. Next, assets can be repaired (R4) or refurbished (R5) if the asset still has a useful lifespan after some reconditioning. If the asset is unsuitable for reuse but the parts are, remanufacturing (R6) can be chosen. In this case, the asset parts are reconditioned and reused in another asset. The last option is that the asset or asset parts are no longer useful for Stedin. In this case, they must be brought into the material recovery loop or repurposed (R7). With re-purposing, the asset is used by other grid asset users, like other DSOs or private companies, or for other applications.

After all the lifespan extension activities, assets can be returned to stock for delivery to the construction site. Here, they can be used in the grid, which means at a certain point decades in the future, they will again enter the same system or enter the return loop and enter the system again at the end of the project. Stedin is the main entity in this system as it directs material and information flows. They must keep the CSC partners in the loop for expected supply and arrange proper handover at interfaces between Stedin and external partners.

6.3. Results meso structure design

From macro to meso

In Figure 6.3, the general meso structure design is shown. This meso design deepens the macro design, so more detailed steps specify the larger activity blocks from the macro design. These steps or activities are still based on the 9R strategies but incorporate more of the Stedin-specific environment where a broader range of companies can use the macro design. This deepening can be seen in the number of physical activity blocks and decision moments. The macro design had 11 process activity blocks and five decision moments, while the meso structure design had 24 process activity blocks and 13 decision moments. This shows the degree of added detail when we move from the macro to meso structure level. All these activities will mainly be on the strategic or tactical decision-making level from the Amir et al. (2023) framework. The tactical level can sometimes already be too detailed for the design objective, and the operational decision level must be considered during the design implementation.

This figure does not feature the stakeholders and information flows anymore because of readability. However, these flows are still highly relevant at this design level. Next to removing the stakeholder and information diagram blocks, two different types of blocks have been introduced. The blue blocks show the points where the assets are in storage, and the red blocks show the points where a material or asset leaves the circular system of Stedin. This can be done by incineration, sale of materials to other manufacturers, or repurposing the asset (parts). Also, the meaning of the arrows has changed. In the macro design, all black arrows were transportation between process steps, which sometimes could not be necessary. In the meso design, a difference is made between actual physical transportation (blue) and a transfer between process steps (black).

6.3.1. General structure meso design

However, the fundamentals of the activities in Figure 6.3 have not changed much compared to the explanation in the previous macro section. The return loop is still the same, the starting point is still the same, and the two main types of loops remain the same. In the R8-R9 loop, the recovery management block is split into six new blocks. They indicate that the materials that enter this loop based on AM/SC policy are first stored on the construction site, collected and transported to the recycling partner, where the assets are pre-processed and dismantled into different material streams. The collection of the assets is one of the building blocks of the Amir et al. (2023) framework and will be done mainly by special containers (for cables) or by loading an asset on a truck (transformers). The containers will be of the recycling partner, and this is a system that is already functioning in the Netherlands. Stedin or an external partner can do the collection by truck. The next building block is the material recovery strategy. If the materials are still useful, they are recycled and processed to be used in new products (R8). It has to be decided at that point whether that is in new Stedin assets or outside the value chain. If they are not useful anymore, they can be incinerated or digested for energy recovery (R9). This is the lowest circular strategy, as the materials are lost and can never be reused.

After entering the lifespan extension loop, the assets are sorted and tested based on AM policy on the asset specification. Cables cannot be reused, so this loop is focused on distribution transformers (DT) in this design. The power transformers have a slightly different design because of their size, weight, very small reverse flow volume and type of location of placement. This design is presented in Figure 6.4 and will be discussed later. After both sorting and testing, it can be decided that an asset is unfit for Stedin and needs to be repurposed (R7) or recycled (R8 - R9), and it enters that loop. If the asset is useful, it can be directly reused (R3) if the asset is in an excellent state. Otherwise, the asset can be repaired (R4) or refurbished (R5). If only the asset part is useful, the asset is dismantled, and the parts are remanufactured (R6). After remanufacturing, the assets can be used in new or repaired/refurbished assets. After reconditioning, all the assets go into stock at a distribution centre in Stedin.

6.3.2. Design adjustment for power transformers

The design for the power transformers is slightly different from the design in Figure 6.3 because of their characteristics. Power transformers (PT) are very large and heavy (up to 150 tons), making collection to a central point impractical. Also, the locations where PTs are decommissioned from the grid are often more secluded than is the case for DTs. For this reason, there is often enough space at the location to perform testing and even minor repairs or refurbishment at these locations. This is made easier from a process perspective as the reverse flow of PTs is only eight (as discussed in Section 4.2). Doing this for hundreds of DTs would be a lot more challenging to organize.

As testing is already done at the construction site, the suitable circular processing strategy is also already determined there. The material recovery and lifespan expansion loops do not differ from the general design, as these strategies remain the same. A difference between the designs is the return loop that is not present for PTs. After the recondition activities, the PTs are placed in a particular DC that can handle the weight and size of the assets. As PTs are so big, they are only ordered on a project-specific basis. This means a PT will never be transported to the construction site or used there.

6.3.3. Design characteristics not visible in process diagram

Process

Figures 6.3 and 6.4 show the physical process activities, and Figure 6.1 also shows the information flows. However, there are also design characteristics that are not visible in these figures. To start, it is important to say something about the decision moments when a choice is made and which circular strategy will be applied. A project lead or contractor will inform the circular logistics department that an asset will be removed. Logistics will determine if the extension of the recovery loop is chosen, as this requires different steps from the project lead. The final decision on what is done with an asset is partly based on technical AM policy/standards and partly on a Life Cycle Analysis (LCA). The aim is to use a circular strategy higher on the R ladder, but in doubtful cases, an LCA can help determine the most sustainable choice. This can be coupled with a cost-benefit analysis (CBA) to see if it is financially worth to refurbish or remanufacture, for example. This assumes that the project lead reports all assets that will be decommissioned. Further processes are needed to make sure this is actually the case.

For repurposing, it is important to stay within the boundaries of the regulatory framework. From the Electricity Law in 1998 and the Progress Energy Transition Law of 20218, DSOs are limited in the type of activities can conduct. They should focus on providing energy infrastructure to the energy market and are very limited in their possible commercial activities (Autoriteit Consument & Markt, 2020). Stedin can engage in non-regulated activities if this adds value to efficient grid administration. There is a gap in the market, and Stedin is uniquely positioned to execute these activities. An internal expert on regulatory affairs (personal communications, 17-04-2024) consulted on the possibilities. Stedin should only repurpose assets against what is left of the regulatory book value set by the ACM and within reconditioning and promoting the asset before sale. So, for R7, no repairs or refurbishments are done beforehand. We can exchange information with other DSOs and some commercial firms, but the sale of the assets should not be heavily marketed to avoid a commercial character.

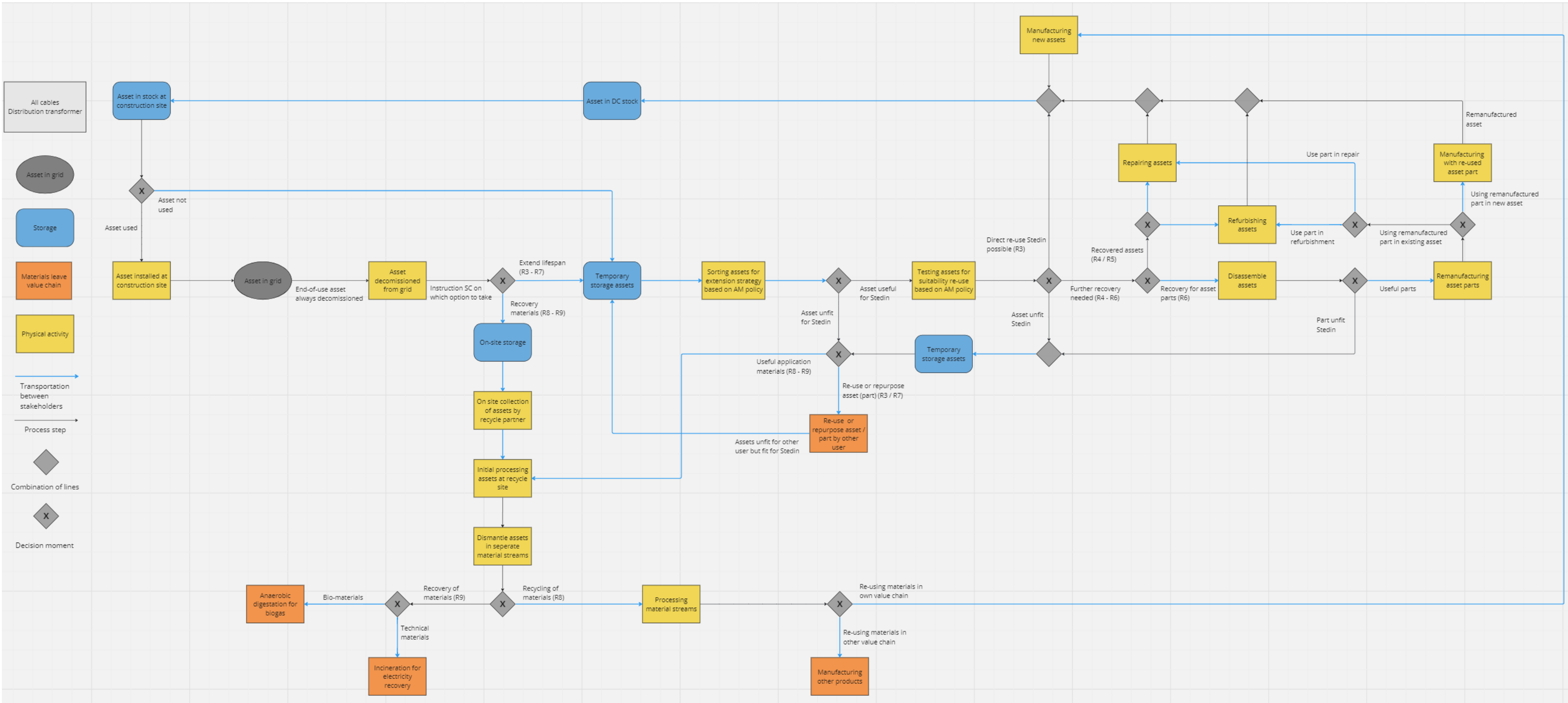


Figure 6.3: Diagram of the general meso structure design with the legend on left side

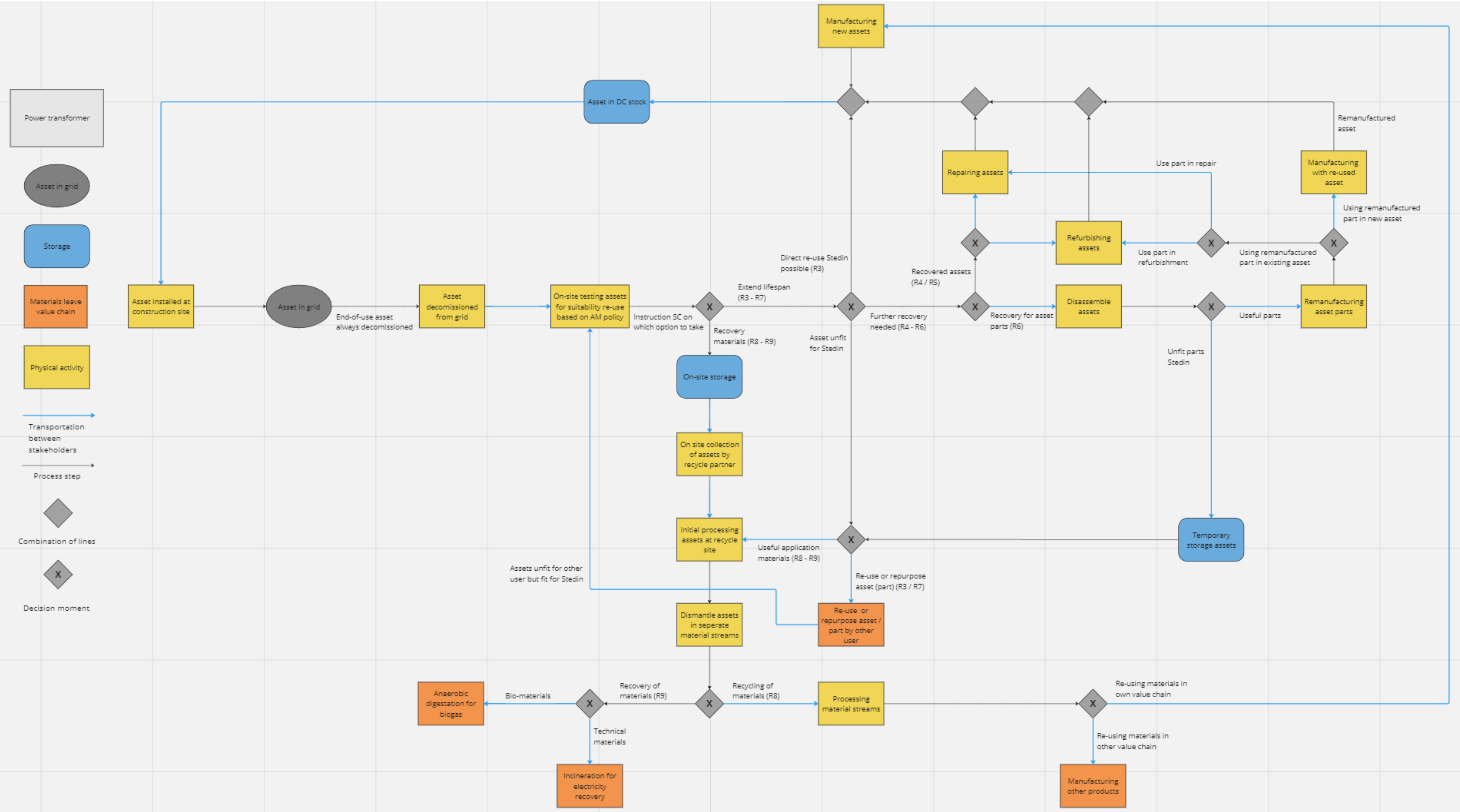


Figure 6.4: Diagram of the PT meso structure design with the legend on left side

Forecast
Every partner in the CSC will receive regular forecasts on the expected reverse flow for their circular activity. An ICT system has to be set up between Stedin and the partners to enable the information flow in a structured way. The minimum data exchanged is the number and type of assets or kilogram volume of materials coming to the partner. This can be expanded later on with more data and a higher frequency of forecast exchange.

In this process, stakeholders can also exchange demand and supply data with each other. VM and logistics have to communicate about the asset demand that VM has from the business and what part logistics can supply with the circular operations (R3 - R6). This should avoid that more assets are reconditioned than necessary for the investment plans and that the right number of new assets are procured. This coordination can both be short term for specific cases and medium term to know how many of the assets that will be decommissioned will be earmarked for reconditioning and how many for recycling. This should also be done with at least other DSOs to enable the exchange of assets. At the same time, information exchange with other CSC partners should help them make their production planning but also give a chance to signal a lack of capacity for reconditioning. In this case, recycling could be an alternative option.

SHQ
Safety, health, and quality are important topics that have also received attention in the system requirements. According to the latest insights, all assets handled by Stedin or external personnel have to be handled safely. At a minimum, handling, transportation, and processing should be done according to the relevant laws, regulations, and quality standards from the government or internally, such as the AM quality requirements. There are, for example, standards for recycling companies that need to be followed and from AM on the specifics of certain assets. It is also important that assets are handled and stored with the quality of the asset in mind. Decommissioning can not happen in such a damaging way that assets can not be redeployed anymore. This is also the case for storage. Assets on the construction site must be protected against external influences during storage. Also important here is the recycling of the isolation oil in transformers. This oil needs special (certified) care when decomposing the asset but can be recycled and used in new assets. This recycling follows the recycle loop of the meso design but will require different partners than metal or plastics recycling.

Conditions environment
Certain conditions in the environment have to be met to enable the (implementation of the) design. Stedin has to ensure sufficient skills/knowledge are available in the organisation so that the design can be implemented and also properly adjusted if new insights prove necessary. Also, the new processes must be made known to the relevant employees within Stedin and external partners. To facilitate the forecast information exchange, data must be collected on the monitoring of the circular performance and expected reverse flows.

Design feasibility evaluation
Within Stedin, a logistics expert is the leader responsible for the implementation of the CSC design. In a validation session with him (personal communication, 03-03-2024), he confirmed the validity and feasibility of the design. In the session, all aspects of the design have been run through. There was no major feedback on the macro or meso-level design. The expert expects that the process could be implemented like this but that a micro-level deepening is necessary to know exactly what to do. His main point of feedback was the importance of coordination between Stedin logistics, VM, and CSC partners to ensure that not too many assets are reconditioned for redeployment. He was not concerned about the feasibility or possibilities for improvement. He stated that this was what he needed to start the implementation of a more professional and formal CSC and that the design contributes to Stedin's circular goals.

6.3.4. Next design step

After the design of the macro and first version of the meso design, the intention was originally to develop design alternatives. These design alternatives should be variations on the meso design and could have been a bit more detailed in the process diagram if that was required to understand the design. The alternatives should be 'corners of the playing field' with unique design traits. They give designers and decision makers (DM) more insight into the options for the final configuration. However, during the meso design development, it was concluded that there are no such unique alternatives for this level of design detail. This is because the design is built on the circularity strategies of Potting et al. (2017), which give a clear set of process design options.

However, it was also concluded that there is a set of key decisions that the meso design leaves open but should be made when implementing the design. Therefore, the focus is on those key decisions instead of developing design alternatives. These are, for example, around whether to in or outsource reconditioning activities or where they are performed, both linked to the network design building block from the Amir et al. (2023) framework. The current design does not state who or where the reconditioning activities take place and these decisions are on the interface between the meso and micro structure design levels. The decisions are introduced in Section 7.1. After these decisions are made, more detailed designs can be made for the relevant process steps in a micro design.

6.3.5. Constraint and objective compliance

In the previous Chapter 5, all the system requirements are defined. These requirements are split into environmental conditions, which were discussed a few paragraphs ago, constraints and objectives. Constraints are requirements that should be complied with to ensure that a design functions according to minimum standards. It is, therefore, important to reflect on constraint compliance of the presented meso design. Of course, the design development is done with the constraints in mind, so the designs comply with these requirements. However, some remarks need to be made on constraint compliance.

SC constraints 1 to 8 are all addressed in the design as the design enables retrieving, collecting, assessing and processing all the assets from the construction site. The actual performance or degree of execution depends on proper implementation and elaborating on activity blocks with detailed process steps that can be used to instruct and direct employees. SC-C 9 to 11 are more difficult to test for compliance. There are no parts of the design that inherently block the ability of the system to reach the 100% goals stated in these constraints. However, the targets can fail to be met due to external influences or inefficient micro-design. The same is the case for Organisational Constraint 2.

O-C 1 and 3 are addressed in the text of design characteristics not visible in the process diagrams. O-C-5 is a requirement that will be met as long as internal experts test compliance with regulations. O-C-1 should also be complied with if forecasting is done accurately enough. Although this requirement is evaluated as a constraint, some asset build-up would be tolerated as they can always be recycled, which would only lead to misspending revision costs. The feasibility (O-C-3) and implementability (O-C-4) are dependant on the choices made for the decisions described in Chapter 7. Currently, there are no design aspects that would be technically unfeasible; they can only be difficult to optimise cost-efficiently. For example, forecast information exchange can be done by email and Excel sheets, or maybe more streamlined and advanced tooling can be developed or bought. For example, whether the design can be implemented depends on whether a new location has to be built for reconditioning and if the right skills can be acquired soon enough.

If the right data is collected and processed on the performance of the CSC and as forecast input, D-C 1, 2, and 5 will be satisfied. D-C-1 will need some type of forecasting method, and D-C-2 will probably need a PowerBI dashboard. D-C 3 and 4 require proper information exchange tools within Stedin and with external partners. All data constraints are complied with if these tools or processes are developed. ESG-C-1 is identified as part of the key decision list discussed in the next chapter. The other five ESG-Cs have a measurement issue. The exact impact of the design on the sustainability goals will be difficult to predict at the moment, and possible gains can be made more concrete when the performance of the CSC is known. The asset retrieval part especially introduces a large uncertainty. Project leaders should decommission end-of-use assets from the grid. However, it is known to happen that cables are left in the ground, missing a valuable opportunity for urban mining.

Whether this is done is also cost, and thus, business case dependent. The most important cost impact is the possible investment in building workshops for reconditioning and hiring the required staff. In other cases, the need for large-scale investment financing will be minimal (B-C-1), and in these outsourcing and location decisions, the business case will play a role (B-C-3). Incentives for partners to participate in the CSC have not yet been discussed. For partners to participate in the CSC, Stedin has to pay a sufficient margin for their services or products. Whether this paid margin will affect asset costs has to be investigated. As assets are reused, a redeployed asset is probably cheaper than a new asset despite the reconditioning costs.

It is explained that measuring or determining whether the design complies with all constraints is difficult and this is even more the case for the objectives. The objectives are requirements on which a design can score better or worse on and are performances where the constraint compliance is binary. On meso-level design, the exact performance of the SC would be hard to measure. Simulation would be necessary to evaluate an SC design on any level, requiring more data on the relationship between the design and KPIs like circularity, CO_2-eq emissions and supply lead times. Assumptions could be made based on the reverse flow calculation in Section 4.2 and key figures on these KPIs. However, the design decisions that need to be taken will not alter the meso-level design but will have a big impact on the performance of the final design. Also, investigating the proper evaluation methods is outside this project's scope. For these reasons, no exact evaluation is done on the objectives.

6.4. Applicability design to other assets

In Chapter 2, the scope of asset types was determined based on the impact on sustainability and the SC a CSC design (and implementation) could have. Therefore, the designs developed and presented in Section 6.3 are suited for all types of cables (LS, MS, HS) and transformers (distribution and power). However, these are only four of the twelve asset types on the initial long list. Introducing a CSC for these assets would have a much lower impact but can nevertheless be valuable for the reduction of CO_2-eq emissions and virgin material use. Therefore, in the requirements, it was stated as an objective that the process is uniform in such a way that other assets can also use the design.

Whether an asset type fits either the general meso design or the PT meso design depends on the characteristics of the asset. A separate PT design has been made because of the low volume, height, weight, and size, as well as the available space on the construction site of the asset. Two types of assets could possibly also fit in this description: the compact distristations and HS switching boards. The problem with the compact distristations is that although they are heavy and bigger than most assets, they are located on the streets and in neighbourhoods that would not allow on-site reconditioning. However, a blend between the two designs could be possible. The assets can be inspected and tested on-site, but all reconditioning is done at other locations. This way, unnecessary complex transport is avoided, and the asset can be entered into the general system design. For HS switching boards, the PT design could work. They are heavier and larger than most assets and are located next to the PTs. However, the volume is higher, so on-site reconditioning could take longer. This would not necessarily be a deal-breaking aspect, and again, a mix of the two designs could be taken as they are so similar to each other after choosing the lifespan expansion or useful application of materials loops. Although reconditioning at the construction site is not or less possible in both cases, the design design would not change, only the possible options.

MS switching boards are a type of asset that would fit the general design as these are not consumer assets and are similar in size and weight to DTs. They would always enter the recycle loop because they cannot be redeployed because of sustainability policy. There are fewer rare metals in these assets, but the steel could still also be reused in the Stedin value chain. The on-site collection of the assets would probably look similar to the DTs (on a truck), or separate containers need to be brought next to the cable container. IEDs and MS / LS sleeves are much smaller in size and weight but not consumer assets. They could go through the general meso design, but attention has to be given to the collection. Especially IEDs are more complex technological assets and need more care in handling than cables, but trucking like DTs is less of an option due to the smaller size. Also, further investigation should be conducted into whether and how these electronic assets can be recycled and redeployed. Maybe different types of partners would be necessary. Sleeves are also more fragile and smaller than the other discussed assets, and special care should be given again to transportation. However, after collection, the process on a meso level will be the same.

Two different types of assets are the smart meters E and the house installation boards. These asset types are used at a consumer's location and placed by different operational teams. One mechanic can place them in projects like LS/MS cables and on a single-unit basis. This means that the mechanic will need to take the asset to a regional Stedin hub for further processing, which differs from the general design. Assets, therefore, always go to a hub or DC and cannot go directly into the recycling loop. Figure 6.5 shows the required change to the design. For house installation boards, little testing has to be done. It is a plastic frame that has been replaced because it is broken, so it can be recycled, or it is still functioning, and there is also little risk of a dangerous situation during redeployment. There can be a need to centralise the assets for both asset types. The new figure brings them to a regional hub by a mechanic. The house installation boards can be put back in stock or brought to the local recycling bin at that hub. However, there can be a need to stock them at the CDC, requiring additional transportation. Stedin is already revising smart meters at the Delft location. They are tested there and either directly reused, recycled or brought to the supplier for revision. If one would want to keep this system, additional centralisation is needed. For house installation boards, reconditioning activities would not be necessary and for smart meters, all activities would be done externally.

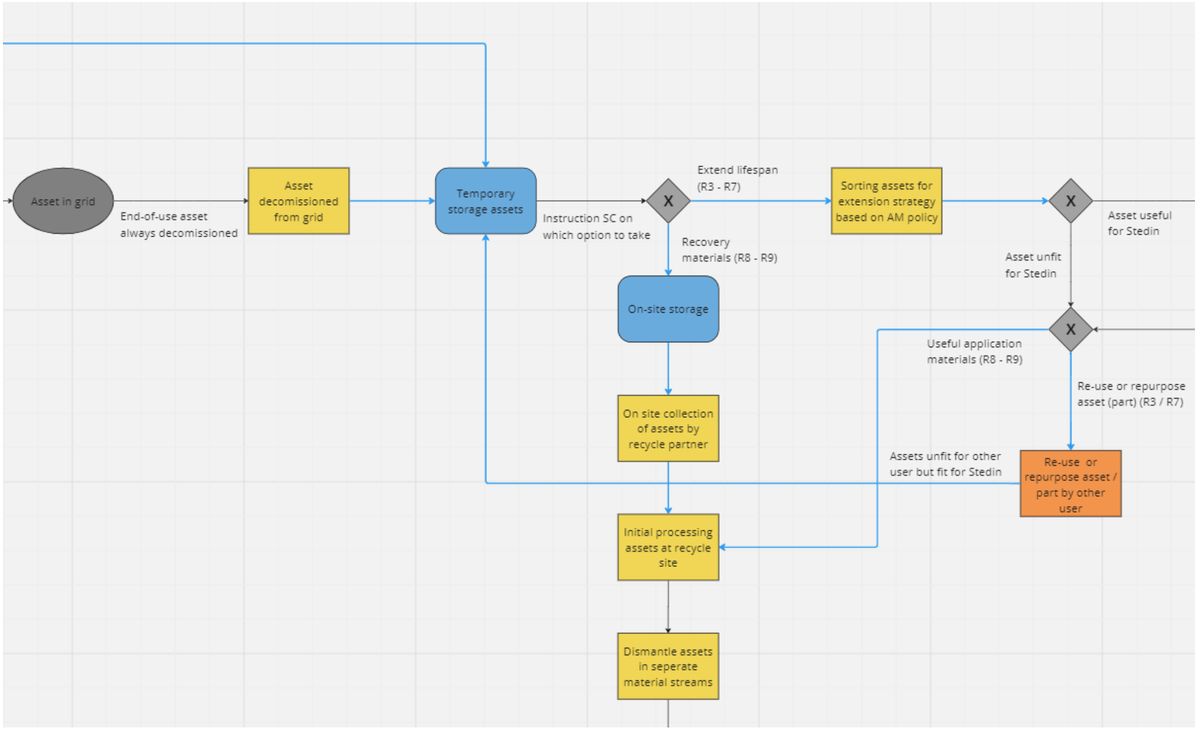


Figure 6.5: Different design for consumer assets like smart meters and house installation boards

The HS buildings are also a different type of asset. It is very difficult to reuse the asset directly because of the concrete foundation underneath and the instability during transport. The building will have to be demolished on-site to collect the material. A recycling partner picks up the debris, and it will be used as a foundation for new roads or train tracks. However, this is down-cycling instead of recycling. This asset type should be investigated with suppliers and partners on how the concrete can be recycled. Initial talks in the industry are happening about using debris as a substitute for sand and gravel in concrete, but one would still need new cement. Investigations would show if there are, now or in the future, technologies available also to recycle the (unused) cement.

7

Key remaining design decisions

In the last chapter it was concluded that there are a set of key decisions that the meso design leaves open but should be made to be able to implement the design. Therefore, the focus is on those key decisions instead of presenting design alternatives. These key decisions are the first step in going from a meso structure design towards a detailed micro structure design. In this chapter, the decisions are briefly introduced in Section 7.1, the relations between the decisions and the dependency are given in Section 7.2, the elaboration framework is discussed in Section 7.3 and in Section 7.4 the nine decisions are elaborated as by the framework. The Section 7.5 of this chapter shows that the meso design from Chapter 6 remains valid independent of the choice made in one of the key decisions.

In the last part of the chapter, Section 7.6, the evaluation framework is used on the two most important remaining design decisions as case studies. First, a short literature review is conducted on the various possible evaluation methods. After the case studies, the evaluation framework is validated in an expert workshop.

7.1. Key decision list

Below, the nine identified key decisions are presented. The decisions are split between the two most important decisions and the seven other decisions. This is done because a more elaborate decision framework for the most important decisions is presented in the next chapter. This list is again validated with the key stakeholder to check whether decisions are missing, are irrelevant or should change importance (Logistics expert, personal communication, 4-4-2024). Based on his feedback, one decision was removed from the list for being too detailed, and one decision, number nine, was added to the list. More elaboration on each decision is given in a subsequent section.

Two most important decisions

1. In-house capabilities or outsourcing for reconditioning activities?
2. Creating a mass-balance system for metal recycling?

Other decisions up for evaluation

3. Where to perform reconditioning activities? (different for distribution and power transformers)
4. Remanufactured parts used in repair/refurbish cycle or new assets?
5. Recover energy from materials in recycling or stockpile the materials?
6. Force recycle partner to strip cables for high-grade processing?
7. Stockpiling new power transformers as a DC for redeployed ones is already necessary?
8. Remanufacture parts if the manufacturer is located at a large distance?
9. Will Stedin do their zero-emission transport, or will we outsource it?

7.2. Relations and dependency decisions

These nine key decisions can not be seen as totally independent from each other. Figure 7.1 shows the relationships between the decisions. The decisions are grouped for clarity in the circular strategies that focus on asset lifespan extension and material recovery or are concerned with transport and storage. As expected, the main relationships are within the blocks of the same type of circular strategies. The lines between the blue blocks represent a fundamental relationship. The solid lines are relationships where the decisions are actually dependent on each other. A choice in one decision leads to a very different decision evaluation for other decisions. The dashed lines represent a lighter form of relationship. These lines show a relationship where there is not a strong dependency but where decisions affect each other. However, these will be smaller effects where a business case slightly changes, not fundamental dependencies.

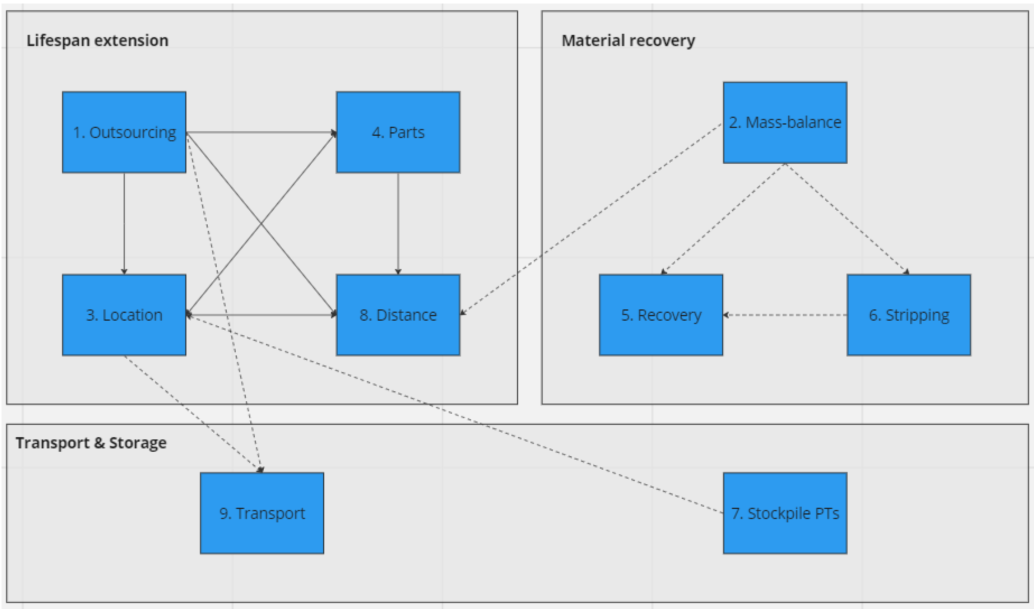


Figure 7.1: Key decision relationship diagram

Solid lines: fundamental dependency between decisions and available choices
Dashed line: only impact on the business case/evaluation

The relationship diagram shows there are only fundamental relationships between the four decisions around the lifespan extension of the assets. Figure 7.2 shows the dependency between these four decisions. This dependency is a subjective hierarchy made by the author and tries to reflect the order of how fundamental the choices for the processes are and/or how much impact the decisions have.

The most important one, which is also why it is listed as a most important decision, is the decision on in-sourcing or outsourcing the lifespan extension activities (decision 1). This decision has a major operational and investment impact and changes the fundamental details of these process steps. The other three decisions in the dependency diagram all have a smaller impact on Stedin's operations. The second most important decision, which is also intertwined with the outsourcing decision, is the location decision (decision 3). As will be explained in Subsection 7.4.3, there are four location options for the lifespan extension activities.

After in-sourcing, the CSC partner location option is no longer logical, and only three options remain. Decision four, on where to use remanufactured parts, is irrelevant if all the activities will be insourced and done on the construction site (so this is only for PTs), as remanufacturing will take too much time on site and is not practical. After outsourcing, all location options are still possible as a partner can perform reconditioning activities at their own location and at Stedin locations. If outsourcing is chosen, a PT can be dismantled at a construction site. However, the remanufacturing happens at one of the other location options.

Decision eight on distance can be relevant for all location options but is only shown for the CSC partner location choice option for clarity of the diagram as here the choice is most relevant. If remanufacturing and the other reconditioning activities are done at a Stedin location, it would be most logical to use the parts in the repair/refurbish cycle if possible, and these facilities would be near the Stedin service area to minimize large distances for small repairs. This changes when it is decided that the asset parts will be used in new assets and a CSC partner location is used. It needs to be decided whether to transport the parts over large distances if the partner is located far away or recycle the part in this situation.

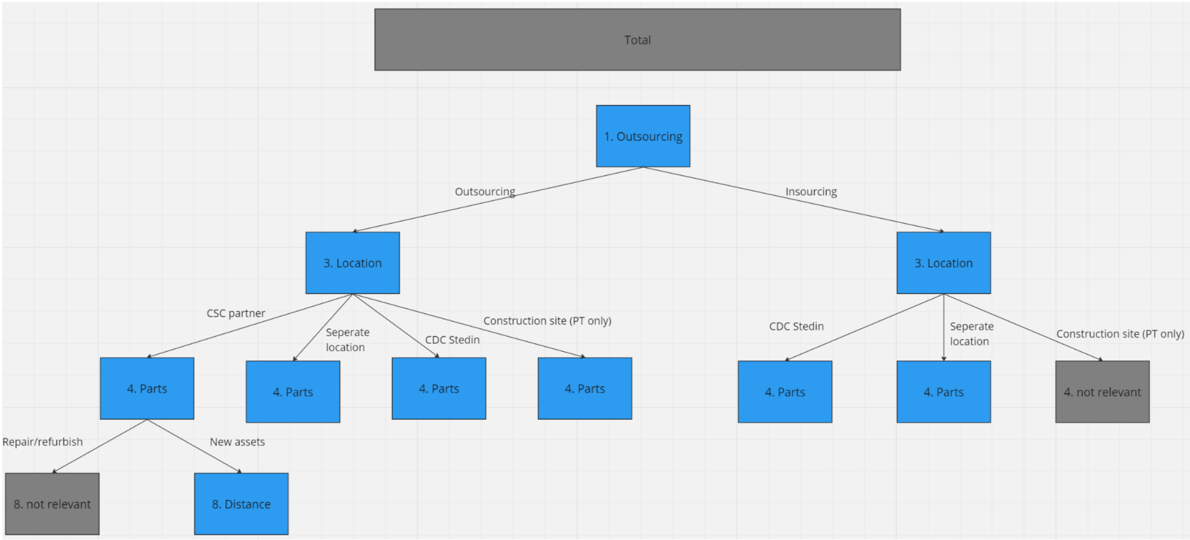


Figure 7.2: Key decision dependency diagram (decision tree)

7.3. Decision elaboration framework

The decisions have to be elaborated on in a structured way to assist future DMs in the decision making process. A short literature search has been done to see if there are popular standard frameworks on what informational elements are required to make a choice. On Google Scholar and ScienceDirect, the following search term combinations were used: strategic AND business AND ”decision making” AND framework, business AND ”decision making” AND framework, ”decision making” AND ”required information” AND businesses AND strategic AND framework. Also, some other minor deviations or synonyms are used in the search process.

In the literature review, no popular standard decision frameworks were found. The aim was to look for a high-level decision framework that can be used in multiple types of decisions and not in very specific contexts. One of the frameworks found was by Snowden and Boone (2007), which identifies four different types of decision environments: complex, complicated, simple and chaotic. However, this framework is more focused on the DM job and danger signals, not on what inputs or steps are required in a decision-making process. The papers of Bhushan and Rai (2004) and Noman and Aziz (2011) do give a process for decision making, but these again do not detail what information or input is needed by the DM to be able to make a sound decision. Both are more focused on generating alternatives and defining team roles, not the input or information.

Stedin does not yet have a formal decision structure for SC-related decisions. In their Governance Authorisation Structure (GAS), the CFO has to be involved in investment decisions of over one million euros. In purchasing decisions, Stedin works with tenders, which limits the informal decision-making they can have. However, the tender structure is procurement-specific and is not a general decision structure or procedure. Within operations, they have a Decision Gate Structure (DGS) in which projects in the grid above 2.5 million have formal decision gates during the process. However, this is not the case for SC or SCC. The biggest decisions go to the Management Team (MT) Strategy, which includes the board of directors, but this is only for large investments and has no formal structure or process. There are deadlines for when preparation documents must be delivered, but then decision-making is done informally. After the decision is taken, a much more structured approach is taken with the SAFe (scaled agile framework) methodology (SC expert, personal communication, 15-04-2024).

For this reason, a new elaboration framework was created based on input from A. van Binsbergen (committee chair, personal communication, 26-03-2024) and a SC expert (personal communication, n.d.). This framework is shown in Figure 7.3 and is split into two parts. The left diagram applies to all decisions and features the key informational elements for each decision. These are an elaboration on the choice itself as it is understood at that moment, a description of the impact of the decision at hand on possible choices, and further information needs to be described to indicate which knowledge gaps have to be filled before the evaluation can take place, and lastly which decision-makers have to be involved. An evaluation can be done for the less impactful or complex decisions.

For the two most important decisions, the evaluation is more detailed. An evaluation method is selected, like MCDA or CBA, and the information needed to perform this evaluation method is stated. In Section 7.6, the frameworks for evaluation are shown in more detail and are also tested in a workshop. These example frameworks will show how the MCDA evaluation tools will look like and give the first options for criteria. However, the performance evaluation of the alternatives are not shown as this has to be done at a later stage by experts.

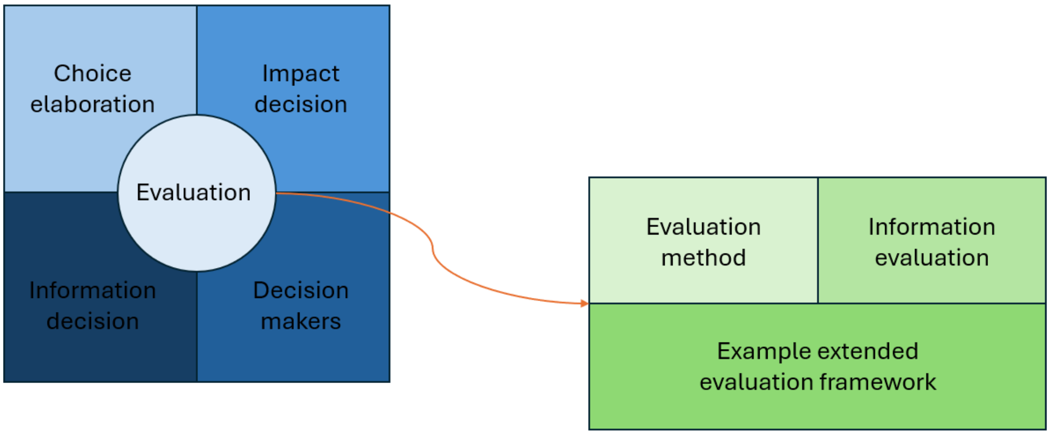


Figure 7.3: Decision elaboration framework

7.4. Decision elaboration

The nine decisions introduced in Section 7.1 are further explained in this section. This is done based on the elaboration framework presented in the previous Section 7.3.

7.4.1. In-house capabilities or outsourcing for reconditioning activities?

Choice elaboration

When assets enter the loop, focusing on the extension of the asset's (parts) lifespan, one of the circular strategies of repair, refurbish or remanufacture is applied to them. One of the most important design decisions is whether to source the capabilities to execute these strategies in-house or outsource the activities to specialists. On the level of the process diagram, this would not change the fundamentals of the design as the choice is concerned with the exact complement of the step. The process diagram's steps are 'Repairing assets', 'Refurbishing assets', 'Disassemble assets', and 'Remanufacture asset parts'. The manufacturing of new assets with remanufactured parts is left outside the scope as this is too far out of the range of Stedin's core business.

For each of these process steps, the choice has to be made between acquiring the in-house capability or outsourcing the activity. The lower the process step is on the circular ladder, the more knowledge and skills will be required to fulfil the step. Insourcing would mean that facilities and tools must be acquired, and personnel must be recruited and trained. This would require considerable effort and investment from Stedin. Because of the activity's complexity, repairing the asset will probably be easier to insource than remanufacturing. For outsourcing the activity, a service partner or supplier would be the most logical option. If the disassembly of assets, before remanufacturing, is outsourced, it could be that the reverse flow of asset parts for material recycling is removed as the assets enter the loop of the remanufacturing or disassembly partner.

Insourcing: create capabilities within Stedin to perform reconditioning activity
Outsourcing: find partner's for the activities. Can also be a temporary solution while building capabilities

Impact decision
If the activities are outsourced, the design is little impacted as the partner firm is concerned with the fulfilment of this activity step. As these companies require some financial return on their activities, it can be expected that the unit price per reconditioned asset will be higher than when Stedin performs the reconditioning. However, one would assume that the long-build expertise of these partners will give them an execution advantage in the short and medium term in terms of efficiency and accuracy compared to in-house build capabilities by Stedin. The insourcing of capabilities will impact the complexity of Stedin operations, investments and supply security. At other DSOs, investments of tens of millions have been made to provide facilities for reconditioning activities, and around forty FTE in technical personnel have been hired which gives some background to the possible investment. The logistic operation of Stedin would need to facilitate more transportation and gain a new team.

The advantage of insourcing is that Stedin obtains more insights into how an asset should be built and can give feedback to asset management on that. Also, Stedin would be in control of the reverse flow of reconditioned assets instead of another supplier dependency. This would benefit the goal of 100% OTIF on materials. An additional advantage of insourcing would be the possibility to crate more participation jobs which is a goal of Stedin. If insourcing for a step is chosen, the activity needs to be broken down into the exact operating procedure, and topics like warehouse routing and layout must be considered.

Impact outsourcing: higher price per reconditioned asset, higher supplier dependency
Impact insourcing: higher organisational complexity, required investment, higher supply security

Information for decision description
The broad overview of the decision is already clear. However, to make an informed decision, it is important to obtain more information on the impact of the decision, such as investments, costs, and complexity. For outsourcing activities, it is important to know the costs per unit and the reliability of supply. For the in-house option, a more detailed process has to be designed to estimate the required investment, personnel requirement, etcetera.

Decision makers
A large-scale insourcing of these life-cycle extension activities requires board-level approval. The investments in both facilities and personnel have to be approved by the CFO. Depending on where the reconditioning activities are placed in the organization, COO approval is required next to that of the SC director. SC does the logistics of the in-house operations. However, as the skills of the technical personnel resemble those of the operations departments more than SC departments, the reconditioning could be placed in an operational department. Employees from these departments could also be recruited for the new activities. If the activities are placed under logistics, the Manager Logistic Services needs to be involved in the decision.

7.4.2. Creating mass-balance system for metal recycling?

Choice elaboration
Conversations have been held with three cable suppliers and two recycle companies. During these conversations, all partners expressed the difficulties they saw in the closed-loop recycling of aluminium and copper back into the cable supply chain. This is both because of the quality demands from Stedin and the relatively small scale of the reverse flow. To start, the recycle flow of cables must be processed diligently to avoid contaminating the separate material flows. Even when the materials are separated it can still be the case that the aluminium is coated which is difficult to remove. If these pure material flows are available, they can be sent to a smelter. Although the reverse flow of cables in 2030 will be a few thousand tons of material, this is still a small flow for a processor. It is expected that it cannot be arranged that exactly the tons Stedin provides will also end up in new cables for Stedin. Also, purely using scrap aluminium or copper can be environmentally and cost-wise challenging if the scrap has to be processed in the ways to obtain cable grade quality. For the plastics in cables it is also difficult but

new techniques are tested to facilitate plastic recycling which are discussed in Subsection 7.4.5.

During a meeting with a cable supplier, it was suggested that a mass-balance system for the metals be set up. A mass-balance system is based on a segregated bookkeeping of material flows and certifying the chain of custody of the materials (Ellen MacArthur Foundation, 2020). Ellen MacArthur Foundation (2020) give four chain of custody models that all have as a goal to have a solid bookkeeping between the input of the production process and the output and attribution to the customers of the input. The difference is in the way the input can be physically linked to the output.

In the mass-balance system, the smelter/processor of the metals would issue a certificate of some sort to Stedin. The certificate would prove the amount of scrap metal handed in and give the circularity credits of the recyclate to Stedin. So, although the actual percentage of recycled material in the new cables would be 10%, as the smelter does not have a higher amount of recyclate, the Stedin cables could have 50% recyclate on paper. This is because the recyclate Stedin handed in is attributed to their cables. This would also guarantee that the amount of materials Stedin hands in is the minimum amount that Stedin's cable supplier will receive, thus securing material availability. There are already systems for recycling that this initiative can be based on. Certification schemes are for example ISCC PLUS or UL2809 (Circularise, 2022). All these schemes depend on the ISO 22095:2020 and ISO14020:2022 norms on chain of custody and environmental statements (Ellen MacArthur Foundation, 2020). One of the suppliers of Stedin have stated that they are already working on a mass-balance system based on ISCC PLUS for copper and that this could be introduced by the end of this year without much effort from Stedin. This would not yet include the use of Stedin recycled material, only recycled material in general.

Implementation: mass-balance system created with suppliers to enhance circular asset content
No implementation: no system changes compared to current situation

Impact decision
The main negative impact is around the administrative burden this system would place on the value chain. Data about the volume supplied by Stedin has to be recorded, and a certificate system has to be conceived and run. This will require administrative personnel at the smelter and the other value chain partners, leading to additional costs. The benefit is that the circularity percentage of Stedin's cables would rise, contributing to achieving the circularity goals. Also, it would secure a material flow of important metals, an important risk identified by HCSS that is partly mitigated this way.

Impact implementation: higher administrative burden and circularity percentage, lower supply risk
Impact no implementation: partner in control of recycle stream, no closed loop system

Information for decision description
Important to know before this decision is to have a first concept of what the mass-balance certification would look like. This way, it can be analysed how much additional work and costs this system would generate for Stedin and the stakeholders. Also, there needs to be an incentive for the other stakeholders to participate, which will most likely result in Stedin paying more for the end product as a customer. How much more will need to be determined together with the smelter and cable supplier. An analysis of how much material will pass through this system and how much material Stedin needs for their cables will give insight into the improvement in recyclate percentage realised with this system.

Decision makers
The decision-makers will have to be determined when the additional costs are clear. It is probable that the CFO will want to be informed at least, as it will result in higher costs and a higher administrative burden. The Director SC is the most important decision maker, as this system will require more work from the vendor management team or the recycling team. Depending on where the workload will end up, will the manager of logistic services or the manager of vendor management need to be consulted. Additionally, the regulatory department has to be involved in the decision to implement the certification system as compliance with standards will be necessary. Lastly, the sustainability strategy manager and the Director SC have to decide if this mass-balance certification is a way they accept to reaching their targets as it is decided that offsetting carbon emissions is also not allowed to reach the stated targets.

7.4.3. Where to perform reconditioning activities?

Choice elaboration

The process design does not show where the reconditioning activities are taking place. As described in the decision for outsourcing the R4-R6 activities, a choice must be made regarding who performs the activities. However, the location also needs to be decided. When the activities are insourced, it has to be decided if the operations occur inside the overall CDC or if a new facility should be acquired dedicated to reconditioning. The decision can differ for distribution transformers (DT) and power transformers (PT). DTs are lighter and more standardized, which enables easy stockpiling and handling.

The weight of PTs requires facilities specifically designed for heavy-weight equipment handling and storage. It could be the case that the in-house activities of DTs and PTs would be at different locations. Also, the PTs can be reconditioned at the decommissioning location. This can be an attractive option if the required work is not substantial. If the activities are outsourced, a location choice will still be made. As DTs are easier to transport, it would be logical to transport them to the location of the outsourcing partner. However, due to the weight and size of PTs, it could also be chosen that the reconditioning activities are done by an external partner but at a location more central in the Stedin service area to reduce difficult transport.

CDC Stedin: integration into new to build CDC
Separate location Stedin: separate Stedin location, is needed for PT reconditioning
Construction site: only viable for PTs as sufficient space is available
Location CSC partner: with outsourcing activities can be done at partner location

Impact decision

The decision's impact is mainly related to the investments in the facilities and the transportation operations and is very much connected to the capabilities sourcing decision. Depending on the location choice, a new facility is needed, with additional investments, or the CDC has less space for other activities when it is chosen as the location. The advantage of a location, both in the insourced and outsourced scenario, more centrally in the Stedin service area is the reduction of the transportation distance, which will most likely be higher if operations are done at partner locations. This would save costs, time, and CO2 emissions, and it may also reduce complexity.

Impact CDC Stedin: better integration in other operations, less space for other operations
Impact separate location Stedin: additional investments, facility specific to circularity
Impact construction site: more complex logistics on site, reduction of off-site movement
Impact location CSC partner: only option with outsourcing, no added complexity Stedin

Information for decision description

A more elaborate analysis has to be made of the advantages and disadvantages of each (type of) location choice. Would the CDC have space for these reconditioning activities, or would other operations be hindered? What would be the investment required for a separate location? How much transportation distance is saved by a more central location? Would a central location reduce logistic complexity compared to a partner location or only reduce travel distance, thus CO2 emissions?

Decision makers

As a large investment would be required for an internal location, the CFO is an important decision-maker in approving the additional costs. Also, the SC director and logistics manager are important in the decision as the impact is mostly related to SC/logistics aspects.

7.4.4. Remanufactured parts used in repair/refurbish cycle or new assets?

Choice elaboration

After remanufacturing asset parts (R6), the parts can be used again in operational assets. The decision needs to be made is whether these remanufactured parts are used in existing or new assets. It can be the case that in the repair or refurbishment activities, up-to-date spare parts are needed to bring the asset back to the standards of asset management. These spare parts can be newly bought from a supplier, or remanufactured ones can be used. Additionally, when it is chosen to use remanufactured parts in existing assets, it needs to be decided if they are used in repair or refurbishment activities or both. The other option is to use the remanufactured parts in newly built assets.

Use in repair/refurbish: integrate activity into other reconditioning activities
Use in new assets: after remanufacturing the asset is used in new asset manufacturing

Impact decision
This decision's main impact is on how the operations and transportation are done and whether the Stedin material loop is closed. If the remanufacturing is done externally, the remanufactured parts must be transported to either the manufacturer of the new assets or to the repair and refurbishment locations. For both destinations, the inflow of remanufactured parts into their operations would be similar to new parts that would be required and stocked. A difference is that when the parts are used in existing assets, the materials stay in the Stedin loop. When a manufacturer of new parts uses them, they will probably be used in new assets for different customers. If the repair and/or refurbishment is done in-house, using the remanufactured parts in these operations would be a useful additional supplier. Also, a manufacturer of new assets would probably charge some margin on the remanufactured asset when selling a new asset to Stedin, which would not be the case if the parts are used in existing assets. There would be an advantage when the remanufacturing and use of remanufactured parts in new assets can be more efficiently coordinated by third parties which would also reduce the complexity for Stedin.

Impact use in repair/refurbish: possibility of integration into R4/R5, parts stay in Stedin loop
Impact use in new assets: extra costs third party, less internal complexity, parts leave Stedin loop

Information for decision description
This decision will influence whether the reconditioning activities are done in-house or outsourced and at which location. If all reconditioning is done in-house at the same location, using the parts in existing assets would make more sense. This way, the remanufacturing activities would be an integrated step in the repair and refurbishment activities and would provide a parts stock with only internal transportation. In general, it would be necessary to understand the price difference per asset (repaired/refurbished or new) depending on where the remanufactured part is used. Also, vendor management or supply planners could analyse how each option would help overall material availability.

Decision makers
The final decision maker here is the Director SC. There are not sufficiently large financial implications that the CFO should be consulted, and other departments are also not impacted. It could be checked with an asset expert from asset management if they have a preference, but they are less involved in the final decision.

7.4.5. Recover energy from materials in recycling or stockpile the materials?

Choice elaboration
Currently, more than half of the plastic weight from cables arriving from the recycling partner is not recycled into new materials. Instead, they are incinerated for energy recovery, something seen as more beneficial than the landfill option. However, this way, the material gets lost and cannot be used in new products at a later time. Plastics are not as valuable to a recycling partner as metals, so Stedin's revenue from this scrap is also low. From the viewpoint of material availability and circularity, Stedin could choose to stockpile the plastics and weight for the moment with new recycling methods that are commercially viable. In conversations with cable manufacturers and recycling companies, chemical recycling or pyrolise were identified as techniques that would enable more plastic recycling. The partners expected that these techniques would be commercially viable around 2030. By stockpiling the plastics now, Stedin can process the old plastics and reuse the materials for new plastics. The decision is whether Stedin lets the recycle partners incinerate plastics or stockpile them. In the case of stockpiling, a location needs to be found to do that.

As plastics are often incinerated, stockpiling this scrap would save raw materials. Metals are already recycled into new products but can also be stockpiled. Stedin could choose to stockpile the aluminium and copper scrap to secure a material supply in the thirties when shortages are expected. Also, for aluminium, stockpiling could lead to a more high-grade recycling procedure if new techniques become available to recycle aluminium so that it can be used for cables again.

Energy recovery: current state of operations, removes possible reuse of materials
Stockpile: stockpile material until new recycle techniques become available

Impact decision
The impact would be financial in the short term, sustainability in the long term and operational in the short and long run. In the short term, stockpiling would mean storage costs for the plastics. A location for Stedin itself, a joined location with other DSOs or a partner, must be found. These costs accrue no benefit in the short term. This location would also need personnel to operate the location. In the long term, this choice would mean that more recyclate would come onto the market, enabling more circular value chains. The disadvantage of the entire decision is that it adds organisational complexity as transportation after splitting the material streams, storage and transportation in the future to the new recycler is needed. An added benefit could be material availability, as Stedin has its own plastics stockpile. However, this is less relevant for plastics than it would be for metals.

Impact energy recovery: direct energy recovery benefit, materials are removed from the loop
Impact stockpile: additional storage costs, possibility for high quality recycling

Information for decision description
More information is necessary on when new recycling methods become commercially available so that the stockpile of scrap can be used for new plastics. When this is known, it can be calculated how big the storage location has to be and what the associated costs of the stockpile operation will be.

Decision makers
The decision-makers are the CFO and the director of SC, as the decision to acquire a storage location and stockpile materials would have a yearly financial impact for the medium term and result in a more complex logistics operation. The manager of SC services has to be consulted, as the new location would fall under that department.

7.4.6. Force recycle partner to strip cables for high-grade processing?

Choice elaboration
Currently, Stedin does not have many demands on the way the recycling partner processes their cables. However, how the cables are processed determines the high grade of the end products in the recycling process. The material streams become much more pure by stripping the cable and separating the plastics from the PE mantel, the copper screen, the XPLE isolation, and the aluminium core. This way, recycling is truly recycling instead of downcycling the materials to lower-value applications.

Stripping: strip the cables to create more pure separate material streams
No stripping: shred the materials which cause impurities

Impact decision
The implications of this demand to the recycling partner are mainly one of costs versus sustainability impact as the design does not change by the decision. Stedin will have to pay for the more laborious and costly processing by either paying for recycling or receiving less for the materials. The advantage is that higher-grade recycling has a higher sustainability impact. The only way the materials could be used in new cables is by high-grade processing of the materials.

Impact stripping: high grade recycling made possible, additional costs probable
Impact not stripping: downcycling materials, no additional costs probable

Information for decision description
The benefits of high-grade recycling are sustainability impact, but who reaps the benefits depends on the buyer of the recycled material. If it is decided that the recycled material is administratively used in the new cables via a mass-balance system, Stedin reaps the benefit of the costlier way of recycling. Otherwise, the benefits are for other end users of the recycled material. Therefore, to make a business case for this decision, it needs to be know whether Stedin will use a certification system. It is also important to know if and by how much the recycling partner will charge for this way of processing.

Decision makers
The main decision-makers are the manager of logistic services and the SC director. They need to decide whether the sustainability gain outweighs the possible additional costs.

7.4.7. Stockpiling new power transformers as a DC for redeployed ones is already necessary?

Choice elaboration
Currently, if PTs are redeployed, they are directly transported from the reconditioning location to the new construction site. In the design, there is an option for storage of the PT in a DC. The DC will not be the current of the new CDC of Stedin as these are not built to handle the large weight of the PTs. Storing PTs after reconditioning allows for the redeployment of these assets, even when a new installation location is not directly available. This way, more PTs can be redeployed, which contributes to Stedin's circularity goals and would help with material availability as there is stock, instead of only having the possibility of ordering new PTs with long lead times.

New PTs are not in stock at the moment, prompting the question: If Stedin has storage facilities for reconditioned PTs, can we also stockpile new PTs? PTs are often not very standardized, but asset management can standardise asset types to overcome this problem. Also, if assets still require some level of specific requirements, more standardized assets can be ordered and tweaked for final use at this Stedin site.

Stockpile new PTs: possibility for installation of PTs from stock instead of on order
No stockpile new PTs: stay with model of direct installation

Impact decision
The impact on the design would be minimal as the storage step is already included. The newly manufactured assets or the new assets with remanufactured parts will also have to be transported to the DC instead of directly to the construction site. This can still be the case when this is logistically more beneficial. Stockpiling more PTs would also require a larger facility than storing just redeployment PTs. This would require a larger investment in the building, and the working capital of Stedin would be impacted as PTs can be worth over a million euros. Stockpiling this asset quickly becomes capital intensive for this reason. The major benefit is that PTs can be delivered from stock in more cases, increasing material availability and reducing lead times.

Impact stockpile new PTs: higher investments needed, increased material availability
Impact no stockpile new PTs: no additional investments, longer lead times

Information for decision description
What replenishment strategy would fit PTs to calculate the required DC space and working capital increase needs to be determined. Also, this policy's contribution to the 100% OTIF goal on materials needs to be evaluated and weighted against the financial implications.

Decision makers
The final decision makers are the CFO and Director SC, as they require large property and working capital investments and would change the procurement policy for PTs.

7.4.8. Remanufacture parts if the manufacturer is located at a large distance?

Choice elaboration
One of the options for the output of the remanufacturing process is to use the parts in a new asset. Whether this scenario should be used if a manufacturer is located at a large distance from the remanufacturing operation has to be decided. For example, one of the PT suppliers is located in Turkey. Will we send remanufactured parts to Turkey, or will it be more environmentally friendly to only use these parts in existing assets or recycle them instead of remanufacturing.

At distance: Transport asset parts to manufacturer located at large distance
No remanufacturing: recycle the assets in stead of reconditioning

Impact decision
If the remanufactured parts are sent to manufacturers at a large distance, higher transport costs and emissions will result. However, this will benefit reusing materials with a strategy higher on the R ladder compared to recycling the materials. In the other scenario, lower transport costs and emissions are incurred but with a lower rate of circularity. There is a sustainability trade-off between circularity and CO_2-eq emissions.

Impact at distance: more materials are reused, higher transport costs and emissions
Impact no remanufacturing: only recycling possible, less transport costs and emissions

Information for decision description
The exact result of this trade-off between circularity and transport sustainability should be calculated in a Life Cycle Assessment (LCA). This way, it is clear which decision is more environmentally friendly. The LCA for this decision is not a model that Stedin already has but can be developed together with expert partners. After this, the cost profile of the two options is required to see which situation results in the lowest costs.

Decision makers
This decision can be made by the manager of logistic services, as recycling and remanufacturing will be under the purview of this manager.

7.4.9. Will Stedin do their zero-emission transport, or will we outsource it?

Choice elaboration
This choice is twofold. The most important part is whether Stedin will do all the transportation with its own trucking fleet or outsource the trucking. At the moment, Stedin has a few trucks to place emergency power generators and transport some of the transformers. The decision needs to be made on whether to keep these trucks and outsource the rest of the transportation work, outsource all the transportation in the circular supply chain, or insource everything, leading to a much bigger fleet.

Additionally, one of the design constraints is to ensure that all transportation has zero emissions. The question is how this can be realised. Although the design is for 2030 and many technological developments will happen until then, the changes are that not all (heavy) transportation can be done with zero emissions due to technological constraints or that there is limited zero-emission capacity in the market. Will Stedin be forcing partners or themselves to work zero emissions, or do we accept that in some situations this is not preferable? This would mean that the requirement is actually not a constraint but an objective.

Insource: insource all transportation of assets for Stedin operations
Partly insource: only use Stedin vehicles for certain types of transport
Outsource: sell all trucks and find partner for additional outsourcing
Strict zero emission: only allow zero emission vehicles in transportation
Flexible zero emission: allow non-zero emission vehicles if alternative is very scare

Impact decision
There is a financial impact of both the sourcing and zero emissions decisions. Insourcing would mean a considerable investment in Stedin's transportation equipment, especially if all equipment has zero emissions. It would also add organisational complexity as Stedin will do more transportation (related) activities. Partly insourcing transportation (like Stedin does now) would offer a flexibility benefit. Outsourcing would remove the necessity for investment, and perhaps the partner has the scale for their transportation operations so that zero-emission investments can be done more efficiently. If they are forced to do all transportation with zero emissions, it would result in higher transportation costs and probably weighting times.

Impact insource: high investments needed, added organisational complexity, more control
Impact partly insource: less investments needed, less control, more flexibility
Impact outsource: no investments needed, higher costs and weighting times
Impact strict zero emission: higher investment/costs and weighting time, larger emission reduction
Impact flexible zero emission: lower investment/costs and weighting time, less emission reduction

Information for decision description
The most important information needed is the associated costs for insourcing transportation and zero-emission transportation. Added complexity resulting from insourcing can also be investigated.

Decision makers
The CFO has to be involved in the decision to invest in insourcing and additional costs for zero-emission transport. The manager of logistic services must determine the desirability of insourcing the activities.

7.5. Testing design validity

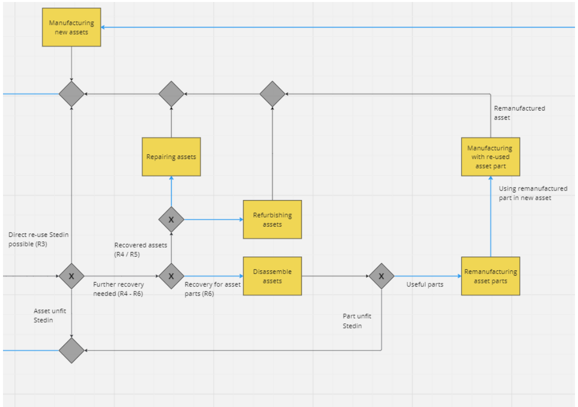
Earlier, it was stated that the meso structure design shown in Figure 6.3 would not fundamentally change by these decisions. Only the implementation of an activity block would change next to minor changes to the overall design. This section will discuss how the decisions will impact the design.

The first decision (D1) on outsourcing does not change the meso design process diagram. Outsourcing means something about how the activity blocks for repair, refurbish and remanufacture will be organized, but the process steps or the sequence of steps remain the same. Also, the blue transportation will remain the same regardless of the outsourcing decision. Some transportation will be required between testing and reconditioning. Especially if activities are in-sourced, a deepening of that block will be very important, and a micro-level design will need to be made with operational decision-level aspects. The outsourcing decision is also connected to the location decision (D3), but the same remarks hold here. The location will not alter the process sequence or steps.

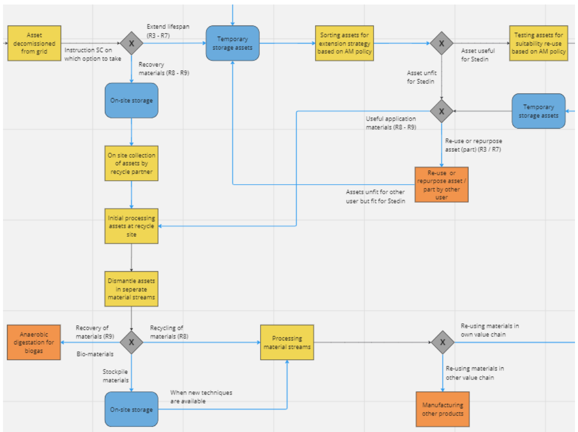
The mass balance decision (D2) will make one line in the diagram less useful. If D2 does not set up such a system, reusing materials in the Stedin value chain will be very hard to organize. By coincidence, it can be that some materials end up in the cable value chain, but this would not be a coincidence choice. There is a difference in the design for D4. If it is decided not to use the parts in the repair or refurbish cycle, the decision point and (transportation) lines are removed from the design, as seen in Figure 7.4a. However, the decision does not further impact the design as a whole.

If it is decided in D5 not to allow recycling partners to incinerate waste, this small part of the design will change, as seen in Figure 7.4b. Only bio-materials will be digested, and formerly incinerated plastics will go to a stockpiling storage location, as seen in the new blue block. If new recycling technologies come to the market, these materials can be fed back into the original recycling loop. For D6, nothing at all would change to the diagram. Stripping is a processing choice made in either the initial processing or dismantling of the assets and is an internal process step for the recycling partner.

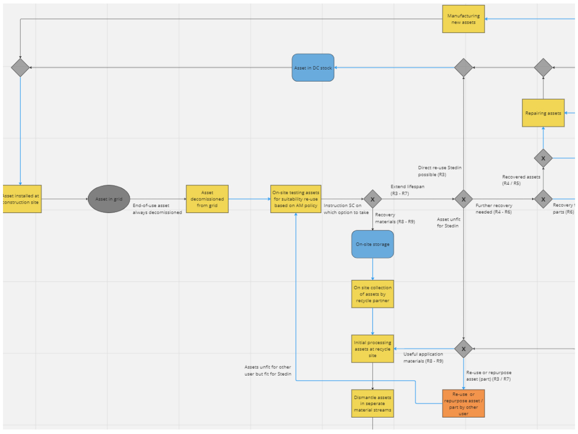
If it is chosen not to stockpile new PTs in D7, the meso structure design diagram for PTs has a slight change, as seen in Figure 7.4c. The new PTs will not be brought to the same location as the reconditioned PTs but will be brought directly to the construction site. Again, this does not affect any further parts of the design. The same is true for D8 if the distance to a manufacturing partner is too long. In Figure 7.2, it can be seen that the activity block for the use of remanufactured parts in new assets is removed. This means these parts can only be used in the repair or refurbish cycle for lifespan expansion or recycling. Choices for D9, on outsourcing transportation and net-zero transportation, do not change the process diagram. They only change who executes the blue transportation lines in the diagram and how sustainable this transportation is.



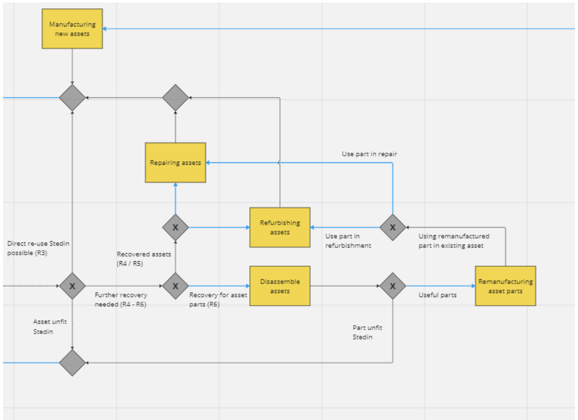
(a) Parts (D3): no link R6 with R4 and R5



(b) Recovery (D5): incineration option removed



(c) Stockpile (D7): no connection between manufacturing and DC



(d) Distance (D8): use of parts in new assets no option

Figure 7.4: Differences in the meso structure design based on decision options

7.6. Evaluation of key remaining decisions

The key design decisions were introduced and elaborated in the previous sections according to the framework shown in Figure 7.3. As explained, the two most important decisions (D1: Outsourcing & D2: Mass-balance) deepen the evaluation part of the framework. For the other seven decisions, the elaboration framework guides the decision-making process. The evaluation building block in the framework for D1 and D2 is split into three parts: the decision evaluation method requires information for elaboration, and the first set-up of the evaluation framework will be discussed in this chapter. First, the types of evaluation methods are discussed, and then the evaluation framework for D1 and D2 is discussed. A workshop is held to validate the functionality of the combination of the elaboration framework and the decision framework, which is discussed in Section 7.6.4.

7.6.1. Evaluation methods

In the methodology section for the material scoping, Section 2.1.2, a brief review was given on evaluation methods and the multi-criteria decision analysis (MCDA) more specifically. The presented evaluation techniques differ in terms of how well they can integrate non-financial data in the evaluation. In methods like a cost-effectiveness analysis (CEA), economic-effects analysis (EEA), and cost-benefit analysis (CBA). The focus is on the monetary implications of a decision or design. The alternatives can be weighted against each other based on the performance or benefits of an alternative against the required costs or investments. These methods are suitable if the impact of the alternatives is only financial. A social cost-benefit analysis (SCBA) tries to incorporate more of the societal implication of the decision into the evaluation by quantifying the social impact. However, when the impact of non-financial effects is difficult to quantify in monetary terms (or at all), an SCBA can not accommodate the effects, and a method suitable for non-financial or more qualitative evaluation has to be chosen.

The MCDA is a group of methods that evaluate alternatives on both qualitative and quantitative criteria and prioritize these criteria by giving weights to them. The alternatives can then be evaluated based on their performance on these weighted criteria, whether that performance is financial, non-financial, qualitative, or quantitative. If the performance can be measured objectively, this can be the role of an analyst. Otherwise, the performance evaluation can become a group process. This is very often already the case for attributing the weights to the criteria as stakeholder and/or expert consensus needs to be reached. In these group decision processes, the decision-makers and the decision impact must be known (those are part of the elaboration framework) to know if DMs have worked together before and that there is common trust (in the Stedin case, almost all DMs already work together), that DMs are familiar with the decision and its aspects (the elaboration framework provides in this) and that there are possibilities for support tools (Salo & Hämäläinen, 2010). As can be seen, the elaboration framework of the previous chapter should create the right circumstances for group decision-making. In Section 7.6.4, one of the frameworks discussed in the next two sections will be validated.

Both the ranking of alternatives as well as the ranking of criteria can be done with methods based on multi-attribute theory variants like Analytic Hierarchy Process (AHP) and Simple Multi-Attribute Rating Technique (SMART) or outranking methods like Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) and ELECTRE. For criteria ranking based on a Group Decision Support System (GDSS), methods variants on earlier methods are proposed, but also methods like the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) and Simple Additive Weighting (SAW) are mentioned (Macharis & Bernardini, 2015). In all these GDSS methods, all stakeholders have the same criteria to prioritize. For additional stakeholder involvement, the Multi-Actor Multi-Criteria Analysis (MAMCA) has been developed where stakeholders can choose their own criteria (Macharis et al., 2010).

Applying evaluation techniques for design element decisions have not been used often. A literature search has been done with search combinations like ”MCDA OR MCA” AND design AND evaluation AND ”design decisions” or ”MCDA OR MCA” AND evaluation AND ”design project” AND decisions AND components. However, no article that used evaluation methods to choose a design element was found. All papers focus on using a MCDA technique to evaluate and rank entire design alternatives. Some papers use it in the final design selection or already in the preliminary design evaluation steps, but it is always an alternative selection. This is the case for a wide range of disciplines like vessel construction (Jorge & Agis, 2015), building construction (Küpfer et al., 2021), public transport (Nalmpantis et al., 2019), healthcare (Mühlbacher & Kaczynski, 2016), solar (Amine et al., 2014), and environmental planning (Lahdelma et al., 2000). It therefore seems that this is a quite novel approach.

7.6.2. In-house capabilities or outsourcing R4-R6 activities?

D1 is the outsourcing decision for the reconditioning activities for repair, refurbishment and remanufacturing, in Section 7.4.1, the decision is elaborated based on the elaboration framework, so the choices are explained and the impact discussed. In Figure 7.2 it is shown that three other decisions are dependant on the decisions taken here. One of the obvious results of insourcing the (part of) reconditioning activities is the need to invest in a location, equipment, new people and capabilities, which would require large capital allocation and could not be immediately realised. It would also permanently add more organisational complexity to Stedin's organisation and introduce a production type of operation with which Stedin is unfamiliar.

The advantages could also be substantial. Stedin would gain more intimate asset knowledge and have the capabilities to act on that knowledge. The circularity department of Alliander (personal communication, 16-04-2024) uses this knowledge to create innovation in the assets themselves and in tooling to handle the assets. They also feel they can better react to possible supply delays or emergencies. Having an in-house supplier would reduce supplier dependency as well. Alliander gives as an example that there is only one firm in the Netherlands that can recondition transformers and that they are already facing capacity constraints. Having insourced this activity can thus not only reduce supplier dependency but also avoid capacity constraints. Additionally, it could be that the outsourcing decision impacts the price of redeployed assets. Partners will require higher margins on their operations than an internal supplier.

Which evaluation method?
Analysing the impact of the decision on Stedin shows that the evaluation can not be a straightforward cost-benefit analysis. If one would only focus on CAPEX (capital expenditures) and OPEX (operational expenditures) investments a clear business case can be made. However, the impact of capacity creation, supplier dependency, knowledge gains or organisational complexity are difficult to monetize and include in a business case. This means a method is required where non-financial aspects can be included in the evaluation.

However, for example, for an SCBA, the impact still has to be quantifiable in financial terms. The effects on organisational complexity and the introduction of a different type of operation, supplier dependency, capacity constraints, increased knowledge, or emergency response possibilities will be hard to monetize. Therefore, an MCDA method would be more suitable to accommodate the non-financial effects of the choices.

Information for evaluation
Although the impacts will not be evaluated strictly financially, more information on the different impacts of the decision is still required to make a sound evaluation of the alternatives. For the financial effects, questions need to be answered, like: How big are the investments that need to be made in (new) facilities and equipment? How much personnel would be needed? Would in-house reconditioned assets be more or less costly than outsourced assets?

For the non-financial effects, more feelings have to be gained on the impact as well, with questions like: How big are the risks for supplier dependency and capacity constraints? What would be the contribution to the 100% OTIF objective in both scenarios? How would we value the additional technical expertise we obtain? How large would the added organisational complexity be, and would this hinder other activities? By answering both the financial and non-financial questions, input is gathered based on which alternative evaluation can be done.

First set-up evaluation framework
Although so far this decision is mainly framed as one, it is actually at least three separate ones as it concerns repair (R4), refurbishment (R5) and remanufacturing (R6), where R6 could be split between the disassembly and actual remanufacturing. However, the effects of outsourcing decisions are similar for all three activities. In outsourcing, each activity would impact investments in location, personnel, equipment and expertise, supplier dependency, capacity constraints, organisational complexity, price per asset or obtained knowledge. Therefore, it is assumed that each decision's criteria will be the same, so one initial framework set-up is presented. For application of the framework in a later stage, it will be important to treat it as three separate decisions that can be influenced by each other. It would be more logical to start with R4 and end with R6 as each strategy lower on the R ladder will require more knowledge and skills so it would also be easier for Stedin to in-source R4.

Criteria
Important in the MCDA is to select the right criteria. At a later stage, Stedin will evaluate the final decision based on a list of criteria approved through stakeholder collaboration or validation. In the meantime, the first suggestion for this list is based on the analysed impacts. This can also be a starting point for further validation of the list.

- Investments
- Price per asset
- Organisational complexity
- Supplier dependency
- Reconditioning market capacity
- Knowledge

After a final list of criteria is approved, the criteria are weighed. A relatively straightforward way which would not require complex tooling is the AHP method. This method models the problem as a hierarchy and uses pairwise comparison to determine criteria weights (Macharis et al., 2010) implicitly. In pairwise comparison, one criterion is compared with another, and combining all these pairs can determine relative importance or weight. This is an easy-to-understand method for the involved stakeholders, and calculation tools are available online like Goepel (n.d.).

Performance evaluation
Different techniques can be used for the performance evaluation. The SMART method is easy to understand and apply in a practical context, where each criterion is scored on a one to ten scale. This can be done by analysts or again as a group decision. In a group decision, the stakeholders evaluate the alternatives on each criterion based on the impact information. The problem with this is that it introduces more subjectivity, as it is likely that not all stakeholders can evaluate the choices on each criterion. Different analysts or experts can be asked to evaluate the alternative on the criterion they are an expert on. These performance results are then combined with the criteria weight to reach a final score and ranking of the choice alternatives.

Table 7.1 shows an example of the evaluation framework with fictional weights for added clarity. As said, after the weights are determined, each alternative is evaluated on each criterion on a scale of one to ten. Multiplying the weights with the scores, a total score for each choice option is obtained, and the choices can be ranked. With this more formal decision process, the aim is to make a more objective end decision.

Table 7.1: Evaluation framework for D1 with example weights and without performance scoring

D1	Investments	Price per asset	Organ. complexity	Supplier depend.	Capacity	Knowlegde	Total
Weights	24%	11%	8%	15%	26%	16%	100%
Outsourcing							
Insourcing							

7.6.3. Creating mass-balance system for metal recycling?

D2 is the decision to create a mass-balance system to certify the administratively closed-loop recycled material flow for aluminium and copper in Section 7.4.2; the decision is elaborated based on the elaboration framework, so the choices are explained, and the impact discussed. Like D1, this decision is binary, whether to create a system or not. There is a bigger information gap in this decision than is the case for D1, as the entire contours of the certification system are not yet known. Many partners in the value chain certainly have to be involved, and the system must be independently audited to guarantee validity. That information exchange is necessary to measure the circular performance of the assets.

Nevertheless, the impact of the decision can be estimated because of the system's character. Data must be collected on the volume of recycled material supplied by Stedin. A certification system has to be created and run afterwards. This will include administrative tasks for all stakeholders involved, resulting in a certificate where the recycled material content of the metal end product is guaranteed in a certificate that is also audited. All these tasks will put an administrative burden on not only Stedin but all participants. This will require additional personnel, resulting in direct costs for Stedin and indirect costs for the assets, as suppliers are likely to increase prices to compensate for administrative burden costs. These administrative tasks will not only incur additional costs but also create more bureaucracy and complexity in vendor management processes.

The upside of this system for Stedin is twofold: circularity and supply security. With a mass-balance certification system, the recyclate of Stedin (and of others) can be attributed to the metal end product of a processor. This means that the percentage of recycled material in a new asset can increase much faster than the availability of recyclate. This way, Stedin's targets on circularity can be reached much faster than otherwise. Using more recycled material in assets can also affect the price when the reused material is cheaper or more expensive than virgin material. The second benefit is supply security. The mass-balance system could be a tool for Stedin to demand that their (volume of) recycled material be available to produce new assets. The critical metal availability is expected to deteriorate, so this would give Stedin more security over metal supply than would otherwise be the case (Netbeheer Nederland, 2023a)

Which evaluation method?
The reasoning behind the evaluation method for this decision is similar to the one just discussed, D1. The costs of administrative burden can be estimated, which would open the possibility of a CBA-like evaluation method. However, how Stedin values an administrative improvement of the circularity KPI and more secure critical metals supply will be hard to quantify monetarily. Because of the stage of the project and associated uncertainty, an evaluation at this initial point also has to include criteria on the practical feasibility of the certification system. Suppose it is too complex to implement the system, or Stedin cannot force implementation alone, which is highly likely given the small size and customer-of-choice policy. In that case, it can be decided not to proceed with a project on mass-balance certification, even if running the system after the initial set-up is not complex or expensive. This is also a non-financial criterion that can be given gradations to indicate the feasibility level but can not be monetized. An MCDA would benefit from both including financial and non-financial criteria and qualitative and quantitative criteria.

Information for evaluation
The impact of the decision needs to be further investigated so that the decision-makers participating in the evaluation can make an informed decision. Partly, this will require forming a better image of what such a certification system would look like. In the previous chapter, some examples and important norms are given on a mass-balance certification system for recycled materials, but this is only a start. When a better grasp of the system is obtained, the impact can also be analysed in more detail.

The costs of the administrative burden can be quantified because it can be calculated how many FTEs will be needed at Stedin to accommodate the certification system, and the chain partners can indicate the additional cables. This will give better insight into the financial impact of the system. Also, it should be investigated how high the paper percentage of recycled material can be in this system. Would 100% be an option, or will this percentage be much lower even with the mass-balance system? This way, the system's contribution to Stedin's circularity targets can be estimated. Also, some analysis must be done on increased supply security and the difference between a no-certified system and a non-certified one.

First set-up evaluation framework
Just as with D1, this subsection provides the first set-up of the evaluation framework. For now, the decision is whether to implement such a system. In the future, at the moment of evaluation and after gaining a better image of the system's workings, multiple types of certification systems could exist, each with its own performance on the selected criteria.

Criteria
As said, it is important in the MCDA to select the right criteria, which stakeholders must validate later to obtain consensus and approval on the criteria list. Below, a first set-up of the list is given, which can be a starting point for validation. Like D1, the AHP is used to create the weights for the criteria.

- Costs Stedin
- Price per asset
- Circularity
- Supply security
- Bureaucracy

Performance evaluation
For the performance evaluation, the SMART method is used for the same reasons as it was chosen for D1. Different experts can be used to evaluate the alternatives on each criterion to avoid a lack of knowledge of the stakeholders participating in the criteria weighing. Combining the weights with the performance evaluation, a ranking of the alternatives can be created on a scale of one to ten of the SMART method. Table 7.2 shows an example of the D2 evaluation framework with fictional weights and two types of mass-balance certification systems as an example. Combining the weights and performance scores will lead to ranking the best decision choices.

Table 7.2: Evaluation framework for D2 with example weights and without performance scoring

D2	Costs Stedin	Price per asset	Circularity	Supply security	Bureaucracy	Total
Weights	18%	23%	32%	12%	15%	100%
Mass-balance system 1						
Mass-balance system 2						
No system						

7.6.4. Framework validation workshop

On 29-04-2024, a workshop was held to validate the elaboration and evaluation framework. The aim of the frameworks is to offer guidance, transparency and stakeholder engagement in decision-making. The workshop is a way to elicit feedback on the usefulness of the framework in practice and to engage important stakeholders to increase the chance of adaptation of the framework. The participating stakeholders were the Team Lead SCC (R. Calame), Manager Logistic Services (R. van der Spoel) and Director SC (M. Baars).

The workshop used the outsourcing decision as a case study to validate the framework. The case was explained and in two parts the participants had the opportunity to give feedback on both parts of the framework. The overall conclusion of the workshop was that the frameworks were useful, are clear and function well. There was some feedback on textual parts of the case, but these items were minor and not relevant to the framework at large. In the elaboration framework a change was made to the texts a the choices are stated at the end of the desperation block to create more clarity.

A concern in the evaluation framework was that the weights would become too similar, a 51% versus 49% scenario, which would raise doubts about the validity of the end result. This is something that can be partly avoided by using a three or five-point range in the AHP method instead of the nine-point method shown in the workshop as an example. It could, of course, still happen that weights become very similar or that the end performance becomes similar. The latter was less explicitly said to be a concern but is still important to address. One could also use a discontinuous one-to-ten scale instead of a continuous one to create more distinction in the results. Another idea was to group criteria into a hierarchy of criteria with a similar theme, but it was decided that this was unnecessary.

8
Design implementation plan

This chapter transforms the results from the design development and key decisions into a concrete implementation plan. First, it is important to address the interfaces between the current state of the CSC and the non-CSC activities of Stedin and the 2030 design. In the next section, all the implementation projects are defined and categorised, and lastly, a project planning is given.

8.1. Interfaces 2030 design

Current state versus 2030 design

In Chapter 4, a current state analysis is done for the asset types in scope. There are some differences between the four assets. However, in principle, the processes are quite similar, with some changes for the PTs. All other assets use one of the loops shown in Figure 4.1. This general current state diagram can be compared with the meso design to see how Stedin can move from the 2024 to the 2030 scenario and where the CSC design has interfaces with the other Stedin operations.

There are many similarities between the current state of the CSC and the vision to be achieved. This is also logical given that the 9R circular strategies of Potting et al. (2017) are finite in number, and all CSC will be based on them. Both the material recovery and lifespan expansion loops are present alongside the return loop for unused assets. The most important difference in the process activities is in the remanufacturing in the 2030 design. Remanufacturing is a strategy currently not so much employed by Stedin, only sometimes for the old HS cable types. The processes for this circular strategy are for the transformers and other assets that are lacking and need to be developed, in-house or outsourced. A second big difference is the explicit reuse of recycled materials into new assets. Currently, the recycling partners do not offer this option. However, this can be done with a mass-balance system and partnerships with processors. Also, a difference is that in the PT design, the option is created to stock both reconditioned and new PTs, which is not happening now.

The other circular strategies have all already been deployed to a greater or lesser extent. In the recycling loop, the process diagrams of both scenarios differ little. A difference in the lifespan expansion loop is the explicit differentiation between repair and refurbishment. Currently, assets are either directly reused or repaired/refurbished by a partner. By dividing these two strategies explicitly, the 2030 design offers an opportunity to create a circular funnel in which less complex strategies can be chosen based on the asset condition.

So, there are some differences between the two scenarios that can be seen in the activities in the process diagram, but many of them are similar. The most significant contribution of the 2030 design is in a more professional and evolved CSC. The current circular activities are already yielding results. However, they are more a result of organic growth than creating a connected and structured system. Examples of the results of this project are the explicit role given to information exchange between CSC partners, key decisions on capabilities and location of reconditioning and the creation of a mass-balance system. These aspects may be challenging to introduce from the start but can be implemented in the coming years by building on the existing operation.

2030 CSC and other Stedin operations

The interfaces between the other operations of Stedin and the CSC activities from the meso design are often very dependent on the choices that will be made in the key decisions. Sorting and testing the assets will be done in the new CDC, which is currently being designed and built in 2025. Space is already considered for these activities, and personnel will be needed to carry out these activities in a structured way. The biggest impact of the operation of Stedin will be if the activities are done at the CDC or a separate location. The current CDC designs do not accommodate further reconditioning activities, which would be a barrier to this location option.

If the activities are outsourced, there will be a clean interface in the handover between testing and the next CSC partner. However, creating in-house capabilities would require integrating that team into the Stedin organisation. The location and outsourcing decisions will also impact the most relevant interface, the distribution of assets. The CDC will do this for new assets, but this may not be true for reconditioned assets. If this is the case, additional processes must be developed to manage this parallel distribution.

The forecast information exchange between CSC partners must be embedded into the SC organisation. This includes the forecasting activities, which would probably be housed in the Supply Chain Center, and the information exchange systems. It could be placed in the current IT systems of Stedin, as these systems are used for other types of information exchange with partners.

There is not much impact on the construction site from the 2030 design. There is little difference between a new and redeployed asset for the on-site teams. Most importantly for them is the proper handling of the assets during decommissioning. It is important that the assets are treated as valuable items and not just as obstacles in the way of placing a new asset. This way, assets are returned in the highest quality, which enhances the circular potential and decreases reconditioning need.

8.2. List of implementation projects

As the current state of functioning for the CSC of Stedin is functioning, implementing the 2030 design is more of a change management process than a greenfield development of a new SC. In change management, two approaches are identified for change: planned and emergent (Bamford & Forrester, 2003). Emergent change accounts for uncertainty and change in the business environment and where change initiatives are formulated along the way. In planned change, the organisation moves from one fixed current state to another through a series of steps or projects (Bamford & Forrester, 2003). In the Stedin case study, there is a clear fixed current state and a future state, and projects can be identified to move between these two states.

8.2.1. Different project types

It is useful to identify the types of projects the business organisation will take to transform, in this case, their circular supply chain. In one approach, the projects are classified based on how they relate to the operation. These project types are business/organisational, ICT systems, engineering/construction, product/service development and research & development (Stretton, 2021). However, this setup does not give more information or handle how to approach the project.

Another method is to classify projects based on their socio-political and structural complexity. The socio-political complexity (SPC) or human complexity concerns the project environment and the possible diverging interests, apprehensions, agendas and expectations of stakeholders. Structural complexity (STC) or technical complexity refers to the volume and variety of project elements and interactions. By assessing this on a three-point scale (low, medium, high) on both axes, five different types of projects emerge (SPC,STC): structured (LL), complicated (LM), complex, complexicated (MM) and chaotic.

In Figure 8.1, the matrix is shown with the two axis's and five project types. Complex projects can be complex on the human side, technical side, or both. Projects with high SPC are classified as chaotic (Ika et al., 2021). There are no chaotic projects in this project as they do not match the high classification for SPC. All projects do not have time pressure, there is time for project planning, the scopes are clear, and objectives can be established.

These five project types indicate the project complexity and can help organisations approach a project. It is outside the scope of this report to explain all the implications of each project type. Ika et al. (2021)

	Socio-political Complexity		
	Low There are few stakeholders, their expectations are clear, well known and aligned; interactions among stakeholders are easily manageable; the project objectives are well defined, understood, accepted by all and should remain quite stable over time; the solution (i.e., the deliverables) is well understood and accepted	***Medium*** There are many stakeholders, their expectations are not all known, clear, or well aligned; the project objectives are defined but not necessarily accepted by all and might change over time; interactions among stakeholders could be numerous and could lead to conflicts; the solution (i.e., the deliverables) might not be understood nor accepted by all the stakeholders	***High*** There are many stakeholders expecting / needing a quick response from the project team, project objectives could be difficult to establish clearly up front, there is limited time for project planning because of the emergency of the situation, the scope of the project could be difficult to assess
Structural Complexity			
Low The deliverables are composed of few parts or sub-systems, and the cause-and-effect relationships between them are known or knowable and can be dealt with effectively by the project team, few and well-known technologies are involved	**Structured**	**Complex (human)**	**Chaotic**
Medium The deliverables are composed of many parts or sub-systems, and the cause-and-effect relationships between them are knowable through expert analysis, there is no obvious best way to produce the deliverables, some of the involved technologies require well-trained experts and sometimes must be developed	**Complicated**	**"Complexicated"**	**Chaotic**
High The deliverables are composed of numerous parts or sub-systems, and the cause-and-effect relationships between them are not all known or knowable beforehand, the solution is not obvious but emerging patterns may guide the way, the involved technologies must be capable of dealing with the numerous and possibly unknown interactions between the components of the deliverables	**Complex (technical)**	**Complex (human and technical)**	**Chaotic**

Figure 8.1: Overview of the project classification matrix by Ika et al. (2021)

gives nine key areas that organisations can consider for each type of project, which are stakeholder expectations, setting objectives, approval of the proposed solution, stakeholders interactions, project planning, PM (project management) management style, PM focus, implementation bias, risk management. When implementing the CSC projects, Stedin and others can get guidance from these areas considering the project type.

8.2.2. Structured projects

In structured projects, both types of complexity are low because of a limited number of manageable stakeholders, clear expectations and objectives, compact and clear deliverables, and well-known technologies. That does not mean these projects will not take time to implement; they are just lower in human or technical complexity.

The first project (**P1**) that is identified and also already worked on is a dashboard to monitor the performance of the CSC. Stedin works with PowerBI for performance dashboarding, and a start is already being made in creating this dashboard by a business analyst. However, this is about some loose KPIs and lacks a clear integrated CSC perspective. It is important to track how many units or kilograms of each asset type have been circularly processed and with which strategy. This way, it can be seen if the other CSC projects yield results and report on the set ESG goals. This dashboard's input can come from partners' reports (like recycling data) or internal Stedin systems for redeployment. This also requires proper data recording as the redeployment data is currently not compiled in a structured way.

Also, a project that has already started is the intake area for return and redeployment items in the new

CDC (**P2**). This is the location where both these flows will arrive from the construction site for the non-PT assets. The most logical would be to have both flows arrive at the same point and let them flow through the same procedure as stated in the design. Knowing how much space this area will require and how assets will move from intake to sorting and testing is important. The CDC logistics project team is responsible for this project.

D4 on the use of remanufactured parts can be a structured project when a decision is taken on the complex projects for the outsourcing and location decisions. Remanufacturing is not something that Stedin currently does, so additional attention has to be paid to implementing this circular strategy. Part of implementing the R7 strategy is a project (**P3**) on where to use the reconditioned parts. Section 7.4.4 explains the decision that needs to be taken. More information has to be gathered on the impact of the decision. After the decision, a plan must be made on which processes will support the choice. The team of the manager logistic services will do this project.

The next project (**P4**) is for key decision D7s on the stockpiling of new PTs, which is described in Section 7.4.7. A separate project (P15) is on the creation of a DC for PTs, and that project is impacted by this one. If a decision is made to stockpile new PTs, the PT DC will require more space and different processes. So, P4 can be seen as part of the analysis phase of P16 and will need more analyses before evaluation. The team of the manager logistic services will do this project.

D8 on the situation when the manufacturer can be taken after the other lifespan expansion decisions as shown in the decision tree in Figure 7.2. In Section 7.4.8, the decision is explained, and a project (**P5**) needs to be started to take this decision after the other decisions are taken. The team of the manager logistic services will do this project.

The project (**P6**) on D6 on the stripping of cables is described in Section 7.4.6. First, the information gap needs to be filled, after which the decision can be made. The recycling partner must be involved in the project, and enough incentives must be presented to the partner. It could be the case that Stedin does not need to offer this incentive, as one of the recycling companies stated that they are already looking into cable stripping. This project will be done by the person responsible for recycling.

8.2.3. Complicated projects

In complicated projects, human complexity is still low, but technical complexity is medium. The medium STC means that there are more complicated deliverables, more expert knowledge is necessary, and there is not necessarily a best way to produce the deliverables.

In the macro-level design, importance was given to the exchange of forecast information with other CSC partners and VM. The first project (**P7**) for this is creating a forecasting tool. In Section 4.2, a first forecast is made for 2030, and this method can be taken as a start. However, the forecast also needs to be done for each year, and preferably each quarter, and more detailed information will be available on the projects in this period. In this project, research has to be done into the best method to forecast the reverse flow for recycling and redeployment of assets. The creation of an exchange tool is a separate project (P9). Part of this project could be that more data has to be accessed within Stedin to make a proper forecast. An example could be that data on the remaining expected lifespan of each asset could be determined. The SCC would best initiate this project.

P8 is concerned with repurposing assets to other DSOs and external partners. More research has to be done by the redeployment team in cooperation with the regulatory team into price setting (which is partly based on regulation) and what handling is within regulatory boundaries. Also, a process has to be developed on how to physically exchange these assets with the buyers. Some exchanges are currently happening, but more formal systems could be developed. One part of this professionalisation is P10 on the data exchange with other DSOs and potential buyers.

8.2.4. Complexicated projects

The complexicated projects have a medium impact on both complexity types with medium technical impact as explained for the complicated projects. Medium human complexity is characterised by more stakeholders with unknown or conflicting expectations and objectives.

The first complexicated project (**P9**) is around data exchange between CSC partners and could be divided into three sub-projects. Data exchange is necessary between VM & Logistics, with CSC partners, DSOs, and other repurposing partners. The data exchange between VM and Logistics is internally within Stedin. It can be based on a regular fixed scheduled meeting or with an Excel information exchange. The data exchange with all types of CSC partners is more complicated. Stedin is starting with the SAP Ariba platform on which information with suppliers will be shared. This could potentially be a system where forecast and demand information with CSC partners can also be exchanged. This must be accompanied by regular contact between the Stedin team responsible for circular processing and the partners. For other DSOs, information exchange could also happen through the Infradock platform or the Ksandr organisation. Initially, the project can be led by the SCC and the team of the manager of logistic services. Later, an IT team should be more involved.

The maximum retrieval of assets is a project (**P10**) that is on the interface between the traditional Stedin operation, building the energy grid, and the CSC. One of the requirements was that all decommissioned assets be retrieved. However, in practice, there is a difference between just decommissioning the asset (i.e., not using the asset anymore for electricity distribution) and actually removing the asset physically out of the grid (for example, getting a cable out of the ground). Within Stedin, the expectation is that a lot of cables are left in the ground, which means valuable materials are left in the ground. Stedin can be a supplier of these materials by urban mining these assets. A project must be initiated to investigate how Stedin can ensure as much material is retrieved from the grid as possible. The forecasting tool (P6) will help in this and allow Stedin to check on which percentage of the expected reverse flow actually came in. This project has to be a collaboration between logistics and operations within Stedin.

The last complexicated project (**P11**) is the creation of sorting and testing policy within Stedin. It has to be made clear what the specifications are for an asset that can enter the lifespan expansion loop and which assets should be recycled. This first classification can be used to instruct project leaders on how to process the assets on the construction site. Then, policy is needed when assets arrive for sorting and testing at the CDC. What is the condition of an asset that determines whether it can be directly reused, needs repair/refurbishment or when only the parts can be remanufactured. A clear funnel needs to be established based on technical asset specifications of AM but also based on an LCA to asses which strategy is the most sustainable choice. AM is an important stakeholder as they will communicate the technical requirements, and the circularity team should bring in knowledge on reconditioning.

8.2.5. Complex projects

Three types of complex projects are identified and the first is human complex projects where the STC is low, and the SPC is medium. These are scores that have already been discussed in other project types. The next type is a technical complex project with high STC. With high structural complexity, the deliverables consist of many parts, the relationships between all parts are not clear beforehand, the solution is not obvious, and possible technologies are needed to deal with the interactions of the components of the deliverable. The last complex project type is with both high technical complexity and medium human complexity.

The most important key decision is on outsourcing the reconditioning activities (D1) as discussed in Section 7.4.1. This is also both a technical and human complex project (**P12**) because decisions have to be taken for all three conditioning strategies, some decisions require significant investments and changes to the organisation, the best way of implementing the decision is not clear and stakeholders can have different interests. The first step in the project is to address the knowledge gaps identified in elaborating the decision, which mainly concerns the impact of the choices. If a decision is taken, with the support of the evaluation framework in Section 7.6.2, it must be executed. Depending on the choice this will require a plan on acquiring own capabilities or searching for partners. This is a project where the manager of logistic services is in the lead. However, multiple other DMs are involved, and a department like HR has to be engaged to attract these capabilities.

The following P12, or it can be seen as a part of it, is to decide on the location of reconditioning activities (D3) as described in Section 7.4.3. This project (**P13**) is heavily influenced by the decisions in P12 and cannot be seen separate from each other. When a CSC partner location is chosen, clear logistics arrangements must be made. More complex choices would be the integration of the activities in the CDC as there is limited space or creating a separate location with associated investments. Again, the manager of logistic services has to be in the lead but multiple DMs will participate. This is a complex human and technical decision due to the wide range of stakeholders and interactions within the deliverable.

Special attention has to be given to the technical complexity of creating the remanufacturing activities (**P14**). As said, this is a circular strategy not previously employed by Stedin so that knowledge will be lacking here. For the other strategies in P12 and P13, there is more experience with reconditioning and what will be needed to execute all the possible choice options. Remanufacturing will require special attention, and likely outside consulting, to assist in filling the knowledge gaps on this theme. This will need to be done by the team of logistic services.

One of the projects (**P15**) coming directly from the design diagrams is on the DC for PTs. This location needs to be created or acquired where reconditioned PTs can be stored before deployment to create more possibilities in reusing entire PTs even when no direct location for reuse is available. This location will need special protection for possible oil leaks from the transformers and the construction will need to handle very large weights. A start has been made in creating such a location by the manager of logistic services, which needs to continue. Also, there is a relation with P11 on possible insourcing as the location purpose will expand from pure storage to a workshop and with P4 on stockpiling new PTs as this will enlarge the required space. This is primarily a technically complex project, but the difference between stakeholders on stockpiling new PTs can humanly complicate the project.

The standard recycling or material recovery process is already running quite well but will be augmented by decisions D2 (mass-balance), D5 (recovery) and D6 (stripping). The first of these projects (**P16**) is on the creation of the mass-balance system as described in Section 7.4.2. This will require collaboration with a strategy on which type of certification will help Stedin within the boundaries of SBTi in reaching sustainability targets and with VM in contact with the suppliers. One of the new sustainability specialists within VM can lead this project and will have a connection with the material passport project they are already running. One of the cable suppliers stated that they are already working on this kind of system, so perhaps it can be easily duplicated by other suppliers. It is at least a technically complex project as expert knowledge is required, and it has yet to be known what the system will look like.

P17 is on the recovery of materials (D5) as described in Section 7.4.5. First, the information gaps in the decision elaboration need to be filled. Suppose the decision is made to stockpile materials that can be better recycled later, most dominantly plastics. In that case, a location will need to be found to stockpile these materials, which the logistics services manager will do. It also means that constant monitoring needs to be done on the progress in recycling techniques for the stockpiled materials. This is a technically complex project if the stockpiling is chosen because of the required location, monitoring of innovation, lack of time, timeline, and monitoring of the stockpiled materials.

Another recycling project (**P18**) is using Stedin materials in new transformers. With cable manufacturers, it was already concluded that direct reuse of materials will not be possible, but this needs to be investigated for the materials in transformers. It could be this case that the different types of steel can be more easily directly used in the production process. If this is the case, the recycling partner will also be involved in delivering the materials to the transformer manufacturer. The reuse of materials needs to be seen as technically feasible in the production process and in light of AM asset specifications. If this cannot be done, a mass-balance system can be used from Project 17. The logistic services team can do this project in cooperation with asset management.

The last key decision (D9) that needs a project (**P19**) is on transportation as explained in Section 7.4.9. The manager of logistic services will do this project and require a decision on the level of transportation insourcing and how sustainable this transport will be. Depending on the decision, the project will continue acquiring new trucks and drivers (or divestment) or looking for transportation partners that can perform according to the sustainability demands.

The last project (**P20**) is on expanding the CSC to other assets, which is complex both humanly and technically. In Section 2.3, it was decided to focus on cables and transformers. However, more asset types can be circularly processed. In Section 6.4, more information is given on how the design can be applied to other assets. This will require further scoping to determine the following focus points and more research into how the design should be adapted.

8.3. Project planning

In the previous section, all 20 projects are explained, and in this section, the planning is given for these projects. This planning uses specific years but should also be seen as a prioritisation. Some projects are quick wins that can also be quickly implemented. Others are planned earlier as they have a large impact on the goals of the CSC or because other projects depend on decisions taken there. The planning is divided into four planning windows and within the window sorted on priority.

Projects for 2024

- P12 Outsourcing: most important project for CSC, fundamental to other choices
- P11 Policy: can run into 2025 but is essential in proper functioning CSC
- P15 PT DC: will always be needed, can facility quick circularity improvement
- P1 CSC dashboard: enables tracking of performance and required for sustainable reporting
- P4 New PTs: necessary to determine scale PT DC
- P2 Asset intake CDC: CDC is being designed in 2024

Projects for 2025

- P16 Mass-balance: biggest improvement in recycling, partner ready in end 2024
- P13 Location: taken into account in P13, this project can be executed
- P14 Remanufacturing: has to be set up after P13, missing part in current state
- P7 Forecasting: start can be made in 24, but first clarity on CSC partners needed
- P9 Forecast exchange: can be done simultaneously to the forecasting tool
- P17 Recovery: complex to execute, less important, but earlier improves return
- P18 Recycling in PTs: important to know P17, takes time to investigate
- P6 Stripping: no priority now but a quick win to be taken later
- P8 Repurposing: not urgent and will benefit from forecasting tool

Projects in years 2026 & 2027

- P10 Retrieval: important to first know the final CSC structure, then improve retrieval
- P3 Remanufactured parts: not the biggest circularity improvement, dependency on other projects
- P19 Transport: less important to CSC but will require time
- P5 Distance: same as for P3

Projects in period 2028 - 2030

- P20 Other assets: can be taken into account earlier, but focus should be on setting up CSC first

8.4. Implementation plan validation

In conversations with the experts and stakeholders of the implementation plan, mainly the employees currently working on redeployment and recycling, it is seen as a valuable tool to take concrete action on the design. There are some questions about the feasibility of the implementation plan. There is a heavy focus on 2024 and 2025 to build the basis of the CSC and then expand the material flow (P10 Retrieval) and included assets (P20 Other assets). This means a heavy workload in the first two years of the implementation plan, for which Stedin currently has no personnel.

This could also be included in the evaluation of the choices for the key design alternatives or the execution. Insourcing reconditioning activities at a Stedin location could take years to complete, which would significantly change the planning. Perhaps a hybrid option would be viable, where the activities are outsourced in the short term to be insourced at a later moment when more resources are available. This option could be included in the evaluation of the key decision.

9 Conclusion & Discussion

This chapter will give a conclusion to the project both on the design approach or methods and on the design results. The chapter's second part discusses the limitations of the research, and recommendations for further research are given.

9.1. Conclusion

This project is focused on design, and therefore, the main goal is to fulfil the design objective of the project that is reintegrated below. As this project had both a scientific contribution to the design methodology and practical CSC design results, the conclusion is split into these two themes.

Designing the 2030 semi-closed-loop circular supply chain for the redeployment and recycling of cables and transformers from the electricity grid of Stedin from a high-level process orientation.

9.1.1. Methods

From the literature review on SC design methods, a combination was chosen of the SCOP method by Corominas et al. (2015), the CSC guiding framework by Amir et al. (2023) and the evolved double diamond (EDD) method by Design Council (n.d.-a). The EDD method helps structure the design process into a research and design part. The research diamond starts with the background study on Stedin and CSCs and also features the current state analysis of the Stedin CSC. The initial idea was to perform the current state analysis after the design phase to avoid the present situation guiding the ideation of the 2030 vision. In practice, the analysis coincided with the background study which could have steered the design development.

Next, to determine the project's material scope, a workshop method was chosen to include qualitative and quantitative data and to create engagement for the project among internal stakeholders. This workshop successfully refined the design objective to help keep focus on the design development. However, improper information provision to one of the participants reduced the smoothness and usefulness of the workshop. The reverse flow estimation was done simultaneously and provided information for the workshop and a sense of scale for the CSC. The estimation method was based on expert consultation and used a data analysis method with data from investment plans and historical data on asset weight and asset removal activities, but it holds many uncertainties, especially around the removal percentages.

The first step in the SCOP is to define the design project, which is also the endpoint of the research diamond, and generate the design requirements. The initial list of requirements was generated by an individual brainstorm and refined and approved in two validation workshops with stakeholders. This provides the starting point for the next two stages in the SCOP method, the macro and meso design. However, starting this process with individual brainstorming also anchored the workshop participants and probably reduced the possibility of introducing new requirements by the stakeholders.

The meso design is a deepening of the initial macro design and is both based on the 9R ladder of circular strategies by Potting et al. (2017). The SCOP method provided a top-down approach in the design process, which was augmented in the meso-level design by the CSC guiding framework to give direction to the design. The fusion of these two methods with the EDD diagram was quite easily done as the CSC framework became part of a step in the SCOP method, and the SCOP steps could be split in the phases of the two diamond. The combination of the EDD, SCOP and CSC guiding framework does give some structure and inspiration to the design process, but lacks clear direction in both the design itself and the design process. Despite these drawbacks, the combination of these methods could be useful in other projects that want to design a CSC, especially in combination with the 9R ladder.

Instead of developing multiple design alternatives, the focus was shifted to key remaining design decisions and evaluating those. The elaboration and evaluation frameworks for decision-making are based on expert input and literature research, and in a validation workshop, it was concluded that they works. The shift in project activities helped make the project results more relevant to Stedin. The frameworks can help Stedin in the decision-making process but may be too elaborate to be practically useful.

The meso design and design decisions were transformed into a list and planning of implementation projects, which was again expert-validated to ensure usefulness for Stedin. This helped Stedin better understand the developed design and make the results more actionable. The EDD did offer some benefits compared to the DD as iterations are more central to the process as well as the inclusion of stakeholders to create buy in.

9.1.2. Design

In the current state analysis, it was found that there currently is a basic functioning structure for the CSC that has organically grown over the years. In particular, the recycling activities are very mature, and there are also already results in the redeployment of transformers. Although a starting CSC, even though it is not yet perceived as a CSC, is already present, this was not directly taken into account in the design of the 2030 vision of the CSC. This was to ensure ample opportunity to develop a new innovative CSC.

The developed design backbone, nevertheless, is quite similar to the current state. This is because every CSC will be built on the circularity strategies of the 9R ladder (Potting et al., 2017). The 2030 vision is, therefore, more a deepening or professionalisation of the current CSC. One of the important differences is the new focus on forecast information sharing between CSC partners. This aspect is stressed in literature and is necessary to coordinate asset flows, optimize reconditioning plannings and align reconditioned asset demand. Other important differences in the process activities are the added remanufacturing strategy (R6) and the possibility of reusing recycled materials in new assets.

Further improvement of the CSC lies in the nine remaining key design decisions. These decisions are important in the execution of certain process activity steps or other characteristics of the design. Most important is the decision on whether to in- or outsource reconditioning activities. In-sourcing would mean significant investments in facilities and people to be able to perform one or more of the lifespan expansion strategies. Related to this decision are the key decisions on reconditioning location choice, asset part use and transport distance.

For the recycle loop, the most important project is the introduction of a mass-balance certification system. This system will enable the reuse of recycled materials in the Stedin SC and increase the on-paper percentage of recycled content in new assets. The project on stockpiling materials that are currently burned could increase the amount of recycled material, and the project on stripping cables will increase the quality of the recycled material. It is also important that project teams on the construction site retrieve all the decommissioned assets to make sure all the old assets are circularly processed.

The implementation plan shows all 20 identified projects from the backbone design and key decisions Stedin should undertake until 2030. Each project is placed in a planning window and prioritized within that window based on relevance to the CSC. The IP will help Stedin convert the earlier results into actionable tasks, while the elaboration and evaluation frameworks provide additional support in project decision-making. This is also confirmed by stakeholders of the project to which the plan is presented.

When implemented, the projects will improve the existing organically grown circular activities and form a consistent CSC that contributes to Stedin's sustainability targets. As calculated in Section 4.2, the CSC has the potential to process a reverse flow of *Redacted* million kilograms of cables and *Redacted* million kilograms of transformers which is around *Redacted* percent of the material demand for these assets. This means that implementing the CSC makes the circularity target achievable and would significantly contribute to the CO_2-eq target while improving material availability which are the main goals of this project.

9.2. Discussion

The final part of this report is the discussion of the methods and results. This section is split into three parts: the generalisation of the findings for other projects, the limitations of the methods used in the project and finally, the recommendations for further research.

9.2.1. Generalisation and reproducibility of findings

Although all the methods are extensively documented in this report, it is not certain that the results will be generalisable and reproducible in other projects or by other researchers with the same case study. The results of the macro and meso designs for the CSC in 2030 should be generalisable to other case studies and other time periods. The goal was to design a vision for the CSC in 2030, but the design would also hold for, for example, 2025. Due to the workload, it is questionable whether the CSC can be realised by this time. Other studies, whether at another DSO or different SC, would come roughly at the same design because of the use of the 9R circular strategies by Potting et al. (2017) and the importance of information exchange stressed in multiple sources.

Deviations from the findings in other cases would mostly be the key design decisions, although some of these, like outsourcing, mass balance or location, would also be needed in other case studies. The choice options for these projects could differ; for example, a mass-balance system could already be implemented in a certain sector. Of course, other case studies could lead to a different set of system requirements, which would also lead to different design choices or the assets that will be processed offer different opportunities or limitations in applicable strategies. For example, consumer products will require a more decentralised collection system at the end-of-use moment than Stedin's assets. Stedin is also very locally oriented, so projects with a European or global SC may need more storage and shipment steps.

In terms of reproducibility, the difficulty lies in the large volume of personal communication used as sources in this project. Eighteen experts are referenced throughout the report; other researchers could have reached out to these experts for information, validation, or input at the time described. However, there is no assurance that those conversations would yield the same outcomes. However, deviations resulting from this would not have resulted in a major change to the design because of the reasons mentioned earlier in this section. The exact results of, for example, the requirement generation are likely to be slightly different, however. The elaboration and evaluation frameworks have also been developed and validated by experts, but the logic of the elements of the frameworks is well documented. It would not significantly alter as it reflects the informational and tooling needs of the consulted experts.

9.2.2. Limitations

In addition to the last section, there are more limitations on the use of expert conversations. One of the limitations is that all these expert conversations have not been recorded or transcribed. A formal interview structure would have added a heavy burden in preparation and limited flexibility to plan and conduct sessions. Also, without a formal structure, the conversations could have been more extensively documented than only the results or opinions shown in the report, which offers more transparency. It is dubious, however, if this benefit would have been worth the large amount of required processing. Also, almost all the experts are from Stedin which poses the risk of group thinking and narrows the possible knowledge base.

Other limitations in the use of experts came in the material scoping workshop. Two participants had more insight into the project, the circularity theme and the workshop's intention. The third participant was a late substitute and should have been much better briefed in hindsight. The preparatory documentation was insufficient for him to get up to speed, which delayed the workshop and deteriorated the results. In general, both the participants and the researcher lacked knowledge of the asset types. Some data on volumes or CO_2-eq impact, like for high voltage assets, was missing, and some assets were not properly enough understood to analyse them.

In the requirements generation, another limitation on expert consultation surfaced. The author generated the initial version of the requirement list, and in two validation workshops, experts and stakeholders had the possibility to give feedback on the list. There were some additions and changes to the list, but overall, it stayed quite the same, and a few new requirements were added. It could be that the initial list anchored them and a method were the stakeholders generated the initial list in a workshop would have yielded additional requirements that were not included now.

There is a big limitation in the method of estimating the reverse flow. The calculation is mainly based on the expectations from the investment plan for 2030 and the DVO codes. This data has been carefully scrutinised but is more unreliable than one would want. The DVO codes showed many variations across different cross-sections, and there is doubt that they are always appropriately recorded. Nevertheless, the investment plans have the right order of magnitude for the assets so that the order will be correct. This still means that with uncertainty in the DVO codes and investment plans, a factor of two or three difference would not surprise for some assets.

An important scientific contribution of this project lies in the use of a combination of the EDD (Design Council, n.d.-a), SCOP (Corominas et al., 2015) and CSC guiding framework (Amir et al., 2023). The combination of the SCOP and EDD was supposed to give structure to the design process, which it did. However, even with both methods combined, it was still unclear which design steps one would take to come to a design, such as the requirement generation. The advantage of the two methods is that they can be applied to many cases and offer structure, but they lack direction. The thinking in macro and meso structures of the SCOP was useful in gradually deepening the design, but one could also have done this without the SCOP method and calling it differently. This was, of course, known beforehand but proved to hold true also in this case study.

The CSC guiding framework does offer direction in the building blocks of a CSC one should focus on. However, it would have been more useful if the microstructure design had also been in the scope, as the examples for the level of decision-making were often quite specific. On the other hand, the mechanisms and CSC example give some inspiration, but the 9R ladder of Potting et al. (2017) is more useful for this. The three methods together have helped structure and inspire the CSC design but still leave gaps in the process and CSC structure that a designer must tackle himself.

Another part of the EDD framework is the engagement and leadership aspects, which are not present in the traditional double-diamond framework. Although they have been kept in mind in the project, they may be more useful in longer projects, projects that include implementation, or with bigger project teams. The expert consultation also functioned as stakeholder engagement, but this was not formalised, and no additional engagement methods were used. When implementing a design, the operational employees also have to be engaged and informed of the usefulness of this overhaul, which has not been taken into account now.

9.2.3. Recommendations

Practical recommendations

The first practical recommendation is executing the implementation plan from Chapter 8. This planning and prioritisation of twenty projects will be a big challenge to complete on time. When the projects are incorporated into a broader Stedin project planning, it has to be assessed whether the given timeline is feasible and how it should be adjusted considering available resources.

The second suggestion for further research is to investigate gas assets. In this project, for a start, only the electric assets were included to narrow the initial scope because the impact and possibilities for circularity were deemed lower. However, these assets should also be circularly processed, and it could be that different focus points arise in a design for a CSC of gas components. Also, the inclusion of the other electricity assets, which are separate projects in the implementation plan, requires further attention as these assets have slightly different dynamics.

Another practical recommendation is to investigate the cost aspect of the design and projects. Stedin focuses on maximal contribution to the strategy, and financing plays a subordinate role. However, costs will still be important in making decisions on specific design aspects, and these costs are excluded from this research. Therefore, during the project's implementation, business cases will have to be made to understand the project's costs and benefits.

Scientific recommendations

As stated in the previous section, there is currently a lot of uncertainty in the reverse flow estimation method used. This method has been carefully thought out but is unsuitable for forecast information exchange with CSC partners and VM. These organisations cannot build on information that can easily be 50% off. Therefore, an improvement method has to be developed to forecast the reverse flow of this type, with very long use times, of assets. This can mean that different data types must be created or accessed. For example, the GIS system of Stedin has most of the assets in the grid registered, so one could combine this with expected lifetime data and grid fortification plans to make a more accurate forecast. For short forecast windows, the method could be based on the exact projects that will be executed if project leaders signal the need for asset retrieval early on.

Following this research project, one could analyse the performance of the design on the design objectives. In the report, the constraint and objective compliance are discussed. However, a proper analysis of what implementing this CSC would mean for CO_2-eq emissions or circularity goals has not been performed due to time constraints. It would be interesting to know before implementation how the design, or maybe the choices in the key design decisions, would influence the final performance. Also, on the theme or requirements, one could split them into method requirements and design requirements. The method requirements should make it easier to determine compliance, and the design requirements would need more simulation or analysis to determine performance.

The use of the MCDA tool for the design components instead of design alternatives seems quite novel in the small additional literature review that has been done on the topic. Although the principle of a MCDA should apply to all decision situations, more research can be done on the use of the method in design component selection. In the situation with design alternatives, the various options are independent of each other. However, in component selection, there can be large dependencies between the choices of the different components. This could influence how the MCDA is best used, and more research would be beneficial to this topic.

The microstructure design has been omitted from this project's scope on purpose. The IP projects contribute to creating this micro design, but additional research has to be done to come to a final detailed micro design. It would be interesting to see if the applied methods provide more or less help in the design process or if entirely new methods, like maybe optimisation methods, will be needed.

On the methodology side, more research is needed into new CSC design methods. As said in the previous section, the combination of the EDD, SCOP and CSC guiding framework has contributed to structuring and inspiring the CSC design. However, there is no widely cited method that experts find to be effective. Ideally, this method would keep the three methods' positive aspects but give more details on which design steps are needed for CSC design and how you structure your CSC design. The circular strategies of Potting et al. (2017) have to be part of this, but integration attention points for specific types of assets can also be part of this, like the difference between assets like the transformers of Stedin that can be centrally handled or consumer items that require central collection and processing.

The last recommendation is around inspiration for the CSC design. This inspiration was obtained from academic and practical literature and experiences of another DSO. However, the first two sources are very generic, and the latter one is in the same sector. Designers should also look more closely at case studies in other sectors that are more advanced in their circular practices or approach the CSC quite differently. By having a dialogue with these designers, a design team can understand why one would make certain choices and discover design options that had not been taken into account before.

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A

Results scoping workshop

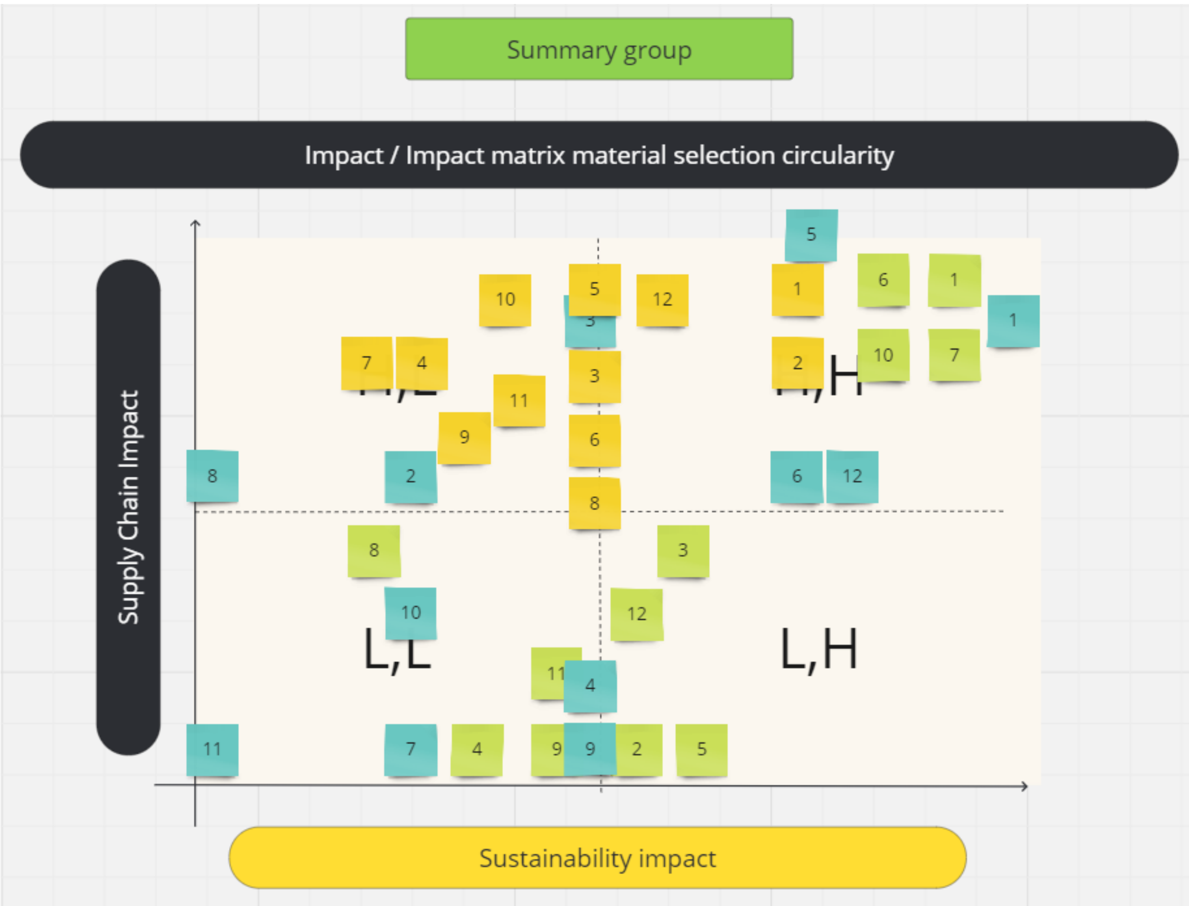

Figure A.1: Combination of individual results from scoping workshop

B

Mind-map brainstorm requirements

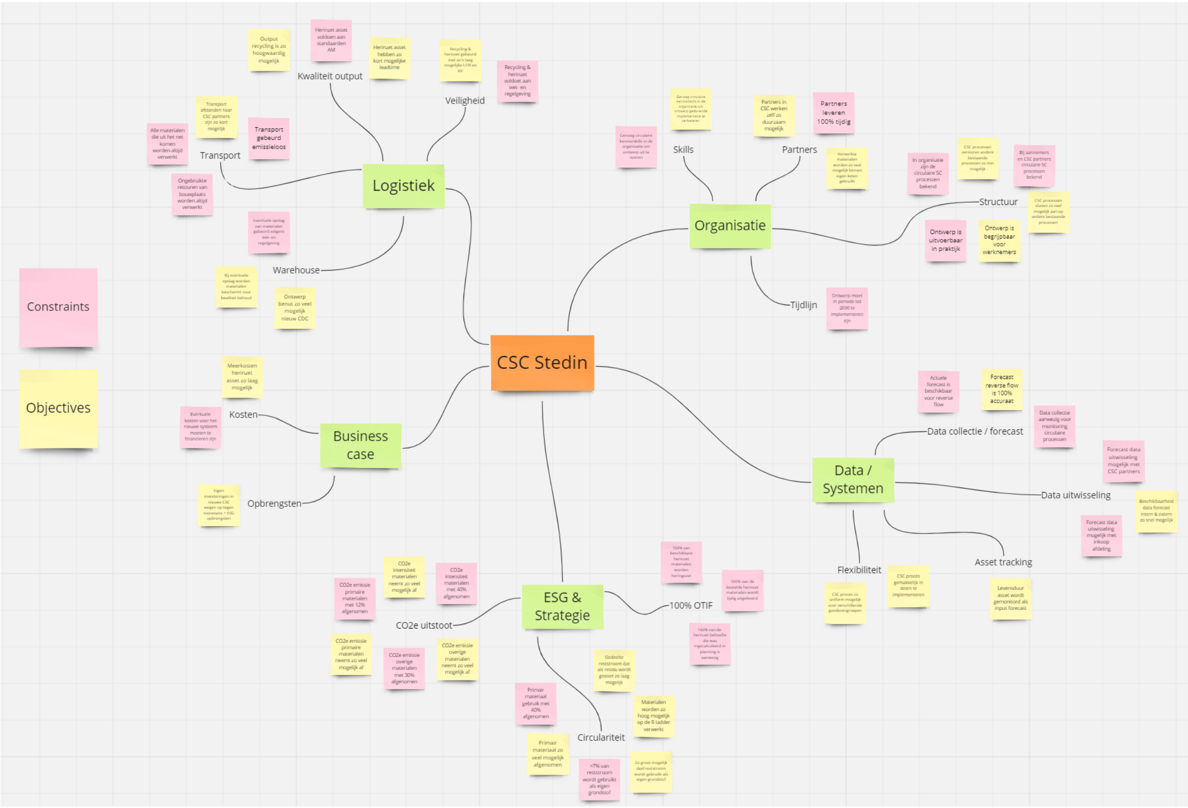

Figure B.1: Individual brainstorm on requirements

C

Initial version requirements

C.1. Constraints

Logistic constraints

Functional

1. All materials decommissioned from the grid are always processed.
2. Unused asset returns from the construction site are always processed.

Non-functional

4. Processes for recycling and reuse of materials comply with relevant laws and regulations.
5. Assets that are redeployed meet the quality requirements from Asset Management.
6. Transport within the SC is always zero emissions.

Organisational constraints

Functional

7. Redeployment partners always deliver materials 100% on time.

Non-functional

8. Sufficient circular knowledge/skills are available in the organization to implement the design.
9. Within Stedin, the new processes for the CSC are known.
10. The circular SC processes are known to contractors and CSC partners.
11. The design is technically feasible.
12. The design should be implementable in the period up to 2030.

Data / systems constraints

Functional

13. An up-to-date forecast of the reverse flow is continuously made.
14. Data is collected for the monitoring of the circular processes.
15. The performance of the CSC is monitored.
16. Forecast data is exchanged with CSC partners.
17. Forecast data is exchanged with the Stedin procurement department.

ESG & Strategy constraints

Non-functional

18. CO_2e intensity of materials should decrease by 40
19. CO_2e emissions from primary materials should decrease by 12

20. CO2e emissions from other materials must decrease by 30
21. Primary material use must decrease by 40
22. More than 7% of the residual stream is used as its raw material.
23. 100% of available reused materials are reused.
24. 100% of ordered reuse materials are delivered on time.
25. 100% of the redeployment requirement that was factored in is in place.

Business case constraints
Non-functional

26. Any costs for the new system should be able to be financed.
27. There should be sufficient incentives for CSC partners to participate in the CSC.

C.2. Objectives

Logistic objectives
Functional

1. In the case storage is required, materials are protected for quality preservation.

Non-functional

2. Recycling and reuse processes are done with the lowest possible LTIR and RIF.
3. Reused assets have the shortest possible lead time.
4. The output of a recycling process is as high quality as possible.
5. Transport distances between CSC partners are as low as possible.
6. The design utilizes the new CDC as much as possible.

Organisational objectives
Non-functional

7. Sufficient circular knowledge/skills are available in the organization to adjust the design even during implementation.
8. Partners in the CSC are working as sustainably as possible.
9. Recycled materials are used as much as possible within the Stedin chain.
10. CSC processes disrupt other processes within Stedin as little as possible.
11. CSC processes connect to the other existing processes as much as possible.
12. The design is understandable for employees.

Data / systems objectives
Non-functional

13. The reverse flow forecast is 100% accurate.
14. Forecast data for internal and external stakeholders is available as soon as possible.
15. Remaining asset life is monitored as input to forecast.
16. The CSC process is as uniform as possible for the different asset groups.
17. The CSC process is easy to implement in parts.

ESG & Strategy objectives
Non-functional

18. CO2e intensity of materials decreases as much as possible.
19. CO2e emissions from primary materials decrease as much as possible.
20. CO2e emissions from other materials decrease as much as possible.
21. Primary material use decreases as much as possible.

22. As much of the residual stream as possible is used as raw material for new Stedin assets.
23. Assets are processed as high as possible on the R ladder.
24. The portion of the residual stream disposed of as residue is as low as possible.

Business case objectives
Non-functional

25. The additional cost of a redeployed asset compared to a new one is as low as possible.
26. The monetary and ESG returns outweigh the required Stedin investment in the new CSCs.

D

Second version requirements

D.1. Supply Chain

Constraints

Functional

1. All assets decommissioned from the grid are retrieved for processing
2. Unused asset returns from the construction site are collected for processing.
3. All assets coming from the construction site are assessed for circular processing.
4. All assets coming from the construction site are processed circularly.
5. Handling of assets is always done safely.
6. Assets are always handled with care to maintain quality.

Non-functional

7. The processes for recycling and reuse of materials comply with relevant laws and regulations.
8. Assets that are redeployed meet the quality requirements from Asset Management.
9. 100% of materials prepared for redeployment are redeployed.
10. 100% of materials ordered for redeployment are delivered on time.
11. 100% of the redeployment needs that had been calculated are present.

Objectives

Functional

1. In the case storage is required, materials are protected for quality preservation.

Non-functional

2. Recycling and reuse processes are done with the lowest possible LTIR and RIF.
3. Reuse assets have the shortest possible lead time.
4. The output of a recycling process is as high quality as possible.
5. Transport distances between CSC partners are as low as possible.

D.2. Organisational

Constraints

Functional

1. Partners in the CSC always return materials 100% on time.
2. No more assets are prepared for redeployment than the business demands.

Non-functional

3. Sufficient circular knowledge/skills are available in the organization to implement the design.
4. Within Stedin, the new processes for the CSC are known.
5. The circular SC processes are known to contractors and CSC partners.
6. The design is technically feasible.
7. The design should be implementable in the period up to 2030.

Objectives
Functional

1. Partners in the CSC are working as sustainably as possible.

Non-functional

2. Sufficient circular knowledge/skills are available in the organization to adjust the design even during implementation.
3. Recycled materials are used within the Stedin value chain as much as possible.
4. The design is understandable for employees.

D.3. Data / systems

Constraints
Functional

1. An up-to-date forecast of the reverse flow is continuously made.
2. Data is collected for the monitoring of the circular processes.
3. The performance of the CSC is monitored on pre-set KPIs.
4. Forecast data is exchanged with CSC partners.
5. Forecast data is exchanged with the Stedin procurement department.

Non-functional

6. The minimum forecast data are per the asset type, the expected volume in numbers, and weight

Objectives
Non-functional

1. The reverse flow forecast is 100% accurate.
2. Forecast data for internal and external stakeholders is available as soon as possible.
3. The CSC process is as uniform as possible for the different asset groups.
4. The CSC process is easy to implement in parts.

D.4. ESG

Constraints
Functional

1. Transport within the SC is always zero emissions.

Non-functional

2. CO2e intensity of materials should decrease by 40
3. CO2e emissions from primary materials should decrease by 12
4. CO2e emissions from other materials must decrease by 30
5. Primary material use must decrease by 40
6. More than 7% of the residual stream is used as its raw material.

Objectives
Non-functional

1. CO2e intensity of materials decreases as much as possible.
2. CO2e emissions from primary materials decrease as much as possible.
3. CO2e emissions from other materials decrease as much as possible.
4. Primary material use decreases as much as possible.
5. As much of the residual stream as possible is used as raw material for new Stedin assets.
6. Assets are processed as high as possible on the R ladder.
7. The portion of the residual stream disposed of as residue is as low as possible.

D.5. Business case

Constraints
Non-functional

1. Any costs for the new system should be able to be financed.
2. There should be sufficient incentives for CSC partners to participate in the CSC.

Objectives
Non-functional

1. The additional cost of a redeployed asset compared to a new one is as low as possible.
2. The monetary and ESG returns outweigh the required Stedin investment in the new CSCs.