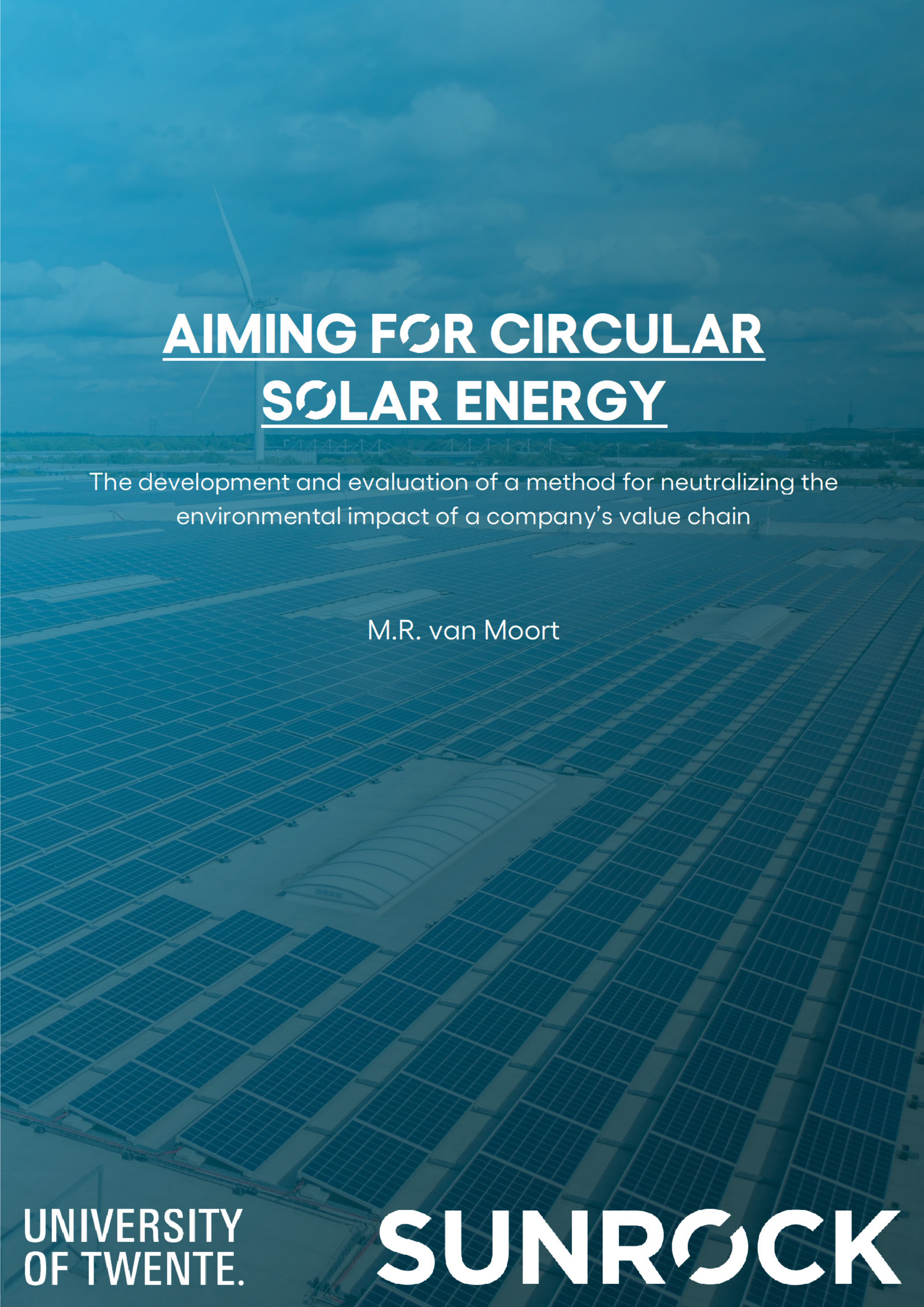

AIMING FOR CIRCULAR SOLAR ENERGY

The development and evaluation of a method for neutralizing the environmental impact of a company's value chain

M.R. van Moort

UNIVERSITY
OF TWENTE.

SUNROCK

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Abstract

Today, most enterprises manufacture their goods according to the linear model, in which resources are extracted, used, and often disposed to never be used again. At the same time, 45% of humanity's total current greenhouse gas (GHG) emissions come from the making of products. A circular model should be adopted to drastically reduce the resource depletion and climate change that go paired with the production and disposal of goods. It is however difficult for companies to transition to this model that limits the generation of GHG emissions and waste.

This study attempts to find out how life cycle assessment (LCA) theory can be used to develop a method that helps companies to eliminate GHG emissions and waste from their value chain in their transition towards circularity. The developed value chain assessment (VCA) method incorporates the guidelines of the GHG Protocol and the ISO. The VCA method consists of six steps (see Figure 0). The first step maps and develops an inventory of the GHG emissions and waste that are generated in a company's value chain; the second step analyzes the results of this value chain inventory (VCI); the third step sets targets for eliminating generated emissions and waste; the fourth step generates a roadmap of actions that should be executed to achieve the set targets; the fifth step presents a report of the results of steps one to four; and the sixth step iterates the steps of the VCA method to update the results and track progress regarding the targets. The VCA method also incorporates the reporting requirements from the ISO and the GHG Protocol to enable direct reporting of the results to organizations such as the Science Based Targets initiative (SBTi).

The VCA method was applied and evaluated through a case study for a company called Sunrock, the market leader in large-scale solar installations in the Netherlands. Though Sunrock's solar installations have a positive effect on the environment, the company wishes to improve its impact. It wants to do this by gaining insight in its direct emissions from the company itself, but also in its indirect emissions from the partner companies Sunrock puts to work. Applying the developed VCA method helped to improve it and prove that it works. The main implication of the developed method is that its results are highly dependent on the quality of the gathered data and the competency and effort of the researcher to analyze it. Though the VCA method already presents a simplified and structured way of estimating and reducing a value chain's emissions and waste, the method could improve through more detailed evaluation and application in more case studies.

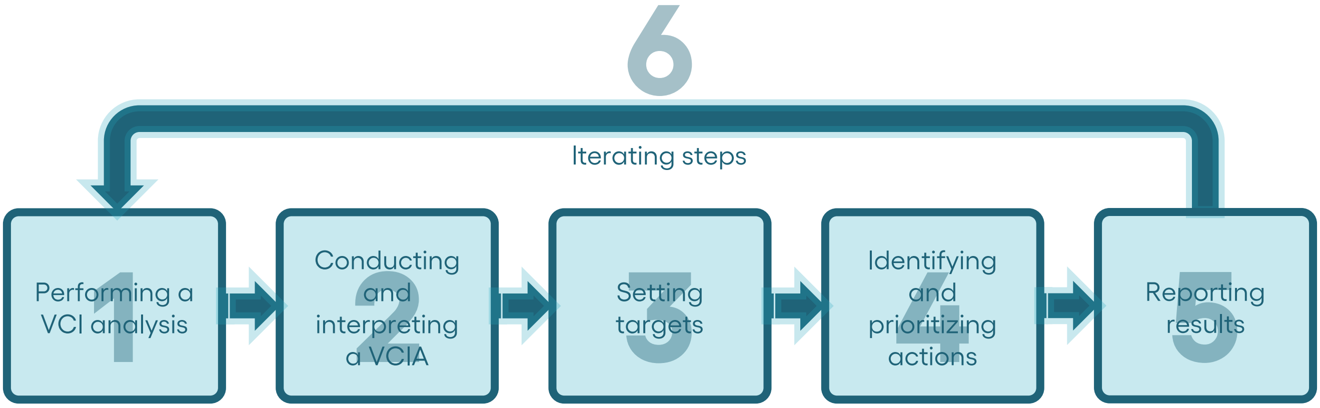

Figure 0 Schematic of the six steps of the developed VCA method.

Preface

There is no way around it: As you read the news, eat some meat, buy a car, heat your home, or throw out the garbage. All the ways in which humanity has a negative impact on the environment become more and more apparent. Our greenhouse gas emission and resource depletion increases, even if our population size stays the same. All of this points to the fact that humans are not in equilibrium with their habitat like mammals normally are. The only way we can keep up this pace of consumerism is to dig deeper and increase our negative impact on the environment. The roots of our environmental problems lie in the old and standardized ways that humanity developed over time to create society as we know it today. The current task at hand is to make people aware of their impact and develop new standards through which we can break free from our virus-like characteristics and establish our equilibrium with nature.

My belief is that our transition towards this equilibrium happens faster if the developed solutions also improve the financial and personal situations of companies and individuals respectively. In other words, solutions must be simple and beneficial for them to thrive. I want to devote myself to finding solutions that are inevitably adopted through rationality. This is why during my bachelor's degree I wrote my thesis on biological solar cells, and at the end of my master's degree I found a company that creates value for organizations through installing solar farms on their roofs or in their gardens. The struggle this company faces provided me with the opportunity to graduate by developing a method that enables companies to transition towards a sustainable business model. This master thesis is therefore directed at all entrepreneurs and companies that wish to achieve their business goals sustainably.

I would like to thank the inspiring people from Sunrock for the opportunity and guidance they provided during this insightful period in which I developed myself both personally and professionally. I also want to express my gratitude towards S. Jokic and M.E. Toxopeus of the University of Twente for their supervision throughout this project.

M.R. van Moort, Amsterdam, 9 June 2022

Lists

Lists were compiled for all figures, tables, and abbreviations that are used in this report.

Tables

Figures

Abbreviations

Abbreviation	Description
AEC	**A**bsolute **E**missions **C**ontraction
A&R	**A**ccounting **&** **R**eporting
C2C	**C**radle-to-**C**radle
CO_2	Carbon dioxide
CO_2e	**CO_2** **e**quivalent
CFC	Chlorofluorocarbon
CH_4	Methane
CP	**C**ontribution **P**ercentage
DECOM	**DECOM**missioning
EIC	**E**conomic **I**ntensity **C**ontraction
EPBT	**E**nergy **P**ay**B**ack **T**ime
EPC	**E**ngineering, **P**rocurement & **C**onstruction
FU	**F**unctional **U**nit
GWP	**G**lobal **W**arming **P**otential
GHG	**G**reen**H**ouse **G**as
H_2O	Water
HFC	Hydrofluorocarbon
IEA	**I**nternational **E**nergy **A**gency
IPCC	**I**ntergovernmental **P**anel for **C**limate **C**hange
ISO	**I**nternational **O**rganization for **S**tandardization
LCA	**L**ife **C**ycle **A**ssessment
LCI	**L**ife **C**ycle **I**nventory
LCIA	**L**ife **C**ycle **I**mpact **A**ssessment
N_2O	Nitrous oxide
O_3	Ozone
O&M	**O**perations **&** **M**aintenance
O-LCA	**O**rganizational **L**ife **C**ycle **A**ssessment
PFC	Perfluorocarbon
PV	**P**hoto**V**oltaic
RC	**R**eporting **C**ompany
SBT	**S**cience **B**ased **T**arget
SBTi	**S**cience **B**ased **T**argets **i**nitiative
SDA	**S**ectoral **D**ecarbonation **A**pproach
SDG	**S**ustainable **D**evelopment **G**oal
SF_6	Hexafluoride
T&D	**T**ransmission **&** **D**istribution
UN	**U**nited **N**ations
VCA	**V**alue **C**hain **A**ssessment
VCIA	**V**alue **C**hain **I**mpact **A**ssessment
VCI	**V**alue **C**hain **I**nventory

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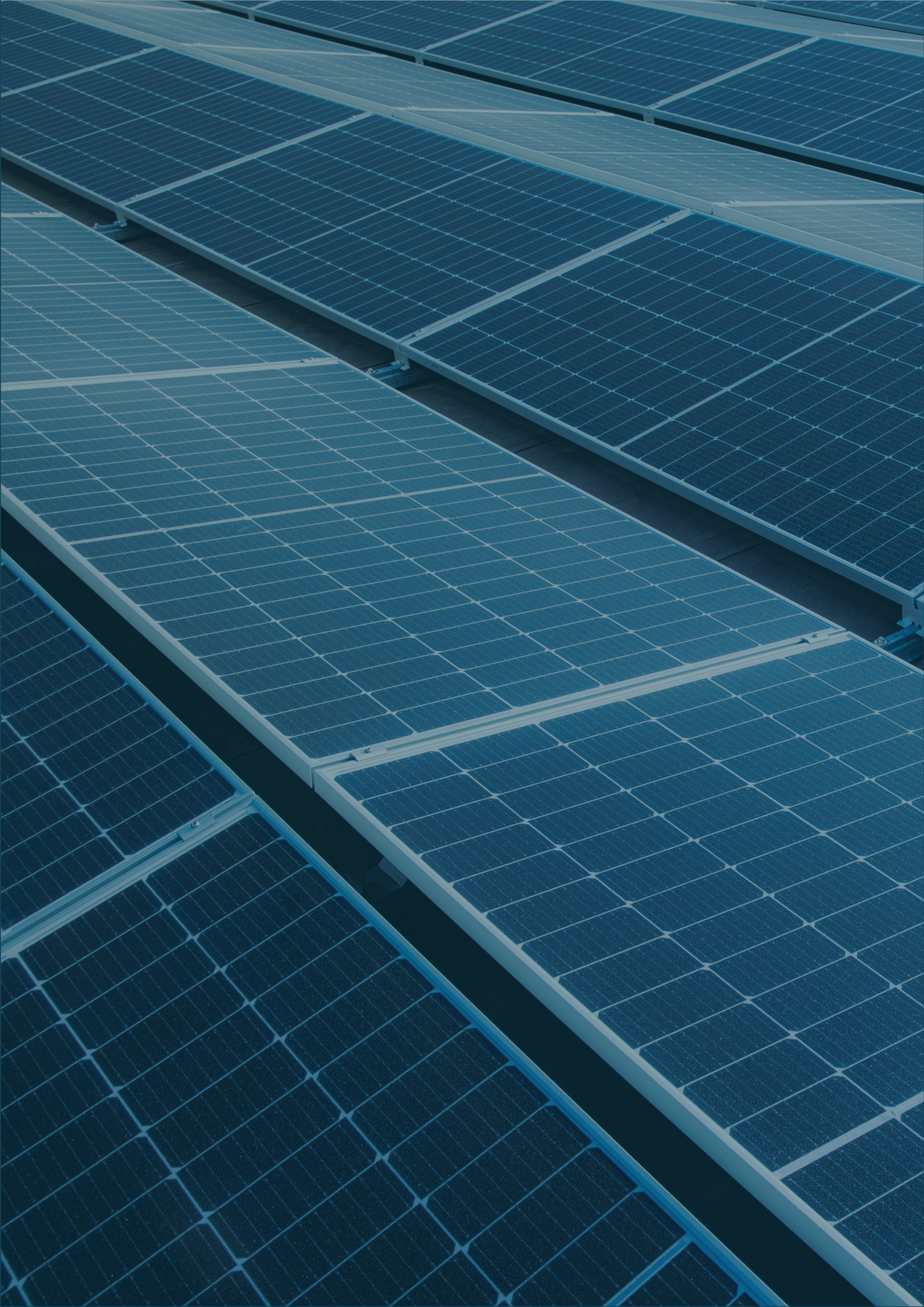

Part 1

Introduction

The introduction will first focus on describing Sunrock, which is the company at which the project was executed. A short company introduction explains what the company does. This is followed by a more elaborate description of what their current and desired situation looks like. The next chapter discusses the project by first going over the project's problem definition. This helps to understand the scope of the project and eventually develop possible solutions. The objectives and research question that follow from the problem definition are mentioned next. The chapter ends by describing the outline of the report.

1.1. Sunrock

A project was executed in collaboration with Sunrock, a developer and owner of large-scale solar installations. Sunrock started in 2012 and is now the biggest developer of solar parks in the Netherlands (Sunrock, 2021). In 2020, Sunrock was acquired by COFRA Holding because of the company's spirit to fight climate change and because of the potential the company has. From their headquarters in Amsterdam, Sunrock realizes projects on roofs and fields of land and water. They want to have a positive impact on the world by providing smart energy solutions that make use of photovoltaics (PVs). Their vision is to enable the transition towards clean energy by supporting clients in their journey towards zero emissions. Recently the company expanded to Germany, where they also ensure that the energy strategy of their clients becomes a success. This report will however only focus on Sunrock's Dutch branch as this branch is fully developed and operational for multiple years.

Sunrock distinguishes itself from its competitors by offering greener solutions, lower prices, and flexibility. The company tries not to only trade in solar panels because the goal is to think with clients about custom innovative solutions that help them in the best way possible. Sunrock approaches companies that possess large empty surface areas. These areas are often roofs, but they can also be fields or lakes. Sunrock then offers to rent these surface areas for the generation of solar energy. When a company agrees to this proposal, Sunrock pays a monthly fee and develops the solar park, arranges the finances, facilitates the construction, and manages the maintenance. The new client now earns some extra money with space it previously did not have any use for, while Sunrock tries to earn back its investment by selling the generated solar energy to energy suppliers. The client can also choose to use the generated energy, which can result in lower total energy costs for the client.

Figure 1.1 One of Sunrock's solar roofs in Tilburg, The Netherlands.

1.1.1. Current situation

As mentioned, Sunrock wants to have a positive impact by helping their clients in their transition to renewable energy sources. To have as much positive impact as possible, Sunrock tries to be as sustainable as possible by limiting its direct greenhouse gas (GHG) emissions and waste generation in its business operations. Direct emissions are generated through fuel combustion for the company's facilities and vehicles. All the non-renewable energy that is bought by Sunrock for its own use also contributes to these direct emissions. Sunrock has signed up to the Science Based Targets initiative (SBTi) to limit the global temperature rise to 1.5°C (SBTi, 2021a) and become net-zero in its carbon emissions, eventually. The SBTi makes the distinction between scope 1, 2, and 3 emissions. They adopted the scope documenting standards from the GHG Protocol (GHG Protocol, 2021), which is a partnership between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). Scope 1 treats the direct emissions from Sunrock's owned or controlled sources. Scope 2 treats indirect emissions from the generation of Sunrock's purchased electricity, steam, heating, and cooling. Scope 3 treats all other indirect emissions that occur in Sunrock's value chain. The SBTi will be discussed in more detail in Chapter 2.3.

Sunrock has expertise in technical project development, finance, and consultancy. To offer the described service, Sunrock cooperates with partners regarding for example solar panel manufacturing, and solar park construction and maintenance. The SBTi does not only focus on direct emissions that are generated by Sunrock itself, but also on indirect emissions that are generated by all companies that Sunrock has partnerships with. Sunrock generates value through many partnerships, and since most of these partners are responsible for processes that emit lots of GHGs, Sunrock's indirect emissions make up a large part of its total emissions. All the components that are required for building a solar park are also still made from materials that must be extracted from nature and/or are not fully recyclable. The manufacturing processes of these components are therefore depleting the Earth's resources and/or generating waste. The environmental, but also the social impact of PVs is discussed further in Chapter 2.1.

1.1.2. Desired situation

Sunrock is not satisfied with the negative impact their PV systems have. They want to adapt for their business to become fully sustainable. For this reason, Sunrock's parent company introduced Sunrock to the SBTi. Through this initiative, Sunrock has committed to reduce its carbon footprint, preferably not by compensating (or "offsetting") its emissions, but by reducing them. Plans are already in place for neutralizing the direct carbon emissions of the company, but since the indirect carbon emissions play such a large part for a company like Sunrock, it is of utmost importance that these emissions are also neutralized. Sunrock therefore wants to map these carbon emissions so that the required actions for neutralization can be identified and executed. Sunrock prioritizes its carbon emissions since carbon plays the largest role in climate change (Schmidt et al., 2010). However, there are substantial climate benefits to managing reductions in emissions of both CO_2 and non-CO_2 emissions (Khalil, 1999; Montzka et al., 2011). Therefore, the emission of other GHGs should eventually also be eliminated.

Though the priority is to eliminate the direct and indirect GHG emissions through conforming to the SBTi, Sunrock also wishes to eventually eliminate the waste that is generated because of the wrong use of materials in its business operations. In the ultimate scenario, all solar park components have circular (or “cradle-to-cradle”) designs, which means that they are made from sustainable materials and recycled completely. By gradually eliminating GHG emissions and waste, Sunrock desires to eventually achieve a circular economy, in which the company would be able to generate energy that is truly sustainable. Since the transition towards complete circularity takes place gradually, Sunrock desires a roadmap for eventually achieving this goal. The concept of circularity is treated in Chapter 2.2.

1.2. The project

1.2.1. Problem definition

The production of energy from renewable sources should be truly sustainable. The overarching problem is that through Sunrock, the generation of solar energy goes paired with GHG emissions and waste generation. The environmental impact of Sunrock's business operations (see Chapter 2.1) in terms of climate change, resource depletion and ecotoxicity should not be neglected (Chen et al., 2016; Fu et al., 2015; García-Valverde et al., 2009). GHG emissions and waste should therefore be eliminated from Sunrock's value chain. As mentioned, the SBTi makes the distinction between direct and indirect emissions in scopes 1, 2, and 3. Scope 1 and scope 2 are straightforward and were already mapped by Sunrock. There also already exist plans to eliminate those direct emissions. No concrete plans exist yet for the elimination of indirect GHG emissions and waste. The company therefore wants to focus on scope 3, which addresses the indirect generation of GHG emissions in the company's value chain.

A value chain refers to all the activities associated with the operations of the organization, including the use of sold products by consumers and the end-of-life treatment of sold products after consumer use. Besides eliminating the GHG emissions that originate from its value chain, Sunrock wishes to eventually eliminate the waste generated by the value chain. Sunrock's entire value chain is built for the realization of their PV projects. There are many partnerships in this value chain, which all contribute to Sunrock's total indirect generation of GHG emissions and waste.

It will be difficult to eliminate the indirect GHG emissions and waste from the value chain because these eliminations will most likely increase the costs for Sunrock's partners. This financial aspect of the problem increases the chance that Sunrock's partners might not adapt their strategy. Sunrock should stimulate their existing partners to adapt and look to find new partnerships where existing partners are not willing to do this. At the end of the day, Sunrock will pay their partners more for their improved strategies, which will make the solution to the stated problem about costs. Sunrock is willing to invest in the solution, but the company must retain a valid business model. On the other hand, Sunrock's lower environmental impact will increase the company's image and might even increase the amount of funds the company raises in the future. Depending on the origin of GHG emission and waste streams there is a range of possibilities for preventing them. A custom solution is required to eliminate all GHG emissions and waste from Sunrock's value chain.

1.2.2. Objectives and research question

The research problem should be addressed through achieving specific objectives. The objectives define the scope of the study and must be reviewed regularly to find out whether any revisions are necessary for addressing the problem. The following main objectives were identified for finding a solution to the stated problem:

- Develop a method for mapping and eventually neutralizing the GHG emissions and waste generated in a company's value chain.
- Evaluate the developed method by applying it to Sunrock's situation.

The method will be of academic value since it is expected that the method is applicable by other companies. The evaluation shows the value of the method and provides many insights for Sunrock. The method should describe how a life cycle assessment (LCA) can be conducted on a company's value chain (LCA theory is discussed in Chapter 2.4). The company that applies this method must be able to share its results with an organization like the SBTi. The method must therefore incorporate the scope categorization of the GHG Protocol. Guidelines for interpreting the results of the scope incorporated value chain LCA must also be provided by the method. The method should help to achieve the following objectives:

- Map the partners and activities in the value chain of the company in question.
- Set the boundaries and determine what information is required.
- Gather and aggregate the required information.
- Perform an LCA on the mapped value chain and incorporate scopes 1, 2, and 3.
- Set accurate, attainable, and trackable targets for the elimination of GHG emissions and waste that are generated in the value chain of the company in question.
- Identify actions for achieving the set targets and prioritizing these actions to form a roadmap.
- Report the generated results and the progress that is made in the transition towards circularity.
- Iterate the created model to improve and update the results.

The study will try to answer the following research question:

> *How can LCA theory be used to develop a method that helps companies to eliminate GHG emissions and waste from their value chain in their transition towards circularity?*

The research question gives a clear idea of what this study aims to achieve. It should therefore be based on the identified problem and objectives. The to-be-developed method should be designed to achieve the identified objectives and answer the research question.

1.2.3. Report outline

This report opened by presenting an abstract, a preface, some lists, and a table of contents. The following chapters are allocated to specific parts. Each of these parts has an introductory page that discusses the structure of that part in more detail. Part 1 formed the introduction and gave some context regarding Sunrock and the project and is concluded with this paragraph. Part 2 delivers a theoretical framework, which presents the required background information by discussing the impact of photovoltaics, the circular economy concept, the Science Based Targets initiative, and the method of life cycle assessment. The theoretical framework does not provide much new information for a reader that has experience with the mentioned topics. The reader can therefore decide whether these chapters are relevant for him or her to read. Part 3 presents the method that is designed for mapping and neutralizing the GHG emissions and waste generated in a company's value chain. Part 4 discusses the results that follow from applying the presented method to Sunrock's value chain. Part 5 is shaped by a discussion and some conclusions. After the references are presented, the report closes with Part 6, which contains the appendices in separate chapters.


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Part 2

Theoretical framework

The theoretical framework will first discuss impact of photovoltaics, where some extra attention is given to the environmental and social impact. Next, the principles of and the transition towards a circular economy are presented, together with the challenges and barriers that come with it. To follow this up, the Science Based Targets initiative (SBTi) and the principles it handles are elaborately described. The part concludes by explaining the concept of LCA, its phases and the software that can be used to conduct it. This part does not provide much new information for a reader that has experience with the mentioned topics. The reader can therefore decide whether these chapters are relevant for him or her to read.

2.1. Impact of photovoltaics

In 2018, the worldwide net consumption of energy was around 16 × 10^4 TWh (IEA, 2021). This consumption will increase each year as more and more applications run on electricity instead of fossil fuels. However, this consumption does not even come close to the amount of energy the Sun emits. Each year the Sun provides the Earth's surface with around 885 × 10^6 TWh, which means that it would take the Sun about 90 minutes to hit the Earth with the amount of energy humanity uses in a year (Philibert, 2011). One can therefore say that the Sun is Earth's most significant source of clean, renewable energy. Capturing this energy is essential for ending humanities dependence on the fossil fuels that contribute to climate change. Figure 2.1 shows the total amount of energy that can be harvested from humanity's most well-known sources.

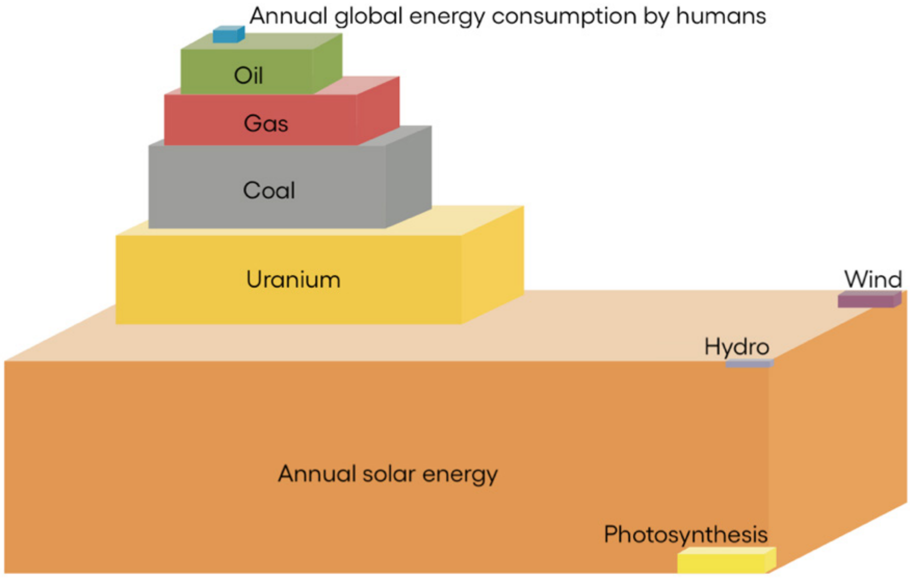

Figure 2.1 Availability of the known resources in the human world (Philibert, 2011).

Figure 2.2 shows the global primary energy consumption in the year 2018 (IEA, 2021). Among renewables are nuclear, hydro, wind, solar, geothermal, and bio-energies. 19.34% of the world's total energy consumption is generated with renewable sources. 16.40% of the energy from renewable sources accounts for the total installed capacity of solar power, which is about 0.36% of the world's total energy consumption. This 0.36% accounts for around 589 TWh (IEA, 2021). Table 2.1 shows the development of the amount of generated solar energy for several years.

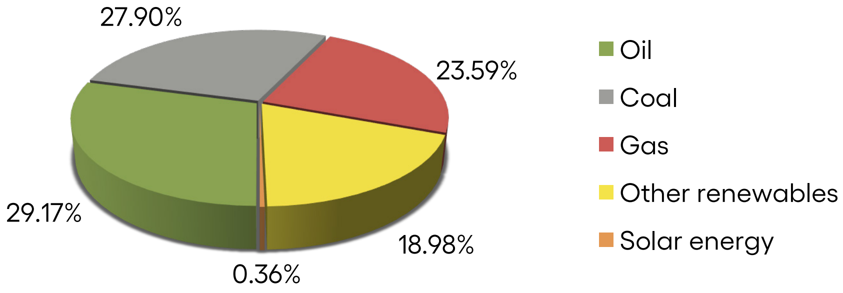

Figure 2.2 Global primary energy consumption in the year 2018 (IEA, 2021).

Table 2.1 Development of the amount of generated solar energy for several years (IEA, 2021).

Year	Solar energy generated (TWh)
2010	32.2
2018	588.8
2019	665.0
2020	821.0
2030*	6970.0

* Projection according to the Net-Zero Scenario.

2.1.1. Environmental

As Table 1.1 shows, the production of PVs is expected to grow rapidly. This means that the total impact of PVs will increase. The increased use of PVs has an increased direct positive impact on the emission of GHGs and therefore also an increased indirect positive impact on human health (Hosenuzzaman et al., 2015). Though the increased positive impact is important to mention, the increased negative impact may not go unnoticed. Although there are no GHGs emitted during the use phase of PVs, a considerable amount of environmental burden is produced during the manufacturing phase (Chen et al., 2016; Fu et al., 2015; García-Valverde et al., 2009). Much energy is consumed, which causes much GHGs to be emitted. The Energy Payback Time (EPBT) of a PV system indicates the time period that is required for this system to generate the same amount of energy it has cost to realize it. Lowering the EPBT indicates that either less energy is consumed during the realization, or the used technology has become more efficient through innovation. Among these environmental impacts of the manufacturing phase is also the potential for abiotic depletion of elements. This is because PVs make use of rare materials, like silicon, cadmium, tellurium, copper, indium, and gallium. Knowing this, and the fact that a significant part of the world's total energy production should be supplied by PV installations, it has been calculated that material supply constraints and scarcity will eventually become a real problem (Davidsson & Höök, 2017; F. Schmidt et al., 2019; Wadia et al., 2009; Zuser & Rechberger, 2011). PVs should eventually be designed out of waste, and they should become fully recyclable.

Through technological improvements the global warming potential of PVs has already been halved in the period from 2005 to 2015 in the United Kingdom and Spain (Stamford & Azapagic, 2018). Reductions have also occurred in other environmental impacts, ranging from 29% (eutrophication potential) to 80% (ozone layer depletion potential) with an average of 45% (Stamford & Azapagic, 2018). Though these numbers are positive, there still is a long way to go before the negative impact of the average PV's manufacturing process on the environment is fully eliminated. These reductions on environmental impacts are much lower in the People's Republic of China (hereinafter referred to as China), which causes Chinese PV modules to have a total global warming potential that is over 20% higher than for example the German PV modules (Stamford & Azapagic, 2018). This increases the total environmental impact considerably since 71% of the world's solar modules and 97% of the world's solar wafers are manufactured by Chinese corporations (Murphy & Elimä, 2021). The environmental impact of manufacturing PVs is not comparable to that of processing and consuming fossil fuels, but an emission net-zero scenario cannot be achieved without off-setting if the GHG emissions of the PV manufacturing process are not eliminated. The constant depletion of rare material supplies and the fact that these supplies will eventually be completely depleted can also not be ignored. The environmental impact of PVs can therefore not be overlooked.

2.1.2. Social

The social impact of PVs also increases with the rapidly growing PV market. On the positive side, the more PVs are visibly installed, the more normal it becomes for people to transition to renewable energy sources. The increased awareness causes an increase in the share of renewable energy in the world. This form of publicity is a great example of the fact that social factors dominate the purchase intentions and attitudes of consumers towards PV systems (Huang et al., 2020). Besides this, the financial and environmental benefits, and the fact that consumers get subsidies because of these benefits, make the acceptance grow even more (Strazzera & Statzu, 2017).

On a less positive note, there are very clear signs that there are critical social issues in the manufacturing process of PV systems and their components. Evidence has come to light that the China has placed millions of indigenous Uyghur and Kazakh citizens from the Xinjiang Uyghur Autonomous Region (XUAR or Uyghur Region) into what the government calls "surplus labor" and "labor transfer" programs (Murphy & Elimä, 2021). The Chinese government has claimed that these people work there voluntarily and that this labor has been orchestrated as an effort to alleviate poverty (Murphy & Elimä, 2021). It seems however that these people work under coercion and that they are subject to re-education and internment (Murphy & Elimä, 2021). Since these people are not able to leave these conditions, they are technically enslaved by the Chinese government. The combination of the presented evidence and the denial of the Chinese government tempers with the transparency of the manufacturing process of PVs. This makes it impossible to guarantee that no human rights were violated through the production of PVs.

Raw materials, manufactured polysilicon, and components like ingots, wafers, cells, and modules are needed to produce PVs. The problem is that China is the main player in all of these supply markets (Sweeney, 2021). As far as known, 80% of the world's solar-grade polysilicon supply is located in China. 45% comes from the Xinjiang region and 35% comes from other Chinese regions, while only 20% comes from outside of China (Murphy & Elimä, 2021). As previously mentioned, 71% of the world's solar modules and 97% of the world's solar wafers are manufactured by Chinese corporations (Murphy & Elimä, 2021). The world's PV market is therefore heavily reliant on the Chinese production that most likely violates human rights. Companies that build their business around purchasing PVs often try to have a positive impact, but they are forced to purchase from Chinese manufacturers. Shifting to for example European suppliers is more expensive since the manufacturing process is more expensive in Europe. These higher prices weaken the validity of the business models of many PV purchasing companies, which can cause them to fail. So even if these companies care about the situation, they are forced to buy from Chinese corporations if they want to have a valid business model and a positive impact at all.

Human rights may not be violated in any manufacturing process, and a solution must be found as quickly as possible. Until governing institutions like the United Nations or the European Union address this problem through regulations, a partial solution can only be implemented if PV purchasing companies invest the extra money and boycott Chinese corporations if their manufacturing process does not become transparent. This solution would however not eliminate the problem since many purchasing companies do not have the resources for a boycott. Market forces will therefore sustain the current situation.

2.2. Circular economy

Today, most enterprises manufacture their goods according to the linear model, in which resources are extracted, used and often disposed to never be used again (Ellen MacArthur Foundation, 2013). This causes significant losses in the world's total resources availability. Waste is generated in the production chain, but also at the end of a product's lifecycle (or the "end-of-life"). At the end-of-life, products can be reused, refurbished, recovered, recycled or even composted to prevent waste creation (Ellen MacArthur Foundation, 2013). During the simplest and most environmentally contaminating treatments these products are burned for heat generation or buried in a landfill where all of the product's remaining energy gets lost (Ellen MacArthur Foundation, 2013). During the manufacturing processes, most energy in the form of fossil fuels are consumed during the extraction of raw materials and the conversion into their commercially usable forms. Besides, the processes of extraction create imbalances in demographics, infrastructure, politics, globalized markets, natural systems, and climate that weigh heavily on economic growth (Ellen MacArthur Foundation, 2013, 2015). Constantly extracting new resources is therefore not the most viable option in many ways. The circular economy concept was designed to tackle this problem.

2.2.1. Principles of a circular economy

A circular economy refers to an industrial economy that is restorative by intention; aims to rely on renewable resources, both in energy and materials; minimizes, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design (Ellen MacArthur Foundation, 2013, 2019). Products should be designed out of waste, and they should be completely recycled when they arrive at their end-of-life. Reducing, reusing, and recycling materials is at the core of a circular economy (Heshmati, 2017). The great environmental challenges due to large scale and rapid industrialization and urbanization; the severe shortage of resources and energy to meet growing demands and high rate of economic growth; and the increased regulations in international trade and tendencies towards implementation of higher production, environmental and labor standards make it imperative to move towards a regenerative sustainable industrial development with a closed loop (Heshmati, 2017). Figure 2.3 shows how biological and technical nutrients cycle through such a closed loop. A circular economy can create economical value for companies in multiple ways (Ellen MacArthur Foundation, 2013, 2015). Companies can save on the costs that are embedded in material, labor, energy, and capital, but also emissions, water, and toxic substances. When it becomes costly for a company to refurbish, recover, or recycle their products, they can also cascade them so that they are used by another company. Value can also be maximized through maintaining purity of materials and quality of products. Currently, recycled material streams become available as mixtures, either because of the selection and combination of materials in a single product, or because they are not segmented during the collection. This all does not preserve the purity and quality of these materials. The reverse cycle can be improved by improving the original design of products and their collection process. This can create benefits for scale economies and efficiencies, but also for the image of the company.

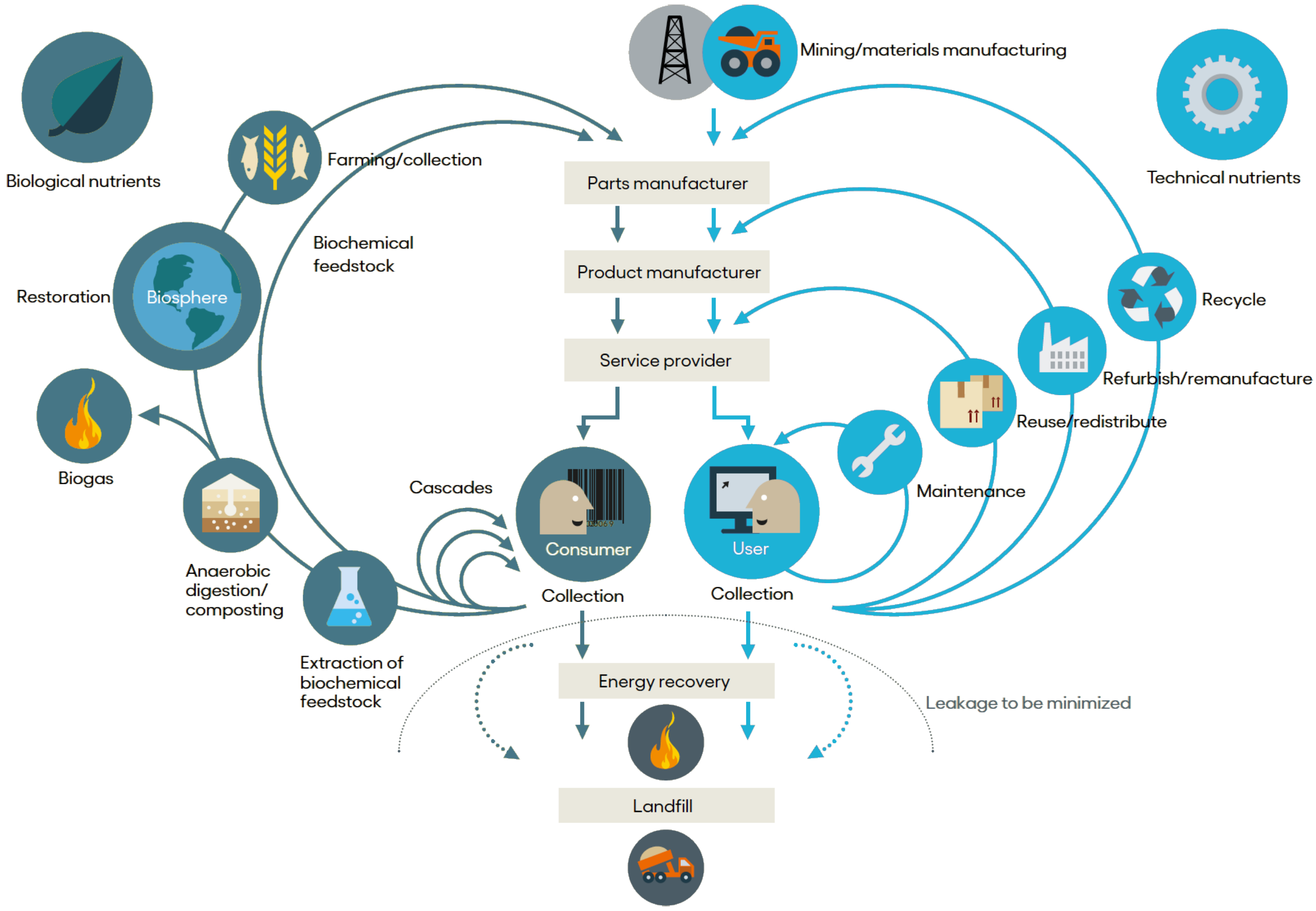

Figure 2.3 Schematic of a circular economy (Ellen MacArthur Foundation, 2013).

2.2.1.1. Emissions

Most of today's efforts to combat climate change focus on increasing the efficiency of energy usage and transitioning to renewable energy. 55% of humanity's total current GHG emissions comes from its direct use of energy, while the remaining 45% comes from the making of products (Ellen MacArthur Foundation, 2019). At the Conference of Parties (COP) meeting in 2015, almost all governments present agreed on the necessity to reduce GHG emissions in order to limit global warming (Stahel & MacArthur, 2019; United Nations, 2016). A target of zero emissions can only be achieved if some drastic changes are made to the designs of products and their manufacturing processes. The most abundant GHGs in the Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) (GHG Protocol, 2011; Schmidt et al., 2010). Emissions should be measured to identify emission hotspots, which give insight in the areas of risk, and which provide opportunities for reducing emissions, increasing efficiency, and saving money. It has been calculated that if an entire nation would shift to a circular economy, this could reduce the nation's total GHG emissions by as much as 66% across and along all supply chains (Ellen MacArthur Foundation, 2013; Wijkman & Skånberg, 2015).

2.2.1.2. Waste

To help achieve a system in which no waste is generated, the cradle-to-cradle (C2C) concept was developed. This design philosophy considers all material involved in industrial and commercial processes to be either biological or technical nutrients (Ellen MacArthur Foundation, 2013). The framework focuses on design for effectiveness in terms of products with a positive impact. Therefore, the C2C concept differentiates itself fundamentally from the traditional design focus. The concept is inspired by nature since it requires the material flows in production processes to be circular (as shown in Figure 2.3). No new exhaustible resources should be extracted from nature and no waste should be generated when the manufactured product reaches the end of its lifecycle. Product and material lifetimes should be stretched by keeping products and materials in use; waste should be treated as a resource for designs; and natural capital should be recovered, restored and regenerated by analyzing and countering environmental impacts (Ellen MacArthur Foundation, 2015). The C2C framework addresses not only materials, but also energy and water inputs (Ellen MacArthur Foundation, 2013). Goods can be certified by an organization called C2C Certified, which states the global C2C standard (C2C Certified, 2022). For manufacturers, C2C goods can either save money over time, but mostly even from the start (McDonough & Braungart, 2010). Either way, an investment must be made for the development of these C2C goods (Toxopeus et al., 2015). C2C goods are therefore not always cheaper to the consumer, which can make it more difficult for these types of goods to conquer a dominant position in the market.

2.2.2. Transition

Though our economies remain strongly locked into a system where everything from production economics to contracts, and from regulation to mindsets, favors the linear model of production and consumption, the shift towards circular economies has begun. This transition is enabled by more apparent resource scarcity and tighter environmental standards; the possession of information technology that allows the shift; and a pervasive change in consumer behavior (Ellen MacArthur Foundation, 2013). The interesting thing about a circular economy is that even without the environmental factors, the advantages of the concept are numerous.

The Ellen MacArthur Foundation (2021) proposed a set of universal circular economy policy goals. To start the gradual transition towards a circular economy, an organization should first focus on stimulating the emergence of circular designs for good and services, and circular business models that keep inorganic and organic materials and goods in use and at the highest value possible. The second goal is achieved when the organization manages its resources and creates multiple circular economy loops in such a way that the value of the goods and materials is preserved (as shown in Figure 2.3). The third goal is to make the economics work by ensuring that the policies and systems that are adopted during the achievement of the first two goals are fully supported. In the fourth step, the organization should invest in innovation, infrastructure, and skills to further help to scale the circular economy. In the fifth and final step, the organization should collaborate with other organizations to stimulate an entire system to make the transition towards a circular economy. It is highly important that national and international alignment and harmonization is achieved. Mechanisms and processes should be developed for including other organizations and providing feedback for policymakers.

2.2.3. Challenges & Barriers

The implementation of circular economies faces several challenges and barriers. From a general perspective, on the corporate side there is a shortage of reliable data and information, advanced technologies, good leadership and management, and determination to depart from the linear model; on the cultural side there is not enough public awareness about the necessity and promises of circular economies; and on the political side there is a lack of strong economic incentives and enforcement of legislations (Adams et al., 2017; Kirchherr et al., 2018; Su et al., 2013). There also is no comprehensive standard system for assessing the performance of an established circular economy (Su et al., 2013). Developing a circular product and office space is rather complex and often requires a substantial initial investment. This, together with an unclear financial case, makes it extremely difficult for companies to decide to make the transition towards a circular economy (Adams et al., 2017). It is therefore quite logical that a clear business case is an important enabler because the analysis of projected costs and benefits plays a dominant role in human decision-making (Adams et al., 2017).

Before any of the more concrete problems can be addressed, something should be done about the lack of interest and knowledge regarding circular economies that exists in companies of today (Adams et al., 2017; Kirchherr et al., 2018). Across all literature it seems that providing an organization with correct and clear information can play a significant role in this organization's eventual transition towards a circular operation. The other mentioned barriers must however also be addressed since such an organization's will to transition to a circular economy might be its first but not its only problem.

2.3. The Science Based Targets initiative

The SBTi is a partnership between the Carbon Disclosure project (CDP), the United Nations Global Compact, World Resources Institute (WRI), and the World Wide Fund for Nature (WWF), that was formed to increase the ambition in the fight against climate change (SBTi, 2021a). The initiative uses science-based targets (SBTs) to show companies how much and how quickly they need to reduce their GHG emissions to prevent the worst effects of climate change. Therefore, the goal of the initiative is to limit global warming to 1.5°C. The most recent report of the Intergovernmental Panel on Climate Change (IPCC) presented the seriousness of the situation (IPCC, 2021). They stated that the most significant effects of climate breakdown can be avoided if the global temperature rise is limited to 1.5°C through halving GHG emissions by 2030 and achieving net-zero emissions before 2050. The SBTi tries to achieve this goal through the following activities (SBTi, 2021a):

- Defining and promoting best practices in emission reductions and net-zero targets that are in line with climate science.
- Providing technical assistance and expert resources to companies who set SBTs in line with the latest climate science.
- Bringing together a team of experts to provide companies with independent assessment and validation of targets.

Companies join the initiative because they become more prepared for future legislation, they look further ahead, or they need to meet expectations of their stakeholders. Joined reporting companies (RCs) start their transition towards a situation where their GHG emissions become net-zero. The initiative's Net-Zero Standard provides a common, robust, and science-based understanding of net-zero (SBTi, 2021a). Through this Standard, all man-made GHG emissions must be removed from the atmosphere through either reduction or prevention. The current momentum of the SBTi shows it is possible to fully decarbonize the economy by 2050, or even sooner. However, this can only be achieved if the opportunity is fully harnessed and supported by all global economic actors (SBTi, 2021a).

2.3.1. Principles of the SBTi

Companies from all sectors and of all sizes can join the movement of the SBTi (SBTi, 2021a). The initiative is developing sector-specific pathways for different sectors to follow. Currently there are no SBTs developed for cities, local governments, public sector institutions, educational institutions, or non-profit organizations. Companies that join the movement can set SBTs through a 5-step process that is shown in Table 2.2.

Table 2.2 Descriptions of the five steps for SBT setting (SBTi, 2021a).

#	Step	Description
1	Commit	Submit a letter establishing the company's intent to set a science-based target.
2	Develop	Work on an emissions reduction target in line with the SBTi's criteria.
3	Submit	Present the company's target to the SBTi for official validation.
4	Communicate	Announce the company's target and inform the company's stakeholders.
5	Disclose	Report company-wide emissions and track target progress annually.

The SBTi offers comprehensive guidance to RCs when they develop their SBTs since the initiative wants to make the movement as approachable as possible. The criteria that must be met for SBTs to be recognized by the SBTi are extensively described (SBTi, 2021b). The methods and rules that are relevant for setting SBTs are treated in more detail in Chapter 3.4. The RCs should also make sure that the SBTs and corporate inventory cover CO_2, CH_4, N_2O, PFCs, HFCs, SF_6, and NF_3 emissions. The total emissions of RCs are reported in kg CO_2 equivalent (CO_2e). Global warming potential (GWP) values are used to indicate how much CO_2e something emits. For any gas, the GWP value says how much more or less than CO_2 this gas warms the Earth. CO_2 is the reference for the GWP and therefore has a value of 1 kg CO_2e per kg CO_2. In a 100-year time horizon, N_2O has a GWP of around 273 kg CO_2e per kg N_2O, which means that over 100 years 1 kg of N_2O warms the earth about 273 times more than 1 kg of CO_2 (IPCC, 2021).

Once the SBTs are set by an RC, the RC must make the effort to put systems in place for measuring and analyzing the direct and indirect GHG emissions that originate from its business operations. Before an RC starts gathering the data, inventory boundaries must be established to determine which business operations and emissions will be accounted for in its GHG emission inventory and which will not (GHG Protocol, 2004). Emission hotspots can be identified when the emissions are measured. These hotspots will hand opportunities to reduce emissions, be more efficient, and save money. Measuring the direct emissions will also provide highly useful data for clients that also have to report their indirect emissions for their SBTs. Once baseline data has been gathered, a plan must be developed to act on the hotspots and reduce their impacts.

2.3.2. Scopes

To compose a complete picture of an RC's direct and indirect emissions, improve transparency, and provide utility for different types of organizations and different types of climate policies and business goals, the GHG Protocol defined three "scopes" (GHG Protocol, 2004). These scopes are elaborately defined for GHG programs like the SBTi to use them. The three scopes are discussed individually in the following paragraphs.

2.3.2.1. Scope 1: Direct GHG emissions

The direct GHG emissions of an RC are allocated to scope 1. These emissions originate from sources that are owned or controlled by the RC (GHG Protocol, 2004). They can come from stationary or mobile fuel combustion, but they can also be fugitive or process emissions. Table 2.3 presents the most common sources for scope 1.

Table 2.3 Most common sources for scope 1 emissions (GHG Protocol, 2004).

Source type	Cause	Sources
Stationary fuel combustion from the RC's facilities	Generation of electricity, heat, or steam	Boilers, furnaces, heaters, ovens, dryers, turbines
Mobile combustion from the RC's vehicles	Transportation of materials, products, waste, and employees	Road vehicles, non-road vehicles, boats, trains, airplanes
Fugitive emissions from leaks	Intentional or unintentional equipment leaks	Refrigerators, air-conditioners, vents, faulty pipelines, gas transport
Process emissions from Processing	Industrial processes and on-site manufacturing	Manufacturing materials and chemicals

2.3.2.2. Scope 2: Electricity indirect GHG emissions

The emissions from the generation of purchased electricity are allocated to scope 2. These emissions originate from the locations where the purchased electricity is generated (GHG Protocol, 2004). The electricity that is used during the transmission and distribution (T&D) of the purchased electricity belongs to the scope 2 of the company that owns and controls the T&D system. Such rules must be formulated in detail to ensure that no double counting takes place. There are many RCs for which scope 2 emissions play the largest role. These problems can be addressed by investing in energy efficient technologies and energy conservation (GHG Protocol, 2004). RCs can also start using energy from renewable sources that have a lower impact on the environment.

2.3.2.3. Scope 3: Other indirect emissions

All other indirect emissions in the value chain of an RC are allocated to scope 3 (GHG Protocol, 2004). These emissions are a consequence of the activities of ab RC, but they occur from sources not owned or controlled by that RC. The GHG Protocol provides a clear guideline that helps RCs to calculate the scope 3 emissions in their value chain through a value chain analysis (GHG Protocol, 2011). Nevertheless, it is still quite difficult to completely map indirect emissions accurately, which is why reporting on scope 3 is optional (GHG Protocol, 2004). In many sectors however, scope 3 emissions have the largest share in the total emissions of RCs, and the share of scope 3 emissions grows the most in each sector (Hertwich & Wood, 2018). Scope 3 emissions therefore become more and more important, and they can most definitely not be ignored. To analyze the value chain in a structured way, the GHG protocol distinguishes 15 activity categories for scope 3. The 15 categories, their descriptions, and their minimum boundaries are presented in Table 6.1 in Appendix 6.A (p. 107-108). A 9-step roadmap has also been developed by the GHG Protocol that helps RCs in their accounting and reporting (A&R) of scope 3. The 9 steps and their descriptions are presented in Table 6.2 in Appendix 6.A (p. 109-110). Figure 2.4 below shows an overview of scopes 1, 2, and 3 and their emission sources. A link for downloading the scope 3 A&R standard of the GHG protocol is presented in Appendix 6.C (p. 149).

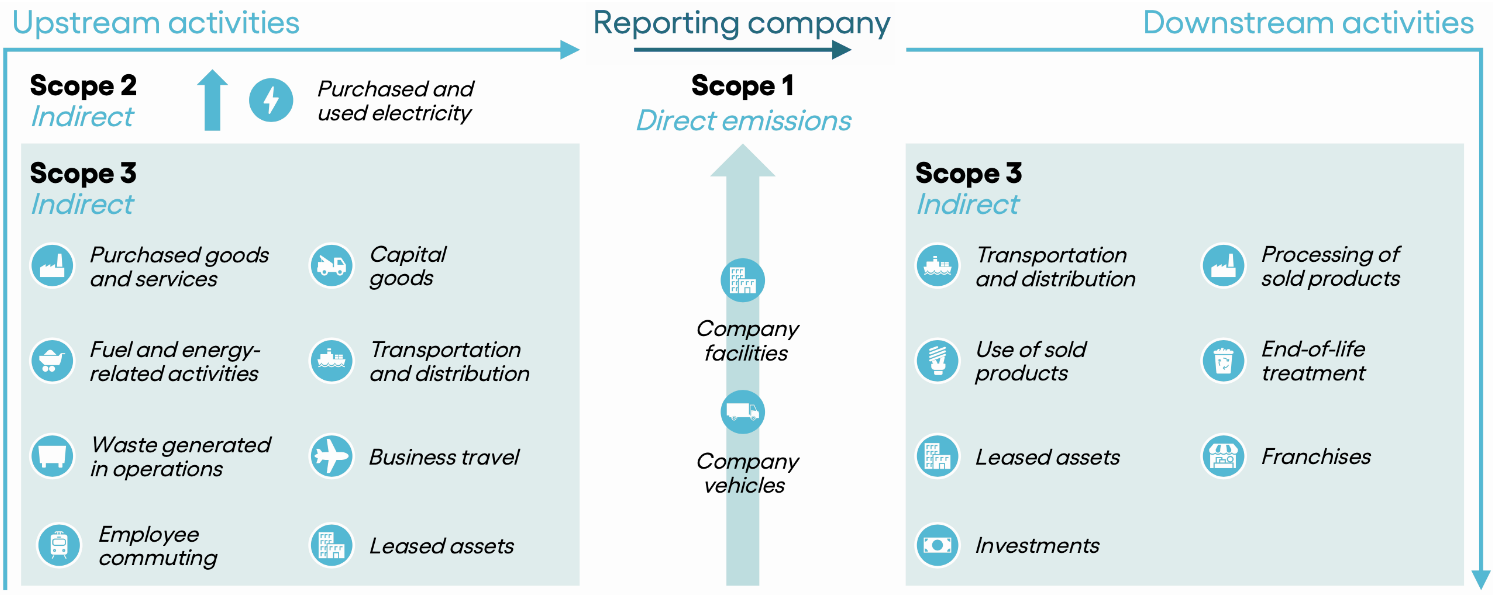

Figure 2.4 Overview of the GHG Protocol scopes and emissions across the value chain.

2.4. Life cycle assessment

LCA is an effective approach that analyzes the environmental impact of a product system by identifying and quantifying the effect of utilized material and energy flows and pollutants emitted to the environment (Chen et al., 2016). The entire life cycle is taken into account systematically and adequately during an LCA, from raw materials acquisition to production, use and disposal (ISO, 2006a). During an LCA, inputs and outputs are compiled, where inputs are the required resources, and outputs are the products and emission and waste streams. The in Chapter 2.2 and Chapter 2.3 mentioned hotspots can be identified through an LCA. Aspects like costs and safety can also be included in an LCA. An LCA can assist in the following matters (ISO, 2006a):

- Identifying opportunities to improve the environmental aspects of products at various points in their life cycle.
- Decision-making in industry, governmental or non-governmental organizations during strategic planning, priority setting, product or process design or redesign.
- Selection of relevant indicators of environmental performance, including measurement techniques.
- Marketing aspects such as an environmental claim, ecolabelling scheme or environmental product declaration.

Indirectly, these benefits can help to understand the bigger picture, identify low-hanging fruits, innovate through information, differentiate the company, increase efficiency, and measure and mitigate business risks (Koffler, 2020). During an LCA it is highly important that the scope, assumptions, description of data sources and quality, methodologies, and output are transparent through clear and appropriate communication (ISO, 2006a). The LCA methodology should be amenable to the inclusion of new scientific findings and improvements in the state-of-the-art of the technology (ISO, 2006a).

2.4.1. Principles of LCA

The International Organization for Standardization (ISO) defined a standard for conducting an LCA. The principles and framework of LCA are described in ISO 14040, while the requirements and guidelines are described in ISO 14044 (ISO, 2006a, 2006b). A link for downloading this standard is presented in Appendix 6.C (p. 149). These standards ensure that a comparative assertion can be disclosed to the public. In this section, the data from these standards is used to describe the principles of LCA. The structure is determined by the following 4 LCA phases (ISO, 2006a):

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

2.4.1.1. Goal and scope definition

In the first phase of an LCA, the goal and scope of the study should be documented. The target group should be clear, and it must be decided whether the LCA will serve as a comparative tool through which several product system options are compared. The product system that will be the subject of the LCA should be described with a certain level of detail, so that any outsider can understand the results when they are presented. Next, the impact categories, or midpoints, must be determined. Generally, these midpoints can be attributed to areas of protection, or endpoints, that have something to do with resource use, human health, or ecological consequences (ISO, 2006a). The depth of detail and the time frame of an LCA study can vary depending on the definition of the goal and scope (ISO, 2006a). The potential data sources and the required data quality can now also be identified. According to the ISO, data quality requirements should be stated that address the topics that are shown in Table 2.4. During all phases of the LCA, many necessary decisions and assumptions about the life cycle of the product system are made. These assumptions and their justifications should be clearly stated. Provisions should also be made to respect confidentiality and proprietary matters (ISO, 2006a).

Table 2.4 Topics that should be addressed by the data quality requirements (ISO, 2006b).

Topic	Description
Time-related coverage	Age of data and the minimum length of time over which data should be collected.
Geographical coverage	Geographical area from which data for unit processes should be collected to satisfy the goal of the study.
Technology coverage	Specific technology or technology mix.
Precision	Measure of the variability of the data values for each data expressed (e.g., variance).
Completeness	Percentage of flow that is measured or estimated.
Representativeness	Qualitative assessment of the degree to which the data set reflects the true population of interest (i.e., geographical coverage, time period and technology coverage).
Consistency	Qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis.
Reproducibility	Qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study.
Sources of the data	It should be specified which sources are deemed essential and accurate for providing usable data.
Uncertainty of the information	Uncertainty in data, models and assumptions should be clearly stated.
Missing data and data gaps	Missing data and data gaps should be documented and treated so that it results in a “non-zero” data value that is explained, a “zero” data value if explained, or a calculated value based on the reported values from unit processes employing a similar technology.

The goal definition should give the reader a clear overview of why, how, and what was researched during the LCA. An LCA can be cradle-to-grave, cradle-to-gate, gate-to-gate, or gate-to-grave. At the start, it must be specified which of these scopes will be handled. Within the set scope, the system boundaries should be defined to determine which data must be included in the LCA and which data should be excluded from the LCA. A ranking procedure should be defined and justified to decide on the significance of each datapoint. The three most important parameters for defining the system boundaries are contribution of mass, required energy and environmental significance, which are influenced processing steps (ISO, 2006b). The system boundaries determine the precision of the results. This step deserves much attention since boundaries that are too narrow will give less accurate results, and boundaries that are too wide will make it difficult to gather the required data accurately. Both situations will eventually cause results that are not as useful as when the boundaries have been set properly. During the LCA, the system boundaries can be adjusted when the impact of each parameter that is or is not included becomes more apparent. This is essential since all the most important aspects should be taken into account during the inventory analysis. Lastly, the functional unit (FU) should be determined. The FU is the quantified performance of a product system for use as a reference unit (ISO, 2006b). In other words, a product system fulfils certain performance requirements, of which the quantified description is the FU. The FU should represent the goal of the LCA's dataset, and keeping the FU the same should allow the comparison of similar systems, processes or products, if needed (Sphera, 2020). This makes the FU the cornerstone of an LCA.

2.4.1.2. Inventory analysis

During the inventory analysis, the life cycle inventory (LCI) is determined through data collection and modeling. First, a process tree should be made to identify all the processes in the system. Every process has the required resources as inputs and products and emission and waste streams as outputs. Both quantitative and qualitative data should be collected for all relevant inputs and outputs of every identified process in the system. Primary data is preferred, but secondary data can also suffice if it is of the required format. Everything that goes in each process must also come out. In the same way, everything that enters the life cycle must also come out at the latest during the end-of-life stage of a product system.

All the collected data should be related to the FU and validated. It can be that data is not directly assignable to the FU due to the fact that part of a product system's life cycle contributes to other life cycles. Allocation must then be modelled properly and according to fitting allocation methods. The data can be collected in a comprehensible table that lists inputs and outputs of processes. The data quality is characterized by the quantitative and qualitative aspects of the data, but also by the used data collection, calculation and integration methods (ISO, 2006b). Data collection, calculation and integration methods are discussed in more detail in Chapter 3.2.

2.4.1.3. Impact assessment

The LCI enables the execution of the life cycle impact assessment (LCIA). The LCIA identifies and evaluates the amount and significance of the potential environmental impacts of a product system (ISO, 2006b). A custom LCIA method can be used, but most LCAs are performed with LCIA methods that are developed by external parties. These methods conduct a series of steps, of which the first is always classification. During classification, inputs and outputs from the LCI are assigned to specific impact categories. The impact categories that were identified should reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration (ISO, 2006b).

A characterization model should be chosen and motivated to relate the LCI results to category indicators, which are quantifiable representations of an impact category, and characterization factors, which are applied to convert LCI results to the common unit of the corresponding category indicator (ISO, 2006b). Combining the LCI results with their relevant category indicators and characterization factors will result in category indicator results. This process is called characterization, which is the second step in calculating the environmental impact (ISO, 2006b). The collection of indicator results is called the LCIA profile. The mentioned terms are clarified through an example in Table 2.5.

A third step could be normalization, which is the calculation of the magnitude of the category indicator results relative to some reference information (ISO, 2006b). This can be helpful for checking inconsistencies; providing and communicating information on the relative significance of the indicator results; and preparing for additional procedures, such as grouping, weighting, or life cycle interpretation (ISO, 2006b). The fourth and final step is weighting, which is the process of converting indicator results of different impact categories by using numerical weighting factors based on value-choices (ISO, 2006b). These values can be determined by the party that conducts the LCA, or by an external party that provides certain standards. In some case the weighted indicator results are aggregated. The last two steps of the impact calculation are dependent on the goal of the LCA and are therefore optional. The mentioned four steps are summarized in Table 2.6. Extra steps are grouping, where impact categories are sorted and possibly ranked, and data quality analysis, where the reliability of the LCIA profile is understood better.

Table 2.5 Examples of important terms from the LCIA (adapted from ISO, 2006b).

Term	Example
Impact category / Midpoint	Climate change
Area op protection / Endpoint	Ecological consequences
LCI result	Amount of GHG per FU
Characterization model	Baseline model of 100 years of the IPCC
Category indicator	Infrared radiative forcing (W/m^2)
Characterization factor	Global warming potential (GWP_{100}) for each GHG (kg CO_2e/kg GHG)
Category indicator result	Kilograms of CO_2e per FU
Environmental relevance	Infrared radiative forcing is a proxy for potential effects on the climate, depending on the integrated atmospheric heat adsorption caused by emissions and the distribution over time of the heat absorption

Table 2.6 Descriptions of the four steps for impact calculation (ISO, 2006b; Sphera, 2020).

#	Step	Description
1	Classification	Assignment of the LCI results to the selected impact categories.
2	Characterization	Calculation of category indicator results.
3	Normalization	Calculation of category indicator results relative to reference information.
4	Weighting	Conversion and possibly aggregation of indicator results across impact categories using numerical factors based on value-choices.

2.4.1.4. Interpretation

The interpretation starts by identifying the significant issues based on the LCI and LCIA results (ISO, 2006b). The results should be structured in accordance with the goal and scope definition. This is because the implications of the methods that were used must be taken into account, such as such as allocation rules, cut-off decisions, selection of impact categories, category indicators and models (ISO, 2006b). The identified issues are interactively linked with the second element of the interpretation phase, which is the evaluation (ISO, 2006b). The evaluation should consider completeness, sensitivity, and consistency checks to establish and enhance confidence in and reliability of the results from the LCI and LCIA, while taking the identified issues into account (ISO, 2006b). Besides analyzing the origin of relevant results, the influence of decisions and assumptions that were made should be evaluated. The evaluation should be presented in a manner that gives any interested party a clear and understandable view of the outcome of the LCA.

In the final element of the interpretation phase, conclusions should be drawn, limitations should be identified, and recommendations should be presented. These should be consistent with the requirements of the goal and scope of the study, including data quality requirements, predefined assumptions and values, methodological and study limitations, and application-oriented requirements (ISO, 2006b). The results from all 4 phases should then be reported in a report that is in line with the ISO 14040 and 14044 standards and that is designed to be easily read and understood. To allow the reader to comprehend the complexities and trade-offs inherent in the LCA, the report should be consistent with the goals of the study, complete and accurate in its contents, transparent and detailed in assumptions and limitations, and without bias to the intended audience (ISO, 2006b). A critical review should take place to validate the results of the LCA, but this is optional if the results of the LCA are only used internally.

2.4.2. GaBi

Software can be used to perform LCAs. One of such programs is GaBi from Sphera. In GaBi, the user can create a plan for a product system to model its entire life cycle. The program contains enormous databases, of which the largest is the EcoInvent database. These databases contain LCI datasets that reflect materials, energy mixes, and manufacturing and transportation processes that can be selected by simply dragging and dropping these datasets into a plan window (Sphera, 2021). A product system plan can contain different types of processes of which parameters can easily be adjusted. Processes are connected with trackable flows, which carry basic information for different types of balances. A flow can contain a material or energy type and it can be elementary if it interacts with nature, or non-elementary if it stays within the life cycle plan. Flows that are connected to processes must balance each other out, which means that everything that goes in must also come out.

Once a product system model is built, the results can be calculated to see the environmental impacts according to all relevant LCIA methods. These results are then displayed in dashboards. A scaling factor can be used to make sure that the created plan, with its processes and flows, conforms to a stated FU. Design scenarios can be compared and analyzed to identify the most sustainable and cost-efficient design. The program can also help in generating custom reports.


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Part 3

Method

In this part, the value chain assessment (VCA) method will first be introduced by shortly going over the six steps of the method. Then, each of the steps is treated in more detail in separate chapters. The first step treats the performance of a value chain inventory (VCI) analysis, in which the activities in the value chain are identified, the study's boundaries are set, and the inventory data is collected. The second step discusses how a value chain impact assessment (VCIA) should be conducted and interpreted. Guidelines are given for using the results of the VCI analysis in GaBi to determine the environmental impact of the RC's value chain. The results of the VCIA can then be interpreted and targets can be set in the third step. The fourth step proposes guidelines for identifying and prioritizing actions to generate a roadmap that can be followed by the RC to transition towards circularity. The fifth step presents the reporting components and requirements. The sixth and final step explains how iteration of the VCA method steps works in terms of updating results and documenting following iterations.

3.1. Value chain assessment

A method has been designed to map and eventually neutralize the GHG emissions and waste generated in the value chain of a company. This value chain LCA, or value chain assessment (VCA), method strives to achieve all the objectives that are stated in Chapter 1.2. When a company applies the VCA method, it becomes an RC. An RC is advised to report the results of the VCA method every year. The first time the VCA method is applied, the RC calculates its base year emissions and waste. The results of every year that follows can be compared to the results of the base year to see the RC's progress.

The designed VCA method is an organizational LCA (O-LCA). An O-LCA uses a life cycle perspective to assess the environmental impact of an organization's facilities and upstream and downstream activities (Martínez-Blanco, Finkbeiner, et al., 2015; Martínez-Blanco, Inaba, et al., 2015). The method provides a step-by-step roadmap that can be followed by companies that are striving to become RCs, or that want to gain insights in the GHG emission and waste streams that result from their value chains. The goal definitions and data requirements are therefore universal for companies that apply the VCA method.

Besides that, the method integrates the 14040 and 14044 LCA standards of the ISO (ISO, 2006a, 2006b) with the A&R standard for scope 3 of the GHG Protocol (GHG Protocol, 2011, 2013). It takes the reporting requirements of the integrated standards into account, which means that if the RC executes the VCA method thorough enough, its results can be used for both internal and external purposes. Internal use can help the RC to reinforce its sustainability strategy, while external use enables the RC to publish its results in scientific papers or marketing and official SBTi reports. The method also automatically serves the business goals that are stated in step one of the A&R roadmap from Table 6.2 in Appendix 6.A (p. 109-110). A company that applies the VCA method can choose for itself whether its results are disclosed to the public or not. Figure 3.1 and Table 3.1 present the steps of the VCA method. The following chapters will discuss the steps of the VCA method in more detail.

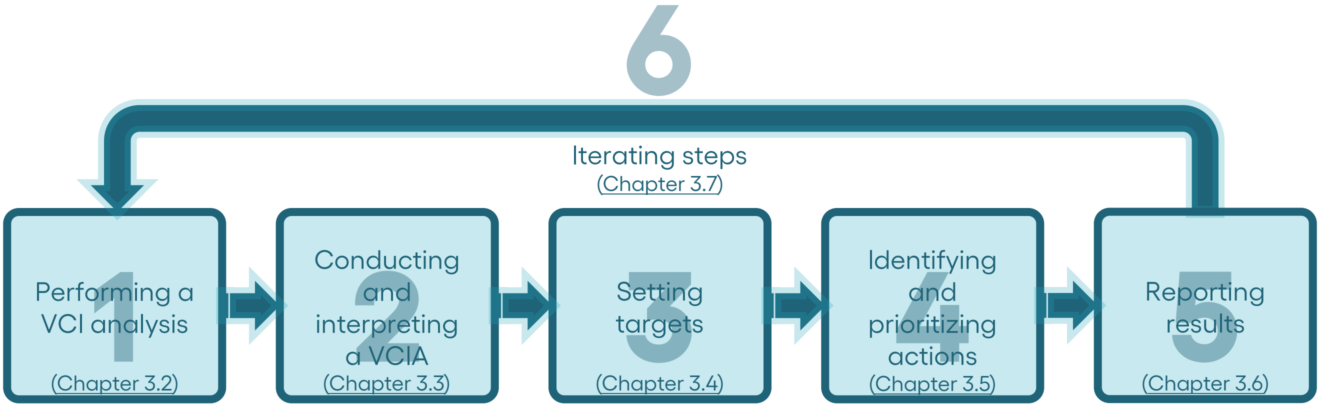


Figure 3.1 Schematic of the six steps of the developed VCA method.

Table 3.1 Descriptions of the six steps of the developed VCA method.

#	Step	Description
1	Performing a VCI analysis	A value chain LCI analysis, or value chain inventory (VCI) analysis, is performed in the first step of the VCA. This step starts by defining the scope of the study. When defining the scope, the partners and activities in the value chain of the RC are mapped, the functional unit is identified, and the system boundaries are calculated and motivated. The system boundaries will only be determined after the activities are identified in line with the 15 scope 3 activity categories of the GHG Protocol. A list of information that is required to complete the VCI, and methods for collecting, calculating, and allocating this information are presented. The VCI analysis will result in a representative baseline VCI that can be used to acquire results fast. The first results are not the most accurate, but the method is designed for these results to be improved over time.
2	Conducting and interpreting a VCIA	The second step of the VCA uses the baseline results of the VCI analysis to perform a value chain LCIA, or value chain impact assessment (VCIA). In this step, GaBi is used to conduct an LCA, and estimate and present the emissions and waste that are generated in a reporting year. A general interpretation of the results of the VCIA is also presented.
3	Setting targets	The results of the VCIA should also be interpreted to assess the impact of an RC's VCI and set accurate, attainable, and trackable targets for the elimination of GHG emission and waste streams.
4	Identifying and prioritizing actions	In the fourth step of the VCA, actions are identified for achieving the set targets. These actions are scored based on several significant aspects. The aspect scores of each activity are then used to prioritize the actions and form a roadmap that can be followed by an RC to achieve its SBTs.
5	Reporting results	Every time step four of the method is completed, the RC can decide to report the results. Steps one to four contain all the aspects that are required to be reported, so simply reporting on those will suffice. The method summarizes the components that should be present in such a report, and it restates the reporting requirements of the ISO and the GHG Protocol.
6	Iterating steps	Next, the RC can decide to iterate the previous steps to improve and update the results of the study. The main objective of this step is to complete the baseline VCI of the first step through additional data collection. The data is completed and re-evaluated by executing steps one to four again. The more complete the VCI becomes, the more accurate the estimated total emissions and waste of a reporting year become during the simulation. It is not required to fully complete the VCI during the first iteration. The method can be iterated until the VCI is as complete as required by the RC.

The following chapters describe the six steps of the VCA method in more detail. In Part 4, the designed method is applied to Sunrock's value chain. The results of this case study help to evaluate the developed VCA method.

3.2. Performing a VCI analysis

The designed VCA starts by performing a VCI analysis that combines the value chain analysis as mentioned by the GHG Protocol (2011) with the LCA's inventory analysis as mentioned by the ISO (2006a, 2006b). In other words, the guidelines from both the GHG Protocol and the ISO will be used to perform an inventory analysis that is in line with the structure and categories that are used by the GHG Protocol and the SBTi. Through this VCI analysis, the inputs and outputs of activities within the value chain will be mapped. To acquire a complete picture of the emission and waste streams in a value chain, both energy and material flows should be tracked. In the VCA, this information will be highly useful for determining where emissions and waste come from within a value chain. The task at hand is therefore to map the indirect energy and material flows in a value chain. Steps three to six of the A&R roadmap from Table 6.2 in Appendix 6.A (p. 109-110) will be used as a basis for the VCI analysis. First, the scope 3 activities should be identified and the boundaries for the data collection should be set. Data can then be collected and allocated within these system boundaries and for each identified activity. Throughout the VCI analysis, it is important that all assumptions are stated in sufficient detail.

3.2.1. Identifying activities

To identify the relevant activities in the value chain, the actors that are present within the value chain must first be identified. This should be done by making a VCI map, which will be a figure that depicts all types of actors in the value chain as blocks. The VCI map provides a graphical and presentable overview of the RC's value chain. It helps to understand the value chain and all the activities that take place in it. A generic example of such a VCI map is presented in Figure 3.2 (p. 42). At the center of this VCI map should be a block that contains the name of the RC. This block represents a facility of the RC. If the RC has multiple relevant facilities, these must be differentiated through different blocks. All groups of actors that are somehow linked to the RC should be represented with a block that is linked to one of the blocks of the RC. The map should eventually represent what is being done in the RC's value chain and by who. It would be highly efficient if the RC has a database that can be consulted to acquire information that is required to map the value chain. Identified activities use energy and possibly materials, which will result in emissions and waste. An actor group performs one or more activities. Each activity should be assigned to one of the 15 scope 3 activity categories from Table 6.1 in Appendix 6.A (p. 107-108). A special exception exists for water suppliers since the upstream processes of purchased water are not included in the categorization of the GHG Protocol. In the VCA method water suppliers fall under activity category 3 because of the analogy between the upstream processes of water and electricity.

Each actor group can be color-coded according to their assigned scope 3 activity categories. The scope 1 and scope 2 data of the identified actor groups determine the scope 3 data of the RC. The actors that determine the scope 1 and scope 2 data of the identified actor groups can be left out of the VCI map. Upstream transportation and distribution activities can be supplemental activities to activity categories 1 and 2 if it is done by the supplier or the buyer. In the same way, downstream transportation and distribution activities can be supplemental activities to activity category 11. These can also be stand-alone activities if a transporting actor group performs specifically these activities. Transportation activities are already included within activity categories 3 and 5. Upstream and downstream distribution activities can be differentiated through color-coded connection arrows with descriptions alongside them. These descriptions should contain the name of the transporting actor group when an actor group solely performs a transportation activity as the transportation activities are represented by arrows and not by blocks.

Other connections that are not defined by a transportation or distribution activity should also be specified. Arrows define the direction in which an interaction between two actors takes place. As the documentation of an RC's value chain can take on complex forms, the VCI map should be presented with a set of notes that clarifies any ambiguities. All the activity categories that are excluded from the VCI should also be listed together with a justification of their exclusion. An activity should not be excluded if this would compromise the relevance of the reported inventory. The criteria that are formulated in step three of the A&R roadmap from Table 6.2 in Appendix 6.A (p. 109-110) are not used for identifying scope 3 activities because the VCI map must represent the complete value chain and not only the relevant actors in it. The VCI map must therefore be checked and validated with one or even multiple suitable employees from the RC that executes the VCA method. The relevance of each of the identified activities will be determined when the system boundaries are set.

When all relevant actor groups of the value chain have been identified, a list should be composed of all companies that belong to the identified actor groups. When there are many different companies in an actor group, these can be grouped as "company combination" if this is disclosed and does not compromise the eventual results of the study. For each company that is a product supplier, the products that the company supplies should be listed with their reference- or type-number. When a supplier supplies many different types of products, such as groceries or office equipment, these can be grouped as "product combination" if this is disclosed and does not compromise the eventual results of the study. The products that the RC sells can also be listed under the product users. For each of the identified actor groups, a description of its specific activities should be given. All this information should be compiled in a table, where letters and numbers can be used to code actor groups, companies, and product types. A generic example of such a table is presented in Table 3.2 (p. 43). The number of activity categories that is noted for each actor group determines how many activities and therefore processes are determined by this actor group. The RC is not included in this table as it does not generate the emissions in scope 3. As the documentation of an RC's value chain can take on complex forms, the value chain actors table should be presented with a set of notes that clarifies any ambiguities. All value chain activities are now identified, together with the actors that perform them and the activity categories to which they belong. A list of all the purchased and sold goods and services is now also available. Because supply chains are dynamic and an RC's supply chain partners can change frequently, it may be useful to choose a fixed point in time or use a representative average of suppliers and service providers (GHG Protocol, 2011).

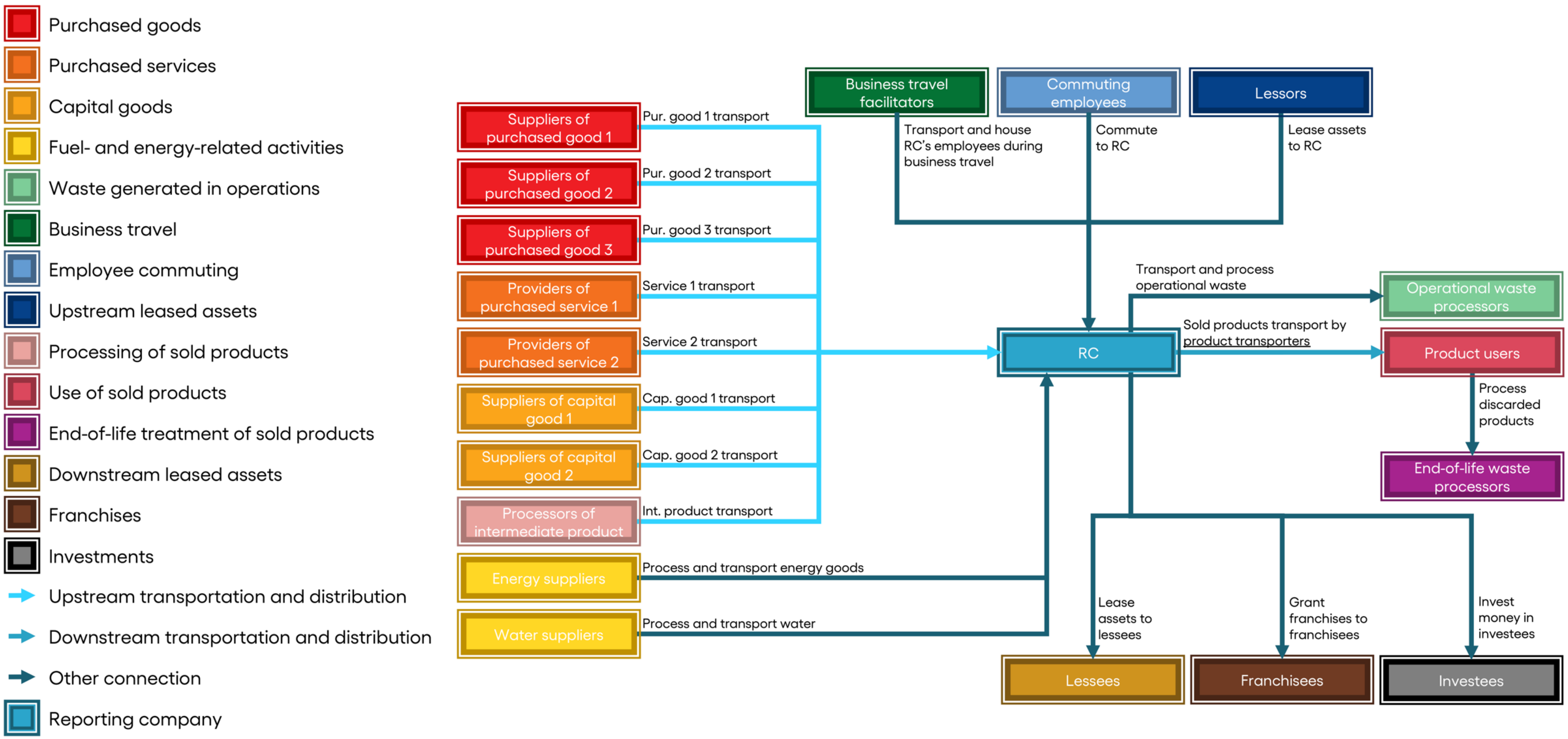


Figure 3.2 Generic example of a VCI map with its actors and connections.

Table 3.2 Generic and concise example of a value chain actors table.

#	Actor group	Activity categories	Companies	Prod. types	Activity description
A1	Suppliers of purchased good 1	1 and 4	A1.1	A1.1.1 A1.1.2	Supply purchased good 1
			A1.2	A1.2.1	
A2	Suppliers of purchased good 2	1 and 4	A2.1	A2.1.1	Supply purchased good 2
A3	Suppliers of purchased good 3	1 and 4	A3.1	A3.1.1	Supply purchased good 3
			A3.2	A3.2.1 A3.2.2	
B1	Providers of purchased service 1	1 and 4	B1.1		Provide purchased service 1
B2	Providers of purchased service 2	1 and 4	B2.1 B2.2		Provide purchased service 2
C1	Suppliers of capital good 1	2 and 4	C1.1	C1.1.1	Supply capital good 1
C2	Suppliers of capital good 2	2 and 4	C2.1	C2.1.1	Supply capital good 2
			C2.2	C2.2.1	
D1	Energy suppliers	3	D1.1	Electr. N. gas	Process and transport energy goods
D2	Water suppliers	3	D2.1	Water	Process and transport water
E	Operational waste processors	5	E.1		Transport and process operational waste
F	Business travel facilitators	6	Company combination		Transport and house RC's employees during business travel
G	Commuting employees	7			Commute to and from RC
H	Lessors	8	H.1		Lease asset to RC
I	Product transporters	9	I.1 I.2	RC.1 RC.2	Transport the RC's products to the buyers.
J	Processor of intermediate product	10	J.1	J.1.1	Process intermediate product for RC
K	Product users	11		RC.1 RC.2	Buy and use the RC's products
L	End-of-life waste processors	12	L.1		Process RC's discarded products
			L.2		
M	Lessees	13	M.1		Lease assets from RC
N	Franchisees	14	N.1		Run franchises for RC
			N.2		
O	Investees	15	O.1		Is invested in by RC
RC	Reporting company				

3.2.2. Setting boundaries

The next step is to set the boundaries for the collection of data. For each of the just identified actor groups, it must be determined which data will be included in the VCI and which data will be excluded from it. The first step in determining the boundaries is to identify the FU that will be applied during the data collection and allocation. This FU should be relatable to the business operations of the RC in a sense that the RC fulfils a multitude of the stated FU in a year. This way, the results of one FU can be used to determine the RC's yearly generated emissions and waste. To determine the system boundaries, an estimation should then be made on how heavy each activity of each identified actor group contributes to the following relevant matters (ISO, 2006b):

- The total mass of the materials that are required to fulfil one FU.
- The total energy that is required to fulfil one FU.
- The environmental burden that is caused by fulfilling one FU.

To execute this estimation process, a table should be made in which the expected contributed mass and energy of each activity that an actor group performs is compared to the total mass and energy that is accounted for by one FU. For each activity of each actor group, an estimation must first be made of how many units this activity must deliver for the fulfilment of one FU. Next, the mass of one unit and the energy that is required to deliver one unit should be estimated. When making these estimations, values of different activity alternatives can be averaged (i.e., the average number of purchased good 1 required), one specific representative activity alternative can be selected (i.e., the mass of capital good C2.2.1), or an outside reference value can be used (i.e., the energy required to produce a liter of gasoline according to the IEA). Different types of reliable internal and external sources can be used for these estimates. However, the sources and assumptions that are required to make the estimations should be noted properly.

Whether the data from an actor group will be included in the VCI is determined through mass and energy contribution percentages (CPs). Ideally, each activity of an actor group will have an estimated CP for both mass and energy, but at least one CP should be calculated. It is important that the mass and energy units in which the estimations of each activity are noted are comparable. The meanings of CP intervals are stated in Table 3.3. Each CP interval has a specific level of detail, ranging from 0 to 4, indicating how much of the to-be-collected data can be based on assumptions. The highest of the two CPs determines the level of detail. Exceptions to the rules of inclusion and level of detail should be clearly stated as they can compromise the eventual results of the study. It must also be disclosed and explained if a level of detail cannot be reached. The RC should then strive for improving this data over time until the level of detail is reached. The level of detail serves as a guideline for ensuring that more time is spent on gathering significant data and less time is spent on gathering insignificant data.

The stated levels of detail indicate the following:

0. No data must be collected.
1. Data can be fully based on assumptions.
2. Data that is expected to have significant impact must be detailed; assumptions are allowed for all other data.
3. Most data must be detailed; some assumptions are allowed.
4. All data must be as detailed as possible; assumptions should be a last resort.

Table 3.3 CP intervals and how they should be interpreted (adapted from ISO, 2006b).

CP interval	Importance	Influence	VCI inclusion	Level of detail
CP ≤ 1%	Not important	Negligible influence	No	0
1% < CP ≤ 2.5%	Little important	Minor influence	Yes	1
2.5% < CP ≤ 7.5%	Fairly important	Some influence	Yes	2
7.5% < CP ≤ 30%	Very important	Relevant influence	Yes	3
CP > 30%	Most important	Significant influence	Yes	4

Whenever there seems to be considerable doubt regarding the outcome of CPs, additional data should be collected to ensure that no relevant actor group is excluded. When an actor group is excluded, the noted sources and assumptions should provide sufficient information to disclose and justify this exclusion. Implications for this exclusion must also be stated. The RC may decide to still include an actor group that is excluded based on the CP values. If documented appropriately, estimated CPs can be changed during data collection, which might lead to late exclusion of an actor group. If the RC decides that specific actor groups are required to be included, without considering the CPs, this should be disclosed. They can then be included and no calculations must be performed to prove the activities of these actor groups are within the system boundaries. The RC must then state and justify the level of detail with which these actor groups are treated. Reaching the level of detail is not required if a value chain partner directly provides LCA results. These results can then be directly transferred to the VCI.

Since there might be actor groups that are estimated to not contribute significantly to either the total mass or energy, an actor group's activity can also be found to be relevant by having an estimated environmental significance. The environmental significance is therefore important for including inputs that are estimated to contribute significantly to one or more specific data topics of the product system that are specially selected because of environmental relevance (ISO, 2006b). If an actor group is estimated to be relevant through its CPs or environmental significance, it is included in the VCI. The environmental significance should be determined for each actor group's activity that is estimated to not have a large enough CP for both mass and energy. Extra research must be done to figure out whether an activity might be environmentally significant. The actor groups that are included because of their environmental significance should be treated with detail level 2 since it is only required to collect detailed data for the data topics that caused their environmental significance. Detail level 4 is required for all effects that are directly caused by the RC.

Determining the environmental significance for an activity of an actor group that has already been estimated to contribute significantly to either mass or energy is not necessary. It can however be done to highlight the environmental relevance of this actor group. For some activities it is not possible or relevant to calculate the contributing mass or energy, like the mass of a known distance of transportation, or the mass of a provided service. The CPs of activities should only be calculated when possible and relevant. Table 3.4 shows an example of how the activities of an actor group should be assessed on their relevance, where the total mass has been taken to be 11,500 kg, and the total energy 15,600 GJ. The system boundaries table should also be presented with a set of notes that clarifies any ambiguities. It is unavoidable that many assumptions are made when making this system boundaries table during the first cycle of the VCA method. Data from data collections can be used for the system boundaries table during all VCA method iterations that follow. This makes the system boundaries table more accurate over time.

Table 3.4 Example of a system boundaries table for one actor group.

#	A1	
Actor group	Suppliers of purchased good 1	
Activity category	1	4
Activity description	Manufacturing purchased good 1	Transporting purchased good 1
Estimated units required per FU	250 pieces	2,200 kilometers
Sources and assumptions for estimation	Source D indicates that 250 pieces are needed to fulfil a FU.	Using source G, the distance that is traveled by truck has been calculated to be 2200 km.
Estimated mass per unit (kg)	18	
Estimated total mass (kg)	4,500.	
Sources and assumptions for estimation	Source E indicates that each good weighs 18 kg.	
Mass CP	39%	
Estimated energy per unit (GJ)	9.3	0.014
Estimated total energy (GJ)	2,325	29.7
Sources and assumptions for estimation	Source F indicates that each good requires 9.3 GJ to manufacture.	Source H says that 3 MJ per ton-km is needed for freight truck transport.
Energy CP	15%	0%
Environmental significance		
Sources and assumptions for environmental significance		
Inclusion	Yes	
Level of detail	4	
Implications of exclusion		

3.2.3. Collecting data

3.2.3.1. Data collection rules

After the boundaries have been set, the data on energy and material flows of the included actor groups should be collected or calculated. When the goal is to perform a VCA, specific information is required about the activities that are performed by the actor groups that have been identified to be included in the VCI. This information is essential for mapping the input and output flows for activities in specific activity categories. Based on the LCA data requirements and the minimal scope 3 boundaries from Table 6.1 in Appendix 6.A (p. 107-108), the exact information that is required for an activity within an activity category has been determined and is shown in Table 6.3 in Appendix 6.A (p. 111-113).

Supplemented with data from the EcoInvent database (or any other certified LCI database), this information is all that is required to identify an activity's relevant flows for the VCI. This required information therefore also automatically determines the level of detail that is expected in the VCI analysis and the following VCIA. Through specific activities, each actor group contributes to specific activity categories, for which the stated required information must be collected if this actor group has been estimated to contribute significantly through either its CPs or environmental significance. Waste can be generated in each of the 15 scope 3 activity categories. Waste data should only be collected and calculated in categories 1, 2, 5, 8, 10, 11, 12, 13, 14 and 15.

Waste that is generated in the other categories will be calculated by GaBi in the next step of the VCA method. Waste can originate from the RC's scope 1 activities if it is generated by the RC's own facilities, or from scope 3 activities if it is generated by one of the RC's partners. Many of the energy and material flows from scope 1 and scope 2 are required to calculate some of the energy and material flows from scope 3. All energy and material flows from scope 1 and scope 2 are therefore integrated in the required information.

The GHG Protocol also published guidelines that can be followed to calculate this scope 1 and scope 2 data (GHG Protocol, 2019). The exponent that is written next to the number of a piece of required information indicates to which scope(s) it belongs. All scope 1 and scope 2 data is relevant for determining scope 3 data in GaBi, except for the data regarding the fugitive emissions. Since the fugitive emissions are not directly connected to another actor group than the RC, the RC can collect this data as general required information. To make the scope analysis of the value chain complete, the fugitive emissions can be considered in the VCA by documenting them as an output of the RC. As reporting on fugitive emissions is not mandatory according to the SBTi, the RC should decide and justify whether fugitive emissions will be part of the VCA.

The activities that each actor group performs are closed systems, or "black boxes", in which all input and output flows associated with that particular process are accounted for (Franklin Associates, 2011). These processes are black boxed as it is a waste of time to map processes in high detail when they do not have a significant impact after the first data interpretation. Primary data should first be collected, after which it can be complemented with secondary data and eventually even proxy-data if there is no other option to acquire the data. When collecting the data, it must be determined and justified whether a specific piece of the stated required information is relevant for a specific activity that is performed by an actor group. To complete the VCI, the same relevant required information should eventually be collected for each actor that performs this activity. This is important since it gives the RC the option to exclude required information from Table 6.3 in Appendix 6.A (p. 111-113) if this information is deemed to have insignificant impact. Sources, assumptions, and calculations are needed to acquire this required information, but also to determine the eventual flows that belong to the activity or process for which the required information has been collected. The tools that are needed to determine the required information and flows of a process depend on the format in which the required information is available.

It is expected that sources, assumptions, and calculation methods, but also problems with data quality, reasons for exclusions, and implications of assumptions, are clearly stated for each piece of required information that should be collected, and for each process flow that must be defined. Whenever a piece of required information cannot be collected, assumptions should be made or data from one of the GaBi databases should be used to ensure that the dataset will be as representative as possible and that the VCI analysis can still be completed. Due to confidentiality issues, it might be that no required information can be directly collected from an actor or even an entire actor group. A suitable solution must be found for gathering sufficient data to still complete the VCI analysis and include such an actor or actor group. It is expected that this solution is disclosed when these problems arise.

The collected or calculated data should be inserted into a custom data template. This data template brings the data from different sources together to provide a unified view. This template therefore enables the correct integration of the collected and calculated data. At the same time, the template helps the RC to keep track of the required information that still must be collected. An exemplary template is presented in Table 3.5 on the next page. Templates for all activity categories can be downloaded through a link in Appendix 6.C (p. 149). At the top, the RC can note general information that can help in the organization of the results. The example provides space to document the required information and the sources, assumptions and calculations that provide it. At the bottom of the template there is space to distill the required information into inputs and outputs of a process that is named after the activity description, the company, and the product type. These inputs and outputs should be noted together with the quantities that are required to fulfil one FU. There is also space to document the sources, assumptions and calculations that are required to define the process flows.

Table 3.5 Exemplary template for data collection and calculation.

#	A1
Actor group	Suppliers of purchased good 1
Activity category	1
Activity description	Manufacturing purchased good 1
Data type	Secondary
Data collection method	Calculation
Company	A1.1
Product type	A1.1.2

#	**Required information**	
1.1	Bill of materials together with the amount of each (raw) material per purchased good. Material A x kg Material B y kg	Sources, assumptions, and calculations - A survey was sent to company A1.1 to have them provide the required information. Company A1.1 provided the full BOM with exact amounts for product A1.1.2 (Company A1.1, 2022).
1.2	Recyclability or potential recovery percentage of each of the used (raw) materials. The recyclability of product A1.1.2 is 90%.	Sources, assumptions, and calculations - Company A1.1 reported that product A1.1.2 has a recyclability of 90% (2022).
1.3	Other manufacturing substances used per purchased good. Water is among these substances. 20 liters of water is used for product A1.1.2.	Sources, assumptions, and calculations - Company A1.1 reported that 20 liters of water are used for manufacturing product A1.1.2 (2022).
1.4	Amounts and types of waste generated by the manufacturer per purchased good. 20 liters of wastewater is created for product A1.1.2.	Sources, assumptions, and calculations - Company A1.1 reported that 20 liters of wastewater is generated when manufacturing product A1.1.2 (2022).
1.5	Amounts and types of GHG emissions per purchased good. This can be an average for combined purchased goods. 19 kg CO_2e is emitted for product A1.1.2.	Sources, assumptions, and calculations - Company A1.1 reported that 19 kg CO_2e is emitted when manufacturing product A1.1.2 (2022). - No distinction is made between different GHGs.
1.6	Number of purchased goods needed per FU. 25 A1.1.2 products are needed.	Sources, assumptions, and calculations - The RC requires 25 A1.1.2 products per FU.
1.7	Expected lifetime of the purchased good. The expected lifetime of products A1.1.2 is 5 years.	Sources, assumptions, and calculations - Company A1.1 reported that the expected lifetime of product A1.1.2 is 5 years (2022).
1.8	Amount of electricity consumed by the manufacturer per purchased good and the sources from which this electricity originates. 0.08 kWh of electricity is used for product A1.1.2	Sources, assumptions, and calculations - Company A1.1 reported that 0.08 kWh is used when manufacturing product A1.1.2 (2022). - The used electricity comes from renewable sources.
1.9	Amounts and types of fuels used (also for generation of electricity) by the manufacturer per purchased good. No fuels are used for product A1.1.2.	Sources, assumptions, and calculations - Company A1.1 reported that no fuels are used when manufacturing product A1.1.2 (2022).
1.10	Types of disposal or treatments used for specific types of generated waste. Wastewater is filtered in a water treatment plant.	Sources, assumptions, and calculations - The generated wastewater goes into the sewer and is filtered in a municipal water treatment plant.
1.11	Modes and distances of transportation of generated waste. No modes of transport are used.	Sources, assumptions, and calculations - No modes of transport are used for transporting the wastewater to the water treatment plant.
1.12	Modes and distances of transportation of the purchased good within the manufacturing facility. No modes of transport are used.	Sources, assumptions, and calculations - No modes of transport are used for transporting product A1.1.2 within the manufacturing facility.
1.13	Amounts and types of materials used for the packaging of the purchased good. 50 g of cardboard is used for packaging product A1.1.2.	Sources, assumptions, and calculations - Company A1.1 reported that product A1.1.2 is packaged with 50 g of cardboard.

Process and flows

Inputs		Process	Outputs	
Material A	25x kg	Manufacturing purchased good 1 – A1.1, A1.1.2	Product A1.1.2	25 units
Material B	25y kg		Wastewater	500 L
Water	500 L		CO_2e	475 kg
Electricity (renewable sources)	2.00 kWh			
Cardboard	1,250 g			

Sources, assumptions, and calculations
- All mentioned amounts have been reported with 25 to allocate the manufacturing process for product A1.1.2 to the stated FU.
- No data is provided for where the inputs come from. Processes from the Sphera database have therefore been used to provide the manufacturing process with its inputs.
- A process from the EcoInvent database has been used for the filtering process of the municipal water treatment plant.

The defined processes and their flows can be summarized at the end of the data collection in a process overview table. The processes from the overview can be assembled in a figure that is based on the VCI map. This figure can be recreated in a GaBi plan in the next step of the VCA method. Data from the software's database can then be used to supplement and complete this plan. An example of such a process overview is presented in Figure 6.1 in Appendix 6.B (p. 136), which does not contain all company, product, and service alternatives of each actor group from Table 3.2, but enough to illustrate the example. The following notes are important for using the provided data template and defining the processes:

- In the VCI map the transportation and distribution activities from categories 4 and 9 are presented as arrows. In GaBi these activities are presented as processes. It is therefore important that these processes are defined by filling in separate data templates for each activity that belongs to these categories.
- The data template for purchased goods differentiates from that for purchased services because these activities require different information to be gathered. Two types of processes can therefore follow from this category since an actor group either supplies a good or provides a service. If an actor group performs both activities, one combined data template can be used to create one combined process.
- In the categorization of the GHG Protocol, processing and transporting waste fall under the same activity category. When defining processes in GaBi however, these activities should be treated as two separate activities because the software already has existing processes for transport. Two differentiating data templates should therefore be used for a single activity. One data template collects the required information regarding the waste processing and specifies the accompanying process, while another data template does the same regarding the waste transport. This is also done for manufacturing and transporting purchased or capital goods, but there it happens automatically since the manufacturing and transportation are seen as two different activities in two different categories.
- When a defined process performs activities from multiple scopes, from multiple activity categories, or at multiple points in time during the lifecycle, the process should be split up to nullify this. This makes it possible to keep the data from different groups separated, and therefore enables the comparison of the different groups in the data analysis. When the process overview is recreated in a GaBi plan, it is also important that the plan is configured in such a way that it enables grouping.
- An actor group can perform activities for which processes are available in one of GaBi's databases. When a process from one of the databases sufficiently represents (a part of) an actor group's activity, this database process can be used in the GaBi plan. The outputs from database processes should be passed on as inputs of the actor group's process. This actor group can then use this input or pass it on as output. Grouping can be used to ensure that the impact of the database process is still allocated to the actor group.
- Database processes can possibly be supplemented with other database processes or with processes that are based on collected data. It is important to note that database processes should only be used if data collection has been limited for some reason, or if it is believed that a database process is more representative than a process that is based on collected data. If collected data is limited, flows of used database processes can also be changed so that database

processes become more representative of the actual process. The use of database processes should always be disclosed as they might compromise the eventual results of the study.
- In the end, when recreating the process overview in a GaBi plan, an extra process should be created for each of the RC's facilities from the VCI map. A facility process is required to let a facility receive all outputs from its inbound processes and provide all inputs for its outbound processes. These processes should always contain flows with their corresponding amounts. Fixing the scaling factors of these processes then automatically causes the other processes in the plan to adopt the correct amounts if the plan is configured correctly.

As mentioned, the two available data collection methods are the direct measurement method and the calculation method. Since this is the data collection of a VCI, much data will be acquired by applying the calculation method to data from some internal, but mostly external sources. Each activity category has a multitude of available calculation methods for determining the required information from Table 6.3 in Appendix 6.A (p. 111-113). The calculation methods per category are shown in Table 6.4 in Appendix 6.A (p. 114-115). They come from a technical guide that supplements the A&R standard of the GHG Protocol (2013). The guide can be used for calculating scope 3 emissions. A download link is presented in Appendix 6.C (p. 149).

The more specific the used data calculation method is, the more accurate the eventual results of the study will be. It is important that ground rules are established before the VCI data collection starts. These ground rules are defined by the data quality requirements. The following data quality requirements are stated for VCI data collection:
- The data that is time-sensitive should be collected over a period of 6 months. This data should also be renewed every 12 months.
- Data should come from or represent the geographical location where the processes behind the data originate from.
- No activity within the value chain can be absent in the VCI, unless exclusion has been disclosed and justified in advance.
- Variability of the data value should be low since most of the data will be calculated from information that is directly provided by official environmental organizations, suppliers, or other value chain partners. A specification is required whenever a data value has a precision that is lower than expected relative to this study.
- All required data must be accounted for in the VCI. Assumptions must made to fill in missing data points. Missing data and data gaps should be documented and treated to result in "non-zero" data values that are explained, "zero" data values if explained, or calculated values based on the reported values from unit processes with a similar technology.
- The stated data collection methods must be selected appropriately per activity and applied consistently throughout the collection of all data values.
- Sources and assumptions should be noted to such a degree that an independent practitioner is able to reproduce the results reported in the study. The reporting of sources and assumptions should also inform on the uncertainty of data values.
- The sources that are essential and deemed to be credible for data collection are direct measurements, official organizations, value chain partners, expert interviews, surveys, and scientific literature.

Activities have already been prioritized by defining the system boundaries. For each of the identified activities, the data type (primary, secondary, or proxy) and necessary data collection method (direct measurement or calculation) must be determined. Data can then either be directly measured when the RC has the ability to do this, or calculated from external sources when the relevant input and output flows are outside the reach of the RC. The data can be collected per FU, or calculations can be made to convert the collected data into data per FU. Collected data can be organized in the data template from Table 3.5, so that it shows the input and output flows per FU of the process(es) each actor in each category performs. Flows can be coded with reference numbers or colors to make it easier to analyze them at a later moment. Within such a template, all sources and assumptions should be noted for each flow. Here it is important that all information that is used to make a calculation and get to the final data value is presented, such as the method, activity data, emission factors and GWP values. For each assumption it must be specified if and how this assumption will influence the resulting data value. After all data is collected, the percentage of emissions and waste calculated using data obtained from suppliers or other value chain partners must be determined and reported.

3.2.3.2. Allocating emissions

Collected primary data might need to be allocated before it represents the FU accurately. During allocation, GHG emissions and waste from a single facility or other system are partitioned among its various outputs (GHG Protocol, 2011). As mentioned, allocation is necessary when a single facility or other system produces multiple outputs during co-production, or when emissions or waste are only quantified for the entire facility or system as a whole (GHG Protocol, 2011). Allocation can also be used when avoided products are generated in one life cycle as waste but used in another life cycle as resource. Allocation should be avoided if it is not necessary since it adds uncertainty to the emission and waste estimates. Allocation can be avoided by finding data for the specific product purchased, by sub-metering outputs of a process separately, or by using engineering models to separately estimate the outputs of a process separately (GHG Protocol, 2011).

All allocation methods try to determine the partition or contribution of a specific part of a larger whole. Physical allocation is preferred and is often based on mass, volume, energy, chemicals, or number of units. This method is used when physical factors reflect the causal relationship between production of the outputs and the resulting emissions or waste best and when data is available on the physical quantities of the outputs produced (GHG Protocol, 2011). If this is not the case, economic allocation is often used, in which the allocation is mostly based on market value (GHG Protocol, 2011). Other relationships can also be used in custom allocation methods. When an allocation method is applied, the decision for this method should be justified and the process should be explained when the sources, assumptions, and calculations are documented.

3.2.3.3. Baseline dataset

Within a value chain there are often many different actors that fulfil the same role. These actors provide a product or service that is an alternative to a product or service that is provided by another actor in the same actor group. Eventually, data should be collected from all these actors to acquire a complete and accurate picture of all emission and waste streams. However, one actor group does not contribute as much to the emission and waste streams of the value chain as another. Therefore, a representative baseline dataset should first be collected that presents an accurate average of the total emission and waste streams of each actor group. Data that will be included in this baseline dataset must be specified before the data is collected. Average values must be calculated for an actor group, or one representative alternative should be chosen to collect data for. This data should then be used in the VCIA, which is performed at a later stage of the VCA. The results of this VCIA will then give an accurate representation of the most significantly contributing actor groups for the fulfilment of one FU. To-be-collected data can then be further prioritized so that the largest contributors are mapped first and the largest part of the VCI is determined as fast as possible. A checklist can be made to keep track of the progress within the data collecting process. As mentioned previously, data collecting will be an iterative process. Quality of collected data can be improved over time. This should first be done for the data that that seems to have the highest significance after the first data interpretation. The data collector should always strive for the highest quality data as this influences the accuracy of the eventual results of the study.

3.3. Conducting and interpreting a VCIA

After the VCI has been mapped, it is time to use the collected data in a VCIA, in which the environmental burden that is created by the VCI is identified and quantified. The steps that are executed in a regular LCA have been described in Chapter 2.4. The first two LCA steps have already been performed for this VCA. The goal and scope definition have been stated in the introduction of the VCA method in Chapter 3.1. A to the RC's value chain adjusted version of the LCI analysis has been performed through the VCI analysis. This chapter will dive deeper into the steps of the LCA that rest, which are the impact assessment and interpretation. During the interpretation, the assurance step of the A&R roadmap from Table 6.2 in Appendix 6.A (p. 109-110) takes place.

3.3.1. Assessing impact in GaBi

The LCA theory that was mentioned in the theoretical framework forms the basis for the VCIA. During the impact assessment, the GHG emission and waste streams of the RC's value chain will be determined by the software through analyzing energy and material flows. The software can use scope 1 or scope 2 data of a process to calculate scope 3 data that comes from this same process. The required information regarding the scope 1 and scope 2 emission and waste streams have been included in Table 6.3 in Appendix 6.A (p. 111-113).

Within GaBi, all actor groups from the VCI map will perform black boxed activities. The actor groups from the VCI map that have been included in the VCI because of the set system boundaries should therefore be copied to the GaBi plan. Each actor that has been elected from each included actor group for the baseline dataset represents a process. The baseline data flows and processes that were defined during the VCI analysis can be transferred to the plan. Wherever the data gathering was limited for any reason, processes from one of GaBi's databases can be used. Scaling factors can be used to incorporate the FU where this is still necessary. This way, the relevant actor groups of the VCI map will be depicted in the plan, together with all their relevant flows that eventually determine their emission and waste streams. Because the plan of the value chain can become quite extensive, it can also be composed of several smaller plans to keep an overview of the entire model. Individual plans can be made for the separate scope 3 activity categories for example. These individual plans can then be combined in the end. The results of the separate scope 3 categories can then also be analyzed individually. This can help for setting targets and actions, or it can help to track the progress towards circularity.

During the VCIA in GaBi, the LCIA method of the IPCC called "IPCC AR6" will be used to present the results regarding the GWP. The baseline characterization model of 100 years has been used, which determines the category indicators and the characterization factors. The sole impact category of the IPCC AR6 method is climate change, of which the category indicator results are expressed in kg CO_2e. The method therefore combines the VCI results with the category indicator and the characterization factors to form a VCIA profile. It is also possible to generate the results both including and excluding biogenic CO_2, which is relevant for eventually reporting GHG emissions. A set of normalization factors is also already implemented. Since the method only contains one environmental impact, it is not possible to implement weighting factors. Depending on the needs of the RC, the created model can of course also still be analyzed with other LCIA methods. This might provide useful insights for setting targets or identifying and prioritizing actions.

The processes in the GaBi plan should be grouped, and can be color-coded, in groups that are “user defined” according to GaBi. The processes in the plan should first be assigned to their corresponding actor groups to provide insights regarding the categorization of the study. Next, the processes should be grouped in either scope 1, scope 2, or scope 3. A copy can be made of the plan, so that the scope 3 processes can also be grouped in user defined groups that carry the name of the 15 scope 3 activity categories. The results of each scope and of each activity category can then be compared when the dashboards are generated. To ensure that emissions and waste that belong to a reporting year are easily distinguishable, it is essential that also a plan is made that contains groups that indicate which of the processes have emissions and waste that are generated at a specific moment in the life cycle, and which take place throughout the entire lifecycle. When finished, the GaBi plans should be exported and presented in the report together with a description of the creation process. A specific VCIA dashboard template has been created that incorporates the IPCC AR6 method to present the GWP of the created groups (see Figure 6.2 in Appendix 6.B, p. 137). A link for downloading the designed dashboard is presented in Appendix 6.C (p. 149). This dashboard also presents the total generated waste and involved energy for each specified group. A data quality analysis should then be performed to understand the significance, uncertainty, and sensitivity of the VCIA results. The results of such a data quality analysis may lead to revisions of the VCI. Specific techniques can help to identify whether significant differences are or are not present, to identify negligible VCI results, or to guide the iterative VCIA process (ISO, 2006b). The following analyses can be performed to estimate and enhance the quality of the used data (ISO, 2006b):

- A gravity analysis can be done to check which of the data points contribute the most to the VCIA profile. These items should then be investigated with increased priority to ensure that the right decisions are made.
- An uncertainty analysis can be performed to determine how uncertainties in data points and assumptions progress in the calculations and how they affect the reliability of the results of the VCIA.
- A sensitivity analysis can be executed to determine how changes in data points and methodological choices affect the results.

GaBi can also be used to export results of the generated model in the form of VCI tables that summarize and categorize the flows of the model in exact numbers (see Figure 6.3 in Appendix 6.B, p. 138). This can be done in several quantities, such as mass, energy, units, emissions, or any other distinct category GaBi lists, which means that these tables come in handy for identifying the generated waste and involved energy. There is no LCIA method that analyzes the amount of generated waste in a simple way. The total amount of generated waste should therefore be identified by analyzing the flows that fall under the category “production residues in life cycle” from the Sphera database, which makes the distinction between the subcategories of “waste for disposal” and “waste for recovery”. Waste for disposal cannot be recycled, while waste for recovery can be. Within the VCA method, different targets can eventually be set for “direct waste” and “indirect waste”. Direct waste is generated through the strategy of the RC and can therefore be eliminated through direct intervention. Indirect waste is generated through the strategies of partner companies and can only be eliminated by strategy adjustments of these companies. Two additional folders for direct and indirect waste should be created within the waste for disposal subcategory. During a dashboard analysis, the mentioned subcategories and the folders in them can be presented in kilograms. All generated waste flows that are assigned to these subcategories and folders are then summed up. To ensure that all generated waste streams fall under this production residues in life cycle category, it is important that all generated waste flows from waste processes are documented in GaBi as flows that either come from these subcategories of the database, or that are created and assigned to these subcategories manually. The VCIA dashboard can then calculate how much waste is generated and how much of this waste can be recycled. At the highest level, the overall origin, treatment, and recycling percentage of a product can already help to define the waste process and differentiate between waste mass for disposal and waste mass for recovery. At a lower level, the origins, disposal treatments and recycling percentages of individual components can be specified to get more accurate results. The emissions and energy that go paired with the waste from waste processes also give an indication of the environmental impact of these processes. This information might be useful for identifying and prioritizing actions that can reduce both emissions and waste.

Data from the VCI tables can also be used by RCs to investigate and clarify specific relations that are important for their specific cases. RCs can use VCI tables in any quantities they deem relevant for their studies. The dashboards and VCI tables from GaBi should be used to eventually present the results they contain in the report. The report should present the study's research process and results in a way that enables an independent researcher to replicate the results of the study. As mentioned, the report should be consistent with the goals of the study, complete and accurate in its contents, transparent and detailed in assumptions and limitations, and without bias to the intended audience (ISO, 2006b). The report should follow the ISO 14040 and 14044 standards (ISO, 2006a, 2006b) to accommodate for the LCA reporting requirements, and the GHG Protocol A&R standard (GHG Protocol, 2011, 2013) to accommodate for the scope 3 reporting requirement. This means that the following results should at least be presented regarding the VCA:

- The yearly scope 1 and scope 2 emissions separately (optionally including fugitive emissions).
- The yearly scope 3 emissions separately per scope 3 activity category (excluding GHG trades, such as purchases, sales, or transfers of offsets or allowances).
- The yearly biogenic CO_2 emissions separately per scope 3 activity category.
- The yearly disposed direct and indirect waste separately.

3.3.1.1. Upscaling results

Before the yearly results can be calculated, the baseline results must be upscaled. This is because the VCIA results from the baseline dataset present the GHG emissions and waste for the fulfilment of only one FU. The results represent a specific configuration, where representative good or service options have been chosen for processes where multiple goods or services were available. For all different types of goods and services in the value chain, the RC should make an estimation of how many of these goods and services were used in the established base year. Together with this information, the results from the baseline configuration can be upscaled to make a first estimation of the total emissions and waste that are generated in the base year. When upscaling the results of the baseline dataset, the RC must determine for each of the relevant actor groups with which factor the results of this actor group must be multiplied for these results to represent the results of this actor group during the base year. The multiplication factor, or M-factor, of an actor group is dependent on how often and with which quantities the process(es) this actor group performs take place during the base year. After the processes of the baseline dataset are configured in a GaBi plan, the RC must compile a table that presents the M-factor for each actor group. Each M-factor must be accompanied by an explanation that states why this M-factor will make the results of the actor group in question representative of the base year. The factors can be applied manually or by using the scaling factors in GaBi. The then calculable emissions and waste of the established base year will be an important reference point for measuring the progress of reaching the targets that are about to be set. This estimation can become more accurate when the VCI becomes more complete by gathering more data for alternative goods and services. The described upscaling technique can also be used to upscale the results of any reporting year that follows the base year.

3.3.1.2. High- and low-level differences

GaBi presents all results on a relatively low-level, which means that the results of more specific and detailed components are incorporated. If the GWP of an operation must be calculated manually, emission factors are essential. Emission factors describe how much GHGs are emitted by a specific amount of a specific substance, or a specific duration of a specific process. These emission factors often take the essential components of a substance or process into account, but their application often results in a GWP that is lower than that calculated by GaBi. For example, GHGs are emitted when driving a gasoline car. An emission factor for this process is described as a specific amount of kg CO_2e per kilometer. This emission factor is often determined by combing the GHGs that are emitted through the combustion of the amount of gasoline that is required for driving one kilometer with the GHGs that are emitted through the processing and transporting of this amount of gasoline. The GaBi process from the EcoInvent database that represents driving a gasoline car also takes into account the production of the car, and the maintenance that is required for the car and the road on which it drives. This causes the GWP that is calculated by GaBi to be higher than the GWP that is calculated manually through emission factors.

Reporting requirements of an organization such as the SBTi often do not require RCs to report their emission on a level as low as GaBi presents its results, and manual calculations with emission factors are detailed enough. When the results of the VCA method are supposed to be reported to such an organization, the RC is allowed to adjust low-level results of the VCA method to higher-level results that still meet the reporting requirements of the organization to which the RC reports. This should always be disclosed and justified as RCs should not try to find unjust ways to decrease their emissions through this rule. Corrections can be made during the generation of the GaBi model by adjusting processes from a GaBi database to exclude flows that are too low-level for the reporting requirements an RC has to follow. Corrections can also be made manually after the results are calculated. It is expected that all corrections to database processes are described in the descriptions of the creation processes of the GaBi plans. All manual corrections should be described when the results are presented.

3.3.2. Interpreting results

As mentioned, the first step of the interpretation is to identify the significant issues based on the results of the VCI and VCIA. Implications of the case-specific chosen data collection and the assessment method must be described. Because the IPCC AR6 method has been chosen for performing the VCIA, the impact categories, category indicators, characterization model, and normalization factors. These topics will be treated in the method evaluation in Chapter 5.1. The RC must however still report on implications of the used allocation rules, cut-off decisions, calculation methods and assumptions. Challenges and tradeoffs that were encountered should also be documented.

The issues that follow from the first part of the interpretation are interactively linked with the evaluation. During the evaluation, the origin of each datapoint and the influence of specific decisions and assumptions should be analyzed. This is where assurance should be provided by assessing the VCI for its completeness, accuracy, consistency, transparency, relevancy, and sensitivity. Because a VCI can be incomplete after completing a cycle of the VCA method, the level of completeness really depends on the completeness the RC would have wanted to have at that point. For each of the mentioned assurance topics, the evaluation should explain why certain problems arose, what their consequences are and how they can be addressed directly or in the future. This puts the results into perspective and increases the reliability of the results of the study.

In the final step of the interpretation, conclusions should be drawn about the results of the VCI and VCIA. The limitations of the study can be deduced from the evaluation and recommendations should be given to improve future research processes and increase the quality of the results, but this may also be done when specifics on the next iteration of the VCA method are documented. As mentioned in the theory, the conclusions, limitations and recommendations should be consistent with the requirements of the goal and scope of the study, including data quality requirements, predefined assumptions and values, methodological and study limitations, and application-oriented requirements (ISO, 2006b). A critical review would help to validate the results of the VCA, which can also be done internally if the results of the study are confidential.

3.4. Setting targets

The results of the VCIA should also be interpreted to set accurate, attainable, and trackable targets regarding the elimination of emissions and waste. This is step eight of the A&R roadmap from Table 6.2 in Appendix 6.A (p. 109-110). When setting the targets, a distinction should be made between emission targets and waste targets. Both for the emission and waste targets, the RC must decide whether to set a single target that covers all relevant scope 3 activity categories or all scopes, or multiple targets that each cover a specific relevant scope 3 activity category (SBTi, 2020). Table 3.6 shows the advantages and disadvantages of different target boundaries. The next paragraphs will discuss methods for setting emission and waste targets. Based on the results of the VCIA and these target-setting methods, the RC must decide how many targets should be set, and which target-setting method(s) should be used for setting them. When setting the targets, general factors that can play an important role in the decision-making process are projected costs, required time, company influence, partner cooperation, and social implications for the actions that go paired with setting the specific targets.

Table 3.6 Comparing different target boundaries (adapted from GHG Protocol, 2011).

Target boundary	Advantages	Disadvantages
A single emission target for all scopes. OR A single waste target for direct and indirect waste.	- Ensures more comprehensive management of emissions or waste across the entire value chain. - Offers more flexibility on where and how to achieve the most cost-effective emission or waste reductions. - Simple to communicate to stakeholders. - Does not require base year re-calculation for shifting activities between scopes or generated waste between waste types.	- May provide less transparency for each scope 3 activity category or waste type (if detail is not provided at the scope 3 activity category level or waste type level). - Requires the same base year for scope 1, scope 2, and scope 3, which may be difficult if scope 1 and scope 2 base years have already been established.
A single emission target for all relevant scope 3 activity categories. OR Separate waste targets for direct and indirect waste.	- Ensures more comprehensive management of emissions or waste and more flexibility on how to achieve reductions across all scope 3 activity categories (compared to separate targets for selected scope 3 activity categories) or across the waste types. - Relatively simple to communicate to stakeholders.	- May provide less transparency for each scope 3 activity category or waste type (if detail is not provided at the scope 3 activity category level or waste type level). - May require base year recalculation for shifting activities between scopes or generated waste between waste types.
Separate emission targets for individual scope 3 activity categories.	- Allows customization of targets for different scope 3 activity categories based on different circumstances. - Provides more transparency for each scope 3 activity category. - Provides additional metrics to track progress. - Does not require base year recalculations for adding additional scope 3 activity categories to the inventory. - Easier to track performance of specific activities.	- May result in less comprehensive management of emissions or waste across the value chain (if multiple scope 3 targets are not set). - May result in "cherry picking" (or the perception thereof) by setting targets only for scope 3 activity categories that are easier to achieve. - More complicated to communicate to stakeholders. - May require base year recalculation for outsourcing or insourcing.

3.4.1. Emission targets

Emission targets are set by following the SBTi's guidelines for setting SBTs. This is helpful because emission targets should serve as SBTs in case the RC want to report the results of this study officially to the SBTi. SBTs must be in line with a manual and a list of specific criteria that have been developed by the SBTi (SBTi, 2020, 2021b). It is expected that the RC has already examined how the SBTi works and how SBTs are set. The requirements of setting SBTs should then be studied by reviewing the Target Validation Protocol (SBTi, 2021d). The RC can then use specific target setting tools to start developing targets (SBTi, 2021a). There are tools for setting targets that are in line with limiting global warming to 1.5°C, but there is also a tool for setting targets that try to reach net-zero. Obviously, this last tool is the most ambitious and should be leading if this is possible. A link for downloading these tools is presented in Appendix 6.C (p. 149).

According to the SBTi (2020), a method for setting SBTs always comprises three components: a carbon budget, an emissions scenario, and an allocation approach. A carbon budget is a finite amount of carbon that can be emitted into the atmosphere before warming will exceed specific temperature thresholds. An emissions scenario represents a way of distributing the available carbon budget over time. The allocation approach refers to the way the carbon budget underlying a given emissions scenario is allocated among companies with the same level of disaggregation. There can then be convergence, where all companies within a given sector reduce their emissions intensity to a common value by a given year as dictated by a global temperature pathway; or contraction, where all companies reduce their absolute emissions or economic emissions intensity at the same rate, irrespective of initial emissions performance (SBTi, 2020). The manual of the SBTi describes the following three methods for setting SBTs (SBTi, 2020):

- Absolute Emissions Contraction (AEC)
- Sectoral Decarbonation Approach (SDA)
- Economic Intensity Contraction (EIC)

During AEC, a base year, a target year, and the base year emissions must be identified, so that a SBT states an overall reduction in the amount of absolute GHGs emitted to the atmosphere by the target year, relative to the base year (SBTi, 2020). This method is very specific and therefore credible, but makes it more difficult to compare results with other RCs (GHG Protocol, 2011). To use the SDA method, the RC also needs to state the base year's activity level and the projected change of this level by the target year, so that convergence is possible and a SBT states reduction in emissions relative to a specific production output of the RC (SBTi, 2020). This method presents the results independent of business growth or decline and enables comparisons with other companies, but is less credible because absolute emissions can rise when sector intensity decreases (GHG Protocol, 2011). When using the EIC method, the RC needs to calculate the value that is added in the base year and the projected change of this value by the target year, so that a SBT states reduction in emissions relative to the financial performance of the RC (SBTi, 2020). The SBTi describes guidelines for specific sectors to use specific methods. AEC and SDA are the preferred methods since the EIC method gives less concrete results. The EIC method must also be in line with the AEC method or modeled using a sector-specific pathway to assure emission reductions for the sector as a whole (SBTi, 2020). Different methods can be explored, but the RC eventually should choose a realistic method that produces the most ambitious SBT.

If the RC's estimated scope 3 emissions account for at least 40% of the total emissions of all scopes, an ambitious emission target is required (SBTi, 2020). The following rules have been stated by the SBTi for setting ambitious SBTs (SBTi, 2020):

- Set targets are considered ambitious if they lead to reductions in absolute emissions or emissions intensity in line with 1.5°C, well-below 2°C, or 2°C pathways or when they have been modelled using a sector-specific method that has been approved by the SBTi.
- SDA targets count as ambitious if they do not lead to growth in absolute emissions and reduce emissions intensity by a linear average of at least 2% per year.
- EIC targets count as ambitious if they reduce the economic intensity per value added by a linear average of at least 7% per year.
- Supplier or customer engagement SBTs can be set to drive the adoption of SBTs amongst suppliers or customers of the RC.
- All emission targets should collectively cover at least 66% of the total scope 3 emissions.

The SBTi created a list of criteria that a SBT must meet (SBTi, 2021b). This list can be found in Appendix 6.D (p. 150-154). The SBTi also formulated a checklist that provides RCs a quick reference to understand if they are ready to submit a full submission form to the SBTi for target validation (SBTi, 2021c). The RC must use the selected method(s) and shape one or more SBTs that address the VCIA results and the criteria stated by the SBTi.

3.4.2. Waste targets

Waste targets should be set by following the same principles as the AEC method or the EIC method. When following the AEC method, a base year, a target year, and the base year waste must be identified. An overall reduction in the amount of absolute waste generated by the target year, relative to the base year. When following the EIC method, the waste target states a waste reduction relative to the financial performance of the RC. This AEC method gives more concrete results and is therefore preferred for setting waste targets. Sectoral targets are not recommended since it is not as usual to report sector-wide on generated waste. The waste that is generated by a complete sector is therefore difficult to map. This makes it also difficult to make comparisons with other RCs. Just like with emission targets, supplier or customer engagement waste targets can be set to drive the adoption of waste targets amongst suppliers or customers of the RC. The tools the SBTi published are not applicable for setting waste targets, but these are not required. An important guideline for setting waste targets is that all waste targets should collectively cover at least 66% of the total waste generated in the RC's value chain. Of course, the RC is encouraged to eliminate the generated waste completely by achieving a target that covers 100% of the total waste generated. The SBT criteria stated in Appendix 6.D (p. 150-154) can be used as a guideline for setting the waste targets, but since there are no official incentives to which the waste targets and reductions must be reported, the RC can decide for itself which waste target criteria should be met. It is recommended that the waste targets are set as ambitious as possible because the RC should strive for a maximum reduction in generated waste.

3.5. Identifying and prioritizing actions

After the targets have been set, it is time to identify actions to achieve them. Actions are acts that provide results. The actions that should be identified to achieve the targets should describe specific activities. For each of these specific activities, clear responsibilities must be set of who will do what by when and how. A distinction should be made between emission actions and waste actions. The consequences of executing each identified action must be stated. After the actions have been identified and their consequences are described, the actions should be prioritized so that a roadmap can be made for the RC to follow.

3.5.1. Identifying actions

The results from the individual GaBi plans can be analyzed to find the origins of the emissions within the scope 3 activity categories, and the origins of the generated direct and indirect waste. An improvement analysis can be performed to start thinking about the things that can and cannot be improved. Sometimes effects simply cannot be reduced due to the nature or complexity of a product, the influence or budget of the RC, or the absence of better alternatives. The RC should then focus on the effects that can be changed because any improvement counts.

3.5.1.1. Emission actions

To try to achieve the set emission targets, a variety of actions can be implemented by the RC. The GHG Protocol provides an exemplary list of emission actions for each of the 15 scope 3 activity categories that can reduce the emissions in the value chain (GHG Protocol, 2011). This list is shown in Table 6.5 in Appendix 6.A (p. 116). These examples form a basis that can help an RC to eventually determine its emission actions. Emission actions should always try to prevent the generation of GHG emissions. When this is not an option, the RC should find ways to offset the generated emissions. When offsets are used, the RC should specify this and how much of the target reduction will be or was achieved using offsets.

3.5.1.2. Waste actions

Specific actions should be identified to neutralize waste targets. These actions are called waste actions. As mentioned, a distinction is made between direct and indirect waste. Direct waste can be addressed by the RC through strategy adjustments since direct waste is waste that is generated because the RC does not recycle recyclable products, or it manufactures materials and products that are not completely recyclable. For direct waste, a case-specific end-of-life strategy must be developed to make sure that used materials, products and their packaging are recycled, and that more recyclable or C2C designs are used to manufacture materials and products. In an end-of-life-strategy, ways of disposal should also be prioritized. Waste should first and foremost be prevented, next it should be prepared for re-use, then it should be recycled, then the energy should be recovered, and if even that is not an option, it can be disposed in landfills (European Commission, 2008; Papargyropoulou et al., 2014). If such a strategy is in place and complete recycling is still not possible, indirect waste is generated. Indirect waste can be addressed by the partner companies of the RC through strategy adjustments of their own since indirect waste is waste that is generated because materials, products and their packaging are not manufactured to be fully recycled. Indirect waste can be eliminated by engaging and stimulating the manufacturers of the concerned materials and products to find or develop more recyclable or even C2C designs. If this is no option, the indirect waste can only be eliminated by replacing such manufacturers with ones that use more recyclable or even C2C designs. This however is sometimes not an option because this might cause the RC's costs to increase by a significant amount, or simply because the technology is not yet at a level at which C2C designs are available. It might also be that there are no alternative products available that are more recyclable than the one the RC is already using. The RC should then develop a better alternative or wait for it to be developed because waste can only be completely eliminated through adjusting waste processing strategies and product designs. Figure 3.3 presents a decision tree for how waste actions can be identified.

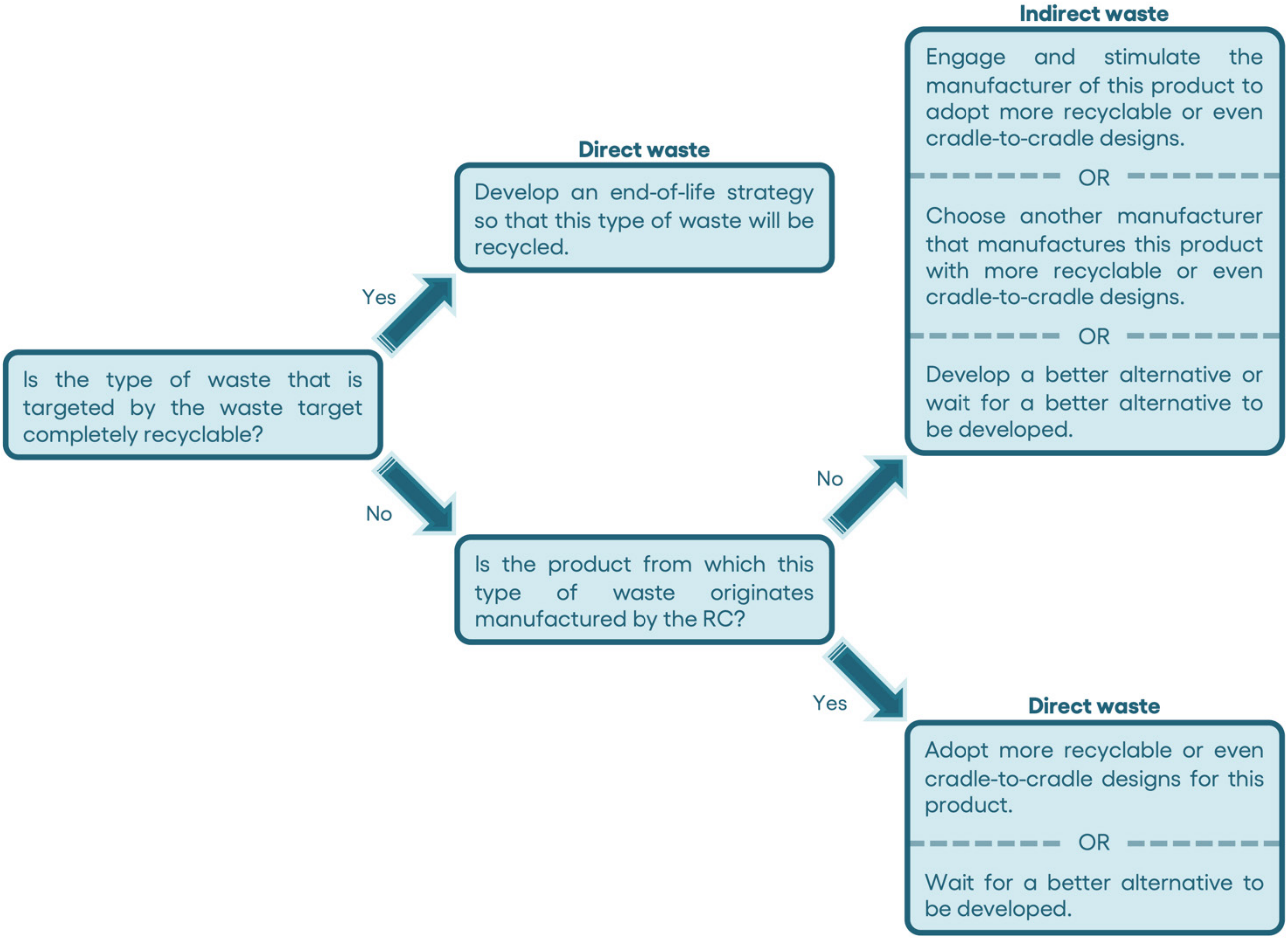


Figure 3.3 Decision tree for identifying waste actions.

3.5.2. Generating a roadmap

A roadmap should be generated to plan the identified actions. The results of this part are highly dependent on the strategy the RC wants to follow. First, each of the identified actions should be prioritized according to the goals of the RC. Then, the prioritized actions should be planned according to their rank and the available time or personnel.

3.5.2.1. Prioritization

The identified actions should be prioritized by comparing them on a set of different aspects. The standard aspects that are determined to be essential for estimating the value of each of the identified actions are presented in Table 3.7.

Table 3.7 Descriptions of the standard action aspects.

Action aspect	Description
Impact on target	The impact the action has on achieving the corresponding target.
Impact on total emissions/waste	The impact the action has on achieving the accumulated targets.
Projected costs	The costs that are expected when the action is executed.
Required time	The time that is required for executing the action.
Influence / Cooperation	The influence the RC has on the outcome of the executed action, or the expected cooperation level of the relevant partner companies.
Social implications	The additional social impact the action can have outside the targets.

The RC can decide to exclude standard aspects or include extra aspects. In both cases, a justification is required for why this exclusion or inclusion takes place. The value of each identified action should be assessed relative to the other actions. First, an estimation is made for each of the stated aspects for each of the identified actions. For each action, each aspect receives a justified rating from 1 to 5, where 1 is poor and 5 is excellent. As the purpose is to compare the aspects among different actions, an action's rating for an aspect must be relative to another action's rating for that same aspect. Each rating must therefore be related to the other ratings. Note that the highest projected cost or required time receives a poor rating, while the highest impact on the target or total emissions receives an excellent rating. The ratings should be summarized in a scorecard as presented in Table 3.8, which presents the ratings for exemplary actions A to E. Each rating should then be multiplied with a weighting factor that is determined and justified by the RC. Each action aspect can be weighted as little important (1), fairly important (2), or very important (3). The weighting factors that are applied in the presented scorecard are noted in brackets below each action aspect. The total scores and weighted scores are presented in the column on the right. Table 3.8 shows that the weighting factors can have a significant impact on the eventual ranking of the actions.

Table 3.8 Exemplary scorecard for exemplary actions A to E.

Action aspect		A	B	C	D	E
Impact on target (3)	Rating	2	2	1	5	4
	Weighted	6	6	3	15	12
Impact on total emissions/waste (3)	Rating	1	1	1	4	2
	Weighted	3	3	3	12	6
Projected costs (1)	Rating	5	3	4	2	1
	Weighted	5	3	4	2	1
Required time (2)	Rating	4	5	2	1	1
	Weighted	8	10	4	2	2
Influence / Cooperation (1)	Rating	3	2	5	1	4
	Weighted	3	2	5	1	4
Social implications (3)	Rating	4	5	1	1	3
	Weighted	12	15	3	3	9
Total	Rating	19	18	14	14	15
	Weighted	37	39	22	35	34

After the weighting factors have been applied, the actions can be prioritized according to their total weighted scores. The RC can decide to prioritize all the emission actions over the waste actions because it can find the emission actions to be of higher urgency. A final ranking list can then be made to provide an overview of how the identified actions are ultimately prioritized.

3.5.2.2. Planning

After the actions have been identified and prioritized, it is time to record them in a planning that can be followed by the RC. It must be decided whether actions will be executed back-to-back or in tandem. This is dependent on the available on the available time or personnel. The number of available employees determines the required amount of time, or the amount of available time determines the required number of employees. The more employees work on the actions, the less time is required and vice versa. The RC must therefore decide how much personnel is available during a specific time period in which the actions are executed. Figure 3.4 shows a schematic of a planning of the exemplary prioritized actions. There are two employees available during the entire planning. Action B requires both employees, while all other actions only require one employee. This means that no actions can be executed in tandem with action B, but all other actions can be executed in tandem to minimize the total required time. No exact scales and units are used in Figure 3.4.

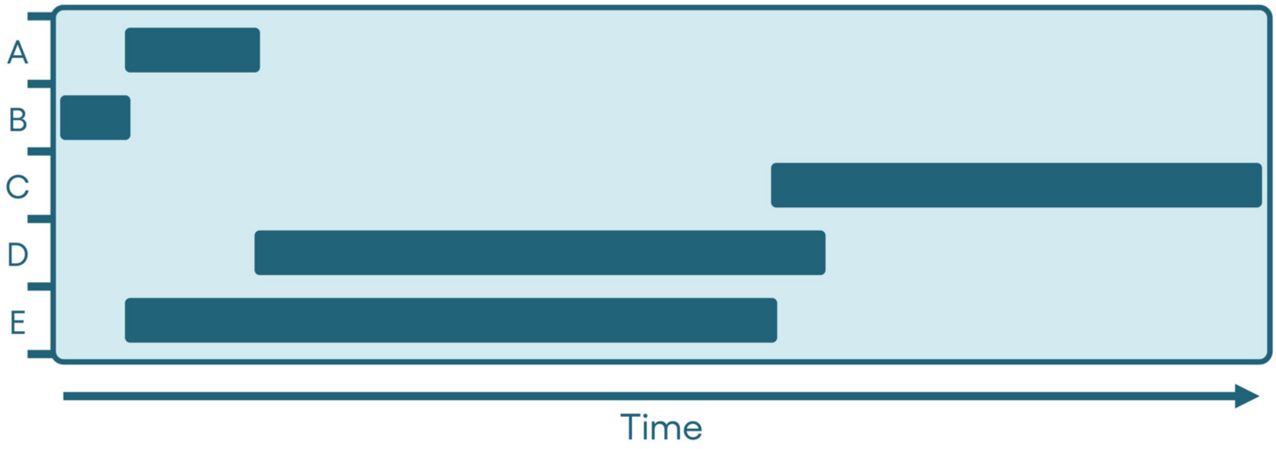


Figure 3.4 Schematic of a planning that shows when exemplary actions A to E can be executed.

Exact values can be estimated for the projected costs and required time of each of the identified actions if the RC wants to eventually estimate the roadmap's total projected costs and required time. The total projected costs can then be determined for achieving net-zero emissions and eventually circularity. The total required time depends on whether the identified actions will be executed back-to-back or in tandem. Exact values can also be estimated for the environmental impact of the identified actions. This information can help the RC in further prioritizing the actions.

3.6. Reporting results

The planning that is generated in the previous step can now be followed by the RC. Every time such a planning is made, the RC should document the results of the study. This is not obligatory, but it is recommended so that previous results can easily be consulted when necessary. It might also be a requirement if the RC wants to share the results with clients, stakeholders, or the SBTi. This chapter will summarize all the components that should be in such a report, and it will mention the reporting requirements that are stated throughout this report.

3.6.1. Components

Table 3.9 shows the steps of the VCA method that should be reported on and the components that belong to them. Obviously, the components of the first four steps should be presented. Additionally, the component that should be reported in the fifth step is the transition log. The transition log should contain the estimated base year emissions and waste. The transition log should also present the history of the set targets and the identified actions and their aspects. It also keeps track of the executed actions and their reduction results. The transition log can therefore be referred to for checking the progress towards net-zero emissions and eventually even circularity. Additional details on the executed actions should also be noted. This way, the transition log can also be used to determine all sorts of information, such as the cumulative costs of the transition towards circularity. The RC can decide on the level of detail of this transition log. The goal of the transition log is to compile the history of the VCA's results and provide an overview of past iterations. It is therefore unnecessary to create a transition log the first time the VCA method is applied since the first report already defines the VCA's complete history. For the sixth step, an overview of the value and requirements for the next iteration should be presented. The iteration of the VCA method is discussed in more detail in Chapter 3.7. The RC should determine what a new iteration should contribute and what is required to deliver this contribution. When the steps of the VCA method are iterated, a new report should be created. In this new report, the RC should update all the previously presented components so that the new report is as accurate as possible. Changes should then be disclosed to prevent any future misunderstandings.

Table 3.9 Steps of the VCA method and their components that should be reported on.

#	Step	Components
1	Performing a VCI analysis	- VCI map - Value chain actors table - System boundaries table - Collected data
2	Conducting and interpreting a VCIA	- Overview of GaBi results - Interpretation of GaBi results
3	Setting targets	- Set targets
4	Identifying and prioritizing actions	- Identified actions - Action prioritization - Planning
5	Reporting results	- Transition log
6	Iterating steps	- Value and requirements of next iteration

3.6.2. Requirements

The VCA method description already included the most relevant reporting requirements of the ISO. Table 6.6 in Appendix 6.A (p. 117) gives an additional overview of the ISO's reporting requirements. The VCA method description and the reporting requirements of the ISO should be followed by the RC as described to deliver a VCA report. The reporting requirements of the GHG Protocol that are stated in step nine of Table 6.2 in Appendix 6.A (p. 109-110) should also be followed if the RC intends to report its results to the SBTi.

3.7. Iterating steps

After the RC has reported its results, it can decide to iterate the steps of the VCA method to improve and update the results of the study. An iteration of the steps of the VCA method requires an updated report. In each updated report, the RC should update its results and disclose the value and requirements of the next iteration. To properly keep track of the RC's progress, it is recommended that the VCA method is iterated every year or when the most recent results are believed to be too inaccurate.

3.7.1. Updating results

The main objective for iterating the steps of the VCA method is to complete the baseline VCI of the first VCA method step through additional data collection. Through iterations, the dataset is completed and re-evaluated by executing steps one to four again. The more complete the VCI becomes, the more accurate the estimated total emissions and waste of a reporting year become. Table 3.10 shows the required result updates for the reporting components of each VCA method step in case of an iteration.

Table 3.10 Required result updates for the reporting components of the VCA method steps.

#	Step	Components	Required updates
1	Performing a VCI analysis	VCI map	- Adjust the map if necessary or in case any changes have taken place. - Present the most recent results if no changes are made.
		Value chain actors table	- Adjust the table if necessary or in case any changes have taken place. - Present the most recent results if no changes are made.
		System boundaries table	- Adjust the table so that it represents the updated VCI map and value chain actors table. - Adjust the existing estimated values if more accurate data is available. - Present the most recent results if no changes are made.
		Collected data	- Add missing VCI data. - Adjust VCI data values if more accurate data is available.
2	Conducting and interpreting a VCIA	Overview of GaBi results	- Adjust the overview so that it represents the updated collected data.
		Interpretation of GaBi results	- Reinterpret the results.
3	Setting targets	Set targets	- Set additional targets if necessary. - Update existing targets if necessary.
4	Identifying and prioritizing actions	Identified actions	- Identify new actions for new targets, updated targets, or unchanged targets if necessary. - Adjust existing actions and their aspects if necessary or if more accurate data is available.
		Action prioritization	- Reprioritize the adjusted set of actions.
		Planning	- Adjust the planning so that it represents the updated results.
5	Reporting results	Transition log	- Update the transition log if necessary.
6	Iterating steps	Value and requirements of next iteration	- Describe the value and requirements of the possibly following iteration.

3.7.2. Documenting the next iteration

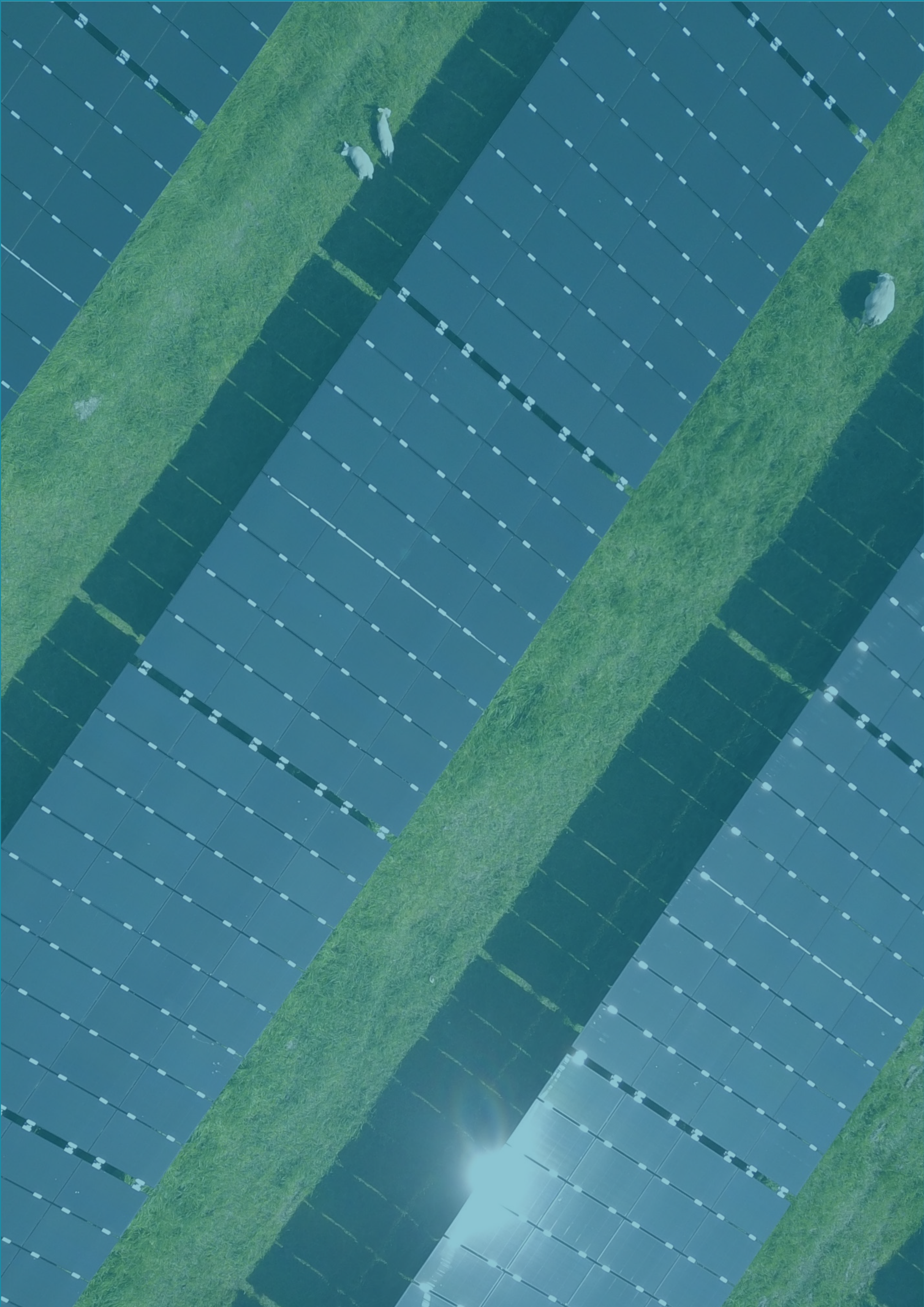
It is important to note that reiteration of the steps of the VCA method is only redundant after the RC's business operations are completely carbon neutral and generate no disposable waste. The VCA method just enables the RC to do it in feasible steps, and it helps the RC to create an overview of its situation. An iteration of the VCA method should always end by providing recommendations on what the next steps of the study should be. It is essential that a next iteration adds value to the study. The final part of the study is therefore to document what results the next iteration should add and what the value of these added results would be. It should then also be found out what resources would be required or what steps should be taken to acquire these additional results. Thoughts might change over time about what the next iteration should look like. The plans for a next iteration are therefore not set in stone. However, directly after completing the steps of the VCA method, the thoughts about the next iteration can be useful for future reference. The documentation on the next iteration should therefore be reviewed before the goal of the next iteration is determined at the start of the iteration.

The first time the VCA steps are executed, only a baseline dataset has been collected. The VCI is therefore not yet complete. There might still be alternatives to the goods and services from the baseline dataset that have not yet been included in the VCI. A next iteration could try to add this missing data to the VCI. The existing GaBi plan can then be adjusted, and scaling factors can be used to adjust the ratios of the included goods and services so that they represent the situation of the reporting year. The method can be iterated like this until the VCI is complete and the entire reporting year of the RC can be simulated, or until the VCI is as complete as required by the RC. A next iteration can then still try to adjust existing VCI data values if more accurate data is available.

Iteration of the VCA steps can cause the value chain to become carbon neutral, and eventually even circular. When circularity is achieved, the mentioned transition log presents the history of steps that were taken to get to that point. An iteration could also try to add not yet adopted potential alternatives, such as C2C designs, to see what such alternatives would have for effect on the eventual results. Lastly, an iteration is required for recalculations. The RC is required to perform a recalculation of the base year data when the following changes occur and have a significant impact on the VCI (GHG Protocol, 2011):

- Structural changes in the reporting organization, such as mergers, acquisitions, divestments, outsourcing, and insourcing.
- Changes in calculation methodologies, improvements in data accuracy, or discovery of significant errors.
- Changes in the categories or activities included in the VCI.

Recalculations are necessary to ensure the consistency and relevance of the results. The first time the steps of the VCA method are followed by the RC, a base year recalculation policy must be developed in which it clearly articulates the basis and context for any recalculations (GHG Protocol, 2011). Recalculations are based on the significance of changes, and the RC should therefore define the significance thresholds that trigger base year recalculations (GHG Protocol, 2011). Appropriate context should be given for any significant data changes that triggered a recalculation. Recalculation is not allowed to account for any expansions the RC undergoes. Reductions are therefore more difficult to achieve in an expanding RC since the set targets refer to the base year.



Part 4

Results

To help evaluate the developed VCA method, this part presents the application of the method on Sunrock's value chain. All steps from the VCA method are executed as presented in Part 3. The results of each of the VCA steps are presented in separate chapters, except for the fifth step. This is because this step describes how the results of the VCA method should be reported. This step is therefore applied throughout the entire following part.

4.1. VCI analysis

Sunrock constructs PV systems and sells the energy these systems produce. No fossil fuels are consumed or GHGs are generated by PV systems. Yet a considerable amount of environmental burden is produced during the activities that must take place before a PV system produces energy (García-Valverde et al., 2009; Fu et al., 2015). It is therefore highly needed to identify and quantify this environmental burden of Sunrock's activities via an effective method (Chen et al., 2016). The VCI analysis will help to acquire a complete picture of the emissions and waste in Sunrock's value chain. The method that has been described in Part 3 will now be applied to Sunrock's situation as described and in the presented order. First, Sunrock's scope 3 activities will be identified and the boundaries for the data collection will be set. Data is then collected and allocated as described.

4.1.1. Activities

A VCI map that contains the actor groups of Sunrock's value chain has been created and is shown in Figure 4.1 on the next page. The map represents what is being done in Sunrock's value chain and by who. The activities within Sunrock's value chain have been identified by studying Sunrock's database (2022). The actor groups have been color-coded to the scope 3 activity categories to which they belong. The following notes should be made by Sunrock's VCI map:

- According to Sunrock's database (2022), only the following activity categories are present in Sunrock's value chain:
    1. Purchased goods and services
    2. Capital goods
    3. Fuel- and energy-related activities
    4. Upstream transportation and distribution
    5. Waste generated in operations
    6. Business travel
    7. Employee commuting
    11. Use of sold products

  All other scope 3 activity categories are therefore excluded.
- A block with "Energy suppliers" is depicted two times in the VCI map because energy suppliers supply energy goods to Sunrock's facilities, but they also buy the electricity from solar energy that is produced by the PV systems. Two blocks are created since both actor groups fulfill different roles and contain different partner companies.
- Two Sunrock facilities are presented in the map. The block that contains the logo of Sunrock represents the office Sunrock runs in the Netherlands. The other facility represents the PV systems Sunrock realizes through its projects.

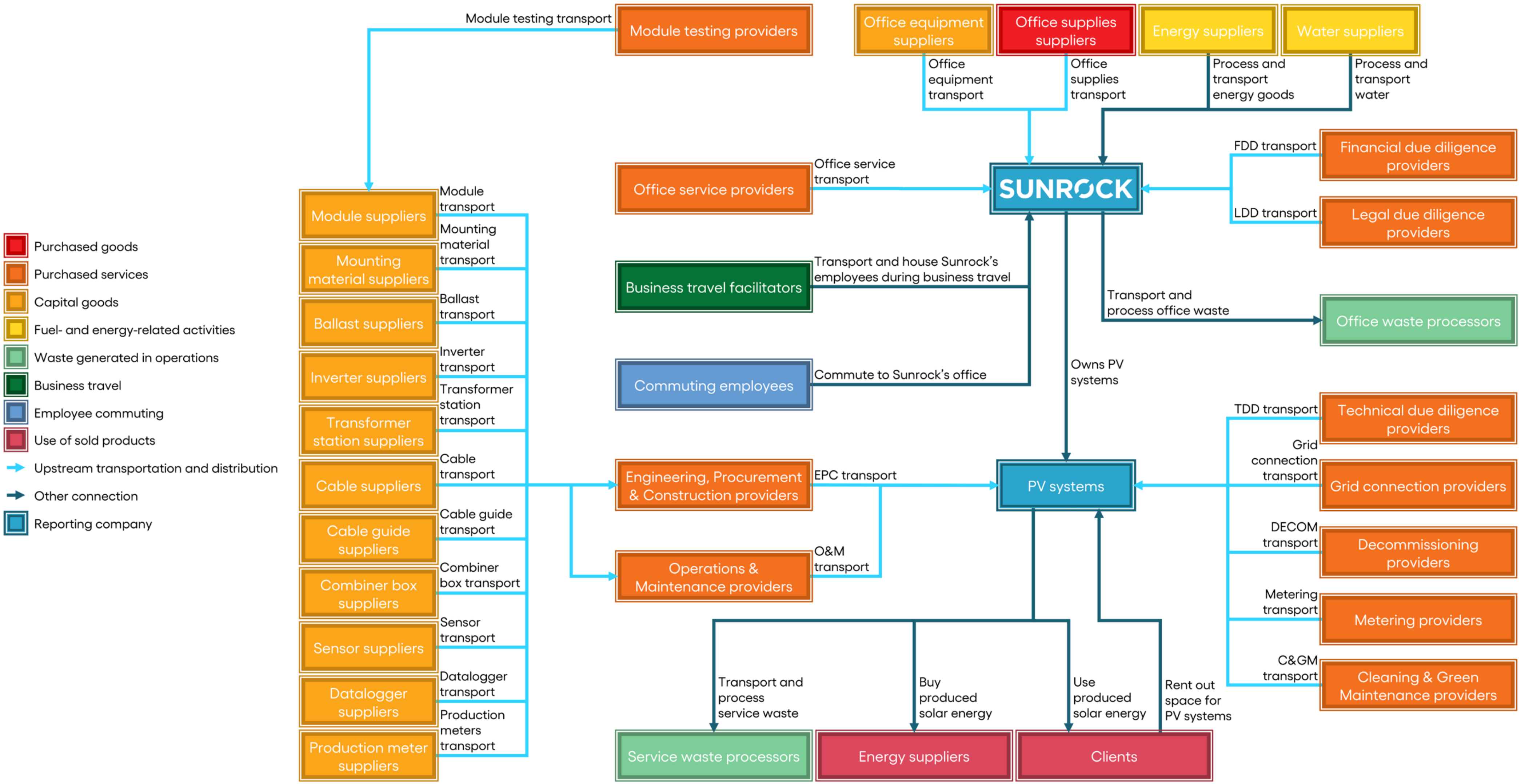


Figure 4.1 VCI map for Sunrock's value chain (information from Sunrock, 2022).

A list has been composed of all companies that belong to the identified actor groups. This list represents the set base year of 2021 and is presented in Table 6.7 in Appendix 6.A (p. 118-119). This year forms a good base year because it represents very accurately how Sunrock does business, and much data is available for it. The product types that each partner company supplies to Sunrock have been found in Sunrock's database (2022). Each actor groups performs one or more activities, and each activity is assigned to one of the 15 scope 3 activity categories. A short description has been given for each of the identified activities. The following notes should be made by Sunrock's value chain actors table:

- Actor groups are coded with a letter. A number is added if multiple actor groups belong to one letter. The letters indicate the following groups:
  A. Capital goods suppliers
  B. Service providers
  C. Office actors
  D. Energy suppliers
  E. Waste processors
  F. Business travel facilitators
  G. Commuting employees
  H. Energy buyers
- Company combinations have been noted for actor groups B9, B10, C1, C2, C3, F, and H because many companies belong to these groups, and it is expected that no data will be directly gathered from specific companies in these actor groups. Details will be gathered when it turns out that these details are required.
- Product combinations have been noted for actor groups C1 and C3 because many different products are supplied by these actor groups, and it is expected that no data will be directly gathered from specific products from actors in these actor groups. Details will be gathered when it turns out that these details are required.
- Transformer stations (A5) are viewed by Sunrock as one product, though they roughly consist of 3 different products, namely transformers, switchgear boxes, and station housings. These subcomponents are marked with A5.1, A5.2, and A5.3 respectively. Custom types are given to transformer stations by the companies that assemble them.
- Cable suppliers (A6) can supply both AC and DC cable. These cables differ substantially, and a distinction must therefore be made. AC cable is marked with A6.1, and DC cable with A6.2.
- The Engineering, Procurement & Construction (EPC) services, the Operations & Maintenance (O&M) services, and Decommissioning (DECOM) services are often executed by the same companies as these companies are familiar with their own construction work.
- Some companies and product types are not officially documented because Sunrock outsources some of the decisions to service providers. Data regarding cables and production meters is not yet part of Sunrock's database (2022).

4.1.2. Boundaries

The system boundaries of the study have been set by creating a system boundaries table according to the stated instructions that is presented in Table 6.8 in Appendix 6.A (p. 120-125), which is a transposed version of the example in Table 3.4. This table provides the basis for estimating the mass and energy CPs for the actor groups in Sunrock's value chain. The FU must first be set to be able to make these estimations. Since Sunrock's value chain revolves around building PV systems, the realization of PV systems can be seen as the main function of Sunrock as a company. With the current technology, a PV system has a power output warranty and therefore an expected lifetime of 25 years, after which it is decommissioned. The following FU has therefore been set for this study:

To realize and maintain a PV system of 1 MWp for 25 years.

When setting the boundaries, the goal is to determine how much the identified actor groups contribute to deliver the stated FU. The sources and assumptions that were used to estimate the required units, mass per unit, energy per unit, and environmental significance have been stated in the table. The estimated numbers are subject to change in next iterations of the VCA method when more accurate data becomes available. The following notes should be made by Sunrock's system boundaries table:

- As this is the first cycle of the VCA method, many assumptions are used in the system boundaries table. These assumptions are however not expected to influence the resulting system boundaries significantly because many of these assumptions have been substantiated.
- Actor groups D to G should be included in the VCI no matter what CPs result from the system boundary calculations. The calculations are therefore not performed for these actor groups. Because Sunrock finds these topics important, these actor groups will be treated with detail level 3.
- Sunrock sells electricity from solar energy to actor group H. However, the calculations are not performed for this actor group because the electricity this actor group purchases does not generate emissions or waste. This means that only the groups that offer goods and services are treated in the calculations.
- The actor groups that should additionally be included in the VCI according to the system boundaries table are A1, A2, A3, A4, A5, A6, B1 and B2. The table discloses for which reason(s) these actor groups are included and with which levels of detail they should be treated.
- The environmental significance of an actor group is only disclosed if this actor group does not have a CP for either mass or energy that is high enough for inclusion. As stated in the method description, the environmentally significant actor groups are treated with detail level 2.
- It was not possible to calculate the mass of a known distance of transportation and the mass of a provided service. The mass CPs have therefore not been calculated for these activities.
- Only the transportation of services that carry a significant and determinable load have been included in the calculations. The transports of the other services are negligible in their required energy. The transportation has therefore only been calculated for actor groups B1 and B2.
- The energy CPs of the transportation activities of actor groups A1, A2, A3, A4, A5, A6, B1, and B2 add up to a total of about 4%, which makes the cumulative transportation fairly important. A detail level 2 is therefore fitting for these combined activities.
- For actor groups C1 and C3 it is rather difficult to determine the amount of goods required per FU due to the high variety of products that are produced within these actor groups. Such inaccuracies would have a negative impact on the results of the system boundaries table. These quantity estimations are therefore excluded from the table. Consequently, the mass CPs for the manufactured goods and the energy CPs for their transportation cannot be calculated with sufficient accuracy and are therefore also excluded. The VCI inclusion of actor groups C1 and C3 is therefore solely dependent on the energy CPs for the manufactured goods.
- All other comments regarding the calculations of the system boundaries table can be found in the table itself.

4.1.3. Collected data

The system boundaries provide an initial basis for prioritizing the to-be-collected data. The required information can now be collected for each activity of each identified actor group that should be included in the VCI. The data collection template from Table 3.5 has been filled in for each of the activities for which the required information should be collected. These filled in data templates are however *confidential*. Necessary sources, assumptions, and calculations will be clearly stated in this template, together with any decisions and methods regarding allocation. When documenting the sources, assumptions, and calculations, the problem with data quality, reasons for exclusions, and implications of assumptions are also discussed. Much of the collected data has been gathered through surveys. Data from manufacturing processes only came from surveys and datasheets. There is a reference to Sunrock's database when survey data is presented since this data has been collected and stored in Sunrock's database, sometimes with the help of the EPC partner. The general required information that is used for allocating the required information to the stated FU is presented in Table 4.1. Data is first collected for the baseline dataset, for which the included companies and product types are presented in Table 4.2 on the next page. This is an adjusted version of Table 6.7 in Appendix 6.A (p. 118-119). The number of activity categories that is noted for each actor group determines how many activities and therefore processes are determined by this actor group. The table also shows what each actor group contributes per FU. These companies were selected in close communication with one of Sunrock's EPC partners. During the study, this EPC partner collaborated with Sunrock in providing useful information and requesting information from suppliers with which this EPC partner is in contact.

Table 4.1 General required information.

	Data type	Primary
	Data collection method	Direct measurement
#	**Required information**	
0.1	Number of projects realized in 2021. Sunrock realized the better part of 31 projects in 2021.	Sources, assumptions, and calculations - According to Sunrock's database (2022), in 2021 Sunrock developed 31 projects to be operational. - Because of direct measurement, this data is of high quality and as accurate as it can be.
0.2	Total MWp of the projects realized in 2021. Through these 31 projects, Sunrock realizes a total of 113 MWp.	Sources, assumptions, and calculations - According to Sunrock's database (2022), in 2021 Sunrock completed the construction preparation of 113 MWp. - Because of direct measurement, this data is of high quality and as accurate as it can be.
0.3	Number of employees per month in 2021. Here it is assumed that the number of employees increased linearly at Sunrock. This information is important since Sunrock grew a lot in one year. Sunrock had the following number of employees at the start of every month: January: 42 April: 54 July: 68 October: 77 February: 47 May: 61 August: 73 November: 83 March: 51 June: 65 September: 75 December: 87	Sources, assumptions, and calculations - Sunrock's database (2022) documents exactly how many employees joined and left the company each month in 2021. - Because of direct measurement, this data is of high quality and as accurate as it can be.

4.1.4. Process overview

Table 6.9 in Appendix 6.A (p. 126-128) summarizes the defined processes and their flows. Figure 6.4 in Appendix 6.B (p. 139) is based on the VCI map and presents an overview of all the defined processes and how they interact. This figure can be recreated in GaBi.

Table 4.2 Companies, activities and product types that are selected for the baseline dataset.

#	Actor group	Activity categories	Company	Product type	Quantity per FU	Level of detail
A1	Module suppliers	2 and 4	*Confidential*	*Confidential*	2,600 units	4
A2	Mounting material suppliers	2 and 4	*Confidential*	*Confidential*	1,300 sets	3
A3	Ballast suppliers	2 and 4	*Confidential*	*Confidential*	3,588 units	3
A4	Inverter suppliers	2 and 4	*Confidential*	*Confidential*	6 units	2
A5	Transformer station suppliers A5.1 Transformers A5.2 Switchgear boxes A5.3 Station housings	2 and 4	1 | *Confidential* 2 | *Confidential* 3 | *Confidential*	1 | *Confidential* 2 | *Confidential* 3 | *Confidential*	1 | 1 unit 2 | 2 units 3 | 1 unit	3
A6	Cable suppliers A6.1 AC cable A6.2 DC cable	2 and 4	1 | *Confidential* 2 | *Confidential*	1 | *Confidential* 2 | *Confidential*	1 | 0.15 km 2 | 30.29 km	3
B1	EPC providers	1 and 4	*Confidential*			2
B2	O&M providers	1 and 4	*Confidential*			2
D1	Energy suppliers	3	MAIN Energie	Electricity Natural gas		3
D2	Water suppliers	3	Waternet	Water		3
E1	Office waste processors	5	Milieu Service Nederland			3
E2	Service waste processors	5	Not known yet			3
F	Business travel facilitators	6	Company combination			3
G	Commuting employees	7				3
RC	Sunrock					4

4.2. VCIA

Now that the baseline dataset of the VCI has been mapped, the collected data can be used in a VCIA. In this chapter, the impact of the baseline data will be assessed and interpreted. The model that is configured in GaBi will first be presented. The model's resulting data will then be presented an interpreted, after which targets for emission and waste reduction will be proposed.

4.2.1. The model

4.2.1.1. Configuration

The flows and processes that were defined for the baseline dataset during the VCI analysis can now be used in GaBi. A separate plan was made for each activity category, where activity category 4 is supplemental to activity categories 1 and 2. In the end, all plans were combined to recreate Sunrock's value chain. The GaBi plans that were made are shown in Figures 6.5 to 6.11 in Appendix 6.B (p. 140-142). Table 6.10 in Appendix 6.A (p. 129-132) presents a list of comments that explains the configurations of these GaBi plans. Each plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing. In these plans, the actor groups and scope 3 activity categories were color-coded according to the color scheme that was used in the VCI map, while the scopes and timing were color-coded with three different shades of blue. The scaling factors were all set to 1 since all the data that was used in the plans was allocated to the 1 MWp project. Facility processes with fixed scaling factors were used to ensure that the results represented the 1 MWp project.

4.2.1.2. Exported data

The GHG emission and waste streams of Sunrock's PV projects will be determined by the software through analyzing energy and material flows. As mentioned, the VCIA dashboard template that has been especially created for the VCA method can be found in Appendix 6.C (p. 149). This dashboard and the accompanying VCI tables present the results of the model in GWP, amount of generated waste, and involved energy. These results are shown for the four specified grouping categories in Figures 6.12 to 6.14 in Appendix 6.B (p. 143-145). By presenting the results in the specified grouping categories, results are automatically separated for each scope and each scope 3 activity category. Biogenic CO_2 emissions are noted separately. The results also distinguish generated recovered from disposed waste. The results regarding the involved energy of the model enables the calculation of the EPBT of the 1 MWp project. The data in the table indicates that about 922,314 kWh is required during the lifecycle of the 1 MWp project. Sunrock's database (2022) says that over 2020 and 2021 the yearly average yield was 930 kWh/kWp. The 1 MWp project therefore produces about 930,000 kWh on average each year. This means that the EPBT of the project is about 0.99 years for the PV system configuration that is presented in the model. Manual corrections were made to the model to eliminate the low-level scope 2 emissions because Sunrock uses electricity from renewable sources and has a certificate to prove this. Table 4.3 on the next page summarizes the results for the lifecycle of a 1 MWp project.

Table 4.3 Summary of the VCIA results.

Grouping category	Group		Results				
			Emissions (kg CO_2e)		Waste (kg)		Energy (kWh)
			Non-biogenic	*Biogenic*	*Direct*	*Indirect*	
Actor groups	A1	Module suppliers	1,508,365.03	2,060.15	-	-	759,353.03
	A2	Mounting material suppliers	96,555.78	-	-	-	50,779.13
	A3	Ballast suppliers	3,874.56	-	-	-	10,918.68
	A4	Inverter suppliers	98,756.32	-	-	-	39,353.70
	A5	Transformer station suppliers A5.1 Transformers A5.2 Switchgear boxes A5.3 Station housings	1 | 2,746.53 2 | 502.56 3 | 1,814.03	1 | - 2 | - 3 | 29.78	-	-	1 | 1,669.24 2 | 231.03 3 | 1,571.64
	A6	Cable suppliers A6.1 AC cable A6.2 DC cable	1 | 2,437.13 2 | 13,212.05	1 | - 2 | -	-	-	1 | 1,539.32 2 | 9,163.88
	B1	EPC providers	782.17	-	-	-	3,378.62
	B2	O&M providers	17.89	-	-	-	77.09
	D1	Energy suppliers	10.24	0.01	-	-	1,439.08
	D2	Water suppliers	0.70	0.36	-	-	2.95
	E1	Office waste processors	8.02	8.65	-	16.68	37.71
	E2	Service waste processors	48,589.32	146.88	-	11,501.36	42,147.95
	F	Business travel facilitators	335.63	0.92	-	-	128.99
	G	Commuting employees	609.88	1.09	-	-	276.84
	RC	Sunrock	108.41	-	-	-	194.75
Scopes	Scope 1		192.50	-	-	-	194.75
	Scope 2		-	-	-	-	697.42
	Scope 3		1,778,533.75	2,247.84	-	11,518.04	921,371.43
Scope 3 activity categories	1	Purchased services	0.00	-	-	-	105.51
	2	Capital goods	1,726,650.45	2,089.91	-	-	867,836.40
	3	Fuel- and energy-related activities	10.94	0.38	-	-	1,442.03
	4	Upstream transportation and distribution	2,401.14	-	-	-	10,093.43
	5	Waste generated in operations	48,597.34	155.54	-	11,518.04	42,185.66
	6	Business travel	288.41	0.92	-	-	128.99
	7	Employee commuting	573.00	1.09	-	-	276.84
Timing	Effects during 2021		1,730,189.13	2,106.02	-	16.68	880,241.66
	Effects linear over 25 years		1,647.78	0.07	-	468.00	1,406.82
	Effects after 25 years		46,889.34	141.75	-	11,033.36	40,615.13
Total results for the lifecycle of a 1 MWp project			1,778,726.25	2,247.84	-	11,518.04	922,263.61

A data quality analysis should now be performed to understand the significance, uncertainty, and sensitivity of the presented results. A gravity analysis explains whether there are any significant contributors that were unexpected. Due to Sunrock's activities it was expected that scope 3 would contribute the most to the results (99.99%). It was also expected that the among the scope 3 activity categories the acquisition of capital goods would contribute the most (97.07%) as Sunrock's business model is based on buying and installing capital goods. These contributors had increased priority from the start, which means that no problems are expected from these results. An uncertainty analysis helps to determine how uncertainties in data points and assumptions impact the calculations and the reliability of the results. The uncertainty analysis will be discussed in the interpretation because it complements the significant issues of the analysis.

A sensitivity analysis has also been performed by changing several of the most contributing data points and by building the model in alternative ways by excluding processes that seem to be insignificant to the study. This analysis did not lead to any changes in the model since the model did not respond in an unexpected way. The seemingly insignificant processes are not excluded from the model because the initial system boundaries are still valid and Sunrock still wishes to report the results from these processes. No other processes are included for the significant processes because the problem with the current model only lies with the uncertainty in the existing significant processes. However, other brands and models for the significant capital goods can be introduced into the model to get more accurate results after upscaling, but this will be discussed in Chapter 4.5.

The baseline model is now ready to be upscaled to calculate the results of the base year 2021. To do this, an estimation must first be made of how often and with which quantities the configured processes were performed in the established base year of 2021. The mentioned upscaling technique can be used to calculate a first estimate of the total emissions and waste Sunrock generated in 2021. To apply the upscaling technique, an M-factor should be determined for each relevant actor group. Table 4.4 (p. 82) shows these M-factors and the motivations for choosing them. The initial results represent a project of 1 MWp. As previously mentioned in the general required information from Table 4.1, in 2021 Sunrock realized 31 projects worth a total of 113 MWp. Wherever it is assumed that the activity of an actor group grows linearly with either the number of projects or the amount of MWp realized, the M-factor should be 31 or 113, respectively.

Most waste that is created in the lifecycle of the 1 MWp project is not allocated to the year 2021 because this waste is only generated when the project is decommissioned at the end of its lifetime. This should be considered when waste targets are proposed since the generation of this waste is inevitable and Sunrock should anticipate on this. The waste from eventually decommissioning the projects that were realized in 2021 should therefore be allocated to the year 2021 when the results are upscaled. The generation of packaging waste from performing maintenance on the projects that were realized in 2021 is also inevitable. However, the amount of packaging waste from this maintenance is insignificant compared to the mentioned amount of waste from decommissioning. Besides, the packaging waste from maintenance is completely recovered and accounted for in each of the following reporting years. The inevitable packaging waste from performing maintenance on the projects that were realized in 2021 is therefore not allocated to the year 2021 when the results are upscaled.

The M-factors were applied by using the scaling factors in GaBi. The fixed scaling factors of the facility processes were changed to 113, so that the entire plan was multiplied by 113. Flow quantities were then changed for all flows that were supposed to be multiplied with a different M-factor. For example, the processes of O&M providers are supposed to be multiplied with 3.76. After the quantities of these flows are multiplied with 113, they must be divided by 30.05 (113/3.76) before quantities represent the base year. Processes that contain flows that should be multiplied with different M-factors should be duplicated before they are adjusted because the quantity ratios of the flows of these processes change. After applying the M-factors, the upscaled results were exported in the designed VCIA dashboard to calculate the total emissions and waste Sunrock generated in 2021. Table 4.5 (p. 83) shows the results for each of the specified grouping categories after upscaling, and the total upscaled results of the base year 2021. Though this estimate can become more accurate over time due to iterations of the VCA method, it can already be used as a reference point for measuring the progress of reaching the targets that are about to be proposed. Charts of these results are shown in Figures 6.15 to 6.17 in Appendix 6.B (p. 146-148).

Table 4.4 M-factors for upscaling the baseline VCIA results.

#	Actor group	M-factor(s)	Explanation
A1	Module suppliers	113 3.76	The number of modules that is installed through EPC services grows about linear with the amount of MWp realized. The number of replacement modules that is installed through O&M services grows with the same M-factor as that of the O&M providers.
A2	Mounting material suppliers	113	The number of units of mounting materials grows about linear with the number of modules.
A3	Ballast suppliers	113	The number of ballast tiles grows about linear with the number of modules.
A4	Inverter suppliers	113 3.76	The number of inverters that is installed through EPC services grows about linear with the amount of MWp realized. The number of replacement inverters that is installed through O&M services grows with the same M-factor as that of the O&M providers.
A5	Transformer station suppliers	31	About one transformer station is placed per project. The number of transformer stations therefore grows about linear with the number of projects realized.
A6	Cable suppliers	113	The amount of cable grows about linear with the number of modules.
B1	EPC providers	113 31	The number of workhours and waste of EPC services grows about linear with the amount of MWp realized. The EPC services pass on the PV system's components from the manufacturers to the project sites. The M-factors from the PV system's components should therefore also be considered by adjusting the quantities required in the EPC services to fit the quantities manufactured by the manufacturers. This means that M-factors of 113 and 31 should be used.
B2	O&M providers	3.76	The number of workhours, waste and replacement components of O&M services grows about linear with the amount of MWp for which O&M services are provided. According to Sunrock's database (2022), during 2021 about one O&M service was provided to all projects that were operational before 2021, which were 49 projects worth a total of 94 MWp. However, the PV system has a power output warranty of 25 years, so it is assumed that the total effects of the O&M services take place linearly over 25 years. The M-factor is therefore 3.76 (94/25).
D1	Energy suppliers	113	The data of the energy suppliers was provided for the year 2021. This data was then allocated to a 1 MWp project by dividing it by 113.
D2	Water suppliers	113	The data of the water suppliers was provided for the year 2021. This data was then allocated to a 1 MWp project by dividing it by 113.
E1	Office waste processors	113	The data of the office waste processors was provided for the year 2021. This data was then allocated to a 1 MWp project by dividing it by 113.
E2	Service waste processors	113/31 3.76 0	Service waste originates from actor groups B1, B2, and B3. The M-factors for actor group E2 are therefore the same as the ones from the corresponding services in these actor groups. Though actor group B3 is not included in the analysis, its M-factor can be determined to be 0 as no projects were decommissioned during 2021.
F	Business travel facilitators	113	The data of the business travel facilitators was provided for the year 2021. This data was then allocated to a 1 MWp project by dividing it by 113.
G	Commuting employees	113	The data of the commuting employees was provided for the year 2021. This data was then allocated to a 1 MWp project by dividing it by 113.
RC	Sunrock	113	All scope 1 data was provided for the year 2021. This data was then allocated to a 1 MWp project by dividing it by 113.

Table 4.5 Results of applying the upscaling technique to the VCIA results.

Grouping category	Group	Results				
		Emissions (kg CO_2e)		Waste (kg)		Energy (kWh)
		Non-biogenic	*Biogenic*	*Direct*	*Indirect*	
Actor groups	A1 Module suppliers	166,400,440.28	227,306.38	-	-	83,680,509.70
	A2 Mounting material suppliers	10,910,802.79	-	-	-	5,738,041.87
	A3 Ballast suppliers	437,825.77	-	-	-	1,233,810.85
	A4 Inverter suppliers	4,475,286.25	-	-	-	1,762,590.04
	A5 Transformer station suppliers A5.1 Transformers A5.2 Switchgear boxes A5.3 Station housings	1| 85,142.30 2|15,579.26 3|56,234.95	1| - 2|- 3|923.12	-	-	1| 51,746.33 2|7,161.78 3|48,720.76
	A6 Cable suppliers A6.1 AC cable A6.2 DC cable	1| 275,395.72 2|1,492,961.75	1| - 2|-	-	-	1| 173,942.64 2|1,035,518.43
	B1 EPC providers	80,843.19	-	-	-	349,700.69
	B2 O&M providers	67.26	-	-	-	289.85
	D1 Energy suppliers	1,156.92	1.38	-	-	162,616.45
	D2 Water suppliers	79.42	41.07	-	-	332.96
	E1 Office waste processors	905.93	977.97	-	1,884.84	4,261.61
	E2 Service waste processors	14,051.69	658.82	-	1,087,645.36	20,517.88
	F Business travel facilitators	38,029.48	103.60	-	-	14,575.83
	G Commuting employees	69,039.60	123.11	-	-	31,282.64
	RC Sunrock	12,250.39	-	-	-	22,006.81
Scopes	Scope 1	21,752.65	-	-	-	22,006.81
	Scope 2	-	-	-	-	78,808.70
	Scope 3	184,344,113.57	230,135.45	-	1,089,530.20	94,236,811.60
Scope 3 activity categories	1 Purchased services	1,382.14	0.01	-	-	11,702.80
	2 Capital goods	184,023,143.53	228,229.49	-	-	93,195,836.24
	3 Fuel- and energy-related activities	1,236.34	42.45	-	-	162,949.41
	4 Upstream transportation and distribution	206,053.84	-	-	-	874,493.90
	5 Waste generated in operations	14,957.61	1,636.79	-	1,089,530.20	24,779.48
	6 Business travel	32,590.71	103.60	-	-	14,575.83
	7 Employee commuting	64,749.39	123.11	-	-	31,282.64
Timing	Effects during 2021	184,365,866.22	230,135.45	-	3,644.52	94,337,627.11
	Effects linear over 25 years	-	-	-	-	-
	Effects after 25 years	-	-	-	1,085,885,68	-
Total upscaled results for the base year 2021		184,365,866.22	230,135.45	-	1,089,530.20	94,337,627.11

4.2.2. Interpretation

As mentioned, the results show that most effects, whether it is about emissions or waste, are caused by the procured capital goods. Among the capital good suppliers, the module suppliers are the largest contributors, followed by the mounting materials and inverter suppliers. The most significant issue with the presented results is that there is an unquantifiable inaccuracy in these results as the used dataset was not as complete and accurate as anticipated. The required information was gathered from all relevant actors through surveys. While all scope 1 and scope 2 data was collected from within Sunrock, practically all scope 3 data was obtained from suppliers or other value chain partners. As in Sunrock's case scope 3 overshadows the other scopes, Sunrock is highly dependent on its partners to provide correct information. All data quality requirements have been met. However, some actor groups did not provide all required information due to confidentiality issues (actor groups A1 and A4) or a lack of knowledge or transparency (actor groups A5, A6, E2, and F). Database processes were used to supplement the required information. These processes were adjusted so that they represent the actual situation as much as possible. However, these processes might still not be representative enough of the actual situation. To make the resulting emissions of these processes representative, the mass was adjusted for some of them. These variable adjustments make the process representative for emissions, but not for other impacts. For this reason, the analysis only treats emissions and waste. Further analyses with different LCIA methods might therefore not generate representative results. This is no problem for this case study since Sunrock only requires the analysis of GWP and waste.

More assumptions were made for actor groups A1, A2, A4, A5, A6, E2, and F than allowed according to their level of detail. The level of detail has therefore not been reached for these actor groups. This use of database data and assumptions impacts the accuracy of the results, especially since actor group A1 is the largest contributor in the results (90.25% of emissions and 91.01% of waste). There was also not much data available for the disposal and treatment types that are used for the decommissioned components. It is therefore not clear which products are built from recovered materials from waste recovery processes. Avoided products are thus not considered during the analysis because there is no data available that says which raw materials the recovered components provide. Waste that is generated during manufacturing processes has also not been considered as this data simply not provided. Sunrock should strive for improving this data over time until these levels of detail are reached. The overall level of detail of the study is impacted through excluding the following things from the study:

- After the trucks have delivered the capital goods to the storage or project site, they must return to the place they came from. This return transportation of the used trucks has not been considered as it is assumed that the lack of cargo makes this process insignificant. The trucks might also be used for other cargo transports that do not have to be allocated to Sunrock. Also, due to a lack of data, for most PV system components only the transportation of the manufactured components was taken into account, not that of the raw materials that were used for them.
- Fugitive emissions have not been included in scope 1 as it is not mandatory to include them for reporting to the SBTi and the fugitive emissions are expected to be of little impact due to the small size of Sunrock's office.
- No distinction is made between the emission of different GHGs as this data was simply not available for most specified processes. Therefore, only the CO_2e has been used when presenting the results.

The mentioned data uncertainties and assumptions most likely have a significant effect on the results and therefore the reliability of the calculations that are done with them. However, it is expected that the uncertainties that were caused by using database processes causes the total emissions to be higher than the actual values due to outdated data and fast-paced innovation in the field of photovoltaics. Besides, worst case scenarios were assumed during assumptions, also increasing the calculated total emissions over the actual total emissions. The uncertainties and assumptions therefore only cause the targets to be set more ambitiously, which is not considered to be a problem. The biggest assumption that might have a significant impact on the results is the fact that the model currently says that all PV system components are decommissioned after the system's 25-year lifetime. Some of the components will still be functional for multiple years after this period of time. However, there is no concrete strategy in place for what will happen to these components after these 25 years. To leave no effects unaccounted for, it is therefore assumed that these components will be decommissioned when the rest of the system is. The treatment types that will be used for the decommissioned components are also not determined. These are dependent on the treatments that are available at the time of decommissioning. Sunrock will try to limit waste generation as much as possible, and it will develop a strategy for what will happen with the decommissioned components in the foreseeable future.

A small problem arose when the biogenic CO_2 emissions were calculated in GaBi. It turned out that in some occasions the GWP values including biogenic CO_2 emissions were lower than the GWP values excluding biogenic CO_2 emissions, which resulted in a negative value for biogenic CO_2 emissions. Several things can be the cause of this effect. It could be caused by the specifications of the used database processes, an inconsistency in the way the IPCC AR6 LCIA method is programmed, or the possibility that processes actually have an opposite effect regarding biogenic CO_2 emissions. Because there currently is no certainty to what actually caused this effect, all negative biogenic CO_2 emissions have been set to zero to ensure that these negative values do not unnecessarily cause the total value for biogenic CO_2 emissions to be lower than the actual value. For now, finding out the exact reasons for this problem is outside the scope of this study. No other major implications were caused by allocation rules, cut-off decisions, or calculation methods. All minor data challenges and implications, but also the origins of each datapoint were stated in the data templates.

Completeness and accuracy are the main bottlenecks of the study. It can therefore be concluded that the limitations of Sunrock's VCA study lie with the ability and willingness of its partners to provide the required information. These limitations do not form a problem for continuing with the VCA method since the results still give a good indication of where Sunrock can try to improve its impact. Also, these limitations can be addressed in a next iteration. The next iteration is documented in Chapter 4.5 and contains recommendations for improving the research process and increasing the quality of the results. Sunrock is thinking about executing a critical review to validate the results of the study.

4.3. Targets

After the general interpretation of the VCIA, another interpretation of the results is needed to set emission and waste targets. These targets are recommendations to Sunrock as the company has not yet decided on its official targets. Emission targets and waste targets will be set separately. As Sunrock intends to report its targets and emissions to the SBTi, the emission targets will be SBTs. Sunrock already made a carbon reduction commitment towards the SBTi. The company committed to a 50% reduction of its scope 1 and scope 2 emissions of 2019 by the year 2030 (Sunrock, 2022). 2019 therefore is the base year for Sunrock's scope 1 and scope 2 emissions. The scope 1 emissions in 2019 were calculated to be 18,736.18 kg CO_2e. As Sunrock already only used electricity from renewable sources, the company already had no scope 2 emissions. Future expansions of the company must be carbon neutral, while the existing emissions must be halved. Sunrock has committed to not off-set but reduce its scope 1 emissions. The company has also committed to document and reduce its scope 3 emissions, which initiated this research. Table 4.6 presents an overview of the proposed emission and waste targets, including the emission target that was already set by Sunrock for scope 1. The following paragraphs will describe how these targets were determined. Note that this first set of targets must be updated in a later iteration to eventually reach circularity.

Table 4.6 Overview of the proposed emission and waste targets.

#	Target	Description
1	Direct emissions	Sunrock commits to reducing scope 1 emissions by 50% per 2030 from a 2019 base year.
2	Capital goods emissions	Sunrock commits to reducing scope 3 emissions from capital goods by 66% per 2035 from a 2021 base year.
3	Business travel emissions	Sunrock commits to reducing scope 3 emissions from business travel by 50% per 2030 from a 2021 base year.
4	Employee commuting emissions	Sunrock commits to reducing scope 3 emissions from employee commuting by 50% per 2030 from a 2021 base year.
5	Indirect waste	Sunrock commits to reducing indirect waste by 66% per 2035 from a 2021 base year.

4.3.1 Emission targets

The VCIA delivered detailed results for each of the scope 3 activity categories, and only a few of those will be important to look at. The decision has therefore been made to set separate emission targets for individual scope 3 categories. The procurement of capital goods contributes almost 100% to Sunrock's scope 3 emissions. A separate scope 3 target should therefore be set for this activity category. Separate targets should also be set for business travel and employee commuting since these are categories in which Sunrock's strategy has a direct influence on the result. The AEC method has been used to set the emission targets as this method is highly credible. A sectoral approach is also quite difficult for Sunrock since many different methods for carbon footprint calculation are used within the PV sector. This causes significant differences between the results of companies, which makes a sectoral comparison difficult. Customer engagement targets will not be set. Module suppliers generate over 90% of Sunrock's scope 3 emissions, and it is not expected that Sunrock can exert significant pressure on any large-scale module supplier that does not already have an emission reduction strategy in place.

As it has been calculated that Sunrock's scope 3 emissions account for more than 40% of the total emissions, ambitious scope 3 targets are required. A target setting tool from the SBTi has therefore been used to find out how much Sunrock's scope 3 emissions must be reduced to make the scope 3 targets in line with 1.5°C (SBTi, 2021a). Using the data from the VCIA in this tool, a reduction of 63% per 2035 from a 2021 base year is required to be in line with 1.5°C. To ensure that there is reasonably enough time for Sunrock to reach its targets, 2035 is set as the target year for all targets Sunrock has no direct influence on. All the targets combined must however cover at least 66% of the total scope 3 emissions. Due to the large contribution of the procurement of capital goods within Sunrock's scope 3 emissions, only a 66% reduction in this category will make Sunrock's scope 3 targets ambitious enough. The targets regarding business travel and employee commuting are therefore only added because Sunrock feels the responsibility to act on the categories it has a direct influence on. The targets for these categories will be set in line with the existing scope 1 target.

4.3.2. Waste targets

Sunrock manufactures no products and recycles all its office waste through enabling waste separation and pointing out the importance or recycling within the company. Regarding the PV system's components, their packaging, and the eventually decommissioned components themselves are and will be recycled to their potential. This means that any disposed waste from component packaging or decommissioned components is indirect waste that is caused by the designs of the manufacturers of these components. It can therefore be concluded that Sunrock does not generate any direct waste for disposal. A waste target can thus only be proposed regarding the generated indirect waste. This target will be set through the credible AEC method. All waste targets together should cover at least 66% of the total waste generated. The indirect waste target should therefore cover the complete 66% that is required. Because Sunrock has no direct influence on the generation of this waste, 2035 has been set as the target year for the proposed waste target.

4.4. Actions

Now that the targets are proposed, actions can be identified and prioritized. Separate emission and waste actions are proposed. These actions are then assessed, prioritized, and planned to create a roadmap.

4.4.1. Identified actions

When identifying actions, it is important to know which effects can and cannot be improved. Targets were proposed for direct emissions and emissions from business travel and employee commuting since these can be directly improved. A target was also proposed for emissions from capital goods because this category plays an essential part in the overall reduction of Sunrock's scope 3 emissions. Sunrock might find difficulties in reducing the high effects from capital goods as these effects can be inherent to the required capital goods for the coming years due to a lack of sophistication in the used technologies. A target is also proposed for reducing the indirect waste from capital goods. However, Sunrock's influence on the manufacturers of capital goods is questionable, and the better alternatives to the procured capital goods are expensive to the extent that a transition to these better alternatives harms Sunrock's business model. Actions must therefore be proposed within Sunrock's boundaries, so that Sunrock can focus on the effects that can be changed. The results from the individual GaBi plans were analyzed to find the origins of the emissions within the scope 3 activity categories, and the origins of the generated indirect waste. Actions could then be identified to target the significant contributors. Table 4.7 presents actions that were identified for the proposed targets. The policy Sunrock wrote for reducing its scope 1 emissions has also been considered. The following paragraphs discuss the actions in more detail.

Table 4.7 Overview of the identified emission and waste actions.

#	Target	#	Action
1	Direct emissions	1.1	Transition to district heating.
		1.2	Improve the insulation at the office.
		1.3	Replace all gasoline and hybrid lease/pool cars with full electric ones.
		1.4	Ensure that the full electric lease/pool cars are only charged with electricity from renewable sources.
2	Capital goods emissions	2.1	Choose module suppliers that are committed to reducing their carbon footprint.
		2.2	Engage and stimulate module suppliers to commit to reducing their carbon footprint.
3	Business travel emissions	3.1	Ensure that business travel trips under 3 hours or 500 km are only traveled per train or full electric car.
		3.2	Instruct employees to use full electric lease/pool cars or trains for business travel.
		3.3	Ensure that only full electric rental cars are used.
4	Employee commuting emissions	4.1	Start supporting employees in traveling with carbon neutral modes of transport.
		4.2	Prevent commute by telling employees to work from home.
5	Indirect waste	5.1	Choose module suppliers that use more recyclable or even C2C designs for their modules.
		5.2	Engage and stimulate module suppliers to adopt more recyclable or C2C designs.

4.4.1.1. Emission actions

Most of Sunrock's direct emissions comes from the company's consumption of natural gas for heating (56.32%). The greatest reduction in Sunrock's direct emissions will therefore come from their future connection to the district heating system of the city of Amsterdam. All emissions regarding the use of natural gas will then be eliminated. The origins of the heat from the district heating system must then be analyzed to find out what emissions go paired with it, but a drastic reduction is imminent as the district heating system uses waste heat from electricity generation and waste incineration. This connection makes a transition to a fully electric office unnecessary. Improving the insulation of the office building in the Netherlands would then help to reduce the emissions from the district heating system even further. Besides the transition to the district heating system, Sunrock should replace all gasoline and hybrid lease/pool cars with full electric ones. These cars should then only be charged with electricity from renewable sources. This would help the remaining partition of Sunrock's direct emissions (43.68%) to also decrease significantly.

The indirect emissions from capital goods can be reduced if Sunrock gives preference to module suppliers that have a commitment to reduce their carbon footprint. Sunrock is already looking at options that are more sustainable. However, the most sustainable options are expensive and damage Sunrock's business model by lowering their profit margins across the lifetime of their PV systems. Sunrock can also try to convince module suppliers to implement a carbon reduction strategy. Suppliers of other capital goods play a less important role. Mounting materials play a significant role, but these are already produced in a sustainable way. Inverters and DC cables are next in line, but so little is to gain in comparison to the modules that Sunrock should just focus on modules. Offsets may be used to neutralize the emissions from capital goods if it turns out that Sunrock will not be able to reach this target. Offsets must be documented appropriately.

Indirect emissions from business travel can be eliminated by reducing the amounts of kilometers that are traveled per plane and gasoline (rental) car. Distances per plane and gasoline car can be reduced by only traveling per train or full electric car for trips under 3 hours of 500 km. Employees that often take part in business travel per car must receive a full electric lease car, while employees that take part in business travel per car sporadically must use a full electric pool car or travel per train at Sunrock's expense. Rental cars contribute significantly to the indirect emissions from business travel. It is therefore recommended that in the future only full electric rental cars will be used.

Finally, the indirect emissions from employee commuting should be addressed by supporting the employees in traveling carbon neutral. Most commute emissions come from the use of gasoline, but also diesel and hybrid cars. An important intervention would be to partly or even completely pay for the commute trips each employee makes per means of public transport. Employees that live at distant locations that are difficult to reach must be offered a full electric lease car. Financial means should also be made available to help employees in purchasing electric or foldable bikes that eventually persuade them to travel carbon neutral. Besides doing something about the means that are used during commute, actions can also be taken to reduce the total amount of kilometers that are traveled for commute. A policy could be made to only allow employees to work a specific number of times per week at the office. Working from the office is not always necessary and each day an employee works from home prevents a return trip.

4.4.1.2. Waste actions

As mentioned, most of the indirect waste that will be generated originates from the great numbers of modules Sunrock procures. Sunrock should try to use modules that are more recyclable. However, more recyclable or C2C module designs are significantly more expensive. Sunrock cannot just buy the most sustainable module alternative as the company is bound to a budget that enables it to exist at all. The most recyclable modules must therefore be bought within the budget. At the same time Sunrock should engage and stimulate module suppliers to develop more recyclable or even C2C module designs. Such designs could also have a positive impact on the emissions from production and eventual waste treatment. This action could therefore help to reach two targets. Sunrock must also look out that it does not start to generate any direct waste by ensuring that all PV system components are recycled to their potential.

4.4.2. Roadmap

4.4.2.1. Prioritized actions

The prioritization depends on the goals of the company. This prioritization serves as a recommendation for Sunrock as the company has not yet decided on what actions should be executed first. Sunrock prioritizes emission targets over waste targets because of how serious the company feels about emissions and because of its obligations towards the SBTi. Nevertheless, waste targets should eventually be achieved. The identified actions will be assessed on all six standard action aspects. Table 6.11 in Appendix 6.A (p. 133-135) presents the action aspect ratings with explanations for each of the identified actions. Table 4.8 shows the scorecard that resulted from the action aspect rating. The ratings are weighted regarding Sunrock's interests and available resources to emphasize the importance the company gives to each aspect in the prioritization.

Sunrock weighted the actions' impact on the target and the total emissions and waste as very important (3) because these aspects directly influence the results regarding emissions and waste. Influence and cooperation are weighted as very important (3) since Sunrock wishes to focus and instantly act on the things the company has a direct influence on. Social implications of the actions are also weighted as very important (3) since Sunrock believes that human welfare cannot be ignored. The urgency to act regarding social implications is always there, but Sunrock makes this commitment with pragmatism as there are many factors the company cannot influence. As costs can run high, projected costs are weighted as fairly important (2). Sunrock must protect its business model without losing sight of the negative impacts that go paired with their business operations. The time that is required to execute an action is seen as continuous improvement as the invested time must be realistic for achieving the targets. Also, since there is still much time left to achieve the targets, the time that is required to execute an action is little important (1). Sunrock however wishes to have a short- and long-term plan. Table 4.9 presents the ranked list of the identified actions after prioritization.

Table 4.8 Scorecard for the identified actions.

Action aspect		**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**3.1**	**3.2**	**3.3**	**4.1**	**4.2**	**5.1**	**5.2**
Impact on target (3)	Rating	5	1	4	1	5	2	5	3	2	5	4	5	2
	Weighted	15	3	12	3	15	6	15	9	6	15	12	15	6
Impact on total emissions/waste (3)	Rating	1	1	1	1	5	2	1	1	1	1	1	5	2
	Weighted	3	3	3	3	15	6	3	3	3	3	3	15	6
Projected costs (2)	Rating	5	5	3	5	1	4	4	4	5	3	5	1	4
	Weighted	10	10	6	10	2	8	8	8	10	6	10	2	8
Required time (1)	Rating	5	4	4	5	2	4	5	5	5	3	5	2	4
	Weighted	5	4	4	5	2	4	5	5	5	3	5	2	4
Influence / Cooperation (3)	Rating	5	5	5	5	5	1	5	5	5	5	5	5	1
	Weighted	15	15	15	15	15	3	15	15	15	15	15	15	3
Social implications (3)	Rating	1	1	1	1	5	5	1	1	1	1	1	5	5
	Weighted	3	3	3	3	15	15	3	3	3	3	3	15	15
Total	Rating	22	17	18	18	23	18	21	19	19	18	21	23	18
	Weighted	51	38	43	39	64	42	49	43	42	45	48	64	42

Table 4.9 Ranked list of the identified actions after prioritization.

Rank	**#**	**Action**	**Total**
1	2.1	Choose module suppliers that are committed to reducing their carbon footprint.	64
2	5.1	Choose module suppliers that use more recyclable or even C2C designs for their modules.	64
3	1.1	Transition to district heating.	51
4	3.1	Ensure that business travel trips under 3 hours or 500 km are only traveled per train or full electric car.	49
5	4.2	Prevent commute by telling employees to work from home.	48
6	4.1	Start supporting employees in traveling with carbon neutral modes of transport.	45
7	3.2	Instruct employees to use trains or full electric lease/pool cars for business travel.	43
8	1.3	Replace all gasoline and hybrid lease/pool cars with full electric ones.	43
9	3.3	Ensure that only full electric rental cars are used.	42
10	2.2	Engage and stimulate module suppliers to commit to reducing their carbon footprint.	42
11	5.2	Engage and stimulate module suppliers to adopt more recyclable or C2C designs.	42
12	1.4	Ensure that the full electric lease/pool cars are only charged with electricity from renewable sources.	39
13	1.2	Improve the insulation at the office.	38

4.4.2.2. Planned actions

The ranked list of actions can now be used to generate the roadmap that can be followed by Sunrock. The resulting roadmap is presented in Figure 4.2. Most of the identified actions take only little time for Sunrock to execute. Many of the identified actions can therefore be executed in tandem. Sunrock recently hired an ESG manager that will keep an eye on the company's progress and the actions that must be executed to achieve it. There is also much time available because Sunrock's scope 1 target must be reached by 2030, and its scope 3 and waste targets must be reached by 2035. Action 1.1 will happen automatically as Sunrock's office is on the waiting list for being connected to the district heating system. Action 1.2 must only be executed after all other actions for direct emissions have been executed since the action might be unnecessary if the target has already been reached through the other actions. Actions 3.1, 3.2, 3.3, and 4.2 are simple organizational changes that require little effort. The new rules must be delivered in a proper way, and it must be monitored whether these new rules are followed. Actions 1.3 and 4.1 are more costly than the just mentioned actions and therefore require some more planning. Actions 2.1, 2.2, 5.1, and 5.2 require much time and/or funding. These actions will play a significant role during all the coming years since Sunrock must always try to find the most sustainable module alternative within its varying budget. Thus, these actions are part of Sunrock's long-term strategy, while all other actions play an important role in the short-term strategy. No budget has yet been determined, but Sunrock will make funds available to achieve its targets. Exact values should still be estimated regarding the impact, projected costs, and required time of the identified actions.

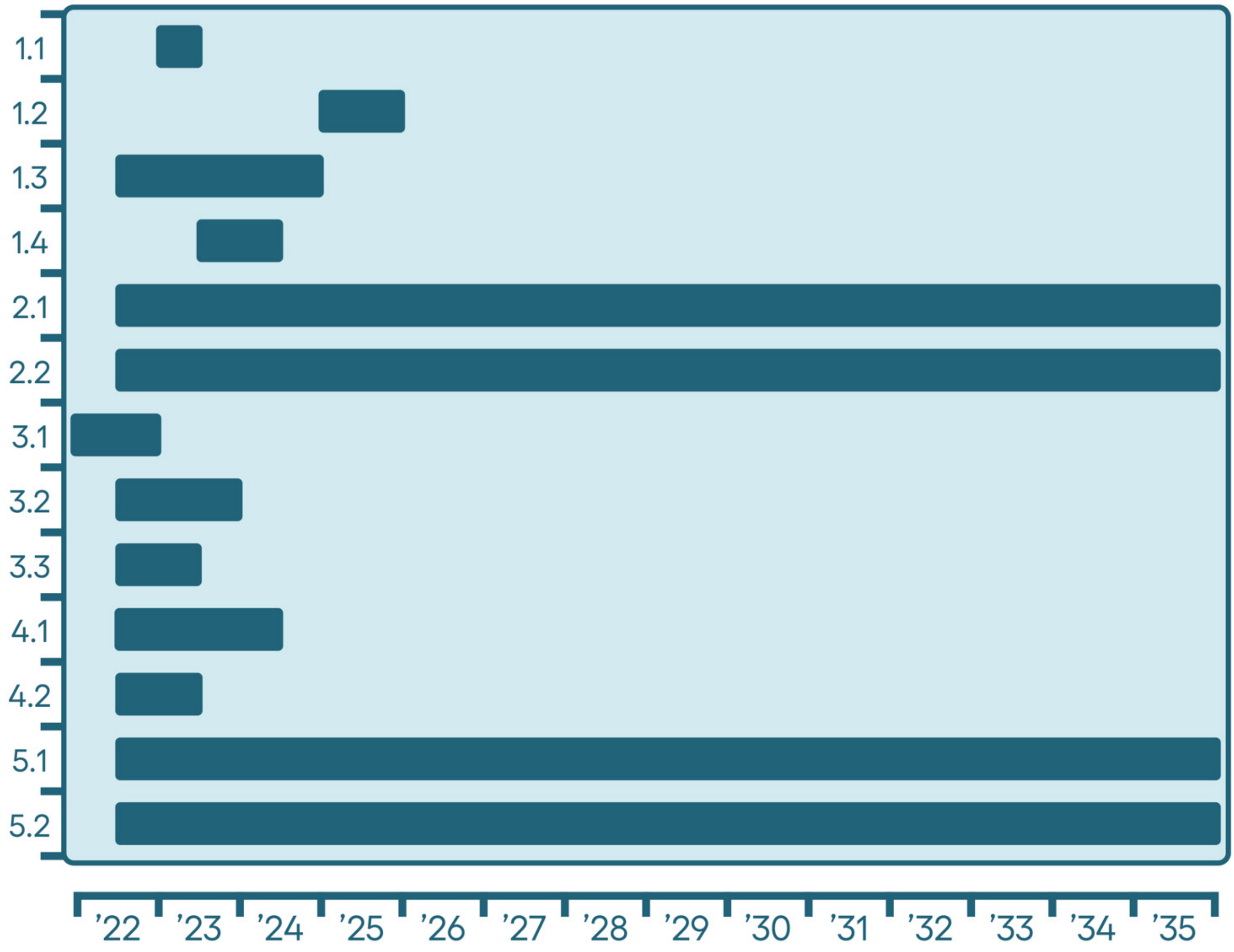


Figure 4.2 Schematic of a planning that shows when the identified actions can be executed.

4.5. Next iteration

To improve and update the results of the study, Sunrock should iterate the steps of the VCA method. This chapter will describe the value and requirements of a following iteration. This information is subject to change, but it provides an overview of the discussion points that were discovered during and right after the study has been executed.

As mentioned, a next iteration after the first time the VCA method has been executed tries to complete the baseline VCI. A more complete VCI provides more accurate results. Table 3.10 describes how the reporting components of each VCI step should be updated in a following iteration, but not all components require as much attention. Sunrock's next iteration should strive to be executed at the beginning of 2023. This iteration will calculate the yearly results for 2022, while any inaccurate data from the first study can be adjusted. Sunrock should give more attention to updating the system boundaries table and collecting more data. The more significant the changes in the VCI are, the more impact it will have on the results from steps two and three. Subsequently, the components from these steps should be updated whenever the VCI undergoes any changes. The results can then be reported, the transition log should be updated, and the value and requirements of a next iteration can be documented.

It should be checked whether the VCI map and the value chain actors table are still up to date. The first system boundaries table has been based on many assumptions. The next iteration can use the data that has been collected during the first data collection to update this table, recalculate the CPs, and adjust the system boundaries so that previously excluded activities can still be included. Sunrock can then decide to still include smaller activities on which it has a direct influence, so that new opportunities can be created. For Sunrock to be able to report its results to the SBTi, data from its German office must first be added to the existing dataset.

The next iteration should update data or add missing data so that results that are representative of the year 2022 can be calculated. Existing VCI values should also be adjusted to reach the levels of detail that were not reached initially. Sunrock must dig deeper to acquire more information from actor groups A1, A4, A5, and A6. Actor group A2 should still provide a value for the GWP per manufactured unit to verify the results that were calculated in the first study. Sunrock should already start thinking about the end-of-life of its PV systems, so that more accurate data can be gathered for actor group E2. Sunrock is also putting a system in place for registering the business travel distances. This system will take away the assumptions that were made for the calculations for actor group F.

The results should eventually be reinterpreted so that the next steps can also be updated. A solution can then be found for the problem regarding the negative values for biogenic CO_2 emissions. The existing sets of targets and actions can be updated. Aspect estimations of the updated set of actions can then be updated to be more accurate. Actions can then be reprioritized so that Sunrock's roadmap for its transition towards circular solar energy is up to date. Exact values for the projected costs and required time have not yet been determined for the identified actions. This can still be determined in a next iteration, so that the total projected costs and required time can be calculated for the created roadmap. Exact values regarding the environmental impact of each of the identified actions have also not yet been determined. Thus, the action aspects might require some extra attention, so that more details can be calculated for Sunrock's roadmap. Sunrock can also document a first transition log to document its progress. The next iteration should be concluded by documenting the details on the one that follows.

The existing model can also be used to see what effects any C2C module alternatives would have on the results. This data has not been included in the first study since the manufacturers of the few C2C module designs did not respond to any of the requests that were sent. The transition to C2C module designs is expected to take some time as the knowledge level is still lacking (Contreras-Lisperguer et al., 2017). A lack of open innovation causes the industry to not progress as fast as required, which causes the most sustainable designs to also be the most profitable ones.

A next iteration can also try to further build the existing model. Things like safety and costs can be included in GaBi. This would enable Sunrock to use the model for strategic decision making in other areas than sustainability. This is just optional as the most important function of the model is to help Sunrock transition towards circular solar energy. The first targets that were proposed help Sunrock to start moving, but reiteration is required for the targets and actions to stay representative. The goal is only reached when Sunrock's business operations are completely carbon neutral and generate no disposable waste.

To ensure the consistency and relevance of the results, a recalculation of the existing data might be required. Whether this should be done depends on the base year recalculation policy. For Sunrock, this policy does not differ from the standard policy that was stated in Chapter 3.7. Recalculation is required when structural changes happen at Sunrock, when it is believed that another calculation methodology should be used, or when there are changes in the categories or activities that are included in the VCI. One of Sunrock's goals is to report accurate results to the SBTi. A recalculation should therefore always be performed if there is any reason to believe that the base year results are not representative anymore. The context for executing a recalculation should always be provided. An interesting thing to mention is the fact that Sunrock is expanding significantly. Sunrock's yearly output is therefore expected to increase rapidly. All effects that are bound to this output will rise with it. Base year recalculation is however not allowed to take this expansion into account. Reductions are therefore much more difficult to achieve in an expanding company since the proposed targets refer to the base year.


AGRO
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Part 5

Discussion & Conclusions

The VCA method has been described extensively, and the results that follow from it when applying it to Sunrock's value chain have been presented. A discussion will follow in which the VCA method is evaluated, and recommendations are given for improving the method over time. The report will finalize by presenting the conclusions that can be drawn from this study.

5.1. Discussion

The VCA method has been designed and applied in a case study. This discussion will first present an evaluation in which the VCA method is interpreted, and in which its implications and limitations are discussed. The evaluation regarding the results of the case study has already been discussed during the interpretation in Chapter 4.2. Therefore, the evaluation will only discuss the design of the VCA method and how it can or should be applied in general. The discussion will continue by giving recommendations regarding the next steps that should be taken in response to the findings of this report. The next steps that should be taken regarding the results of the case study have already been discussed when documenting the next iteration in Chapter 4.5. The recommendations section will therefore only discuss the practical actions and scientific research that should follow regarding the VCA method.

5.1.1. Evaluation

When interpreting the designed VCA method and how it is applied, the meaning of the method should be clarified. The method offers a relatively simple roadmap for companies to become more sustainable regarding their energy and material use. At the same time this method is valid for setting SBTs for the SBTi if the RC that applies the method takes the SBT criteria of the SBTi into account. A company can apply the method if its goals align with those of the method. Besides that, an RC needs sufficient in-house experience with LCAs and the software that can be used to conduct them. The RC must also be able to accurately gather data, make calculations, and present results in the described manners. It is also expected that the RC has some prior knowledge regarding the standards of the ISO and GHG Protocol.

When thinking about the implications of the VCA method, the question of why the method matters must be answered. No generic roadmap existed for companies to join the transition towards a sustainable future. The VCA method therefore adds much value since it presents a generic roadmap that combines the 14040 and 14044 LCA standards of the ISO (ISO, 2006a, 2006b) with the A&R standard for scope 3 of the GHG Protocol (GHG Protocol, 2011, 2013). The reporting requirements from both organizations have been considered, which entails that if the method is followed properly, the results accommodate both standards. In a world where sustainability, circularity, and scope 3 emissions become increasingly important (Ellen MacArthur Foundation, 2013; Hertwich & Wood, 2018), and where scope 3 mapping and LCAs are deemed too complicated and unspecific (Patchell, 2018), the VCA method presents a simplified and structured way of quickly estimating a value chain's generated emissions and waste and improving this estimate over time.

When speaking of the VCA method's limitations, the focus should be on everything the method cannot tell us. Though the VCA method tries to simplify the data gathering and analysis, there still are some limitations to compiling a VCI and analyzing it through an LCA. During the compilation of a VCI, interdependent factors such as transaction costs, power, responsibility allocation, uncertainty, location contingency, and production costs inhibit the GHG Protocol's ambition of promoting the measurement and management of GHG emissions throughout the value chain (Patchell, 2018). Value chains can be mapped, and emissions and waste can be audited, but this does not mean they can always be measured in practice. Whenever weak or broken data links are discovered at any point in the value chain, the flow of data is disrupted and it becomes more difficult to produce a report that resembles what the GHG Protocol or SBTi asks for (Patchell, 2018). The VCA method states that an RC can decide for itself whether its results are disclosed to the public or not. This freedom might however lead to greenwashing if a published report is not verified in advance by an independent assessor. It is therefore expected that the RC handles this responsibility appropriately.

There also are limitations that are implicit to LCAs. Standards such as those of the ISO are required for conducting LCAs. Otherwise, anyone could do an LCA according to their own views of how a study should be done and what methods would be appropriate to use. Ten different studies on the same product could otherwise harvest ten completely different sets of results. However, though LCA standards help to normalize these efforts, the standards are not as restrictive and even if these ten studies conform to the known standards there is no guarantee that similar sets of results are generated (Matthews et al., 2015). Aside from that, the ISO recognizes that the following limitations are present in LCAs (2006a):

- The nature of choices and assumptions made in LCA (e.g., system boundary setting, selection of data sources and impact categories) may be subjective.
- Models used for inventory analysis or to assess environmental impacts are limited by their assumptions and may not be available for all potential impacts or applications.
- Results of LCA studies focused on global and regional issues may not be appropriate for local applications, i.e., local conditions might not be adequately represented by regional or global conditions.
- The accuracy of LCA studies may be limited by accessibility or availability of relevant data, or by data quality (e.g., gaps, types of data, aggregation, average, site-specific).
- The lack of spatial and temporal dimensions in the inventory data used for impact assessment introduces uncertainty in impact results. This uncertainty varies with the spatial and temporal characteristics of each impact category.

These limitations of LCAs are directly transferrable to the limitations of the VCA method. However, two of these limitations are most significant for the VCA method. The method leaves things open for decisions by the RCs. Because these decisions can have a significant impact on the results of a VCA study, it is important that an RC keeps true to the intentions of conducting a VCA, and that it does as much as possible to get the best results. The accessibility, availability, and quality of relevant data will have a negative impact on the results of the study. An RC should acknowledge these uncertainties and put the results of the VCA method in perspective accordingly. The significance of the effects of the other three LCA limitations is case-specific, but the VCA method tries to take them into account. Any effects regarding the time and location should be countered by the data quality requirements that consider time- and geographical sensitivity. The described VCI analysis has been performed for the inventory analysis and the IPCC AR6 method has been used to assess the environmental impact. The IPCC AR6 method has been selected because it fits the required application and therefore essentially does not limit the results that follow from the VCA method.

Applying the upscaling technique to the baseline dataset might not necessarily result in a dataset that is similar to the actual complete dataset. It is only assumed that the baseline dataset represents the average dataset per FU. It is therefore only assumed that performing the VCIA on the baseline dataset eventually results in the average results per FU. The M-factors that were determined for upscaling the results cause additional inaccuracy as these factors are only an estimation. Averages that are used during the VCA method do not necessarily form a problem. The problem lies with the accuracy of the used averages. The accuracy of used database data is also important. Data from the Sphera and EcoInvent databases is usually accurate, but from year to year this data might not be updated. The results from database processes might therefore not change from one year to the next, which can be a problem if the RC reports yearly.

When configuring the model in GaBi, the RC must keep its eye on the required results. There are many ways of configuring a model in GaBi for it to be representative of the situation that should be analyzed. Each way can have consequences for the eventual results of the study, which means that the RC should always look out to choose a way that does not have a negative impact on the eventual results that are required by the RC. The required results are different for each RC, so it is up to the RC to know its goals and develop a model that helps to achieve them. This freedom the RCs have in their application and interpretation of the VCA method makes it difficult to compare the results of different RCs that applied the method. To compare different studies, they must first be analyzed to see where their differences lie. This is no problem as the VCA method is developed to provide an RC with results that are required by this RC, not other RCs. As mentioned, the results from the VCA method are also not directly comparable with results that were calculated manually through emission factors due to the low-level analysis that is performed through using LCA software. Such a low-level analysis makes the eventual VCA results turn out higher. The direct emissions of manufacturers, which are often presented in sustainability reports, therefore often turn out lower than the emissions calculated in the VCA. This is because the VCA does not only take the direct emissions of the manufacturers into account, but also those of their suppliers of raw materials.

5.1.2. Recommendations

Now to discuss the next steps that should be taken regarding this research. A first thing to state is that step nine of the A&R roadmap from Table 6.2 in Appendix 6.A (p. 109-110) is not yet fully executed because the identified SBTs have not yet been submitted to the SBTi. It is the RC's responsibility to use the results of the VCA method the way they intended to use them. If the RC has committed to the SBTi, it should follow the steps from Table 2.1 to conform to the norm of setting SBTs and report on its progress. Though the A&R standard of the GHG Protocol is the most widely used standard (GHG Protocol, 2021), the VCA results can also be shared with other GHG initiatives if some adjustments are made to the reporting requirements. The report that has been written can also be disclosed to clients and stakeholders if required. By doing this, the RC can effectuate an image boost or become a role model for other companies that strive to become more sustainable.

The VCA method can be improved by integrating the standards of the ISO and the GHG Protocol with more detail. Especially the A&R standard of the GHG Protocol is quite extensive and provides many details for each individual step. The goal is not to repeat the many pages of the GHG Protocol's A&R standard. Information from this standard has been analyzed and presented during the VCA method description whenever it supplemented the VCA method. Though it is not wished that the VCA method repeats every detail, it could refer more to these details whenever they are relevant. For now, it is therefore expected that the RC has some prior knowledge regarding the used standards. The VCA method can also be improved by performing more case studies. Each case study is different and therefore each case study provides new input for improving certain parts of the method. As an example, how an RC sets targets, identifies actions, and prioritizes those actions is highly dependent on the RC's capabilities and priorities. Data from additional case studies might help to develop a more detailed generic way for executing these steps. Data from additional case studies might also indicate the need for the integration of additional concepts in the VCA method. One of such concepts is offsetting waste, which RCs might want to apply in case they have no means to reduce their indirect waste. Such additional concepts must be worked out completely before they can be integrated.

Documenting the results of the VCA method can generate quite some accounting work for larger RCs. Though the current version of the method already provides exemplary templates, more effort can be put into creating more and better standard templates that increase the workflow of larger companies during the organization of their VCA results. Again, more case studies can provide useful input for improving such templates. More case studies provide more material for further evaluating and improving the VCA method. However, an open innovation mentality is required to reach the level of collaboration that is required for improving the VCA method through more case studies. In collaboration with the ISO or GHG Protocol the method might even be presented as a new standard for value chain LCAs. Such a standard could also try to include other LCA software than just GaBi. Before any of this can happen, more case studies, additions, and adjustments are required to further improve the method.

5.2. Conclusions

Business operations often go paired with the emission of GHGs and the generation of waste. Many companies wish to make the transition to a more sustainable and eventually even circular business model. However, no standard method existed for companies to follow in their quest for sustainability. The VCA method was developed for companies to map and eventually neutralize their environmental impact. This method combines standards from the ISO and the GHG Protocol to help companies in structuring, analyzing, and eventually reducing the environmental impact of their value chains through LCA. The method then helps the companies to set targets and identify and prioritize actions for achieving these targets. The reiterative character of the method enables companies to improve their results and keep track of their progress regarding the targets they set and the actions they identified and seek to execute. The developed method has been evaluated by applying it in a case study for Sunrock. The results of this case study showed that the VCA method can be used by companies as a tool for gaining insights in the GHG emission and waste streams that result from their value chains. Companies can then decide to act on these insights accordingly.

The case study pointed out that the results of the VCA method are highly dependent on the quality of the gathered data and the competency and effort of the researcher to analyze it. Negligence can cause the results to be highly inaccurate and therefore unusable. It can therefore be concluded that some effort is required to apply the VCA method. Though the VCA method already presents a simplified and structured way of estimating and reducing a value chain's emissions and waste, the method could improve through more detailed evaluation and application in more case studies. An open innovation environment and insights from different sectors are required to evolve the method into something that is universally applicable. Sharing progress and the means for achieving it is key to making the transition towards circularity appealing and accessible to all organizations. Humanity's equilibrium with nature will be difficult to realize without humanity's willingness for such collaboration.

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Part 6

Appendices

This part contains the appendices to which is referred to in the report's previous parts. The first and second appendices contain all large tables and figures that had a negative impact on the readability of the report; the third appendix presents download links for files that are relevant for applying the VCA method; the fourth appendix contains the list of SBT criteria; the fifth appendix presents the filled in data templates; and the sixth appendix gives an overview of the results of the employee commute survey.

6.A. Large tables

Table 6.1 Descriptions and minimum boundaries of the 15 scope 3 categories (GHG Protocol, 2011).

#	Category	Description	Minimum boundary
1	Purchased goods and services	Extraction, production, and transportation of goods and services purchased or acquired by the RC in the reporting year, not otherwise included in Categories 2 – 8.	All upstream (cradle-to-gate) emissions of purchased goods and services.
2	Capital goods	Extraction, production, and transportation of capital goods purchased or acquired by the RC in the reporting year.	All upstream (cradle-to-gate) emissions of purchased capital goods.
3	Fuel- and energy-related activities	Extraction, production, and transportation of fuels and energy purchased or acquired by the RC in the reporting year, not already accounted for in scope 1 or scope 2, including: a. Upstream emissions of purchased fuels (extraction, production, and transportation of fuels consumed by the RC). b. Upstream emissions of purchased electricity (extraction, production, and transportation of fuels consumed in the generation of electricity, steam, heating, and cooling consumed by the RC). c. Transmission and distribution (T&D) losses (generation of electricity, steam, heating, and cooling that is consumed (i.e., lost) in a T&D system) – reported by end user. d. Generation of purchased electricity that is sold to end users (generation of electricity, steam, heating, and cooling that is purchased by the RC and sold to end users) – reported by utility company or energy retailer only.	a. For upstream emissions of purchased fuels: All upstream (cradle-to-gate) emissions of purchased fuels (from raw material extraction up to the point of, but excluding, combustion). b. For upstream emissions of purchased electricity: All upstream (cradle-to-gate) emissions of purchased fuels (from raw material extraction up to the point of, but excluding, combustion by a power generator). c. For T&D losses: All upstream (cradle-to-gate) emissions of energy consumed in a T&D system, including emissions from combustion. d. For generation of purchased electricity that is sold to end users: Emissions from the generation of purchased energy.
4	Upstream transportation and distribution	- Transportation and distribution of products purchased by the RC in the reporting year between the RC's tier one suppliers and its own operations (in vehicles and facilities not owned or controlled by the RC). - Transportation and distribution services purchased by the RC in the reporting year, including inbound logistics, outbound logistics (e.g., of sold products), and transportation and distribution between the RC's own facilities (in vehicles and facilities not owned or controlled by the RC).	- The scope 1 and scope 2 emissions of transportation and distribution providers that occur during use of vehicles and facilities (e.g., from energy use). - Optional: The life cycle emissions associated with manufacturing vehicles, facilities, or infrastructure.
5	Waste generated in operations	Disposal and treatment of waste generated in the RC's operations in the reporting year (in facilities not owned or controlled by the RC).	- The scope 1 and scope 2 emissions of waste management suppliers that occur during disposal or treatment. - Optional: Emissions from transportation of waste.
6	Business travel	Transportation of employees for business-related activities during the reporting year (in vehicles not owned or operated by the RC).	- The scope 1 and scope 2 emissions of transportation carriers that occur during use of vehicles (e.g., from energy use). - Optional: The life cycle emissions associated with manufacturing vehicles or infrastructure.
7	Employee commuting	Transportation of employees between their homes and their worksites during the reporting year (in vehicles not owned or operated by the RC).	- The scope 1 and scope 2 emissions of employees and transportation providers that occur during use of vehicles (e.g., from energy use). - Optional: Emissions from employee teleworking.

8	Upstream leased assets	Operation of assets leased by the RC (lessee) in the reporting year and not included in scope 1 and scope 2 – reported by lessee.	- The scope 1 and scope 2 emissions of lessors that occur during the RC's operation of leased assets (e.g., from energy use). - Optional: The life cycle emissions associated with manufacturing or constructing leased assets.
9	Downstream transportation and distribution	Transportation and distribution of products sold by the RC in the reporting year between the RC's operations and the end consumer (if not paid for by the RC), including retail and storage (in vehicles and facilities not owned or controlled by the RC). * Outbound transportation and distribution services that are purchased by the RC are excluded from category 9 and included in category 4 because the RC purchases the service.	- The scope 1 and scope 2 emissions of transportation providers, distributors, and retailers that occur during use of vehicles and facilities (e.g., from energy use). - Optional: The life cycle emissions associated with manufacturing vehicles, facilities, or infrastructure.
10	Processing of sold products	Processing of intermediate products sold in the reporting year by downstream companies (e.g., manufacturers).	The scope 1 and scope 2 emissions of downstream companies that occur during processing (e.g., from energy use).
11	Use of sold products	End use of goods and services sold by the RC in the reporting year.	- The direct use-phase emissions of sold products over their expected lifetime (i.e., the scope 1 and scope 2 emissions of end users that occur from the use of: products that directly consume energy (fuels or electricity) during use; fuels and feedstocks; and GHGs and products that contain or form GHGs that are emitted during use). - Optional: The indirect use-phase emissions of sold products over their expected lifetime (i.e., emissions from the use of products that indirectly consume energy (fuels or electricity) during use).
12	End-of-life treatment of sold products	Waste disposal and treatment of products sold by the RC (in the reporting year) at the end of their life.	The scope 1 and scope 2 emissions of waste management companies that occur during disposal or treatment of sold products.
13	Downstream leased assets	Operation of assets owned by the RC (lessor) and leased to other entities in the reporting year, not included in scope 1 and scope 2 – reported by lessor.	- The scope 1 and scope 2 emissions of lessees that occur during operation of leased assets (e.g., from energy use). - Optional: The life cycle emissions associated with manufacturing or constructing leased assets.
14	Franchises	Operation of franchises in the reporting year, not included in scope 1 and scope 2 – reported by franchisor.	- The scope 1 and scope 2 emissions of franchisees that occur during operation of franchises (e.g., from energy use). - Optional: The life cycle emissions associated with manufacturing or constructing franchises.
15	Investments	Operation of investments (including equity and debt investments and project finance) in the reporting year, not included in scope 1 or scope 2.	The scope 1 and scope 2 emissions of investments regarding the share or proportion of the RC.

Table 6.2 Descriptions of the steps of the scope 3 A&R roadmap (adapted from GHG Protocol, 2011).

#	Step	Description
1	Define business goals	The RC must be clear on the business goals it has for the A&R of scope 3. The following business goals are served by a scope 3 GHG inventory: - Identifying and understanding risks and opportunities associated with value chain emissions. - Identifying GHG reduction opportunities, setting reduction targets, and tracking performance. - Engaging value chain partners in GHG management. - Enhancing stakeholder information and corporate reputation through public reporting.
2	Review A&R principles	The RC must be clear on the A&R principles. The RC must go over these principles thoroughly to completely understand them. A&R of a scope 3 inventory are based on the following principles: relevance, completeness, consistency, transparency, and accuracy.
3	Identify scope 3 activities	The RC must determine how its activities contribute to scope 3 emissions. The RC must understand its value chain and identify to which of the 15 categories its emissions should be allocated. The RC should not exclude any activity that would compromise the relevance of the reported inventory. The following criteria are formulated for identifying relevant scope 3 activities: - Size: The activity must contribute significantly to the RC's total anticipated scope 3 emissions. - Influence: There are potential emissions reductions that could be undertaken or influenced by the RC. - Risk: The activity contributes to the RC's risk exposure. - Stakeholders: The activity is deemed critical by key stakeholders. - Outsourcing: The activity is outsourced but previously performed in-house. - Sector guidance: The activity has been identified as significant by sector-specific guidance. - Other: The activity meets any additional criteria for determining relevance developed by the RC or industry sector.
4	Set the scope 3 boundary	The RC must determine which emissions must be included and which will be excluded in the inventory. This will determine the level of detail of the inventory analysis. The following requirements are set for this step: - The RC shall account for all scope 3 emissions and disclose and justify any exclusions. - The RC shall account for emissions from each scope 3 activity category according to the mentioned minimum boundaries. - The RC shall account for scope 3 emissions of CO_2. The emissions of CH_4, N_2O, HFCs, PFCs, and SF_6 should also be included if they are emitted in the value chain, but they can be excluded when this is disclosed and justified. - Biogenic CO_2 emissions that occur in the value chain shall not be included in the scopes, but they shall be included and separately reported in the public report.
5	Collect data	Next, the RC should collect data. There are two main methods to quantify emissions. The direct measurement method uses direct emissions data and GWP values to calculate the total emission, while the calculation method uses activity data, emission factors and GWP values. Activity data is a quantitative measure of a level of activity that results in GHG emissions, such as liters of fuel consumed. An emission factor is a factor that converts activity data into GHG emissions data, such as kg CO_2 emitted per liter of fuel consumed. Data should be collected and evaluated according to an iterative process. The following steps should be taken when collecting data: 1. The identified activities must be prioritized based on the estimated magnitude of their GHG emissions, the expected financial spend or revenue, or another factor that is important for the RC or its stakeholders. 2. The RC should select the data of sufficient quality to ensure that the inventory appropriately reflects the GHG emissions of the company, supports the company's goals, and serves the decision-making needs of users, both internal and external to the company. Data should be selected based on the RC's business goals, the relative significance of scope 3 activities, the availability of primary and secondary data, and the quality of available data. Data quality indicators are technological, temporal, and geographical representativeness. Data completeness and reliability are also very important. 3. Secondary data should be collected, and data gaps should be filled. Databases should be prioritized and if data of sufficient quality is not available, the RC may use proxy data to fill data gaps. Proxy data is data from a similar activity that is used as a stand-in for the given activity. Proxy data can be extrapolated, scaled up, or customized to be more representative of the given activity. 4. The quality of the collected data should be improved over time. The data quality should be assessed when data sources are selected and after the data has been collected. Over time, the RC should seek to improve the data quality of the inventory by replacing lower quality data with higher quality data as it becomes available. In particular, the RC should prioritize data quality improvement for activities that have relatively low data quality or relatively high emissions. For data that must be improved the RC goes back to step two of collecting data.
6	Allocate emissions	Allocation is the process of partitioning GHG emissions from a single facility or other system. Allocation is necessary when a single facility or other system produces multiple outputs, or when emissions are only quantified for the entire facility or system as a whole. Allocation should be avoided or minimized as much as possible since it adds uncertainty to the emission estimates. There are different types of allocation methods. Physical allocation is often based on mass, volume, energy, chemicals, or number of units. Economic allocation is mostly based on market value. Sometimes custom allocation methods must be designed.
7	Set a target & track emissions over time	The A&R of GHG emissions allows the RC to track and report its emissions performance over time. Setting targets and tracking them is important for following up on the business goals that were stated in the beginning. Targets can be set for the total emissions (scope 1, 2, and 3 together), but targets can also be set for just the total scope 3 emissions or even separate targets for individual scope 3 activity categories. Actions should be identified for reducing scope 3 emissions to reach the set targets. The RC should follow the following steps to track scope 3 performance over time: - Choosing a base year and determining base year emissions.

		- Setting scope 3 reduction goals/targets. - Developing a recalculation policy that articulates the basis for any recalculations. - Recalculating base year emissions when significant changes in the RC's structure or inventory methodology occur. - Accounting for scope 3 emissions and reductions over time. When accounting for scope 3 emissions, the RC can take avoided emissions and double counting into account. Avoided emissions are emissions that are avoided because of the use of the RC's products and solutions compared to alternative products and solutions can be reported separately. Double counting takes place because scope 3 emissions are the scope 1 emissions of another entity. To ensure transparency and avoid misinterpretation of data, the RC should acknowledge any potential double counting of reductions or credits when making claims about scope 3 reductions.
8	Assure emissions	Emission should be assured by the RC to provide the level of confidence that the inventory is complete, accurate, consistent, transparent, relevant and without material misstatements. Assurance is not a requirement of the A&R standard, but it is valuable for RCs and other stakeholders when making decisions using the inventory results. First party assurance comes from within the RC but is independent of the GHG inventory process conducts internal assurance. Third party assurance comes from an organization that independent conducts third party assurance of the scope 3 inventory process. The highest level of assurance is a reasonable assurance, while any level of assurance below that is a limited assurance. The following steps should be performed during the assurance process: 1. Planning and scoping (e.g., determining risks and material misstatements). 2. Identifying emission sources included in the scope 3 inventory. 3. Performing the assurance process (e.g., gathering evidence, performing analytics, etc.). 4. Evaluating results. 5. Determining and reporting conclusions.
9	Report emissions	The RC should present a credible emissions report based on the mentioned A&R principles. It should be based on the best data available and be transparent about its limitations. The results of each step must be documented in detail to make sure that the report is as complete as possible. The following requirements are stated for such a report: - A scope 1 and scope 2 emissions report in conformance with the GHG Protocol Corporate Standard (GHG Protocol, 2004). - Total scope 3 emissions reported separately by scope 3 activity category. - For each scope 3 activity category, total GHG emissions reported in metric tons of CO_2 equivalent, excluding biogenic CO_2 emissions and independent of any GHG trades, such as purchases, sales, or transfers of offsets or allowances. - A list of scope 3 activity categories and activities included in the inventory. - A list of scope 3 activity categories or activities excluded from the inventory with justification of their exclusion. - Once a base year has been established: the year chosen as the scope 3 base year; the rationale for choosing the base year; the base year emissions recalculation policy; scope 3 emissions by category in the base year, consistent with the base year emissions recalculation policy; and appropriate context for any significant emissions changes that triggered base year emissions recalculations. - For each scope 3 activity category, any biogenic CO_2 emissions reported separately. - For each scope 3 activity category, a description of the types and sources of data, including activity data, emission factors and GWP values, used to calculate emissions, and a description of the data quality of reported emissions data. - For each scope 3 activity category, a description of the methodologies, allocation methods, and assumptions used to calculate scope 3 emissions. - For each scope 3 activity category, the percentage of emissions calculated using data obtained from suppliers or other value chain partners.

Table 6.3 Required information for activities within the 15 scope 3 categories to perform a VCA.

#	Category		#	Required information
0	General		0.1 0.2 0.3	*Some general information is required for allocating the required information of the other categories to the FU. This information is project specific and must be determined by the RC.*
1	Purchased goods and services	Goods	1.1	Bill of materials together with the amount of each (raw) material per purchased good.
			1.2	Recyclability or potential recovery percentage of each of the used (raw) materials.
			1.3	Other manufacturing substances used per purchased good. Water is among these substances.
			1.4	Amounts and types of waste generated by the manufacturer per purchased good.
			1.5	Amounts and types of GHG emissions generated by the manufacturer per purchased good. This can be an average for combined purchased goods.
			1.6	Number of purchased goods needed per FU.
			1.7	Expected lifetime of the purchased good.
			1.8	Amount of electricity consumed by the manufacturer per purchased good and the sources from which this electricity originates.
			1.9	Amounts and types of fuels used (also for generation of electricity) by the manufacturer per purchased good.
			1.10	Types of disposal or treatments used for specific types of generated waste.
			1.11	Modes and distances of transportation of generated waste.
			1.12	Modes and distances of transportation of the purchased good within the manufacturing facility.
			1.13	Amounts and types of materials used for the packaging of the purchased good.
		Services	1.14	Disposable materials used per purchased service.
			1.15	Amounts and types of waste generated by the service provider per purchased service.
			1.16	Amounts and types of GHG emissions per purchased service. Emission sources must be identified for each service so that specific questions can be asked, and specific data can be gathered.
			1.17	Number of purchased services needed per FU.
			1.18	Amount of electricity consumed by the service provider per purchased service and the sources from which this electricity originates.
			1.19	Average amounts and types of fuels used (also for generation of electricity) by the service provider in a year for the RC.
			1.20	Types of disposal or treatments used for specific types of generated waste.
2	Capital goods		2.1	Bill of materials together with the amounts of each (raw) material per capital good.
			2.2	Recyclability or potential recovery percentage of each of the used (raw) materials.
			2.3	Other manufacturing substances used per capital good. Water is among these substances.
			2.4	Amounts and types of waste per capital good.
			2.5	Amounts and types of GHG emissions generated by the manufacturer per capital good. This can be an average for combined capital goods.
			2.6	Number of capital goods needed per FU.
			2.7	Expected lifetime of the capital good.
			2.8	Amount of electricity consumed by the manufacturer per capital good and the sources from which this electricity originates.
			2.9	Amounts and types of fuels used (also for generation of electricity) by the manufacturer per capital good.
			2.10	Types of disposal or treatments used for specific types of generated waste.
			2.11	Modes and distances of transportation of generated waste.
			2.12	Modes and distances of transportation of the capital good within the manufacturing facility.
			2.13	Amounts and types of materials used for the packaging of the capital good.
3	Fuel- and energy-related activities		$3.1^{1/3}$	Amounts and types of fuels consumed in the RC's facilities in the reporting year. This data should be collected for each facility of the RC. Fuels used for the generation of electricity should also be included. ∗ Direct emissions from consuming these fuels belong to scope 1, while indirect emissions from the extraction, production, and transportation of these fuels belong to scope 3.
			3.2^{2}	Amount of electricity consumed in the RC's facilities in the reporting year and the sources from which this electricity originates. This data should be collected for each facility of the RC. Electricity the RC generated by using fuels and electricity the RC used for charging electric vehicles should be excluded to prevent double counting. ∗ If electricity is purchased, indirect emissions that follow from the generation of this electricity belong to scope 2. If electricity is generated by the RC with fuels, direct emissions from consuming these fuels belong to scope 1, while indirect emissions from the extraction, production, and transportation of these fuels belong to scope 3.
			3.3	Amounts and types of purchased or generated energies that are sold to others in the reporting year.
			3.4	Amount of water purchased by the RC for consumption in the reporting year. This data should be collected for each facility of the RC.
4	Upstream transportation and distribution		4.1	Definition of the transported payload.
			4.2	Exact location(s) from where the payload is sent.
			4.3	Exact locations(s) to which the payload is delivered.
			4.4	Modes and distances of transportation for the route(s) the good(s) or service travels.

5	Waste generated in operations	Transport	5.1	Definition of the transported payload.
			5.2	Exact location(s) from where the waste is transported.
			5.3	Exact location(s) to where the waste is transported.
			5.4	Modes and distances of transportation for the entire route the waste travels.
		Process	5.5	Amounts and types of waste from purchased goods that were purchased in the reporting year. This will most likely be an average and can be calculated per facility.
			5.6	Amounts and types of waste from capital goods that were purchased in the reporting year. This will most likely be an average and can be calculated per facility.
			5.7	Types of disposal or treatments used for specific types of waste from purchased (capital) goods.
6	Business travel		$6.1^{1/2/3}$	Number of kilometers traveled in the reporting year by employees for business-related activities in vehicles owned or operated by the RC. The modes of travel must be specified together with the traveled distance per mode. * With fuel-based vehicles, direct emissions from their consumption of fuels belongs to scope 1, while indirect emissions from the extraction, production, and transportation of these fuels belong to scope 3. With electric vehicles, indirect emissions that follow from the generation of their consumed electricity belong to scope 2.
			6.2	Number of kilometers traveled in the reporting year by employees for business-related activities in vehicles not owned or operated by the RC. The modes of travel must be specified together with the traveled distance per mode.
			6.3	Total amount of nights spent by employees in hotels in the reporting year.
7	Employee commuting		$7.1^{1/2/3}$	Number of kilometers traveled in the reporting year by employees between their homes and their worksite(s) in vehicles owned or operated by the RC. The modes of travel must be specified together with the traveled distance per mode. * With fuel-based vehicles, direct emissions from their consumption of fuels belongs to scope 1, while indirect emissions from the extraction, production, and transportation of these fuels belong to scope 3. With electric vehicles, indirect emissions that follow from the generation of their consumed electricity belong to scope 2.
			7.2	Number of kilometers traveled in the reporting year by employees between their homes and their worksite(s) in vehicles not owned or operated by the RC. The modes of travel must be specified together with the traveled distance per mode.
8	Upstream leased assets		8.1	Amounts and types of GHG emissions in the reporting year from scope 1 and scope 2 of lessors that occur during the RC's operation of the leased asset.
			8.2	Amounts and types of waste generated during the manufacturing and end-of-life of the leased asset.
			8.3	Expected lifetime of the leased asset.
			8.4	Amount of time the RC used the leased asset per FU.
			8.5	Amounts and types of GHG emissions during the lifecycle of the leased asset.
			8.6	Types of disposal or treatments used for specific types of generated waste.
			8.7	Modes and distances of transportation of generated waste.
9	Downstream transportation and distribution		9.1	Definition of the transported payload.
			9.2	Exact location(s) of where sold goods are manufactured.
			9.2	Exact locations(s) of the destination(s) where sold goods are delivered.
			9.3	Modes and distances of transportation for the entire route a sold good travels.
10	Processing of sold products		10.1	Amounts and types of GHG emissions in the reporting year from scope 1 and scope 2 of companies that have a role in processing intermediate products that are purchased and eventually used by the RC.
			10.2	Amounts and types of waste generated during the manufacturing of intermediate products that are purchased and eventually used by the RC.
			10.3	Types of disposal or treatments used for specific types of generated waste.
			10.4	Modes and distances of transportation of generated waste.
11	Use of sold products		11.1	Amounts and types of GHG emissions directly caused by the sold products/services during their use-phase over their expected lifetime.
			11.2	Amounts and types of GHG emissions indirectly caused by the sold products/services during their use-phase over their expected lifetime.
			11.3	Amounts and types of waste directly caused by the sold products/services during their use-phase. For products this can be packaging, while for services this can be all types of things.
			11.4	Types of disposal or treatments used for specific types of generated waste. For product packaging this can be an estimation.
			11.5	Modes and distances of transportation of generated waste. For product packaging this can be an estimation.
12	End-of-life treatment of sold products		12.1	Amounts and types of waste of products sold by the RC at the end of their life.
			12.2	Types of disposal or treatments used for specific types of generated waste. This can be an estimation since this is dependent on the disposal or treatment by the product users.
			12.3	Modes and distances of transportation of generated waste. This can be an estimation since this is dependent on the disposal or treatment by the product users.

13	Downstream leased assets	13.1	Amounts and types of GHG emissions in the reporting year from scope 1 and scope 2 of lessees that occur during the operation of the leased asset.
		13.2	Amounts and types of waste generated during the manufacturing and end-of-life of the leased asset.
		13.3	Expected lifetime of the leased asset.
		13.4	Amount of time the RC leased the asset to other entities per FU.
		13.5	Amounts and types of GHG emissions during the lifecycle of the leased asset.
		13.6	Types of disposal or treatments used for specific types of generated waste.
		13.7	Modes and distances of transportation of generated waste.
14	Franchises	14.1	Amounts and types of GHG emissions caused by the franchisor.
		14.2	Amounts and types of waste caused by the franchisor.
		14.3	Types of disposal or treatments used for specific types of generated waste.
		14.4	Modes and distances of transportation of generated waste.
15	Investments	15.1	Amounts and types of GHG emissions caused by the investment. These emissions can be allocated proportionally regarding the investment share of the RC for as long as the RC is involved in the investment.
		15.2	Amounts and types of waste caused by the investment. These emissions can be allocated proportionally regarding the investment share of the RC for as long as the RC is involved in the investment.
		15.3	Types of disposal or treatments used for specific types of generated waste.
		15.4	Modes and distances of transportation of generated waste.

Table 6.4 Data calculation methods for the 15 scope 3 categories (adapted from GHG Protocol, 2013).

#	Category	Method	Description
1	Purchased goods and services	Supplier-specific method	This method collects product-level cradle-to-gate inventory data directly from goods or services suppliers. This data. With this method the data is specific to the supplier's product.
		Hybrid method	This method uses a combination of supplier-specific activity data (where available) and secondary data to fill the gaps. This method involves: - Collecting allocated scope 1 and scope 2 data directly from suppliers. - Calculating upstream emissions and waste of goods and services from suppliers' activity data on the number of materials, fuel, electricity, used, distance transported, and waste generated from the production of goods and services and applying appropriate emission factors. - Using secondary data to calculate upstream emissions and waste wherever supplier-specific data is not available. With this method the scope 1 and scope 2 data is specific to the supplier's product, while all other upstream emissions and waste are either supplier specific or an average.
		Average-data method	This method estimates emissions for goods and services by collecting data on the mass (e.g., kilograms or pounds), or other relevant units of goods or services purchased and multiplying by the relevant secondary (e.g., industry average) emission factors (e.g., average emissions per unit of good or service). With this method all emissions and waste are based on secondary process data.
		Spend-based method	This method estimates emissions and waste for goods and services by collecting data on the economic value of goods and services purchased and multiplying it by relevant secondary (e.g., industry average) emission factors (e.g., average emissions per monetary value of goods). With this data all emissions are based on secondary EEIO data.
2	Capital goods	Uses the exact same calculation methods as category 1.	
3	Fuel- and energy-related activities	Supplier-specific method	This method involves collecting emissions data from power generators.
		Average-data method	This method involves estimating emissions by using grid average emission rates.
4	Upstream transportation and distribution	Fuel-based method	This method involves determining the amount of fuel consumed (i.e., scope 1 and scope 2 emissions of transportation providers) and applying the appropriate emission factor for that fuel.
		Distance-based method	This method involves determining the mass, distance, and mode of each shipment, then applying the appropriate mass-distance emission factor for the vehicle used.
		Spend-based method	This method involves determining the amount of money spent on each mode of business travel transportation and applying secondary (EEIO) emission factors.
		Site-specific method	This method involves site-specific fuel, electricity, and fugitive emissions data and applying the appropriate emission factors.
		Average-data method	This method involves estimating emissions for each distribution activity, based on average data (such as average emissions per pallet or cubic meter stored per day).
5	Waste generated in operations	Supplier-specific method	This method involves collecting waste data and waste-specific scope 1 and scope 2 emissions data directly from waste treatment companies (e.g., for incineration, recovery for recycling).
		Waste-type-specific method	This method involves using emission factors for specific waste types and waste treatment methods.
		Average-data method	This method involves collecting the total waste going to each disposal method and estimating emissions based on average emission factors for each disposal method.
6	Business travel	Fuel-based method	This method involves determining the amount of fuel consumed during business travel (i.e., scope 1 and scope 2 emissions of transportation providers) and applying the appropriate emission factor for that fuel.
		Distance-based method	This method involves determining the distance and mode of business trips, then applying the appropriate emission factor for the mode used.
		Spend-based method	This method involves determining the amount of money spent on each mode of business travel transportation and applying secondary (EEIO) emission factors.
7	Employee commuting	Fuel-based method	This method involves determining the amount of fuel consumed during commuting and applying the appropriate emission factor for that fuel.
		Distance-based method, which	This method involves collecting data from employees on commuting patterns (e.g., distance traveled, and mode used for commuting) and applying appropriate emission factors for the modes used.
		Average-data method	This method involves estimating emissions from employee commuting based on average (e.g., national) data on commuting patterns.

8	Upstream leased assets	Asset-specific method	This method involves collecting asset-specific (e.g., site-specific) energy use and waste generation data or scope 1 and scope 2 data from individual leased assets.
		Lessor-specific method	This method involves collecting the scope 1 and scope 2 data from lessor(s) and allocating emissions and waste to the relevant leased asset(s).
		Average-data method	This method involves estimating emissions and waste for each leased asset, or groups of leased assets, based on average data, such as average emissions and waste per asset type or floor space.
9	Downstream transportation and distribution	Uses the exact same calculation methods as category 4.	
10	Processing of sold products	Site-specific method	This method involves determining the amount of fuel and electricity used and the amount of waste generated from processing of sold intermediate products by the third party and applying the appropriate emission factors.
		Average-data method	This method involves estimating emissions and waste for processing of sold intermediate products based on average secondary data, such as average emissions per process or per product.
11	Use of sold products	Direct use-phase method for energy products	This method is for products that directly consume energy (fuels or electricity) during use. It involves breaking down the use phase, measuring emissions and waste per product, and aggregating emissions and waste.
		Direct use-phase method for fuels and feedstocks	This method collects fuel use data and multiplying them by representative fuel emission factors.
		Direct use-phase method for GHGs	This method is for GHGs and products that contain or form GHGs that are emitted during use. It collects data on the GHG contained in the product and multiplying them by the percent of GHGs released and GHG emission factors.
		Indirect use-phase method for energy products	This method is for products that indirectly consume energy or produce waste (fuels or electricity) during use. It calculates emissions or waste by creating or obtaining a typical use-phase profile over the lifetime of the product and multiplying by relevant emission factors.
12	End-of-life treatment of sold products	Uses the exact same calculation methods as category 5.	
13	Downstream leased assets	Uses the exact same calculation methods as category 8.	
14	Franchises	Franchise-specific method	This method involves collecting site-specific activity data or scope 1 and scope 2 data from franchisees.
		Average-data method	This method involves estimating emissions and waste for each franchise, or groups of franchises, based on average statistics, such as average emissions and waste per franchise type or floor space.
15	Investments	Investment-specific method for equity investments	This method involves collecting scope 1 and scope 2 data from the investee company and allocating the emissions and waste based upon the share of investment.
		Average-data method for equity investments	This method involves using revenue data combined with EEIO data to estimate the scope 1 and scope 2 data from the investee company and allocating emissions and waste based upon share of investment.
		Project-specific method for project finance	This method involves collecting scope 1 and scope 2 data for the relevant project(s) and allocating these emissions and waste based on the investor’s proportional share of total project costs (total equity plus debt).
		Average-data method for project finance	This method involves using EEIO data to estimate the scope 1 and scope 2 data from the investee company and allocating emissions and waste based on share of total project costs (total equity plus debt).

Table 6.5 Illustrative examples of actions to reduce scope 3 emissions (GHG Protocol, 2011).

#	Category	Emission action example
1	Purchased goods and services	- Replace high-GHG-emitting raw materials with low-GHG-emitting raw materials. - Implement low-GHG-procurement/purchasing policies. - Encourage tier 1 suppliers to engage their tier 1 suppliers (i.e., the RC's tier 2 suppliers) and disclose these scope 3 emissions to the customer in order to propagate GHG reporting throughout the supply chain.
2	Capital goods	- Replace high-GHG-emitting capital goods with low-GHG-emitting capital goods.
3	Fuel- and energy-related activities	- Reduce energy consumption. - Change energy source (e.g., shift toward lower-emitting fuel/energy sources). - Generate energy on site using renewable sources.
4	Upstream transportation and distribution	- Reduce distance between supplier and customer. - Source materials locally if it leads to net GHG reductions. - Optimize efficiency of transportation and distribution. - Replace higher-emitting transportation modes (e.g., air transport) with lower-emitting transportation modes (e.g., marine transport). - Shift toward lower-emitting fuel sources.
5	Waste generated in operations	- Reduce quantity of waste generated in operations. - Implement recycling measures that lead to net GHG reductions. - Implement lower-emitting waste treatment methods.
6	Business travel	- Reduce the amount of business travel (e.g., encourage video conferencing and web-based meetings as an alternative to in-person meetings). - Encourage more efficient travel. - Encourage lower-emitting modes of travel (e.g., rail instead of plane).
7	Employee commuting	- Reduce commuting distance (e.g., locate offices/facilities near urban centers and public transportation facilities). - Create disincentives for commuting by car (e.g., parking policies). - Provide incentives for use of public transport, bicycling, carpooling, etc. - Implement teleworking/telecommuting programs. - Reduce number of days worked per week (e.g., 4 days x 10-hour schedule instead of 5 days x 8-hour schedule).
8	Upstream leased assets	- Increase energy efficiency of operations. - Shift toward lower-emitting fuel sources.
9	Downstream transportation and distribution	- Reduce distance between supplier and customer. - Optimize efficiency of transportation and distribution. - Replace higher emitting transportation modes (e.g., air transport) with lower emitting transportation modes (e.g., marine transport). - Shift toward lower-emitting fuel sources.
10	Processing of sold products	- Improve efficiency of processing. - Redesign products to reduce processing required. - Use lower-GHG energy sources.
11	Use of sold products	- Develop new low- or zero-emitting products. - Increase the energy efficiency of energy-consuming goods or eliminate the need for energy use. - Shift away from products that contain or emit GHGs. - Reduce the quantity of GHGs contained/released by products. - Decrease the use-phase GHG intensity of the RC's entire product portfolio. - Change the user instructions to promote efficient use of products.
12	End-of-life treatment of sold products	- Make products recyclable if it leads to net GHG reductions. - Implement product packaging measures that lead to net GHG reductions (e.g., decrease amount of packaging in sold products, develop new GHG-saving packaging materials, etc.). - Implement recycling measures that lead to net GHG reductions.
13	Downstream leased assets	- Increase energy efficiency of operations. - Shift toward lower-emitting fuel sources. - Invest in lower-emitting investments, technologies, and projects.
14	Franchises	- Increase energy efficiency of operations (e.g., set efficiency standards). - Shift toward lower-emitting fuel sources.
15	Investments	- Invest in lower-emitting investments, technologies, and projects.

Table 6.6 LCA reporting requirements of the ISO (ISO, 2006b).

Topic	Reporting requirements
General	The results and conclusions of the LCA shall be completely and accurately reported without bias to the intended audience. The results, data, methods, assumptions, and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the study.
Goal definition	The goal definition of the study should include: - The reasons for carrying out the study. - The study's intended applications. - The target audiences of the study. - A statement as to whether the study intends to support comparative assertions intended to be disclosed to the public.
Scope definition	The scope definition of the study should include: - The function of the study. - The FU of the study. - The system boundary of the study. - Cut-off criteria for initial inclusion of inputs and output.
LCI analysis	The LCI analysis should include: - The data collection procedures. - The qualitative and quantitative descriptions of unit processes. - The sources of published literature. - The calculation procedures. - The validation of data. - The sensitivity analysis for refining the system boundary. - The allocation principles and procedures.
LCIA	The LCIA should include: - The LCIA procedures, calculations, and results of the study. - The limitations of the LCIA results relative to the defined goal and scope of the LCA. - The relationship of LCIA results to the defined goal and scope. - The relationship of the LCIA results to the LCI results. - Impact categories and category indicators considered, including a rationale for their selection and a reference to their source. - The descriptions of or reference to all characterization models, characterization factors and methods used, including all assumptions and limitations. - The descriptions of or reference to all value-choices used in relation to impact categories, characterization models, characterization factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions, and recommendations. - A statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
Interpretation	The interpretation should include: - The results. - The assumptions and limitations associated with the interpretation of results, both methodology and data related. - The data quality assessment. - Full transparency in terms of value-choices, rationales, and expert judgements.

Table 6.7 Value chain actors table for Sunrock's value chain (information from Sunrock, 2022).

#	Actor group	Activity categories	Companies	Product types	Activity description
A1	Module suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the modules that are used in Sunrock's PV systems.
A2	Mounting material suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the mounting materials that are used in Sunrock's PV systems.
A3	Ballast suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the ballast that is used in Sunrock's PV systems.
A4	Inverter suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the inverters that are used in Sunrock's PV systems.
A5	Transformer station suppliers A5.1 Transformers A5.2 Switchgear boxes A5.3 Station housings	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the transformer stations that are used in Sunrock's PV systems. These transformer station include transformers, switchgear boxes and station housings.
A6	Cable suppliers A6.1 AC cable A6.2 DC cable	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the AC and/or DC cable that are used in Sunrock's PV systems.
A7	Cable guide suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the cable ladders and wire trays that are used in Sunrock's PV systems.
A8	Combiner box suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the combiner boxes that are used in Sunrock's PV systems.
A9	Sensor suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the sensors that are used in Sunrock's PV systems.
A10	Datalogger suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the dataloggers that are used in Sunrock's PV systems.
A11	Production meter suppliers	2 and 4	*Confidential*	*Confidential*	Manufacture and transport the production meters that are used in Sunrock's PV systems.
B1	Engineering, Procurement & Construction providers	1 and 4	*Confidential*		Provide EPC services during which components are ordered and transported, and during which Sunrock's PV systems are constructed.
B2	Operations & Maintenance providers	1 and 4	*Confidential*		Provide O&M services during which Sunrock's PV systems are monitored and maintained, and during which replacement components are ordered, transported, and installed.
B3	Decommissioning providers	1 and 4	*Confidential*		Provide DECOM services during which Sunrock's PV systems are decommissioned and used components are collected for disposal.
B4	Module testing providers	1 and 4	*Confidential*		Provide module testing services during which ordered modules are inspected.
B5	Grid connection providers	1 and 4	*Confidential*		Provide grid connection services during which the grid connection for Sunrock's PV systems is realized.
B6	Metering providers	1 and 4	*Confidential*		Provide metering services during which the production of Sunrock's PV systems is measured.
B7	Cleaning & Green Maintenance providers	1 and 4	*Confidential*		Provide C&GM services during which Sunrock's PV systems and their surroundings are cleaned.
B8	Technical due diligence	1 and 4	*Confidential*		Provide TDD services during which the suitability and risks of project sites are assessed and documented.
B9	Financial due diligence	1 and 4	Company combination		Provide FDD services during which the financials of projects are arranged, assessed, and documented.

B10	Legal due diligence	1 and 4	Company combination		Provide LDD services during which the legal situations of projects are investigated and documented.
C1	Office supplies suppliers	1 and 4	Company combination	Product combination	Manufacture and transport office supplies that are used up by Sunrock's employees when they are at the office, such as groceries and stationery articles.
C2	Office service providers	1 and 4	Company combination		Provide office services during which Sunrock's office is cleaned and maintained.
C3	Office equipment suppliers	2 and 4	Company combination	Product combination	Manufacture and transport office equipment such as furniture, fixtures, and electronics.
D1	Energy suppliers	3	MAIN Energie	Electricity Natural gas	Process and transport energy goods that are used at Sunrock's office.
D2	Water suppliers	3	Waternet	Water	Process and transport water that is used at Sunrock's office.
E1	Office waste processors	5	Milieu Service Nederland		Transport and process waste that is generated at Sunrock's office.
E2	Service waste processors	5	Not known yet		Transport and process waste that is generated during EPC, O&M, and DECOM services.
F	Facilitators for business travel	6	Company combination		Transport and house Sunrock's employees during business travel
G	Commuting employees	7			Commute to Sunrock's office independently or by using transportation carriers
H	Energy buyers	11	Company combination	Electricity from solar energy	Buy and use or resell the electricity from solar energy that is generated by Sunrock's PV systems.
RC	Sunrock				

Table 6.8 System boundaries table for Sunrock's value chain (information from Sunrock, 2022).

#	Actor group	Activity category	Activity description	Estimated units required per FU	Sources and assumptions for estimation	Estimated mass per unit (kg)	Estimated total mass (kg)	Sources and assumptions for estimation	Mass CP	Estimated energy per unit (GJ)	Estimated total energy (GJ)	Sources and assumptions for estimation	Energy CP	Environmental significance	Sources and assumptions for environmental significance	Inclusion	Level of detail	Implications of exclusion
A1	Module suppliers	2	Manufacture modules	2,630 units	Sunrock's database (2022) says modules that are often used are 380 Wp modules. This means that around 2630 modules are needed to deliver 1 FU.	22.50	59,175.00	Sunrock's database (2022) says that a module of 380 Wp weighs 22.5 kg.	42.04%	7.66	20,145.80	According to Bhandari et al. (Bhandari et al., 2015), the average silicon module has an embedded energy of around 3.95 GJ/m^2. The module has a surface area of 1.94 m^2, and thus an embedded energy of 7.66 GJ.	51.77%			Yes	4	
		4	Transport modules	200 truck kilometers 19,300 ship kilometers	The modules are produced in China. It is estimated that the modules are transported per truck for about 200 km, and per ship for about 19,300 km (SeaRates, 2022).					0.18 per truck km 0.05 per ship km	949.17	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	2.44%					
A2	Mounting material suppliers	2	Manufacture mounting materials	1,753 sets	Sunrock's database (2022) says that a set of mounting materials can carry 1 or 2 modules, depending on the direction in which it is installed. It is assumed that one set carries an average of 1.5 modules.	7.63	13,377.93	Sunrock's database (2022) says that a set of mounting materials weighs 7.63 kg.	9.50%	1.53	2,675.59	According to Gutowski et al. (2013), about 100 MJ is required for processing 1 kg of stainless steel or aluminum. It is assumed that another 100 MJ is required for turning this 1 kg into a metal construction. Therefore, it is assumed that a total of 200 MJ is required per kg.	6.87%			Yes	3	
		4	Transport mounting materials	150 truck kilometers	The mounting materials are manufactured in Den Hoorn, the Netherlands. It is estimated that the mounting materials are transported per truck for about 150 km.					0.04 per truck km	6.02	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.02%					
A3	Ballast suppliers	2	Manufacture ballast	3,500 units	Sunrock's database (2022) says that about 3500 ballast tiles are required for 2,630 modules.	9.00	31,500.00	Sunrock's database (2022) says that each ballast tile weighs 9 kg.	22.38%	0.04	126.00	According to Gutowski et al. (2013), about 4 MJ is required for processing 1 kg of brick.	0.32%			Yes	3	
		4	Transport ballast	150 truck kilometers	It is assumed that the ballast is manufactured in the Netherlands. It is estimated that the ballast is transported per truck for about 150 km.					0.09 per truck km	14.18	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.04%					
A4	Inverter suppliers	2	Manufacture inverters	9 units	Sunrock's database (2022) says inverters that are often used can process about 110 kW each. So about 9 inverters are needed to deliver 1 FU.	89.00	801.00	Sunrock's database (2022) says that the inverter of 110 kW weighs 89 kg.	0.57%	124.43	1,244.33	According to Peng et al. (2013), on average an inverter requires 1244.33 MJ per kWp, which is 1244.33 GJ per MWp.	3.20%			Yes	2	
		4	Transport inverters	250 truck kilometers 19,500 ship kilometers	The inverters are produced in China. It is estimated that the inverters are transported per truck for about 250 km, and per ship for about 19,500 km (Searates, 2022).					0.003 per truck km 0.0007 per ship km	14.55	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.03%					

A5	Transformer station suppliers A5.1 Transformers A5.2 Switchgear boxes A5.3 Station housings	2	Manufacture transformer stations that include transformers, switchgear boxes and station housings	2	transformers	Sunrock's database (2022) says that one transformer is enough for delivering one FU. An extra unit can be added if the client wants to use the produced solar energy. Since this happens often, a total of 2 transformers is required.	2,308.00	4,616.00	Sunrock's database (2022) says that Voltens transformer IEC-60076-EU-2021 weighs 2308 kg.	10.56%	3,231.20	9,693.60	It is assumed that a transformer has the same energy intensity per kg as an inverter, which is 1244.33 GJ per 890 kg, or 1.40 GJ per kg.	26.50%		Yes	3	
				2	switch-gear boxes	Sunrock's database (2022) says that 2 switchgear boxes would be required to deliver one FU, one for medium and one for low voltage. An extra unit can be added if a buying station must still be installed for the PV system, or when the client wants to use the produced solar energy. In most cases however, 2 switchgear boxes are sufficient.	750.00	1,500.00	Based on Sunrock's database (2022), it is estimated that each switchgear box weighs about 750 kg.		1,050.00	4,200.00	It is assumed that a switchgear box has the same energy intensity per kg as an inverter, which is 1244.33 GJ per 890 kg, or 1.40 GJ per kg.					
				1	station housing	Sunrock's database (2022) says that 1 transformer station would be required to deliver one FU. When a buying station must be installed for the PV system, an extra unit can be added, of which is assumed that it has the same specifications. In most cases however, 1 station housing is sufficient.	8,750.00	8,750.00	According to Sunrock's database (2022), an empty transformer station of the size that is required to deliver one FU weighs about 8,750 kg.		1,750.00	8,750.00	According to Gutowski et al. (2013), about 100 MJ is required for processing 1 kg of stainless steel or aluminum. It is assumed that another 100 MJ is required for turning this 1 kg into a metal construction. Therefore, it is assumed that a total of 200 MJ is required per kg.					
		4	Transport transformer stations that include transformers, switchgear boxes and station housings	250 19,300	truck kilometers ship kilometers	It is assumed that the transformer stations are produced in China. It is estimated that the transformer stations are transported per truck for about 250 km, and per ship for about 19,300 km (Searates, 2022).					0.013 per truck km 0.004 per ship km	443.99	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.62%				
A6	Cable suppliers A6.1 AC cable A6.2 DC cable	2	Manufacture AC and DC cable	0.50	kilometers AC cable	Sunrock's database (2022) says that an average of about 50 m of AC cable is required per inverter, and about 50 kilometers of DC cable is required per MWp.	1,698.00	849.00	Sunrock's database (2022) says that a meter of AC cable weighs 1698 kg.	14.46%	2.08	105.26	According to De Wild-Scholten (2013), on average the cabling requires 105.26 MJ per kWp, which is 105.26 GJ per MWp.	0.27%		Yes	3	
				50	kilometers DC cable		390.00	19,500.00	Sunrock's database (2022) says that a meter of TopSolar DC cable weighs 390 kg.									
		4	Transport AC and DC cable	250 19,300	truck kilometers ship kilometers	It is assumed that the cables are produced in China. It is estimated that the cables are transported per truck for about 250 km, and per ship for about 19,300 km (Searates, 2022).					0.06 per truck km 0.02 per ship km	329.45	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.85%				

A7	Cable guide suppliers	2	Manufacture cable ladders and wire trays	217.50	meters wire trays	At a square solar park, wire trays run around three of the 4 sides. With 2,630 modules that all have a surface area of about 2 m^2, the solar rood will have a total surface area of about 5,260 m^2. The square root of 5,260 says that such a square PV system would have 4 sides of 72.5 m. This means 217.5 m of wire trays are required. Furthermore, the assumption is made that 5 individual cable ladders are used, each with a length of 12 m. This means that 60 m of cable ladders are required.	1.20	261.00	Sunrock's database (2022) says that wire trays weigh about 1.2 kg per meter and cable ladders about 5 kg per meter.	0.40%	0.24	112.20	According to Gutowski et al. (2013), about 100 MJ is required for processing 1 kg of stainless steel or aluminum. It is assumed that another 100 MJ is required for turning this 1 kg into a metal construction. Therefore, it is assumed that a total of 200 MJ is required per kg.	0.29%	No	The few cable guides that are used are solely made of metals that are abundant. Therefore, the cable guides are found to have no environmental significance.	No	0	Though the mass CP is almost 0.5%, no implications are expected. The expected impact of the cable guides would however provide a good reference point for the other results.
				60	meters cable ladders		5.00	300.00			1.00								
		4	Transport cable ladders and wire trays	150	truck kilometers	The NIEDAX cable guides are manufactured in Moordrecht, the Netherlands. It is estimated that the mounting materials are transported per truck for about 150 km.					0.002 per truck km	0.25	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.00%					
A8	Combiner box suppliers	2	Manufacture combiner boxes	5	units	It is quite difficult to decide how many combiner boxes are required for a PV system, as one project does not use them and another project does. The assumption has been made that if they are used, 1 combiner box is used for every 2 inverters.	30.00	150.00	Sunrock's database (2022) says that an average combiner box weighs about 30 kg.	0.10%	42.00	210.00	It is assumed that a combiner box has the same energy intensity per kg as an inverter, which is 1244.33 GJ per 890 kg, or 1.40 GJ per kg.	0.49%	No	The combiner boxes are not made of rare materials. Also, since they are often not used for a PV system, the average number of combiner boxes per PV system is so low that there is no environmental significance.	No	0	Though the energy CP is almost 0.5%, no implications are expected. The expected impact of the combiner boxes would however provide a good reference point for the other results.
		4	Transport combiner boxes	250 19,300	truck kilometers ship kilometers	It is assumed that the combiner boxes are produced in China. It is estimated that the combiner boxes are transported per truck for about 250 km, and per ship for about 19,300 km (Searates, 2022).					0.0005 per truck km 0.0001 per ship km	2.43	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.01%					
A9	Sensor suppliers	2	Manufacture sensors	2	units	Sunrock's database (2022) says that often 2 pyranometers are used to deliver one FU.	0.60	1.20	Sunrock's database (2022) says that each sensor weighs about 0.6 kg	0.00%	0.84	1.68	It is assumed that a sensor has the same energy intensity per kg as an inverter, which is 1244.33 GJ per 890 kg, or 1.40 GJ per kg.	0.00%	No	So few sensors are used that there is no environmental significance.	No	0	No implications are expected.
		4	Transport sensors	150	truck kilometers	A sensor that is often used is manufactured in the Netherlands. It is estimated that the mounting materials are transported per truck for about 150 km.					0.00 per truck km	0.00	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.00%					
A10	Datalogger suppliers	2	Manufacture dataloggers	1	unit	Sunrock's database (2022) says that often 1 datalogger is used to deliver one FU.	0.50	0.50	Sunrock's database (2022) says that each datalogger weighs about 0.5 kg.	0.00%	0.70	0.70	It is assumed that a datalogger has the same energy intensity per kg as an inverter, which is 1244.33 GJ per 890 kg, or 1.40 GJ per kg.	0.00%	No	So few dataloggers are used that there is no environmental significance.	No	0	No implications are expected.
		4	Transport dataloggers	150	truck kilometers	A sensor that is often used is manufactured in the Netherlands. It is estimated that the mounting materials are transported per truck for about 150 km.					0.00 per truck km	0.00	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.00%					

A11	Production meter suppliers	2	Manufacture production meters	1	unit	Sunrock's database (2022) says that often 1 production meter is used to deliver one FU.	0.50	0.50	It is assumed that a production meter has about the same weight as a data-logger and therefore weighs about 0.5 kg.	0.00%	0.70	0.70	It is assumed that a production meter has the same energy intensity per kg as an inverter, which is 1244.33 GJ per 890 kg, or 1.40 GJ per kg.	0.00%	No	So few production meters are used that there is no environmental significance.	No	0	No implications are expected.
		4	Transport production meters	150	truck kilometers	A sensor that is often used is manufactured in the Netherlands. It is estimated that the mounting materials are transported per truck for about 150 km.					0.00 per truck km	0.00	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.00%					
B1	Engineering, Procurement & Construction providers	1	Perform EPC services	1,540	hours	Sunrock's database (2022) says that about 1 week is required to start the construction, and 2 weeks are required to install 1 MWp. This construction is done by 10 to 15 construction workers. Then another week of preparation is added, performed by 1 person.					0.15	223.55	According to Peng et al. (2013), the installation of a solar park requires 34 MJ per m^2. It is assumed that on average 2.5 m^2 is required to install a module with a surface area of 1.94 m^2.	0.57%	Yes	Much waste is generated during construction due to packaging. The EPC provider determines the strategy that is handled to process this waste, which can play an important part in the environmental impact of a PV system. Also, some components of the PV system are transported through the EPC service, which makes the service essential in the value chain. The level of detail is set to 2.	Yes	2	
		4	Transport during EPC services	150		It is estimated that the PV system components are transported per truck over about 150 km.					0.42 per truck km	63.02	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport. It is assumed that the EPC service providers transports all PV system components per truck.	0.15%					
B2	Operations & Maintenance providers	1	Perform O&M services	800	hours	Sunrock's database (2022) says that O&M services take place 1 or 2 times each year. At a later stage of the PV system's 25-year lifetime it is expected that more maintenance is required. Therefore, an average of 2 O&M services is taken. It is assumed that such a service is performed by 2 engineers in 1 day.					0.15	2,297.92	It is assumed that an O&M service requires the same energy per hour as an EPC service, which is 0.15 GJ. Besides that, it is assumed that 5% of the PV system is replaced during its lifetime. Therefore, 5% of the total energy that is required for the PV system's components is added to the O&M service.	4.98%			Yes	2	
		4	Transport during O&M services	150	truck kilometers	It is estimated that the replacement PV system components are transported per truck over about 150 km.					0.002 per truck km	2.74	According to the EEA (2022), the energy intensity is about 3 MJ per ton-km for freight truck transport, and about 0.8 MJ per ton-km for freight ship transport.	0.01%					
B3	Decommission-ing providers	1	Perform DECOM services	385	hours	It is estimated that a PV system is decommissioned in about 25% of the time it takes to install it.					0.15	55.89	It is assumed that a DECOM service requires the same energy per hour as an EPC service, which is 0.15 GJ.	0.14%	No	The decommissioning service requires relatively little time and resources. This service also has no connection to the eventual treatment of the PV system's decommissioned components, as this depends on Sunrock's strategy. Therefore, this service has no environmental significance.	No	0	No implications are expected.
		4	Transport during DECOM services																

B4	Module testing providers	1	Perform module testing services	24	hours	Sunrock's database (2022) says that 3 people work for a full day to test the modules before they are installed.		0.15	3.48	It is assumed that a module testing service requires the same energy per hour as an EPC service, which is 0.15 GJ.	0.01%	No	The module testing service requires relatively little time and resources. Therefore, this service has no environmental significance.	No	0	No implications are expected.
		4	Transport during module testing services													
B5	Grid connection providers	1	Perform grid connection services	48	hours	It is assumed that on average 2 people work for 3 full days to realize a grid connection between the PV system and the grid.		0.15	6.97	It is assumed that a grid connection service requires the same energy per hour as an EPC service, which is 0.15 GJ.	0.02%	No	The grid connection service requires relatively little time and resources. Therefore, this service has no environmental significance.	No	0	No implications are expected.
		4	Transport during grid connection services													
B6	Metering providers	1	Perform metering services	8	hours	The metering providers install their production meters once. One full day of work is counted for this installation. After this installation the production of the PV system will be measured and shared automatically.		0.15	1.16	It is assumed that a metering service requires the same energy per hour as an EPC service, which is 0.15 GJ.	0.00%	No	The metering services require relatively little time and resources. Therefore, these services have no environmental significance.	No	0	No implications are expected.
		4	Transport during metering services													
B7	Cleaning & Green Maintenance providers	1	Perform C&GM services	701	hours	It is assumed that the PV system has a lifetime of 25 years. Sunrock's database (2022) says that on average a cleaning service is required every 2.5 years. The PV system is therefore cleaned about 10 times if the modules are also cleaned before decommissioning. One person cleans 300 modules in a full day (Sunrock, 2022). So, each module requires 1.6 minutes to clean.		0.15	101.81	It is assumed that a C&GM service requires the same energy per hour as an EPC service, which is 0.15 GJ.	0.26%	No	The CG&M services require relatively little time and resources. Therefore, these services have no environmental significance. It is assumed that no toxic substances are used during the CG&M services.	No	0	There might be implications if the CG&M services require toxic substances. This should be checked.
		4	Transport during C&GM services													
B8	Technical due diligence	1	Perform TDD services	80	hours	Sunrock's database (2022) says that about 10 full working days are required for TDD services.		0.15	11.61	It is assumed that a TDD service requires the same energy per hour as an EPC service, which is 0.15 GJ.	0.03%	No	The TDD services require relatively little time and resources. Therefore, these services have no environmental significance.	No	0	No implications are expected.
		4	Transport during TDD services													
B9	Financial due diligence	1	Perform FDD services	16	hours	Sunrock's database (2022) says that about 2 full working days are required for FDD services.		0.01	0.16	According to Odyssee-Mure (2021), in 2019 an office employee in the Netherlands on average used 5,374 kWh per year, which is 19.35 GJ. It is assumed that 5 weeks of vacation are granted to an office employee. This leaves 47 weeks of 40 workhours.	0.00%	No	The FDD services require relatively little time and resources. Therefore, these services have no environmental significance.	No	0	No implications are expected.
		4	Transport during FDD services													

B10	Legal due diligence	1	Perform LDD services	24	hours	Sunrock's database (2022) says that about 3 full working days are required for LDD services.		0.01	0.25	According to Odyssee-Mure (2021), in 2019 an office employee in the Netherlands on average used 5,374 kWh per year, which is 19.35 GJ. It is assumed that 5 weeks of vacation are granted to an office employee. This leaves 47 weeks of 40 workhours left for work.	0.00%	No	The LDD services require relatively little time and resources. Therefore, these services have no environmental significance.	No	0	No implications are expected.
		4	Transport during LDD services													
C1	Office supplies suppliers	1	Manufacture office supplier					-	0.55	According to Junnila (Junnila, 2006), the yearly office supplies of an employee generate 31 kg CO_2e. Sunrock's database (2022) says that in 2021, on average there were 65 employees working at the company. Assuming that the required energy for office supplies increases linearly, Sunrock's office supplies for 2021 would generate 2,015 kg CO_2e. Sunrock's database (2022) says that in 2021, 31 projects were realized. This means that the office supplies generate 67.17 kg CO_2e per project. Since 1 kWh generates 0.427 kg CO_2e (CO_2emissiefactoren, 2022), the office supplies require about 157.30 kWh, which is 0.57 GJ.	0.00%	No	It is assumed that the office supplies are generally not manufactured from materials with a high environmental impact. Besides, waste from office supplies is separated and recycled. Therefore, these goods have no environmental impact.	No	0	No implications are expected.
		4	Transport office supplies													
C2	Office service providers	1	Perform office services	208	hours	It is estimated that the office's cleaning and maintenance services on average require about 4 hours per week.		0.15	31.20	It is assumed that office services require the same energy per hour as an EPC service, which is 0.15 GJ.	0.08%	No	The office services require relatively little time and resources. Therefore, these services have no environmental significance.	No	0	No implications are expected.
		4	Transport during office services													
C3	Office equipment suppliers	2	Manufacture office equipment					-	6.28	According to Junnila (2006), the yearly office supplies of an employee generate 355 kg CO_2e. Sunrock's database (2022) says that in 2021, on average there were 65 employees working at the company. Assuming that the required energy for office supplies increases linearly, Sunrock's office supplies for 2021 would generate 23,075 kg CO_2e. Sunrock's database (2022) says that in 2021, 31 projects were realized. This means that the office supplies generate 769.17 kg CO_2e per project. Since 1 kWh generates 0.427 kg CO_2e (CO_2emissiefactoren, 2022), the office supplies require about 1,801.33 kWh, which is 6.48 GJ.	0.02%	No	It is assumed that the office equipment is generally not manufactured from materials with a high environmental impact. Besides, waste from office equipment is separated and recycled. Therefore, these goods have no environmental impact.	No	0	No implications are expected.
		4	Transport office equipment													
FU To realize and maintain a PV system of 1 MWp for 25 years.							**Total estimated mass** 140,764.59 kg	**Total estimated energy** 38,910.81 GJ								

Table 6.9 Summary of the defined processes and their flows.

B1 Engineering, Procurement & Construction providers				
Electricity Modules Mounting materials Ballast Inverters Transformers Switchgear boxes Station housings AC cable DC cable	26.26 kWh 2,600 units 1,300 sets 3,588 units 6 units 1 unit 2 units 1 unit 0.15 km 30.29 km	Perform EPC services – *Confidential*	Modules Mounting materials Ballast Inverters Transformers Switchgear boxes Station housings AC cable DC cable	2,600 units 1,300 sets 3,588 units 6 units 1 unit 2 units 1 unit 0.15 km 30.29 km
Modules Mounting materials Ballast Inverters Transformers Switchgear boxes Station housings AC cable DC cable	2,600 units 1,300 sets 3,588 units 6 units 1 unit 2 units 1 unit 0.15 km 30.29 km	Transportation during EPC services – *Confidential*	Modules Mounting materials Ballast Inverters Transformers Switchgear boxes Station housings AC cable DC cable	2,600 units 1,300 sets 3,588 units 6 units 1 unit 2 units 1 unit 0.15 km 30.29 km
B2 Operations & Maintenance providers				
Electricity Modules Inverters	0.51 kWh 65 units 9.75 units	Perform O&M services – *Confidential*	Modules Inverters	65 units 9.75 units
Modules Inverters	65 units 9.75 units	Transportation during O&M services – *Confidential*	Modules Inverters	65 units 9.75 units
A1 Module suppliers				
Photovoltaic panel, single si-wafer	2,665 units	Manufacture modules – *Confidential, Confidential*	Modules – *Confidential, Confidential*	2,665 units
Modules – *Confidential, Confidential*	2,600 units	Transport modules – *Confidential, Confidential*	Modules – *Confidential, Confidential*	2,600 units
A2 Mounting materials suppliers				
Photovoltaic mounting system, for flat-roof installation	1,300 sets	Manufacture mounting materials – *Confidential, Confidential*	Mounting materials – *Confidential, Confidential*	1,300 sets
Mounting materials – *Confidential, Confidential*	1,300 sets	Transport mounting materials – *Confidential, Confidential*	Mounting materials – *Confidential, Confidential*	1,300 sets
A3 Ballast suppliers				
Not specified		Manufacture ballast – *Confidential, Confidential*	Ballast – *Confidential, Confidential*	3,588 units
Ballast – *Confidential, Confidential*	3,588 units	Transport ballast – *Confidential, Confidential*	Ballast – *Confidential, Confidential*	3,588 units
A4 Inverter suppliers				
Inverter, 500kW	15.75 units	Manufacture inverters – *Confidential, Confidential*	Inverters – *Confidential, Confidential*	15.75 units
Inverters – *Confidential, Confidential*	15.75 units	Transport inverters – *Confidential, Confidential*	Inverters – *Confidential, Confidential*	15.75 units

		A5.1 Transformer suppliers		
Transformer, high voltage use	1 unit	Manufacture transformers – *Confidential, Confidential*	Transformers – *Confidential, Confidential*	1 unit
Transformers – *Confidential, Confidential*	1 unit	Transport transformers – *Confidential, Confidential*	Transformers – *Confidential, Confidential*	1 unit
		A5.2 Switchgear box suppliers		
Electronics, for control units	2 units	Manufacture switchgear boxes – *Confidential, Confidential*	Switchgear boxes – *Confidential, Confidential*	2 units
Switchgear boxes – *Confidential, Confidential*	2 units	Transport switchgear boxes – *Confidential, Confidential*	Switchgear boxes – *Confidential, Confidential*	2 units
		A5.3 Station housing suppliers		
Concrete block Metal working, average for aluminium product manufacturing	7,000 kg 1,750 kg	Manufacture station housings – *Confidential, Confidential*	Station housings – *Confidential, Confidential*	1 unit
Station housings – *Confidential, Confidential*	1 unit	Transport station housings – *Confidential, Confidential*	Station housings – *Confidential, Confidential*	1 unit
		A6.1 AC cable suppliers		
Cable, unspecified	0.15 km	Manufacture AC cable – *Confidential, Confidential*	AC cable – *Confidential, Confidential*	0.15 km
AC cable – *Confidential, Confidential*	0.15 km	Transport AC cable – *Confidential, Confidential*	AC cable – *Confidential, Confidential*	0.15 km
		A6.2 DC cable suppliers		
Cable, unspecified	30.29 km	Manufacture DC cable – *Confidential, Confidential*	DC cable – *Confidential, Confidential*	30.29 km
DC cable – *Confidential, Confidential*	30.29 km	Transport DC cable – *Confidential, Confidential*	DC cable – *Confidential, Confidential*	30.29 km
		D1 Energy suppliers		
Natural gas Electricity (renewable sources)	45.39 m^3 130.01 kWh	Process and transport energy goods – MAIN Energie	Natural gas Electricity (renewable sources)	45.39 m^3 130.01 kWh
		D2 Water suppliers		
Fresh water	0.99 m^3	Process and transport water – Waternet	Fresh water	0.99 m^3
		E1 Office waste processors		
Residual waste PMD Paper Glass	16.68 kg 1.20 kg 4.08 kg 0.96 kg	Transport office waste – Milieu Service Nederland	Residual waste PMD Paper Glass	16.68 kg 1.20 kg 4.08 kg 0.96 kg
Residual waste PMD waste Glass waste Paper waste	16.68 kg 1.20 kg 0.96 kg 4.08 kg	Process office waste – Milieu Service Nederland	Residual waste PMD waste Glass waste Paper waste	16.68 kg 1.20 kg 0.96 kg 4.08 kg

E2 Service waste processors				
Plastic waste	66.78 kg	Transport service waste – Not known yet	Plastic waste	66.78 kg
Paper waste	505.10 kg		Paper waste	505.10 kg
Modules (recovered)	50,968.13 kg		Modules (recovered)	50,968.13 kg
Modules (disposed)	8,994.38 kg		Modules (disposed)	8,994.38 kg
Mounting materials (recovered)	9,757.80 kg		Mounting materials (recovered)	9,757.80 kg
Ballast (recovered)	32,292.00 kg		Ballast (recovered)	32,292.00 kg
Inverters (recovered)	937.13 kg		Inverters (recovered)	937.13 kg
Inverters (disposed)	401.63 kg		Inverters (disposed)	401.63 kg
Transformers (recovered)	3,255.00 kg		Transformers (recovered)	3,255.00 kg
Transformers (disposed)	1,395.00 kg		Transformers (disposed)	1,395.00 kg
Switchgear boxes (recovered)	658.00 kg		Switchgear boxes (recovered)	658.00 kg
Switchgear boxes (disposed)	42.00 kg		Switchgear boxes (disposed)	42.00 kg
Station housings (recovered)	8,225.00 kg		Station housings (recovered)	8,225.00 kg
Station housings (disposed)	525.00 kg		Station housings (disposed)	525.00 kg
AC cable (recovered)	421.80 kg		AC cable (recovered)	421.80 kg
AC cable (disposed)	22.20 kg		AC cable (disposed)	22.20 kg
DC cable (recovered)	2,302.04 kg		DC cable (recovered)	2,302.04 kg
DC cable (disposed)	121.16 kg		DC cable (disposed)	121.16 kg
Plastic waste	66.78 kg	Process service waste – Not known yet	Plastic waste	66.78 kg
Paper waste	505.10 kg		Paper waste	505.10 kg
Modules (recovered)	50,968.13 kg		Modules (recovered)	50,968.13 kg
Modules (disposed)	8,994.38 kg		Modules (disposed)	8,994.38 kg
Mounting materials (recovered)	9,757.80 kg		Mounting materials (recovered)	9,757.80 kg
Ballast (recovered)	32,292.00 kg		Ballast (recovered)	32,292.00 kg
Inverters (recovered)	937.13 kg		Inverters (recovered)	937.13 kg
Inverters (disposed)	401.63 kg		Inverters (disposed)	401.63 kg
Transformers (recovered)	3,255.00 kg		Transformers (recovered)	3,255.00 kg
Transformers (disposed)	1,395.00 kg		Transformers (disposed)	1,395.00 kg
Switchgear boxes (recovered)	658.00 kg		Switchgear boxes (recovered)	658.00 kg
Switchgear boxes (disposed)	42.00 kg		Switchgear boxes (disposed)	42.00 kg
Station housings (recovered)	8,225.00 kg		Station housings (recovered)	8,225.00 kg
Station housings (disposed)	525.00 kg		Station housings (disposed)	525.00 kg
AC cable (recovered)	421.80 kg		AC cable (recovered)	421.80 kg
AC cable (disposed)	22.20 kg		AC cable (disposed)	22.20 kg
DC cable (recovered)	2,302.04 kg		DC cable (recovered)	2,302.04 kg
DC cable (disposed)	121.16 kg		DC cable (disposed)	121.16 kg
F Business travel facilitators				
Gasoline l/p car business travel	174.07 v-km	Facilitate business travel – Company combination	Gasoline l/p car business travel	174.07 v-km
Hybrid l/p car business travel	98.32 v-km		Hybrid l/p car business travel	98.32 v-km
Full electric l/p car business travel	260.13 v-km		Full electric l/p car business travel	260.13 v-km
Gasoline car business travel	354.60 v-km		Gasoline car business travel	354.60 v-km
Rental car business travel	154.71 v-km		Rental car business travel	154.71 v-km
Taxi business travel	1.28 v-km		Taxi business travel	1.28 v-km
Train business travel	852.19 t-km		Train business travel	852.19 t-km
Bus business travel	2.54 t-km		Bus business travel	2.54 t-km
Airplane business travel	881.78 t-km		Airplane business travel	881.78 t-km
Hotel stays	0.27 nights		Hotel stays	0.27 nights
G Commuting employees				
Gasoline lease car commute	184.34 v-km	Employee commute	Gasoline lease car commute	184.34 v-km
Full electric lease car commute	223.35 v-km		Full electric lease car commute	223.35 v-km
Train commute	1,096.27 t-km		Train commute	1,096.27 t-km
Bus/tram/metro commute	349.36 t-km		Bus/tram/metro commute	349.36 t-km
Gasoline car commute	868.15 v-km		Gasoline car commute	868.15 v-km
Diesel car commute	188.86 v-km		Diesel car commute	188.86 v-km
Hybrid car commute	311.37 v-km		Hybrid car commute	311.37 v-km
Full electric car commute	118.26 v-km		Full electric car commute	118.26 v-km
Scooter commute	6.55 v-km		Scooter commute	6.55 v-km
eBike commute	465.54 v-km		eBike commute	465.54 v-km
eScooter commute	465.54 v-km		eScooter commute	465.54 v-km
Bicycle commute	308.10 v-km		Bicycle commute	308.10 v-km

Table 6.10 Comments for the configured GaBi plans from Figures 6.5 to 6.11 in Appendix 6.B (p. 140-142).

GaBi plan	Comments

Categories 1 and 4	- Service performing processes have been created for all relevant provided services:
	  - EPC: The "Perform EPC services" process was composed manually, as it simply passes on the PV system components from the manufacturers to the project site. A process from the Sphera database ("NL: Electricity grid mix 1kV-60kV") is used for providing the electricity that is required for the EPC services.
	  - O&M: The "Perform O&M services" process was composed manually, as it simply passes on the replacement PV system components from the manufacturers to the project site. A process from the Sphera database ("NL: Electricity grid mix 1kV-60kV") is used for providing the electricity that is required for the O&M services.
	- A process from the Sphera database ("GLO: Truck, EURO 6, more than 32t gross weight / 24.7t payload capacity") has been used to create the process for transportation during services. Each service has a separate transportation process. The distances from the data templates were used in the transportation processes. All transported flows come together at the facility process that represents Sunrock's PV system of 1 MWp. Another process from the Sphera database ("NL: Diesel mix at filling station") is used to provide the described truck transportation with diesel.
	- A facility process represents Sunrock's PV system of 1 MWp. Through the mentioned transports, this facility process receives the outputs of the service providers as inputs. The facility process must be programmed to receive and provide the exact amounts of each flow as documented in the data template. The scaling factor of the facility process can then be fixed and used to upscale the results of the plan.
	- The plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing:
	  - Actor groups: The EPC processes were assigned to actor group B1, the O&M processes to actor group B2, and the DECOM processes to actor group B3.
	  - Scopes: All processes belong to scope 3.
	  - Scope 3 categories: All processes regarding providing services belong to activity category 1, while all processes regarding the transportation during services belong to activity category 4.
	  - Timing: The emissions from the EPC service processes take place in 2021, while the emissions from the O&M service processes take place linearly over the entire PV system lifetime of 25 years.

Categories 2 and 4	- Manufacturing processes have been created for all relevant PV system components:
	  - Modules: A process from the EcoInvent database ("RoW: Photovoltaic panel production, single si-wafer") has been used to create the process for manufacturing modules. To split up the database process into its subprocesses, the "u-so" process variant for single operation was used instead of the "agg" process variant for the simple LCI result. This makes it possible to adjust the materials and subprocesses that are used in the process. This process manufactures the modules per m^2. The used module has a surface area of *X* m^2 and a weight of *X* kg *(confidential)*. This information and the bill of materials for the used modules were used to calculate and adjust the required quantities in the EcoInvent process. The manufacturing process has the output from the EcoInvent process as input, and the used modules as output. This process also manufactures replacement modules for the O&M in the replacement ratio that is mentioned in the data template.
	  - Mounting materials: A process from the EcoInvent database ("RER: Photovoltaic mounting system production, for flat-roof installation") has been used to create the process for manufacturing mounting materials. To split up the database process into its subprocesses, the "u-so" process variant for single operation was used instead of the "agg" process variant for the simple LCI result. This makes it possible to adjust the materials and subprocesses that are used in the process. This process manufactures the mounting materials per m^2 of modules. The used module has a surface area of *X* m^2, while the mounting materials weigh *X* kg per module *(confidential)*. This information and the bill of materials for the used mounting materials were used to calculate and adjust the required quantities in the EcoInvent process. The manufacturing process has the output from the EcoInvent process as input, and the used mounting materials as output.
	  - Ballast: The process for manufacturing ballast contains data that came directly from the LCA results of the used ballast *(confidential)*. The raw materials are not mentioned in these results, but the energy use and GWP are. This process is therefore not highly detailed, but does contain all the data that is required for the analysis.
	  - Inverters: A process from the EcoInvent database ("RoW: Inverter production, 500kW") has been used to create the process for manufacturing inverters. To split up the database process into its subprocesses, the "u-so" process variant for single operation was used instead of the "agg" process variant for the simple LCI result. This makes it possible to adjust the materials and subprocesses that are used in the process. This process manufactures the inverters per unit of 500 kW. The used inverter has a capacity of *X* kW and a weight of *X* kg *(confidential)*. This information was used to calculate and adjust the required quantities in the EcoInvent process. The GWP value of the created manufacturing process is similar to the GWP that is calculated for manufacturing a Huawei solar inverter with similar specifications (Huawei Device Co. Ltd., 2020). The manufacturing process has the output from the EcoInvent process as input, and the used inverters as output. This process also manufactures replacement inverters for the O&M service in the replacement ratio that is mentioned in the data template.
	  - Transformers: A process from the EcoInvent database ("GLO: Transformer production, high voltage use") has been used to create the process for manufacturing transformers. To split up the database process into its subprocesses, the "u-so" process variant for single operation was used instead of the "agg" process variant for the simple LCI result. This makes it possible to adjust the materials and subprocesses that are used in the process. This process manufactures the transformers per unit. The average *X* transformer has a GWP of *X* kg CO_2e, and the weight of an often-used transformer is *X* kg *(confidential)*. This information was used to calculate and adjust the required quantities in the EcoInvent process. The manufacturing process has the output from the EcoInvent process as input, and the used transformers as output.
	  - Switchgear boxes: A process from the EcoInvent database ("RER: Electronics production, for control units") has been used to create the process for manufacturing switchgear boxes. To split up the database process into its subprocesses, the "u-so" process variant for single operation was used instead of the "agg" process variant for the simple LCI result. This makes it possible to adjust the materials and subprocesses that are used in the process. This process manufactures the switchgear boxes per unit. The average switchgear box has a GWP

	of X kg CO_2e, the average weight of often-used switchgear boxes is X kg *(confidential)*. This information was used to calculate and adjust the required quantities in the EcoInvent process. The manufacturing process has the output from the EcoInvent process as input, and the used switchgear boxes as output.
	  - Station housings: The process for manufacturing station housings has been composed manually. The process simply combines a concrete block with an aluminum construction. The average station housing has a GWP of X kg CO_2e, the weight of an often-used station housing is X kg *(confidential)*. This information was used to calculate and adjust the required quantities in the EcoInvent process.
	  - AC cable: A process from the EcoInvent database ("GLO: Cable production, unspecified") has been used to create the process for manufacturing AC cable. To split up the database process into its subprocesses, the "u-so" process variant for single operation was used instead of the "agg" process variant for the simple LCI result. This makes it possible to adjust the materials and subprocesses that are used in the process. This process manufactures the AC cable per kg. The used AC cable weighs X kg per meter *(confidential)*. This information and the bill of materials for the used AC cable were used to calculate and adjust the required quantities in the EcoInvent process. The manufacturing process has the output from the EcoInvent process as input, and the used AC cable as output.
	  - DC cable: A process from the EcoInvent database ("GLO: Cable production, unspecified") has been used to create the process for manufacturing DC cable. To split up the database process into its subprocesses, the "u-so" process variant for single operation was used instead of the "agg" process variant for the simple LCI result. This makes it possible to adjust the materials and subprocesses that are used in the process. This process manufactures the DC cable per kg. The used DC cable weighs X kg per meter *(confidential)*. This information and the bill of materials for the used DC cable were used to calculate and adjust the required quantities in the EcoInvent process. The manufacturing process has the output from the EcoInvent process as input, and the used DC cable as output.
	- A process from the Sphera database ("GLO: Truck, EURO 6, more than 32t gross weight / 24.7t payload capacity") has been used to create the process for transporting the PV system's components with trucks. Each component has a separate truck transportation process. Another process from the Sphera database ("NL: Diesel mix at filling station") is used to provide the described truck transportation with diesel. The modules and inverters are also transported per ship. A process from the Sphera database ("GLO: Container ship, 5,000 to 200,000 dwt payload capacity, ocean going") has been used to create the process for transporting the modules and inverters with ships. The modules and inverters have separate ship transportation processes. Another process from the Sphera database ("US: Heavy fuel oil at refinery") is used to provide the described ship transportation with oil. The distances from the data templates were used in all transportation processes. All transported flows come together at the EPC provider. Separate transportation processes were created for the replacement components.
	- As all capital goods are directly transported to the EPC service provider, the "Perform EPC services" process receives all flows of transported capital goods as inputs.
	- The plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing:
	  - Actor groups: The module processes were assigned to actor group A1, the mounting materials processes to actor group A2, the ballast processes to actor group A3, the inverter processes to actor group A4, the transformer station processes to actor group A5, and the cable processes to actor group A6.
	  - Scopes: All processes belong to scope 3.
	  - Scope 3 categories: All processes regarding manufacturing components belong to activity category 2, while all processes regarding the transportation of components belong to activity category 4.
	  - Timing: The emissions from all processes take place in 2021.

Category 3	- Processes from the Sphera database ("NL: Natural gas mix" and "NL: Green electricity grid mix") are used to represent the processing and transporting of the natural gas and electricity that are consumed by Sunrock's office. These Sphera processes are directly linked to the energy supplier, as the energy supplier is responsible for supplying Sunrock with the natural gas and electricity that come from these Sphera processes. The process of the energy supplier thus receives and passes on both the natural gas and electricity flows. The energy supplier process must therefore be programmed to pass on the exact amounts of natural gas and electricity that were consumed by Sunrock's office in 2021. - The solar roof of Sunrock's office building produces electricity that Sunrock also uses. A process from the Sphera database ("NL: Electricity from photovoltaic") has been used to represent the generation of this electricity. This process is directly linked to the facility process that represents Sunrock's office, as the energy supplier performs no activities in the generation and distribution of this electricity. - The processes "NL: Green electricity grid mix" and "NL: Electricity from photovoltaic" were corrected to not emit any GHGs, as the SBTi does not require Sunrock to report any emissions that are caused by the consumption of electricity that is generated sustainably. - A process from the EcoInvent database ("Europe without Switzerland: Tap water production, direct filtration treatment") is used to represent the processing and transporting of the water that is consumed by Sunrock's office. This EcoInvent process is directly linked to the water supplier, as the water supplier is responsible for supplying Sunrock with the water that comes from this EcoInvent process. - After the water from the water supplier is used at Sunrock's office, the wastewater that is left is treated in a process from the Sphera database ("NL: Municipal wastewater treatment"). This process represents the treatment the wastewater undergoes after it is generated. - A facility process represents Sunrock's office. This facility process receives the outputs of the energy and water suppliers as inputs. It also directly receives the output of the process that represents the solar roof of the office building as input. The mentioned wastewater is an output of this facility process. The natural gas that is consumed by Sunrock's office is burned locally in a boiler to generate heat for the central heating of the office. The flows of a process from the EcoInvent database that represents the burning of natural gas in a boiler ("Europe without Switzerland: Heat production, natural gas, at boiler modulating <100kW") have been copied to the facility process. The facility process therefore incorporates the burning of natural gas in a boiler. The facility process must be programmed to receive and provide the exact amounts of each flow as documented in the data template. The scaling factor of the facility process can then be fixed and used to upscale the results of the plan. - The plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing:

	- Actor groups: The energy processes were assigned to actor group D1, and the water processes to actor group D2. - Scopes: Only the facility process belongs to scope 1. The processing and transporting of electricity belongs to scope 2. All other processes belong to scope 3. The emissions that come from the solar roof are indirect emissions from scope 3, as these are caused by the manufacturing of the PV system. - Scope 3 categories: All scope 3 processes belong to activity category 3. No group is specified for all processes that do not belong to scope 3. - Timing: The emissions from all processes take place in 2021.

Category 5	- A facility process represents Sunrock's office. This facility process generates the waste outputs that originate from Sunrock's office. The facility process must be programmed to receive and provide the exact amounts of each flow as documented in the data template. The scaling factor of the facility process can then be fixed and used to upscale the results of the plan.
	- A process from the Sphera database ("GLO: Truck, EURO 6, more than 32t gross weight / 24.7t payload capacity") has been used to create the process for transporting office waste. The process for transporting office waste has been used four times, as the four waste streams are transported separately. A distance of 13.9 km is traveled when transporting the office waste. All transported waste streams come together again at the process for processing office waste. Another process from the Sphera database ("NL: Diesel mix at filling station") is used to provide the described truck transportation with diesel.
	- Processes from the Sphera and EcoInvent databases are used to represent the processing of office waste. The office waste is separated into residual waste, plastic waste, glass waste, and paper waste. The following database processes were chosen regarding the waste processing strategy of Milieu Service Nederland:
	  - Residual: Residual waste is incinerated for energy recovery and is therefore represented by "EU-28: Municipal waste in waste incineration plant".
	  - Plastic: Plastic waste is sorted and recycled into plastic granulates and is therefore represented by "CH: Treatment of waste plastic (unspecified), sorting plant" and "IN: Plastic granulate production, unspecified, recycled".
	  - Glass: Glass waste is only sorted before it is ready to be reused and is therefore represented by "RoW: Treatment of waste glass from unsorted public collection, sorting".
	  - Paper: Paper waste is also only sorted before it is ready to be reused and is therefore represented by "Europe without Switzerland: Treatment of wastepaper, unsorted, sorting".
	- Processes from the Sphera and EcoInvent databases are used to represent the processing of service waste. The service waste is separated into waste from packaging and waste from decommissioned components. The following database processes were chosen regarding the assumptions that were made for processing service waste:
	  - Packaging: Plastic waste is sorted and recycled into plastic granulates and is therefore represented by "CH: Treatment of waste plastic (unspecified), sorting plant" and "IN: Plastic granulate production, unspecified, recycled". Paper waste is only sorted before it is ready to be reused and is therefore represented by "Europe without Switzerland: Treatment of wastepaper, unsorted, sorting".
	  - Decommissioned components: The recovery of the fractions of modules, inverters, and transformers is represented by "GLO: Treatment of used industrial electronic device, mechanical treatment". The disposal of the resting fractions of these components is represented by "RoW: Treatment of residue from mechanical treatment, industrial device, municipal waste incineration". The recovery of the mounting materials and station housings is represented by "Europe without Switzerland: Treatment of metal scrap, mixed for recycling, unsorted, sorting". The recovery of the ballast is represented by "RoW: Treatment of waste brick, recycling". The recovery of the fraction of switchgear boxes is represented by "RER: Treatment of electronics scrap from control units". The recovery of the fractions of AC and DC cable is represented by "GLO: Treatment of used cable". The disposal of the resting fractions of switchgear boxes and AC and DC cable is represented by "EU-28: Commercial waste in municipal waste incineration plant". Replacement components are treated in separate processes, as these are grouped differently regarding timing.
	- The plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing:
	  - Actor groups: The office waste processes were assigned to actor group E1, and the service waste processes to actor group E2.
	  - Scopes: All processes belong to scope 3.
	  - Scope 3 categories: All processes belong to activity category 5.
	  - Timing: The emissions from all office waste processes take place in 2021. The emissions from the EPC service waste processes take place in 2021, while the emissions from the O&M service waste processes take place linearly over the entire PV system lifetime of 25 years.

Category 6	- Processes from the EcoInvent database are used to represent the facilitating of business travel process. Within the business travel activity category, the distinction is made between lease/pool car travel, carrier travel, and hotel stays: - Lease/pool cars: Gasoline lease/pool car business travel is represented by "RER: Transport, passenger car, medium size, petrol, EURO 5". Full electric lease/pool car business travel is represented by "GLO: Transport, passenger car, electric". No database process existed for hybrid car travel, so the database processes that were used for gasoline and full electric cars were combined to create a representative process for hybrid lease/pool car business travel. The gasoline consumption was decreased for the process, as in hybrid cars the share of electric driving is about 37% (Plötz et al., 2020). This means that the process for the hybrid cars uses 63% of the gasoline that is used in the database process for gasoline cars, and 37% of the electricity that is used in the process for electric cars. Each lease/pool car process for business travel has an adjusted name with adjusted flows so that it is clear that the process and its flows belong to business travel with lease/pool cars. To split up the database processes into their subprocesses, the "u-so" process variants for single operations were used instead of the "agg" process variants for simple LCI results. This makes it possible to only group the emissions from burning fuels as scope 1 emissions, and from processing and transporting consumed electricity as scope 2 emissions. This is required, as Sunrock owns the lease/pool cars. Used fuels or electricity can then also be changed to fuels or electricity from the Netherlands.

	- Carriers: Independent car, rental car, and taxi business travel are represented by “RER: Transport, passenger car, medium size, petrol, EURO 5” if the car runs on gasoline. Each business travel car process has an adjusted name with adjusted flows so that it is clear that the process and its flows belong to business travel with a specific type of car. Train business travel is represented by “CH: Transport, passenger train, regional”, and bus/tram/metro business travel is represented by “RoW: Transport, tram”, as these processes represented the emission factors for public transportation as presented by CO_2emissiefactoren (2022) best. Airplane business travel is represented by “GLO: Market for transport, passengers, aircraft, medium haul”. - Hotels: Hotel night stays during business travel are represented by “GLO: Market for building operation, budget hotel”. - A facility process represents Sunrock’s office. This facility process receives the outputs of the business travel facilitators as inputs. The facility process must be programmed to receive and provide the exact amounts of each flow as documented in the data template. The scaling factor of the facility process can then be fixed and used to upscale the results of the plan. - The plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing: - Actor groups: All processes were assigned to actor group F. - Scopes: The process that is responsible for burning the gasoline in the lease/pool cars belongs to scope 1. The process that is responsible for processing and transporting the electricity that is consumed in the lease/pool cars belongs to scope 2. All other processes belong to scope 3. - Scope 3 categories: All scope 3 processes belong to activity category 6. No group is specified for all processes that do not belong to scope 3. - Timing: The emissions from all processes take place in 2021.
Category 7	- Processes from the EcoInvent database are used to represent the employee commuting process. Within the employee commuting activity category, the distinction is made between lease car commute, public transportation commute, and independent commute: - Lease cars: Gasoline lease car commute is represented by “RER: Transport, passenger car, medium size, petrol, EURO 5”. Full electric lease car commute is represented by “GLO: Transport, passenger car, electric”. Each lease car process for employee commute has an adjusted name with adjusted flows so that it is clear that the process and its flows belong to employee commute with lease cars. To split up the database processes into their subprocesses, the “u-so” process variants for single operations were used instead of the “agg” process variants for simple LCI results. This makes it possible to only group the emissions from burning fuels as scope 1 emissions, and from processing and transporting consumed electricity as scope 2 emissions. This is required, as Sunrock owns the lease cars. This also made it possible to change the used fuels or electricity to fuels or electricity from the Netherlands. - Public transport: Train commute is represented by “CH: Transport, passenger train, regional”, and bus/tram/metro commute is represented by “RoW: Transport, tram”, as these processes represented the emission factors for public transportation as presented by CO_2emissiefactoren (2022) best. - Independent: Independent gasoline car commute is represented by “RER: Transport, passenger car, medium size, petrol, EURO 5”. Independent full electric car commute is represented by “GLO: Transport, passenger car, electric”. No database process existed for hybrid car travel, so the database processes that were used for gasoline and full electric cars were combined to create a representative process for independent hybrid car commute. The gasoline consumption was decreased for the process, as in hybrid cars the share of electric driving is about 37% (Plötz et al., 2020). This means that the process for the hybrid cars uses 63% of the gasoline that is used in the database process for gasoline cars, and 37% of the electricity that is used in the process for electric cars. Independent scooter commute is represented by “GLO: Market for transport, passenger, motor scooter”. Independent eBike/eScooter commute is represented by “RoW: Transport, passenger, electric bicycle” and “GLO: Transport, passenger, electric scooter”, where the total distance is equally divided among the two different modes. Independent bicycle commute is represented by “RoW: Transport, passenger, bicycle”. - A facility process represents Sunrock’s office. This facility process receives the outputs of the commuting employees as inputs. The facility process must be programmed to receive and provide the exact amounts of each flow as documented in the data template. The scaling factor of the facility process can then be fixed and used to upscale the results of the plan. - The plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing: - Actor groups: All processes were assigned to actor group G. - Scopes: The process that is responsible for burning the gasoline in the lease cars belongs to scope 1. The process that is responsible for processing and transporting the electricity that is consumed in the lease cars belongs to scope 2. All other processes belong to scope 3. - Scope 3 categories: All scope 3 processes belong to activity category 6. No group is specified for all processes - Timing: The emissions from all processes take place in 2021.
Value chain	- All individual plans have been combined to form the value chain plan. This plan is based on Figure 6.4 in Appendix 6.B (p. 139). - The two facility processes that were used in the individual plans (“Sunrock office 2021” and “Sunrock PV system 1MWp 2021”) form the center of the value chain plan, as all other processes are connected to them by either providing inbound flows or receiving outbound flows. The flows of all facility processes from the individual plans are combined in the facility processes of the value chain plan. The facility processes must be programmed to receive and provide the exact amounts of each flow as documented in the data templates. The scaling factor of the facility processes can then be fixed and used to upscale the results of the plan. - The value chain plan is grouped regarding actor groups, scopes, scope 3 activity categories, and timing. The processes of the value chain plan are grouped the same as the processes in the individual plans.

Table 6.11 Action aspect ratings for the identified actions.

1.1 Transition to district heating.

Action aspect	Rating	Explanation
Impact on target	5	Emissions from the consumption of natural gas for heating make up more than 50% of Sunrock's direct emissions. This action will significantly decrease those emissions.
Impact on total emissions	1	The direct emissions are only a small portion of Sunrock's total emissions.
Projected costs	5	The total costs for the use of the district heating system will not be higher than the usual costs for the consumption of natural gas.
Required time	5	Sunrock does have to wait for the connection to be realized, but no direct action must be taken by Sunrock.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

1.2 Improve the insulation at the office.

Action aspect	Rating	Explanation
Impact on target	1	Improved insulation will have only little impact on the target after Sunrock's office has transitioned to district heating.
Impact on total emissions	1	The direct emissions are only a small portion of Sunrock's total emissions.
Projected costs	5	This action is expected to cost relatively little.
Required time	4	It will take some time for the improved insulation to be installed.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

1.3 Replace all gasoline and hybrid lease/pool cars with full electric ones.

Action aspect	Rating	Explanation
Impact on target	4	The use of lease/pool cars makes up the second largest part of Sunrock's direct emissions. This action will significantly decrease those emissions.
Impact on total emissions	1	The direct emissions are only a small portion of Sunrock's total emissions.
Projected costs	3	Replacing the current gasoline and hybrid lease/pool cars with full electric ones will be a moderate investment.
Required time	4	It will take some time to replace the current gasoline and hybrid lease/pool cars with full electric ones.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

1.4 Ensure that the full electric lease/pool cars are only charged with electricity from renewable sources.

Action aspect	Rating	Explanation
Impact on target	1	The electricity use of lease/pool cars does not yet contribute significantly to Sunrock's direct emissions. These emissions will however increase if the share of full electric lease/pool cars grows.
Impact on total emissions	1	The direct emissions are only a small portion of Sunrock's total emissions.
Projected costs	5	Charging the full electric lease/pool cars with electricity from renewable sources will not cost much more than charging them with electricity from non-renewable sources.
Required time	5	Charging the full electric lease/pool cars with electricity from renewable sources will not take any more time than charging them with electricity from non-renewable sources.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

2.1 Choose module suppliers that are committed to reducing their carbon footprint.

Action aspect	Rating	Explanation
Impact on target	5	Emissions from the procurement of modules make up more than 90% of Sunrock's indirect emissions. This action will significantly decrease those emissions.
Impact on total emissions	5	Emissions from the procurement of modules make up more than 90% of Sunrock's total emissions. This action will significantly decrease those emissions.
Projected costs	1	Choosing suppliers that manufacture modules with a significantly lower carbon footprint is currently much more expensive.
Required time	2	It will take time for Sunrock to find suitable module suppliers and develop a strategy for investing in their modules.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	5	Module suppliers also have an impact on the working conditions of the people working at their factories. There currently are problems with transparency in the module manufacturing process. This action provides Sunrock with an opportunity to choose a supplier that also provides the required transparency regarding working conditions.

2.2 Engage and stimulate module suppliers to commit to reducing their carbon footprint.

Action aspect	Rating	Explanation
Impact on target	2	It is not expected that engagement and stimulation will drive large-scale module suppliers to change their strategy. If it works however, this action will have a significant impact since emissions from the procurement of modules make up more than 90% of Sunrock's indirect emissions.
Impact on total emissions	2	It is not expected that engagement and stimulation will drive large-scale module suppliers to change their strategy. If it works however, this action will have a significant impact since emissions from the procurement of modules make up more than 90% of Sunrock's total emissions.
Projected costs	4	Besides making business trips to meet with module suppliers, it is not expected that this action requires much funding.
Required time	4	It will cost some time to try and persuade module suppliers.
Influence / Cooperation	1	It is expected that Sunrock has little to no influence on the outcome of this action.
Social implications	5	Module suppliers also have an impact on the working conditions of the people working at their factories. There currently are problems with transparency in the module manufacturing process. This action provides Sunrock with an opportunity to engage and stimulate suppliers to also provide the required transparency regarding working conditions.

3.1 Ensure that business travel trips under 3 hours or 500 km are only traveled per train or full electric car.

Action aspect	Rating	Explanation
Impact on target	5	Emissions from the use of planes makes up the largest part of Sunrock's business travel emissions. This action will significantly decrease those emissions.
Impact on total emissions	1	The business travel emissions are only a small portion of Sunrock's total emissions.
Projected costs	4	It will cost only a little more money to travel per train or full electric car.
Required time	5	It will not cost much time to implement this action. The total duration of a trip will most likely increase though.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

3.2 Instruct employees to use trains or full electric lease/pool cars for business travel.

Action aspect	Rating	Explanation
Impact on target	3	Emissions from the use of cars makes up a large part of Sunrock's business travel emissions. This action will significantly decrease those emissions.
Impact on total emissions	1	The business travel emissions are only a small portion of Sunrock's total emissions.
Projected costs	4	The use of trains will be slightly more expensive than traveling per car. The demand for lease/pool cars will also increase. It will cost some money to acquire more full electric lease/pool to meet this demand. However, the existing lease/pool cars will also be used more frequently.
Required time	5	Stimulating the use of the existing lease/pool cars will take little time. Some time is required to acquire additional full electric lease/pool cars.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

3.3 Ensure that only full electric rental cars are used.

Action aspect	Rating	Explanation
Impact on target	2	Emissions from the use of cars makes up a moderate part of Sunrock's business travel emissions. This action will significantly decrease those emissions.
Impact on total emissions	1	The business travel emissions are only a small portion of Sunrock's total emissions.
Projected costs	5	Using full electric rental cars will not cost much more than using gasoline rental cars.
Required time	5	No extra time is required for Sunrock to start with only using full electric rental cars.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

4.1 Support employees in traveling with carbon neutral modes of transport.

Action aspect	Rating	Explanation
Impact on target	5	All employee commuting emissions from come from employees that use modes of transportation that cause emissions. This action will significantly decrease those emissions.
Impact on total emissions	1	The employee commuting emissions are only a small portion of Sunrock's total emissions.
Projected costs	3	Supporting Sunrock's employees financially for their carbon neutral commute will not be cheap because every employee will require a form of compensation.
Required time	3	It will take time to build a platform that enables Sunrock to find out how employees can be supported and what expenses are required to offer this support.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

4.2 Prevent commute by telling employees to work from home.

Action aspect	**Rating**	**Explanation**
Impact on target	4	All emissions from employee commuting are caused by the fact that employees have to commute. Letting employees work from home addresses the employee commuting emissions at the source. This action will therefore decrease those emissions significantly.
Impact on total emissions	1	The employee commuting emissions are only a small portion of Sunrock's total emissions.
Projected costs	5	No extra funds are required for letting employees work from home.
Required time	5	Not much time is required to make rules regarding working from home.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	1	No social implications are targeted through this action.

5.1 Choose module suppliers that use more recyclable or even C2C designs for their modules.

Action aspect	**Rating**	**Explanation**
Impact on target	5	Indirect waste from the procurement of modules makes up more than 90% of Sunrock's generated indirect waste. This action will significantly decrease that waste.
Impact on total waste	5	Waste from the procurement of modules makes up more than 90% of Sunrock's total generated waste. This action will significantly decrease that waste.
Projected costs	1	Choosing for suppliers that manufacture modules that cause significantly lower waste generation is currently much more expensive.
Required time	2	It will take time for Sunrock to find suitable module suppliers and develop a strategy for investing in their modules.
Influence / Cooperation	5	Sunrock has full control over whether this action will be successful or not.
Social implications	5	Module suppliers also have an impact on the working conditions of the people working at their factories. There currently are problems with transparency in the module manufacturing process. This action provides Sunrock with an opportunity to choose a supplier that also provides the required transparency regarding working conditions.

5.2 Engage and stimulate module suppliers to adopt more recyclable or C2C designs.

Action aspect	**Rating**	**Explanation**
Impact on target	2	It is not expected that engagement and stimulation will drive large-scale module suppliers to change their strategy. If it works however, this action will have a significant impact since indirect waste from the procurement of modules makes up more than 90% of Sunrock's indirect waste.
Impact on total waste	2	It is not expected that engagement and stimulation will drive large-scale module suppliers to change their strategy. If it works however, this action will have a significant impact since waste from the procurement of modules makes up more than 90% of Sunrock's total generated waste.
Projected costs	4	Besides making business trips to meet with module suppliers, it is not expected that this action requires much funding.
Required time	4	It will cost some time to try and persuade module suppliers.
Influence / Cooperation	1	It is expected that Sunrock has little to no influence on the outcome of this action.
Social implications	5	Module suppliers also have an impact on the working conditions of the people working at their factories. There currently are problems with transparency in the module manufacturing process. This action provides Sunrock with an opportunity to engage and stimulate suppliers to also provide the required transparency regarding working conditions.

6.B. Large figures

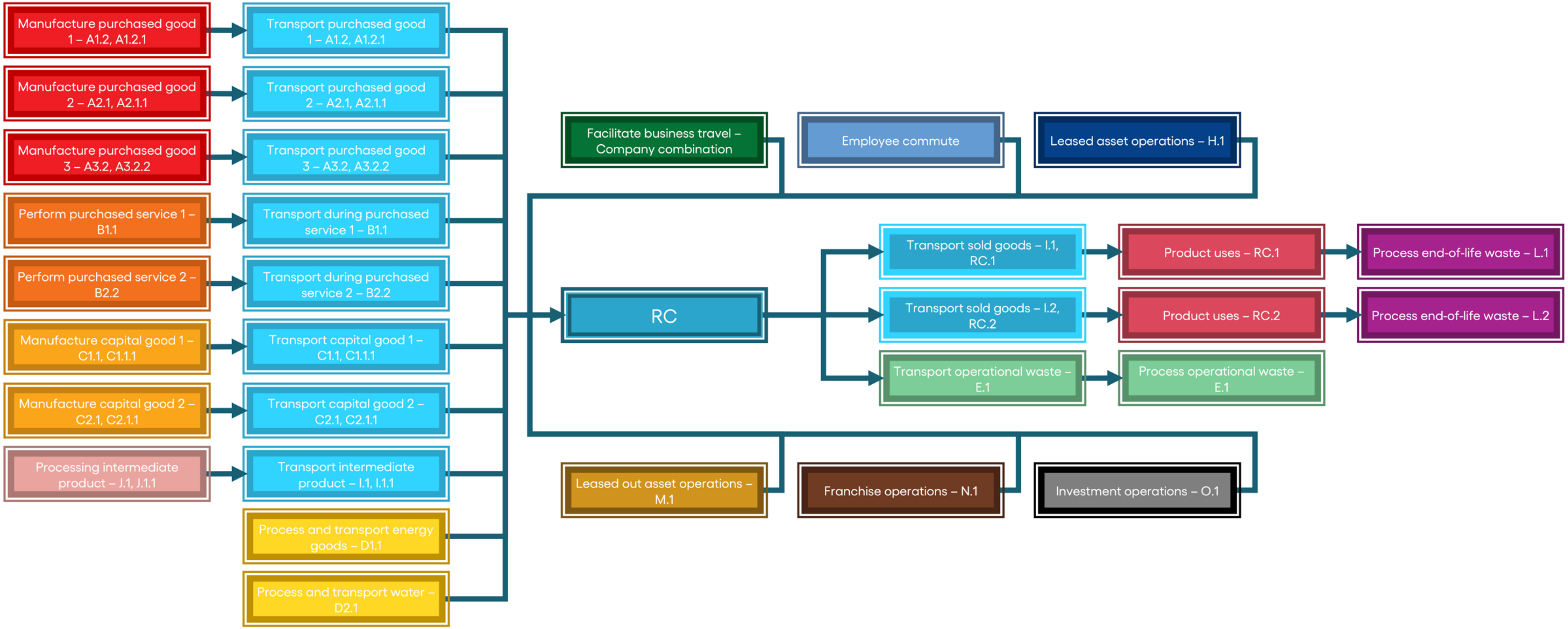
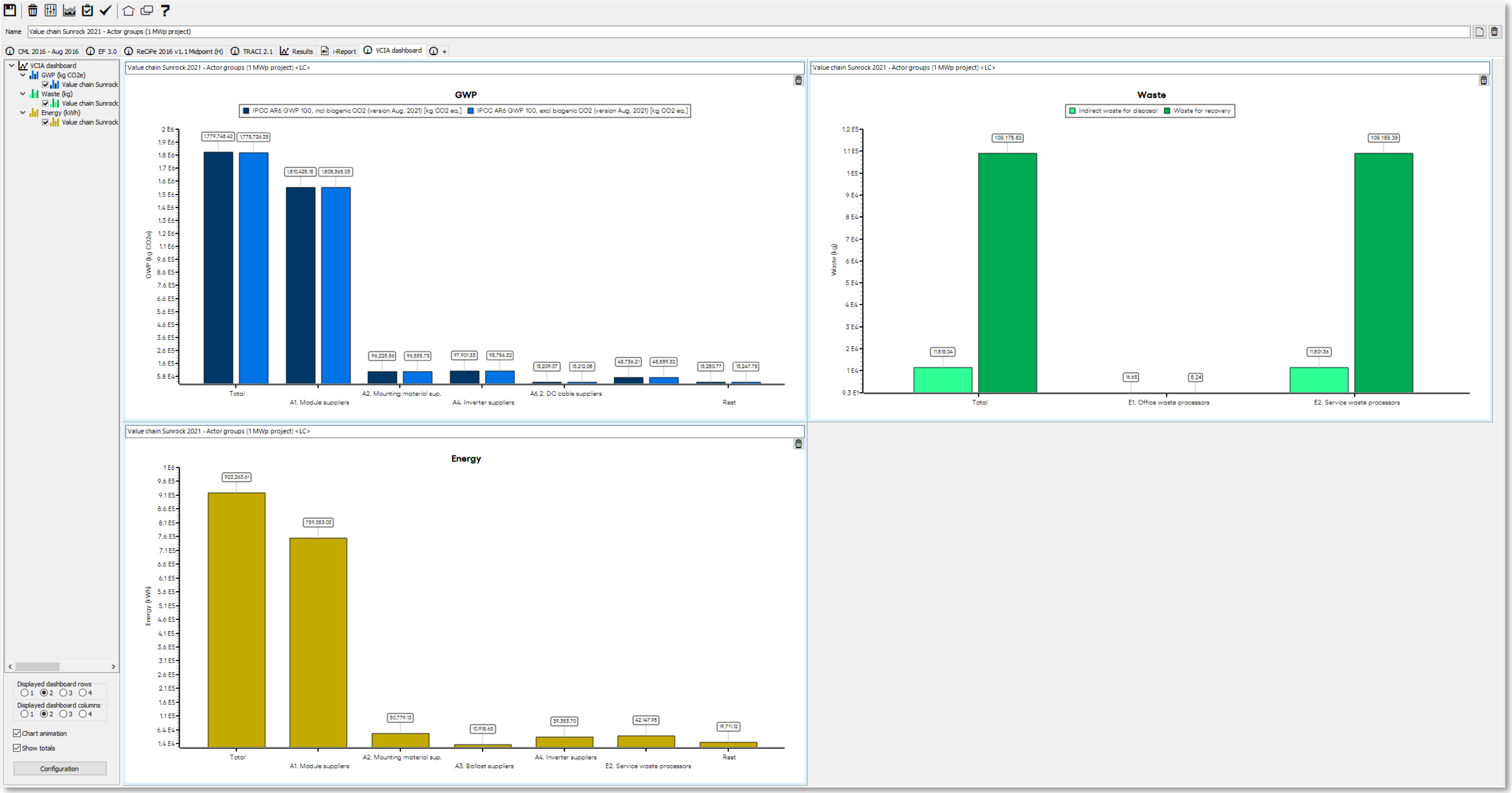


Figure 6.1 Generic example of a process overview based on Table 3.2 and Figure 3.2.



Name: Value chain Sunrock 2021 - Actor groups (1 MWp project)

Value chain Sunrock 2021 - Actor groups (1 MWp project) <LC>

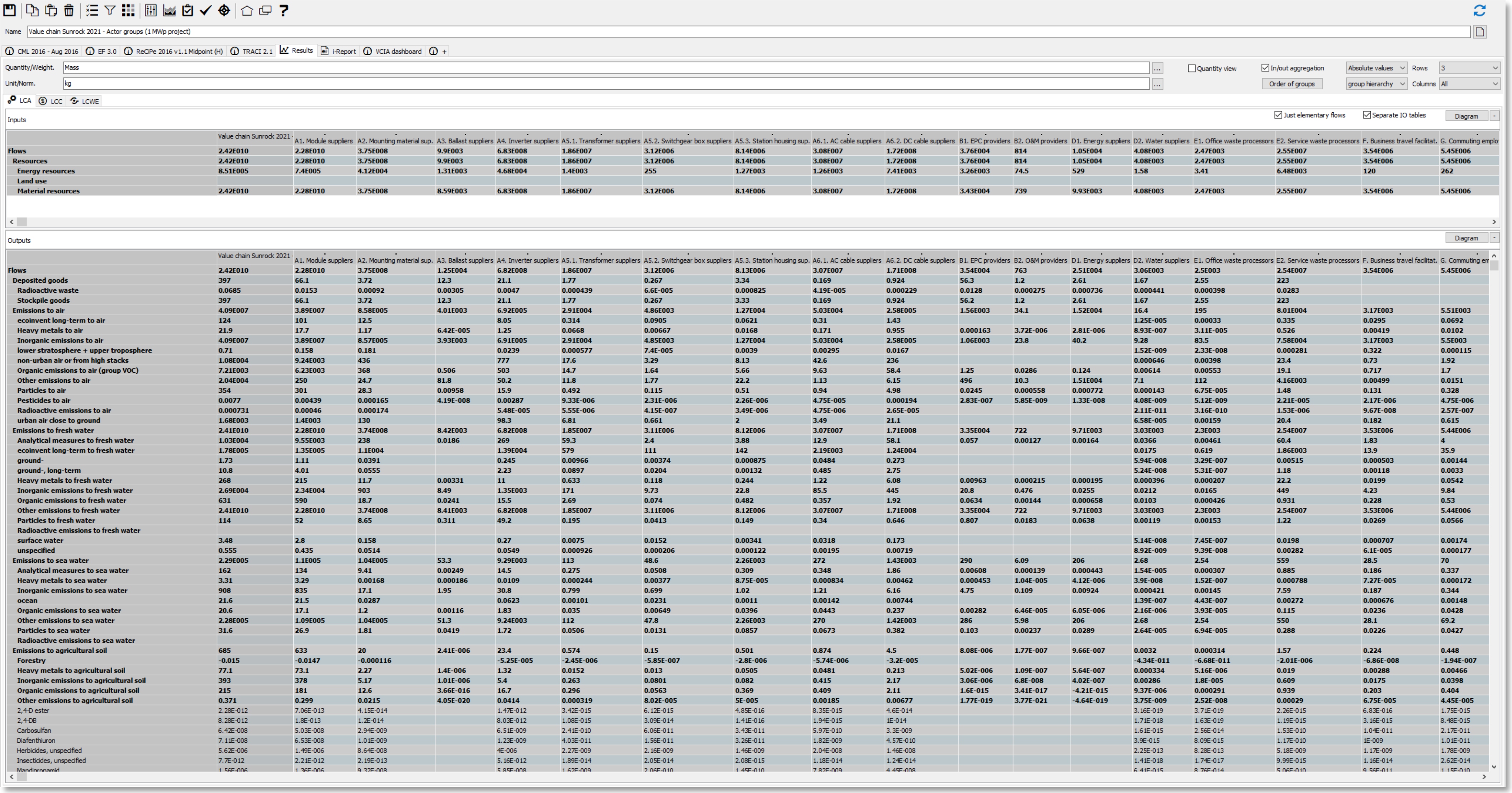
Displayed dashboard rows
○ 1 ● 2 ○ 3 ○ 4

Displayed dashboard columns
○ 1 ● 2 ○ 3 ○ 4

☑ Chart animation

☑ Show totals

Figure 6.2 Screenshot of the VCIA dashboard in GaBi.



Name: Value chain Sunrock 2021 - Actor groups (1 MWp project)

Quantity/Weight. Mass

Unit/Norm. kg

☐ Quantity view
☑ In/out aggregation
Absolute values
Rows: 3
Order of groups
group hierarchy
Columns: All

Inputs

☑ Just elementary flows
☑ Separate IO tables

	Value chain Sunrock 2021	A1. Module suppliers	A2. Mounting material sup.	A3. Ballast suppliers	A4. Inverter suppliers	A5.1. Transformer suppliers	A5.2. Switchgear box suppliers	A5.3. Station housing sup.	A6.1. AC cable suppliers	A6.2. DC cable suppliers	B1. EPC providers	B2. O&M providers	D1. Energy suppliers	D2. Water suppliers	E1. Office waste processors	E2. Service waste processors	F. Business travel facilitat.	G. Commuting emplo
Flows	2.42E010	2.28E010	3.75E008	9.9E003	6.83E008	1.86E007	3.12E006	8.14E006	3.08E007	1.72E008	3.76E004	814	1.05E004	4.08E003	2.47E003	2.55E007	3.54E006	5.45E006
Resources	2.42E010	2.28E010	3.75E008	9.9E003	6.83E008	1.86E007	3.12E006	8.14E006	3.08E007	1.72E008	3.76E004	814	1.05E004	4.08E003	2.47E003	2.55E007	3.54E006	5.45E006
Energy resources	8.51E005	7.4E005	4.12E004	1.31E003	4.68E004	1.4E003	255	1.27E003	1.26E003	7.41E003	3.26E003	74.5	529	1.58	3.41	6.48E003	120	262
Land use																		
Material resources	2.42E010	2.28E010	3.75E008	8.59E003	6.83E008	1.86E007	3.12E006	8.14E006	3.08E007	1.72E008	3.43E004	739	9.93E003	4.08E003	2.47E003	2.55E007	3.54E006	5.45E006

Outputs

	Value chain Sunrock 2021	A1. Module suppliers	A2. Mounting material sup.	A3. Ballast suppliers	A4. Inverter suppliers	A5.1. Transformer suppliers	A5.2. Switchgear box suppliers	A5.3. Station housing sup.	A6.1. AC cable suppliers	A6.2. DC cable suppliers	B1. EPC providers	B2. O&M providers	D1. Energy suppliers	D2. Water suppliers	E1. Office waste processors	E2. Service waste processors	F. Business travel facilitat.	G. Commuting em
Flows	2.42E010	2.28E010	3.75E008	1.25E004	6.82E008	1.86E007	3.12E006	8.13E006	3.07E007	1.71E008	3.54E004	763	2.51E004	3.06E003	2.5E003	2.54E007	3.54E006	5.45E006
Deposited goods	397	66.1	3.72	12.3	21.1	1.77	0.267	3.34	0.169	0.924	56.3	1.2	2.61	1.67	2.55	223		
Radioactive waste	0.0685	0.0153	0.00092	0.00305	0.0047	0.000439	6.6E-005	0.000825	4.19E-005	0.000229	0.0128	0.000275	0.000736	0.000441	0.000398	0.0283		
Stockpile goods	397	66.1	3.72	12.3	21.1	1.77	0.267	3.33	0.169	0.924	56.2	1.2	2.61	1.67	2.55	223		
Emissions to air	4.09E007	3.89E007	8.58E005	4.01E003	6.92E005	2.91E004	4.86E003	1.27E004	5.03E004	2.58E005	1.56E003	34.1	1.52E004	16.4	195	8.01E004	3.17E003	5.51E003
ecoinvent long-term to air	124	101	12.5		8.05	0.314	0.0905	0.0621	0.31	1.43				1.25E-005	0.00033	0.335	0.0295	0.0692
Heavy metals to air	21.9	17.7	1.17	6.42E-005	1.25	0.0668	0.00667	0.0168	0.171	0.955	0.000163	3.72E-006	2.81E-006	8.93E-007	3.11E-005	0.526	0.00419	0.0102
Inorganic emissions to air	4.09E007	3.89E007	8.57E005	3.93E003	6.91E005	2.91E004	4.85E003	1.27E004	5.03E004	2.58E005	1.06E003	23.8	40.2	9.28	83.5	7.58E004	3.17E003	5.5E003
lower stratosphere + upper troposphere	0.71	0.158	0.181		0.0239	0.000577	7.4E-005	0.0039	0.00295	0.0167				1.52E-009	2.33E-008	0.000281	0.322	0.000115
non-urban air or from high stacks	1.08E004	9.24E003	436		777	17.6	3.29	8.13	42.6	236				0.000646	0.00398	23.4	0.73	1.92
Organic emissions to air (group VOC)	7.21E003	6.23E003	368	0.506	503	14.7	1.64	5.66	9.63	58.4	1.25	0.0286	0.124	0.00614	0.00553	19.1	0.717	1.7
Other emissions to air	2.04E004	250	24.7	81.8	50.2	11.8	1.77	22.2	1.13	6.15	496	10.3	1.51E004	7.1	112	4.16E003	0.00499	0.0151
Particles to air	354	301	28.3	0.00958	15.9	0.492	0.115	0.51	0.94	4.98	0.0245	0.000558	0.000772	0.000143	6.75E-005	1.48	0.131	0.328
Pesticides to air	0.0077	0.00439	0.000165	4.19E-008	0.00287	9.33E-006	2.31E-006	2.26E-006	4.75E-005	0.000194	2.83E-007	5.85E-009	1.33E-008	4.08E-009	5.12E-009	2.21E-005	2.17E-006	4.75E-006
Radioactive emissions to air	0.000731	0.00046	0.000174		5.48E-005	5.55E-006	4.15E-007	3.49E-006	4.75E-006	2.65E-005				2.11E-011	3.16E-010	1.53E-006	9.67E-008	2.57E-007
urban air close to ground	1.68E003	1.4E003	130		98.3	6.81	0.661	2	3.49	21.1				6.58E-005	0.00159	20.4	0.182	0.615
Emissions to fresh water	2.41E010	2.28E010	3.74E008	8.42E003	6.82E008	1.85E007	3.11E006	8.12E006	3.07E007	1.71E008	3.35E004	722	9.71E003	3.03E003	2.3E003	2.54E007	3.53E006	5.44E006
Analytical measures to fresh water	1.03E004	9.55E003	238	0.0186	269	59.3	2.4	3.88	12.9	58.1	0.057	0.00127	0.00164	0.0366	0.00461	60.4	1.83	4
ecoinvent long-term to fresh water	1.78E005	1.35E005	1.1E004		1.39E004	579	111	142	2.19E003	1.24E004				0.0175	0.619	1.86E003	13.9	35.9
ground-	1.73	1.11	0.0391		0.245	0.00966	0.00374	0.000875	0.0484	0.273				5.94E-008	3.29E-007	0.00515	0.000503	0.00144
ground-, long-term	10.8	4.01	0.0555		2.23	0.0897	0.0204	0.00132	0.485	2.75				5.24E-008	5.31E-007	1.18	0.00118	0.0033
Heavy metals to fresh water	268	215	11.7	0.00331	11	0.633	0.118	0.244	1.22	6.08	0.00963	0.000215	0.000195	0.000396	0.000207	22.2	0.0199	0.0542
Inorganic emissions to fresh water	2.69E004	2.34E004	903	8.49	1.35E003	171	9.73	22.8	85.5	445	20.8	0.476	0.0255	0.0212	0.0165	449	4.23	9.84
Organic emissions to fresh water	631	590	18.7	0.0241	15.5	2.69	0.074	0.482	0.357	1.92	0.0634	0.00144	0.000658	0.0103	0.000426	0.931	0.228	0.53
Other emissions to fresh water	2.41E010	2.28E010	3.74E008	8.41E003	6.82E008	1.85E007	3.11E006	8.12E006	3.07E007	1.71E008	3.35E004	722	9.71E003	3.03E003	2.3E003	2.54E007	3.53E006	5.44E006
Particles to fresh water	114	52	8.65	0.311	49.2	0.195	0.0413	0.149	0.34	0.646	0.807	0.0183	0.0638	0.00119	0.00153	1.22	0.0269	0.0566
Radioactive emissions to fresh water																		
surface water	3.48	2.8	0.158		0.27	0.0075	0.0152	0.00341	0.0318	0.173				5.14E-008	7.45E-007	0.0198	0.000707	0.00174
unspecified	0.555	0.435	0.0514		0.0549	0.000926	0.000206	0.000122	0.00195	0.00719				8.92E-009	9.39E-008	0.00282	6.1E-005	0.000177
Emissions to sea water	2.29E005	1.1E005	1.04E005	53.3	9.29E003	113	48.6	2.26E003	272	1.43E003	290	6.09	206	2.68	2.54	559	28.5	70
Analytical measures to sea water	162	134	9.41	0.00249	14.5	0.275	0.0508	0.309	0.348	1.86	0.00608	0.000139	0.000443	1.54E-005	0.000307	0.885	0.186	0.337
Heavy metals to sea water	3.31	3.29	0.00168	0.000186	0.0109	0.000244	0.00377	8.75E-005	0.000834	0.00462	0.000453	1.04E-005	4.12E-006	3.9E-008	1.52E-007	0.000788	7.27E-005	0.000172
Inorganic emissions to sea water	908	835	17.1	1.95	30.8	0.799	0.699	1.02	1.21	6.16	4.75	0.109	0.00924	0.000421	0.00145	7.59	0.187	0.344
ocean	21.6	21.5	0.0287		0.0623	0.00101	0.0231	0.0011	0.00142	0.00744				1.39E-007	4.43E-007	0.00272	0.000676	0.00148
Organic emissions to sea water	20.6	17.1	1.2	0.00116	1.83	0.035	0.00649	0.0396	0.0443	0.237	0.00282	6.46E-005	6.05E-006	2.16E-006	3.93E-005	0.115	0.0236	0.0428
Other emissions to sea water	2.28E005	1.09E005	1.04E005	51.3	9.24E003	112	47.8	2.26E003	270	1.42E003	286	5.98	206	2.68	2.54	550	28.1	69.2
Particles to sea water	31.6	26.9	1.81	0.0419	1.72	0.0506	0.0131	0.0857	0.0673	0.382	0.103	0.00237	0.0289	2.64E-005	6.94E-005	0.288	0.0226	0.0427
Radioactive emissions to sea water																		
Emissions to agricultural soil	685	633	20	2.41E-006	23.4	0.574	0.15	0.501	0.874	4.5	8.08E-006	1.77E-007	9.66E-007	0.0032	0.000314	1.57	0.224	0.448
Forestry	-0.015	-0.0147	-0.000116		-5.25E-005	-2.45E-006	-5.85E-007	-2.8E-006	-5.74E-006	-3.2E-005				-4.34E-011	-6.68E-011	-2.01E-006	-6.86E-008	-1.94E-007
Heavy metals to agricultural soil	77.1	73.1	2.27	1.4E-006	1.32	0.0152	0.013	0.0505	0.0481	0.213	5.02E-006	1.09E-007	5.64E-007	0.000334	5.16E-006	0.019	0.00288	0.00466
Inorganic emissions to agricultural soil	393	378	5.17	1.01E-006	5.4	0.263	0.0801	0.082	0.415	2.17	3.06E-006	6.8E-008	4.02E-007	0.00286	1.8E-005	0.609	0.0175	0.0398
Organic emissions to agricultural soil	215	181	12.6	3.66E-016	16.7	0.296	0.0563	0.369	0.409	2.11	1.6E-015	3.41E-017	-4.21E-015	9.37E-006	0.000291	0.939	0.203	0.404
Other emissions to agricultural soil	0.371	0.299	0.0215	4.05E-020	0.0414	0.000319	8.02E-005	5E-005	0.00185	0.00677	1.77E-019	3.77E-021	-4.64E-019	3.75E-009	2.52E-008	0.00029	6.75E-005	4.45E-005
2,4-D ester	2.28E-012	7.06E-013	4.15E-014		1.47E-012	3.42E-015	6.12E-015	4.85E-016	8.35E-015	4.6E-014				3.16E-019	3.71E-019	2.26E-015	6.83E-016	1.75E-015
2,4-DB	8.28E-012	1.8E-013	1.2E-014		8.03E-012	1.08E-015	3.09E-014	1.41E-016	1.94E-015	1E-014				1.71E-018	1.63E-019	1.19E-015	3.16E-015	8.48E-015
Carbosulfan	6.42E-008	5.03E-008	2.94E-009		6.51E-009	2.41E-010	6.06E-011	3.43E-011	5.97E-010	3.3E-009				1.61E-015	2.56E-014	1.53E-010	1.04E-011	2.17E-011
Diafenthiuron	7.11E-008	6.53E-008	1.01E-009		1.23E-009	4.03E-011	1.56E-011	3.26E-011	1.82E-009	4.57E-010				3.9E-015	8.09E-015	1.17E-010	1E-009	1.01E-011
Herbicides, unspecified	5.62E-006	1.49E-006	8.64E-008		4E-006	2.27E-009	2.16E-009	1.46E-009	2.04E-008	1.46E-008				2.25E-013	8.28E-013	5.18E-009	1.17E-009	1.78E-009
Insecticides, unspecified	7.7E-012	2.21E-012	2.19E-013		5.16E-012	1.89E-014	2.05E-014	2.08E-015	1.18E-014	1.24E-014				1.41E-018	1.74E-017	9.99E-015	1.16E-014	2.62E-014
Mandipropamid	1.56E-006	1.36E-006	9.32E-008		5.85E-008	1.62E-009	2.06E-010	1.45E-010	7.82E-009	4.45E-008				6.41E-015	8.76E-014	5.06E-010	9.56E-011	1.15E-010

Figure 6.3 Screenshot of a VCI table for mass in GaBi.

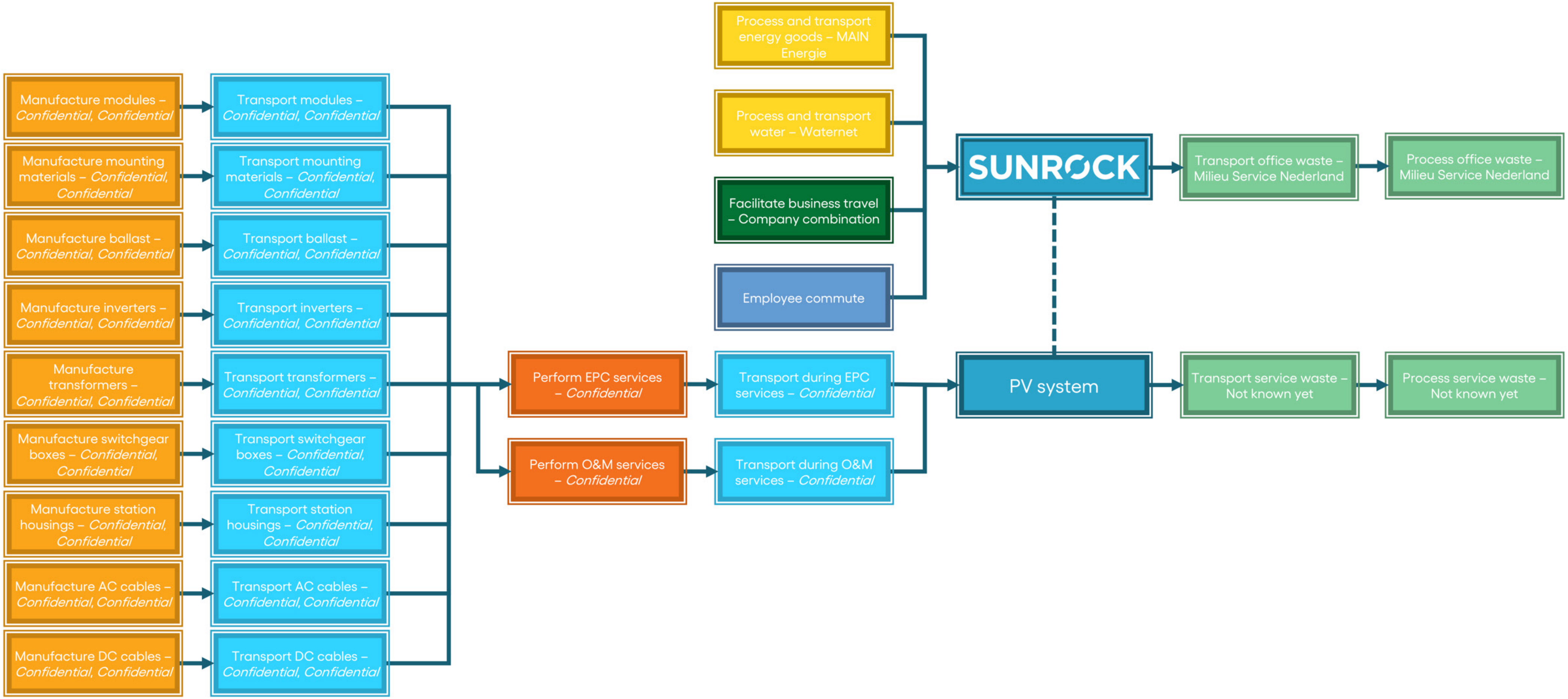


Figure 6.4 Overview of the defined relevant processes in Sunrock's value chain.

Figure 6.5 GaBi plan for activity categories 1 and 4.

Figure 6.7 GaBi plan for activity category 3.

Figure 6.6 GaBi plan for activity categories 2 and 4.

Figure 6.8 GaBi plan for activity category 5.

Figure 6.9 GaBi plan for activity category 6.

Figure 6.10 GaBi plan for activity category 7.

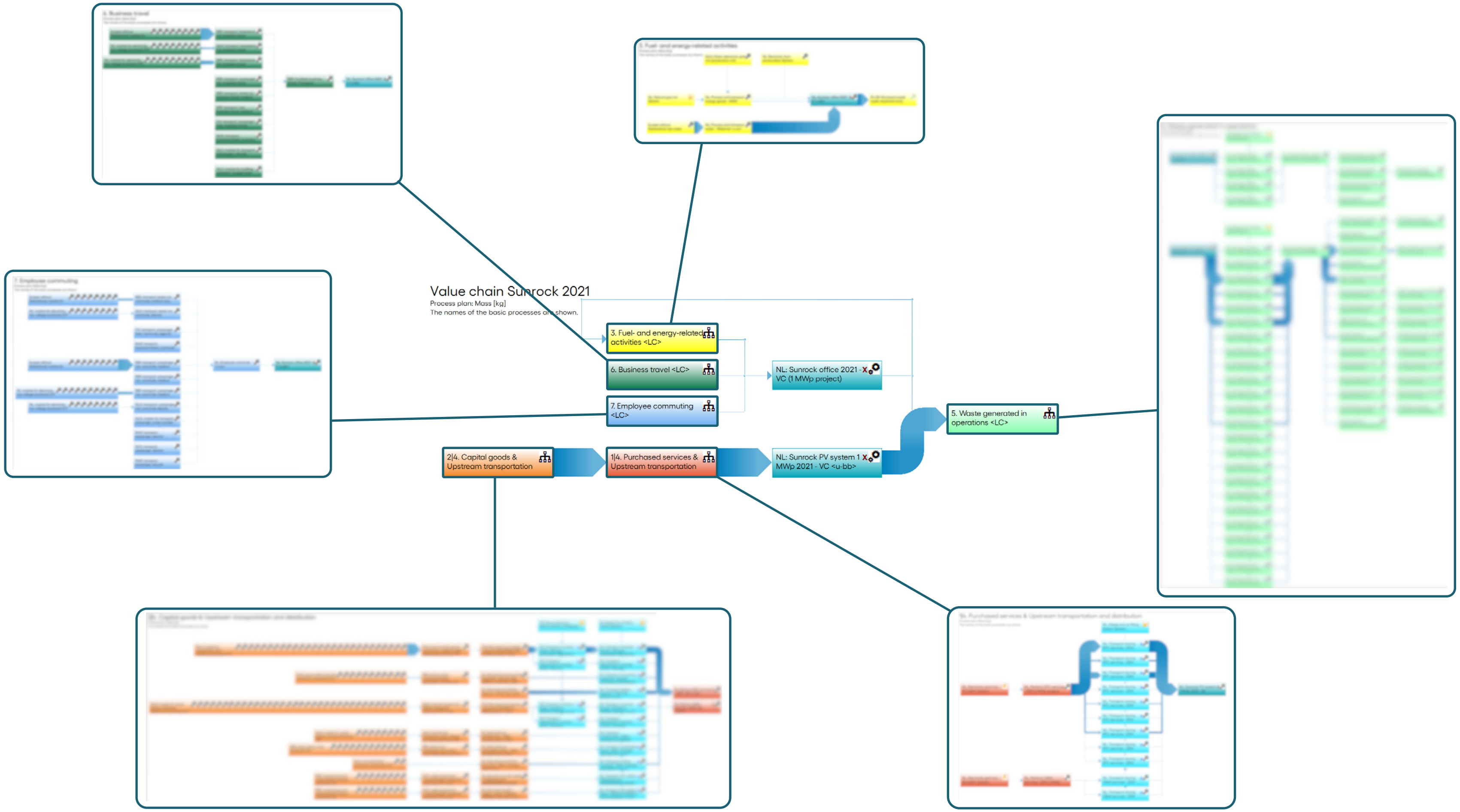


Figure 6.11 GaBi plan for Sunrock's value chain.

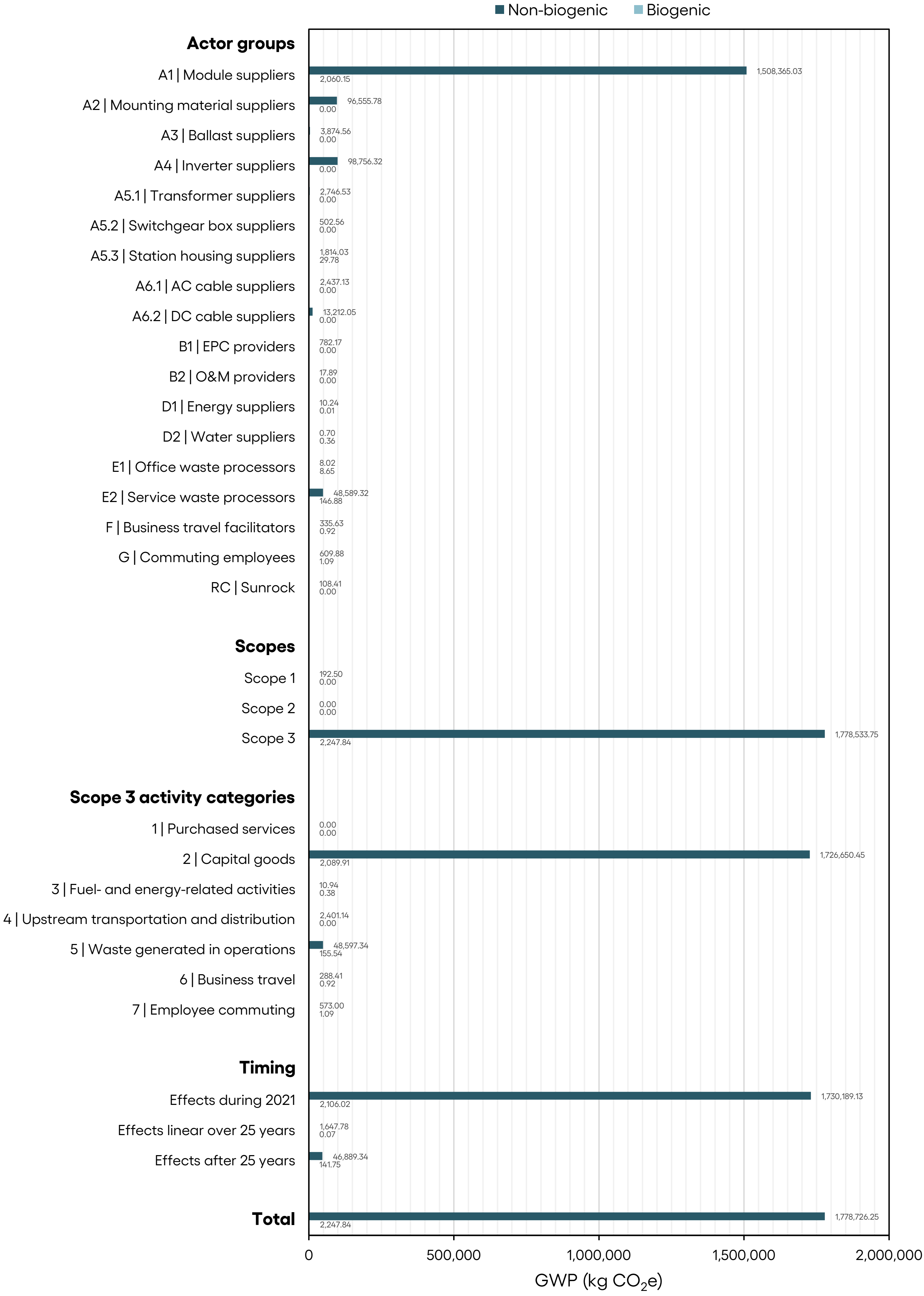


Figure 6.12 VCIA results regarding the GWP of the 1 MWp project.

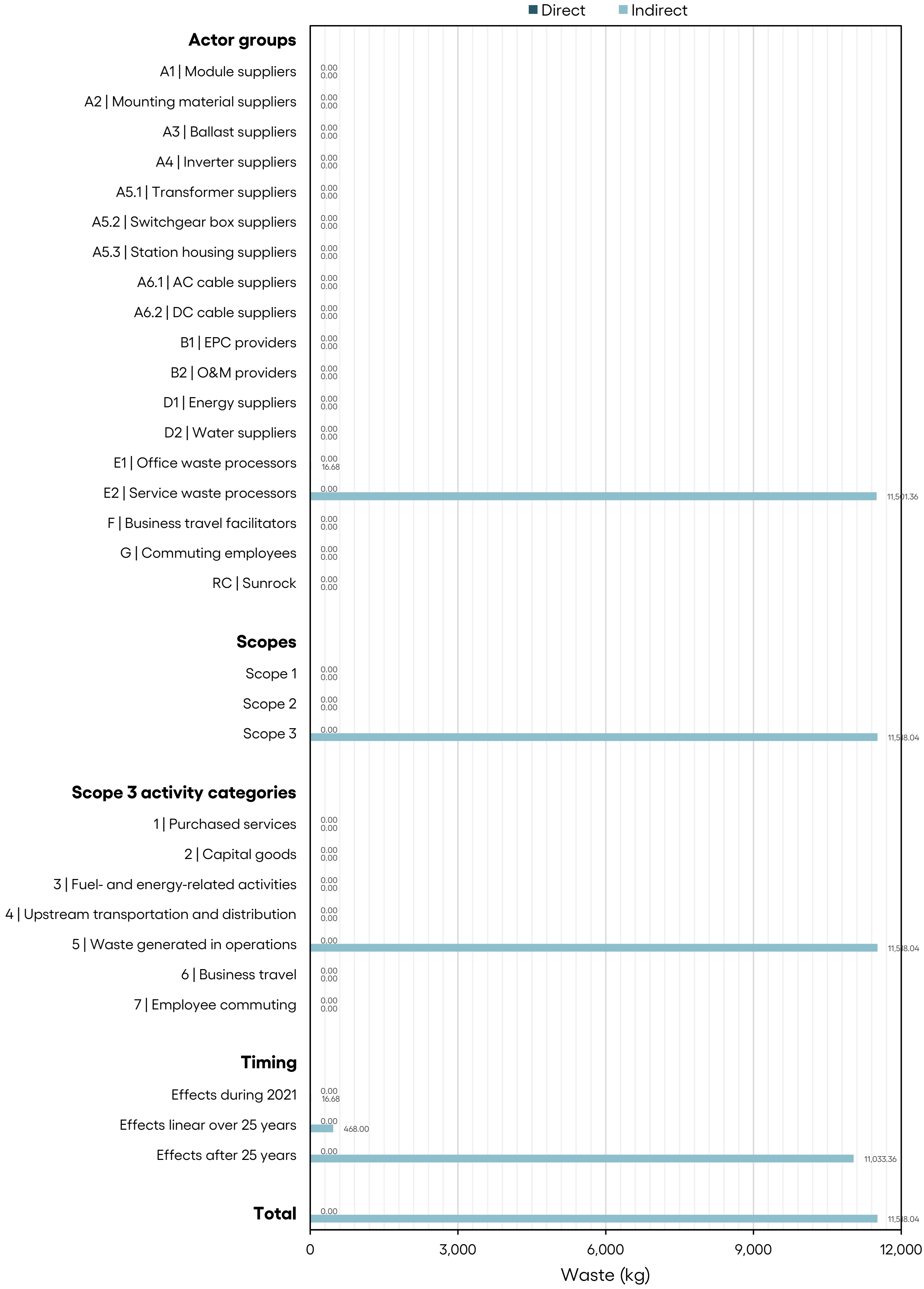


Figure 6.13 VCIA results regarding the generated waste of the 1 MWp project.

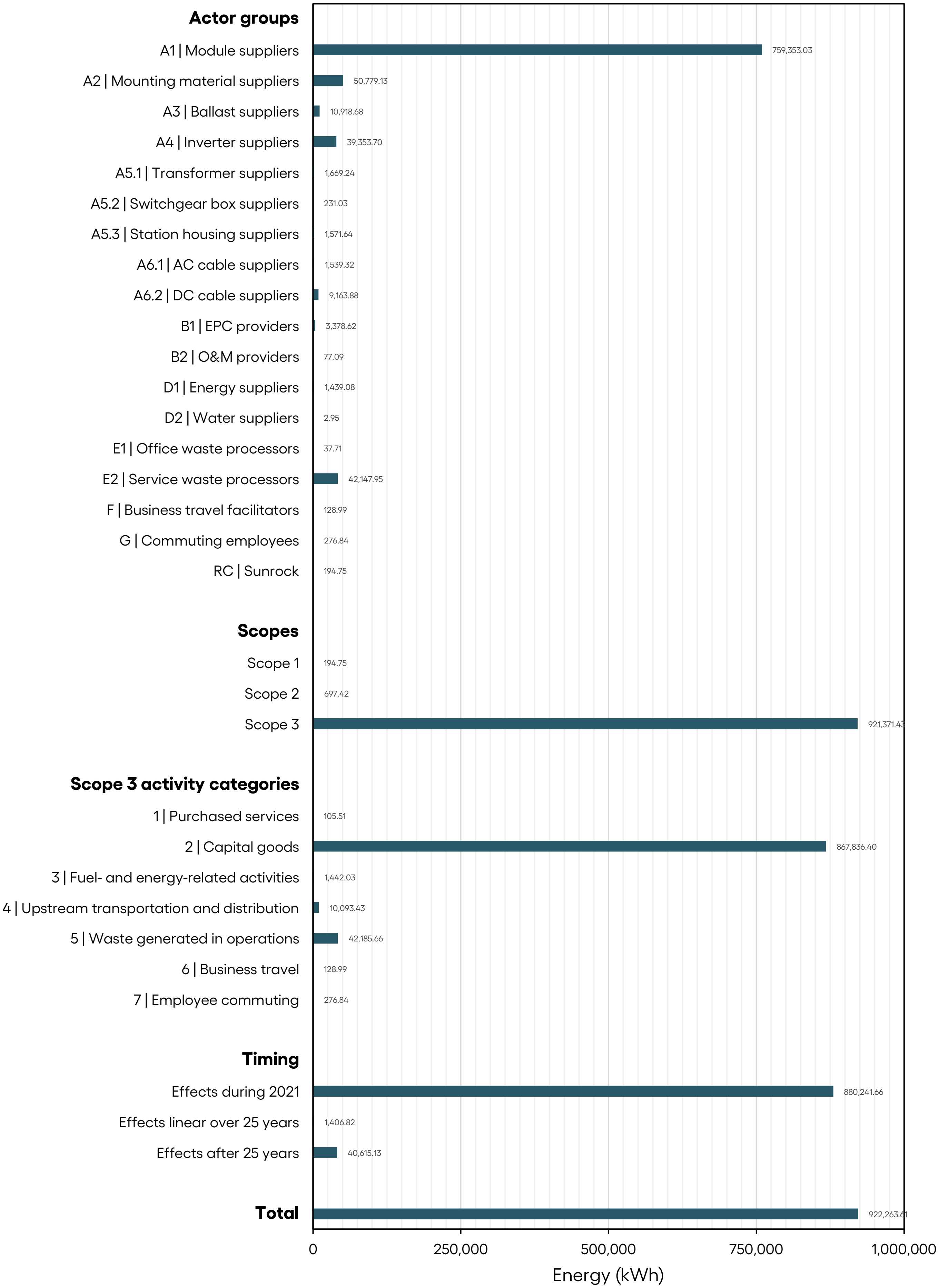


Figure 6.14 VCIA results regarding the involved energy of the 1 MWp project.

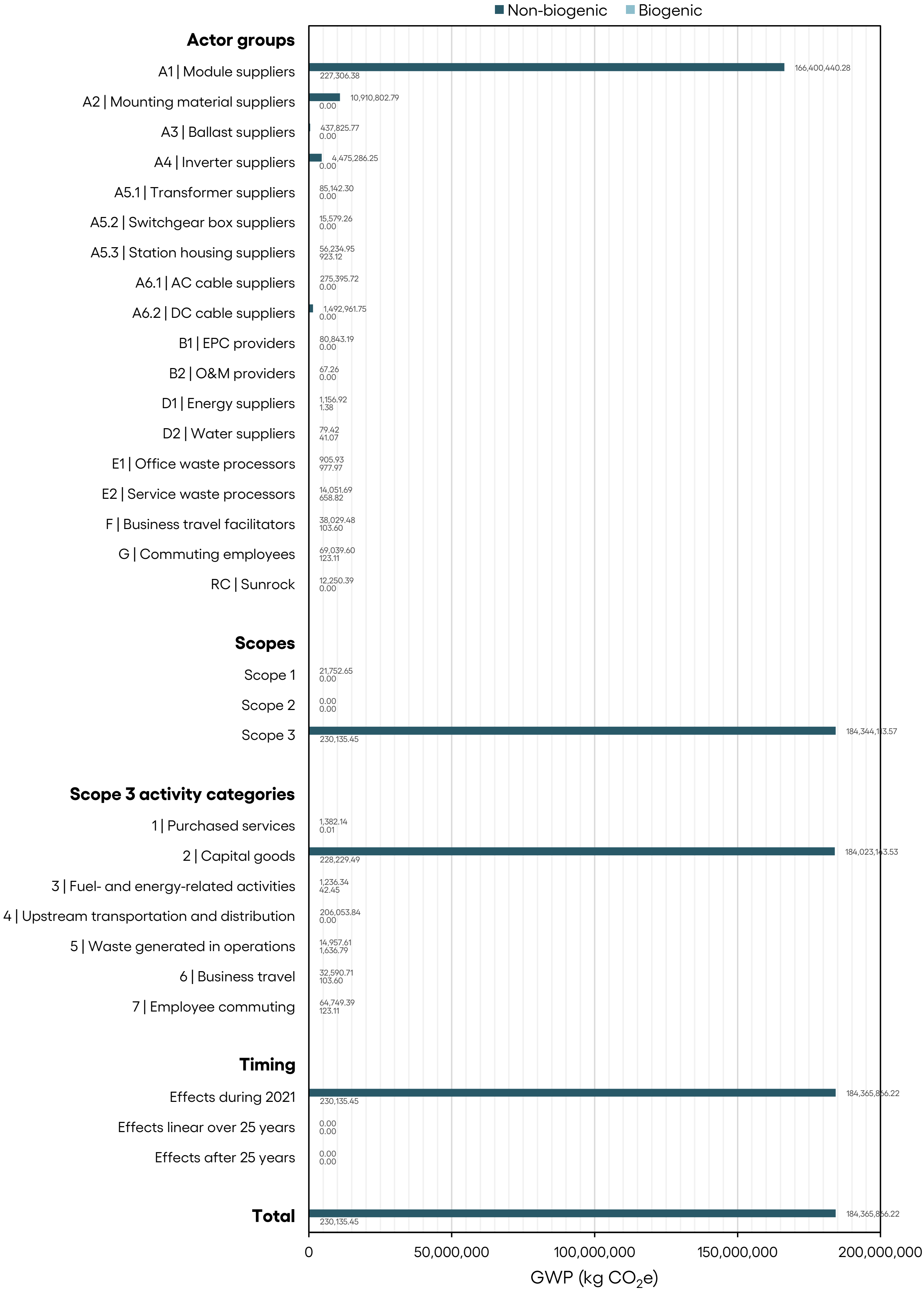


Figure 6.15 VCIA results regarding the GWP of the base year 2021.

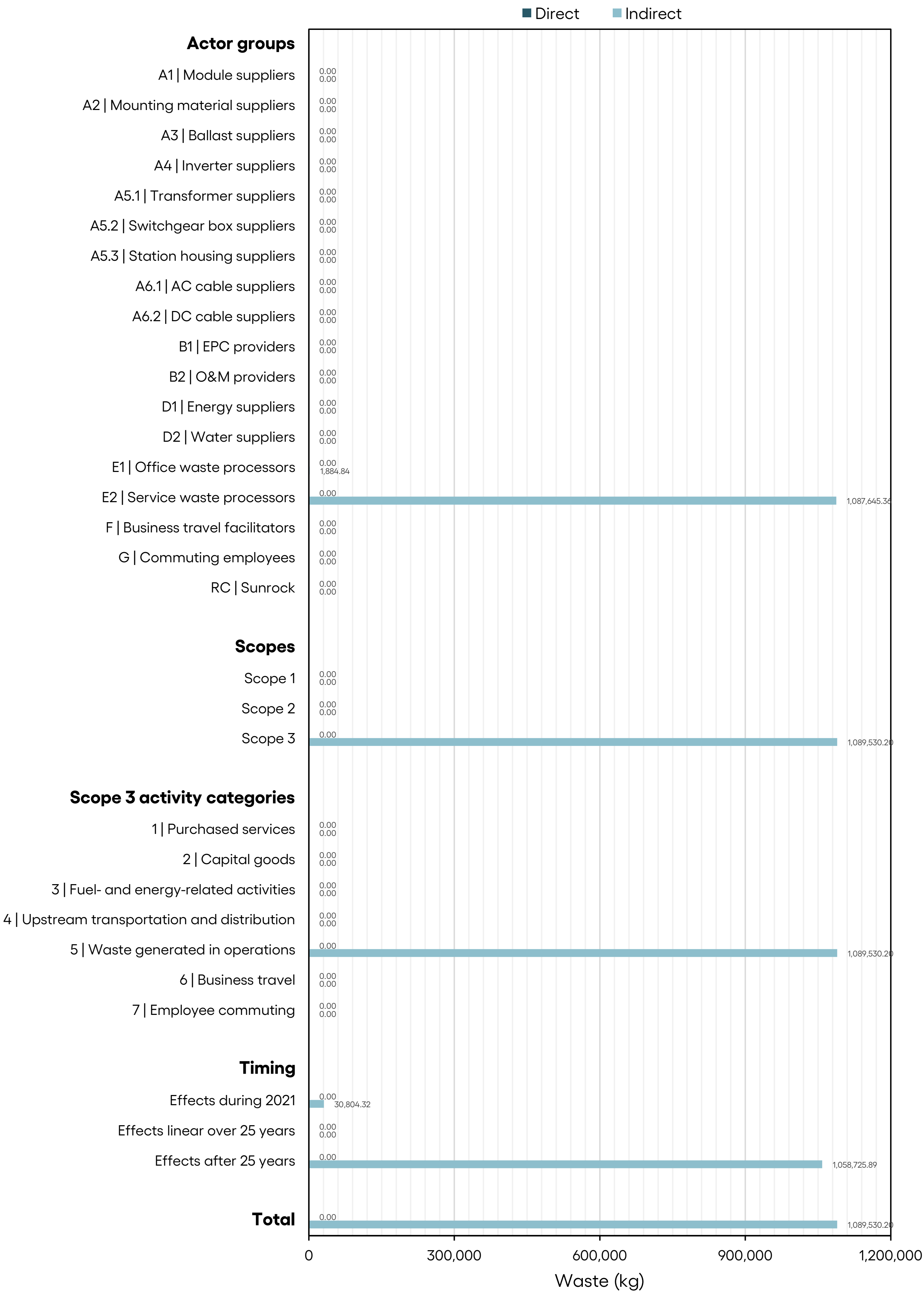


Figure 6.16 VCIA results regarding the generated waste of the base year 2021.

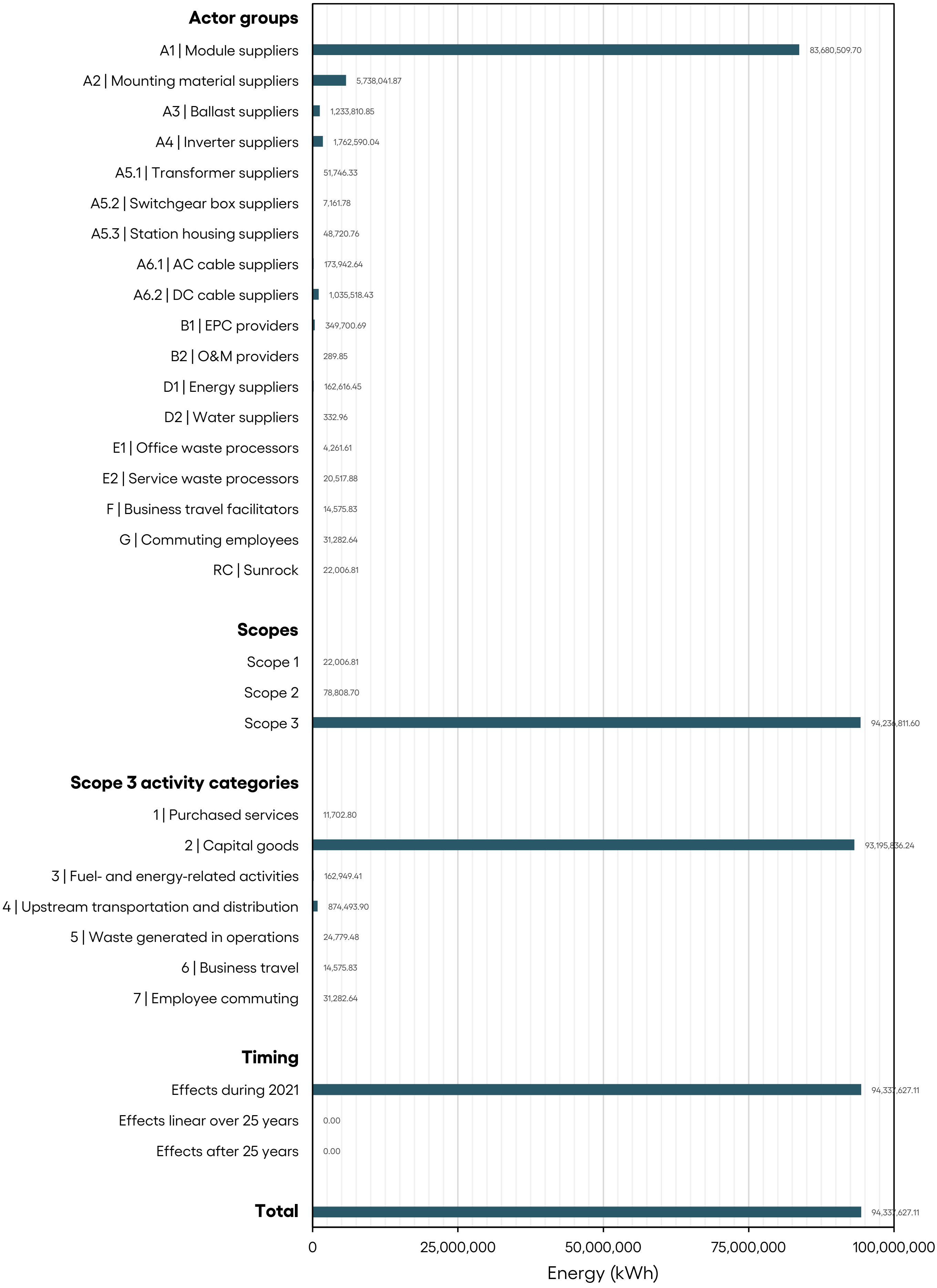


Figure 6.17 VCIA results regarding the involved energy of the base year 2021.

6.C. Download links

GHG Protocol
A&R standard

ISO LCA
standard

Data collection
templates

VCIA dashboard

Target tools
from the SBTi

6.D. SBT criteria

This appendix explains the SBT criteria as stated by the SBTi (2021b). Precise language is used to indicate requirements, recommendations, and allowable options that RCs may choose to follow.

- The terms “shall” or “must” are used throughout this document to indicate what is required for targets to be in conformance with the criteria.
- The term “should” is used to indicate a recommendation, but not a requirement.
- The term “may” is used to indicate an option that is permissible or allowable.

Unless otherwise noted (including specific sections), all criteria apply to all scopes. Criteria are noted with a C, while recommendations and additional guidance are noted with an R.

1. GHG Emissions Inventory and Target Boundary

Target boundary

- C1 - Organizational boundary: It is recommended that companies submit targets only at the parent- or group-level, not at the subsidiary level. Parent companies must include the emissions of all subsidiaries in their target submission, in accordance with boundary criteria above. In cases where both parent companies and subsidiaries submit targets, the parent company’s target must also include the emissions of the subsidiary if it falls within the parent company’s emissions boundary given the chosen inventory consolidation approach.
- R1 - Setting organizational boundaries: The SBTi recommends that the RC’s organizational boundary, as defined by the GHG Protocol Corporate Standard (GHG Protocol, 2004), is consistent with the organizational boundary used in the RC’s financial accounting and reporting procedures.

GHG coverage

- C2 - Greenhouse gases: The targets must cover all relevant GHGs as required per the GHG Protocol Corporate Standard.

Scope coverage

- C3 - Scope 1 and scope 2: The targets must cover company-wide scope 1 and scope 2 emissions, as defined by the GHG Protocol Corporate Standard (GHG Protocol, 2004).
- C4 - Requirement to have a scope 3 target: If an RC’s relevant scope 3 emissions are 40% or more of total scope 1, 2, and 3 emissions, a scope 3 target is required. All companies involved in the sale or distribution of natural gas and/or other fossil fuels shall set scope 3 targets for the use of sold products, irrespective of the share of these emissions compared to the total scope 1, 2, and 3 emissions of the RC.

Emissions coverage

- C5 - Scope 1 and 2 significance thresholds: Companies may exclude up to 5% of scope 1 and scope 2 emissions combined in the boundary of the inventory and target.
- C6 - Scope 3 emissions coverage for near-term targets: Companies must set one or more emission reduction targets and/or supplier or customer engagement targets that collectively cover(s) at least two-thirds (67%) of total scope 3 emissions considering the minimum boundary of each scope 3 activity category in conformance with the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard (GHG Protocol, 2011).
- R2 - Targets covering optional scope 3 emissions: Targets to reduce scope 3 emissions that fall outside the minimum boundary of scope 3 activity categories are not required, but are encouraged when these emissions are significant. This can include targets to influence the behavior of end-users (e.g., education campaigns) or to drive the adoption of science-based targets on customers (e.g., customer engagement targets). Companies may cover these emissions with a scope 3 target, but such targets cannot count towards the two-thirds threshold defined in C6 for scope 3 emissions (i.e., these targets are above and beyond the RC’s scope 3 targets). For reference, consult page 48 in the GHG Protocol Scope 3 Standard and the Target Validation Protocol for a list of products that generate direct and indirect use-phase emissions.

6

2. Method validity

- C7 - Method validity: Targets must be modelled using the latest version of methods and tools approved by the initiative. Targets modelled using previous versions of the tools or methods can only be submitted to the SBTi for validation within 6 months of the publication of the revised method or the publication of relevant sector-specific tools.

3. Emissions accounting requirements

Timeframe

- C8 - Scope 2 accounting approach: Companies shall disclose whether they are using a location- or market-based accounting approach as per the GHG Protocol Scope 2 Guidance to calculate base year emissions and to track performance against a science-based target. GHG Protocol requires measuring and reporting scope 2 emissions using both approaches. However, a single and consistent approach shall be used for setting and tracking progress toward a SBT (e.g., using location-based approach for both target setting and progress tracking).
- C9 - Scope 3 screening: Companies must complete a scope 3 inventory covering gross scope 3 emissions for all its emissions sources as set out as the minimum boundary of each scope 3 activity category per the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard (GHG Protocol, 2011).
- C10 - Bioenergy accounting: CO_2 emissions from the combustion, processing and distribution phase of bioenergy and the land use emissions and removals associated with bioenergy feedstocks, shall be reported alongside an RC's GHG inventory. Furthermore, CO_2 emissions from the combustion, processing and distribution phase of bioenergy and the land use emissions and removals associated with bioenergy feedstocks shall be included in the target boundary when setting a science-based target (in scopes 1, 2, and/or 3, as relevant) and when reporting progress against that target. Land-related emissions accounting shall include CO_2 emissions from direct land use change (LUC) and non-LUC emissions, inclusive of N_2O and CH_4 emissions from land use management. Including emissions associated with indirect LUC is optional. Companies are expected to adhere to any additional GHG Protocol Guidance on bioenergy accounting when released in order to maintain compliance with criterion 10.
- C11 - Carbon credits: The use of carbon credits must not be counted as emission reductions toward the progress of companies' near-term science-based targets. Carbon credits may only be considered to be an option for neutralizing residual emissions (see Net-Zero C30) or to finance additional climate mitigation beyond their science-based emission reduction targets (see Net-Zero R3).
- C12 - Avoided emissions: Avoided emissions fall under a separate accounting system from corporate inventories and do not count toward science-based targets.
- R3 - Biofuel certification: The SBTi recommends that companies using or producing biofuel(s) for transportation should support their bioenergy GHG accounting with recognized biofuel certification(s) to disclose that the data on land-related emissions and removals represents the relevant biofuel feedstock production.
- R4 - Bioenergy data reporting: The SBTi recommends that companies report direct biogenic CO_2 emissions and removals from bioenergy separately. Emissions and removals of CO_2 associated with bioenergy shall be reported as net emissions according to C10, at a minimum, but companies are encouraged to also report gross emissions and gross removals from bioenergy feedstocks.

4. Target formulation

Timeframe

- C13 - Base and target years: Targets must cover a minimum of 5 years and a maximum of 10 years from the date the target is submitted to the SBTi for validation. The choice of base year must be no earlier than 2015.
- C14 - Progress to date: The minimum forward-looking ambition of targets is consistent with reaching net-zero by 2050, assuming a linear absolute reduction, linear intensity reduction, or intensity convergence between the most recent year and 2050 (not increasing absolute emissions or intensity).

- R5 - Long-term target year: Targets that cover more than 10 years from the date of submission are considered long-term targets. Companies are encouraged to develop such long-term targets up to 2050 in addition to near-term targets required by C13 (see Net-Zero C17). At a minimum, long-term targets must be consistent with the level of decarbonization required to keep global temperature increase to 1.5°C compared to pre-industrial temperatures to be validated and recognized by the SBTi.
- R6 - Consistency: It is recommended that companies use the same base years for all near- term targets.

5. Ambition

Scope 1 and 2 near-term targets

- C15 - Level of ambition for scope 1 and 2 targets: At a minimum, scope 1 and scope 2 targets must be consistent with the level of decarbonization required to keep global temperature increase to 1.5°C compared to pre-industrial temperatures.
- C16 - Absolute targets: Absolute reductions must be at least as ambitious as the minimum of the approved range of emissions scenarios consistent with the 1.5°C goal.
- C17 - Intensity targets: Intensity targets for scope 1 and scope 2 emissions are only eligible when they are modelled using an approved 1.5°C sector pathway applicable to companies' business activities.
- R7 - Choosing an approach: The SBTi recommends using the most ambitious decarbonization scenarios that lead to the earliest reductions and the least cumulative emissions.

Scope 3 near-term targets

- C18 - Level of ambition for scope 3 emissions reductions targets: At a minimum, near-term scope 3 targets (covering the entire value chain or individual scope 3 activity categories) must be aligned with methods consistent with the level of decarbonization required to keep global temperature increase well-below 2°C compared to pre-industrial temperatures.
- C19 - Supplier or customer engagement targets: Near-term targets to drive the adoption of science-based emission reduction targets by their suppliers and/or customers are in conformance with SBTi criteria when the following conditions are met:
    - Boundary: Companies may set engagement targets around relevant and credible upstream or downstream categories.
    - Formulation: Companies shall provide information in the target language on what percentage of emissions from relevant upstream and/or downstream categories is covered by the engagement target or, if that information is not available, what percentage of annual procurement spend is covered by the target.
    - Timeframe: Companies' engagement targets must be fulfilled within a maximum of 5 years from the date the RC's target is submitted to the SBTi for an official validation.
    - Level of ambition: The RC's suppliers/customers shall have science-based emission reduction targets in line with SBTi resources.
- R8 - Supplier engagement: Companies should recommend that their suppliers use the SBTi guidance and tools available to set science-based targets. SBTi validation of supplier science-based targets is recommended but not required. It is recommended that suppliers classified as small- and medium-sized enterprises (SMEs), submit targets through the SME streamlined route.

Combined targets

- C20 - Combined scope targets: Targets that combine scopes (e.g., 1+2 or 1+2+3) are permitted. When submitting combined targets, the scope 1+2 portion must be in line with at least a 1.5°C scenario and the scope 3 portion of the target must be in line with at least a well- below 2°C scenario. For sectors where minimum target ambition is further specified for companies' scope 3 activities, C24 supersedes C20.

Renewable electricity targets

- C21 - Renewable electricity: Targets to actively source renewable electricity at a rate that is consistent with 1.5°C scenarios are an acceptable alternative to scope 2 emission reduction targets. The SBTi has identified 80% renewable electricity procurement by 2025 and 100% by 2030 as thresholds (portion of renewable electricity over total electricity use) for this approach in line with the recommendations of RE100. Companies that already source electricity at or above these thresholds shall maintain or increase their use of renewable electricity to qualify.

- R9 - Purchased heat and steam: For science-based target modelling purposes using the SDA, it is recommended that companies model purchased heat and steam related emissions as if they were part of their direct (i.e., scope 1) emissions.
- R10 - Efficiency considerations for target modelling: If companies are using a method that does not already embed efficiency gains for the specific sector, market, and the decarbonization projected for the power sector based on 1.5°C scenario, it is recommended that these factors be taken into account when modelling electricity-related scope 2 targets.

Fossil fuel sales, distribution, and other business

- C22 - Fossil fuel sales or distribution: All companies involved in the sale or distribution of natural gas and/or other fossil fuels products shall set near-term and long-term scope 3 targets that are at a minimum consistent with the level of decarbonization required to keep global temperature increase to 1.5°C, irrespective of the share of these emissions compared to the total scope 1, 2, and 3 emissions of the RC. Customer engagement targets as described in C19 are not eligible for this criterion. More guidance is detailed in C23 on the 50% revenue threshold for companies with fossil fuel activities.
- C23 - Companies in the fossil fuel production business or with significant revenue from fossil fuel business lines: Companies involved in exploration, extraction, mining and/or production of oil, natural gas, coal as well as other fossil fuels cannot get their targets validated at this stage, irrespective of percentage revenue generated by these activities. Companies that derive 50% or more of their revenue from fossil fuels cannot have their targets validated at this time and must follow the respective sector methodology once published.

6. Sector specific guidance

- C24 - Requirements from sector-specific guidance: Companies must follow requirements for target setting and minimum ambition levels as indicated in relevant sector-specific methods and guidance at the latest, 6 months after the sector guidance publication. A list of the sector- specific guidance and requirements is available below, in the Target Validation Protocol, and the Corporate Manual.

7. Reporting and recalculation

- C25 - Frequency: The RC shall publicly report its company-wide GHG emissions inventory and progress against published targets on an annual basis.
- C26 - Mandatory target recalculation: To ensure consistency with the most recent climate science and best practices, targets must be reviewed, and if necessary, recalculated and revalidated, at a minimum every 5 years. For companies with targets approved in 2020 or earlier, the latest year targets must be revalidated is 2025. Companies with an approved target that requires recalculation must follow the most recent applicable criteria at the time of resubmission.
- C27 - Target validity: Companies with approved targets must announce their target publicly on the SBTi website within 6 months of the approval date. Targets unannounced after 6 months must go through the approval process again unless a different publication time frame has been agreed in writing with the SBTi.
- R11 - Where to disclose: There are no specific requirements regarding where the inventory and progress against published targets should be disclosed, as long as it is publicly available. The SBTi recommends disclosure through standardized, comparable data platforms such as CDP's climate change annual questionnaire, though annual reports, sustainability reports and the RC's website are acceptable.
- R12 - Triggered target recalculation: Targets should be recalculated, as needed, to reflect significant changes that could compromise relevance and consistency of the existing target. The following changes should trigger a target recalculation:
  - Scope 3 emissions become 40% or more of aggregated scope 1, 2, and 3 emissions.
  - Emissions of exclusions in the inventory or target boundary change significantly.
  - Significant changes in company structure and activities (e.g., acquisitions, divestitures, mergers, insourcing or outsourcing, shifts in goods or service offerings)

  - Significant adjustments to the base year inventory or changes in data to set targets such as growth projections (e.g., discovery of significant errors or a number of cumulative errors that are collectively significant).
  - Other significant changes to projections/assumptions used in setting the science-based targets.
- R13 - Validity of target projections: The SBTi recommends that companies check the validity of target-related projections on an annual basis. The RC should notify the SBTi of any significant changes and report these major changes publicly, as relevant.

8. Sector-specific requirements

- Sector-specific guidance and methods are currently available for many sectors. All new, sector-specific guidance that becomes available will be uploaded to the sector development page on the SBTi website. The SBTi has sector-specific requirements related to the use of target-setting methodologies and minimum ambition levels.

For the most up-to-date information on sector developments, please refer to the Sector Development page of the SBTi website.