Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 116 (2023) 552–557

www.elsevier.com/locate/procedia

30th CIRP Life Cycle Engineering Conference

VCA, a method for mapping and neutralizing the environmental impact of a company's value chain

M.R. van Moort[a,b], M.E. Toxopeus[a]*, & S. Jokic[a]

[a]*University of Twente, Faculty of Engineering Technology, P.O. Box 217, 7500AE, Enschede, The Netherlands*
[b]*Sunrock Investments B.V., Anthony Fokkerweg 1, 1059CM, Amsterdam, The Netherlands*

* Corresponding author. Tel.: +31-53-4894516. *E-mail address:* m.e.toxopeus@utwente.nl.

Abstract

Companies need to reduce the greenhouse gas (GHG) emissions and waste from their value chains in order to minimize the climate change and resource depletion that are caused by their business operations. However, it is difficult for companies to assess their current state and to plan and keep track of improvements. This paper will discuss how life cycle assessment (LCA) can be used to develop a value chain assessment (VCA) method that supports companies with their ambition to assess and neutralize the environmental impacts of their value chains. The 6-step VCA method was developed and evaluated through a case study regarding the realization of large-scale solar parks. The method incorporates the guidelines and reporting requirements of the GHG Protocol standard for accounting and reporting emissions and the ISO standards for LCAs. Similar to LCAs, the developed VCA method is highly dependent on the level of detail and quality of gathered data, but also on the competency of the assessor. The VCA method does however provide suggestions for considering data gaps and inaccuracies. The method already presents a simplified and organized way of structuring, estimating, analyzing, reporting, and reducing a value chain's emissions and waste. The performed case study proved that the method could improve through more detailed evaluation and application in more case studies.

© 2023 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the 30th CIRP Life Cycle Engineering Conference

Keywords:; Impact assessment; Value chain; GHG emissions; Waste generation; Emission scopes, Environment, Climate change, Resource depletion, LCA

1. Introduction

In order to contribute to a sustainable future, companies should reduce the amount of greenhouse gas (GHG) emissions and material waste generated through their activities. The GHG Protocol makes the distinction between scope 1, 2, and 3 emissions [1]. Scope 1 treats a company's direct emissions from its owned or controlled sources; scope 2 treats indirect emissions from generating a company's purchased electricity, steam, heating, and cooling; and scope 3 treats all other indirect emissions that occur in a company's value chain. In practice, it seems difficult for an organization to map scope 3 emissions, because the data required for mapping them comes from partner organizations, which often do not have this data or have trouble sharing it due to confidentiality [2]. Factors such as transaction costs, power, responsibility allocation, uncertainty, location contingency, and production costs impact the chance of a company's compliance to the scope 3 standard of the GHG Protocol [3–5]. Not enough working guidelines exist for scope 3 mapping [6]. Methods based on emission factors are frequently used, but they often result in wide discrepancies [7]. Companies face practical and methodological difficulties in the concrete implementation of methods, such as the wide diversity of methods and the number of products, intermediates, and suppliers for which data has to be collected [2].

Meanwhile, scope 3 becomes increasingly important, as the share of the world's scope 3 emissions increases [8]. An initial literature research on this topic showed that there seems to be no standardized and structured way of mapping and neutralizing the environmental impact (EI) of a company's

2212-8271 © 2023 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the 30th CIRP Life Cycle Engineering Conference
10.1016/j.procir.2023.02.093

value chain. This study's primary goal was therefore to find out how companies can be supported in structuring, estimating, analyzing, reporting, and reducing their EI regarding the generation of emissions and waste. A method for value chain assessment has been developed for this purpose. This method is explained and illustrated with an industry case study.

The industry case study was executed in collaboration with Sunrock, a developer and owner of large-scale photovoltaic (PV) installations in the Netherlands [9]. To maximize its positive impact, the company tries to limit its direct emissions and waste generation in its business operations. The company dedicated itself to eventually become net-zero in its emissions. Through Sunrock, the generation of solar energy goes paired with emissions and waste generation. Therefore, the case study did not only serve as an evaluation of the developed method, but it also provided useful insights for Sunrock.

2. Theoretical framework

2.1. The concept of LCA

Aside from their inaccuracy, emission factor based methods are widely applied because of their simplicity. Another method that is increasingly used is the method of life cycle assessment (LCA) [10]. During an LCA, the EI of processes is analyzed by counting the process' inputs, often energy and materials, and outputs, often products, emissions, and waste. Results between emission factor based methods and LCAs seem quite consistent in relative terms [11]. However, the total magnitude of the EI differs significantly between the two concepts. Also, the emission factor based methods only focus on a single impact category, which can lead to burden shifting [11]. LCAs have been proven to be of use in GHG reporting [12]. Results of an LCA are deemed accurate when the method is executed properly by following renowned standards, such as the ISO's 14040 and 14044 standards [13,14]. The accuracy and completeness of LCA provide a basis for assessing the EI of something as complex as a value chain. The concept of LCA will help to identify, distinguish, and analyze all the different processes in a value chain. Preparing for an LCA will also help in structuring the data required for an EI assessment.

A significant challenge in conducting LCAs is obtaining appropriate inventory data [15]. Using LCA for business operations is more difficult than for products due to more inventory data, more complex activities, and data and organizational change [2]. Another problem is that in literature on conducted LCA's, the methods are not always described in detail. Corporate organizations do not share their best practices due to confidentiality and a lack of open innovation. The scientific community publishes relevant articles that are accessible to organizations that wish to reduce their EI. However, there are many scientific papers on the use of LCAs in which LCA results are presented without an elaborate method description [11,16–20]. This makes it difficult for others to follow the steps taken and put the results into perspective. The concept of LCA can therefore be of use in a method for value chain assessment, but the steps of such a method's process must be described clearly to ensure that the method can be adopted by any type of organization.

2.2. Data requirements

Large quantities of data are required to be collected and processed in an EI assessment. In the developed method, data refers to information that supports the mapping of value chain processes and their EI. Data regarding energy and material flows are prioritized since the method's goal is to eliminate emissions and waste. Data is most likely not available for every process in a company's value chain. Therefore, only significant processes must be included in the study. Proper system boundaries are necessary to avoid wasting time on acquiring data that has no impact on the eventual results [13]. Collected data must meet the data requirements of the 14040 and 14044 LCA standards of the ISO [13,14] and the minimal scope 3 boundaries of the GHG Protocol standard [3,5].

Collected data should be allocated to a stated functional unit (FU). This provides a fair basis for comparison as it eliminates influences of a fluctuating yearly output when comparing results between different years of operation [13,14]. A value chain requires resources to operate and generate FUs. It must be determined which and how many resources are required to fulfill one FU. Allocation is required if data is not provided for the required quantities per FU. Provided quantities must then be up- or downscaled to match the required quantities per FU.

When performing an LCA, data quality requirements should be stated to address specific topics that from the ISO standards for LCAs [13,14]. Data can be acquired from value chain partners. If not, a reliable database can be consulted, such as EcoInvent [21]. As a last resort, substantiated assumptions can be made to compensate for the missing data. To put the eventual results of the study into perspective, it is expected that the sources, assumptions, and calculation methods, but also the problems with data quality, reasons for data exclusions, and implications of assumptions are clearly stated for inventory data that is required according to the defined system boundaries. These documentations should be accompanied by justifications for why and how decisions are made in the data collection process. This is also essential for future reference or external use of the data.

3. A value chain assessment method

The designed value chain LCA method, or value chain assessment (VCA) method, integrates the concept of organizational LCA. An organizational LCA uses a life cycle perspective to assess the EI of an organization's facilities and upstream and downstream activities [22,23]. The VCA method consists of six steps, which are described in Figure 1 on the next page. When a company applies the VCA method, it becomes a reporting company (RC) and is advised to report the results of the VCA method every year. When the results are reported to an external organization, the RC must ensure that the right reporting requirements are met. It could be that additional reporting requirements, besides those of the VCA method, are necessary. The first time the VCA method is applied, the RC calculates its base year EI. The results of every following year can be compared to the results of the base year to evaluate the RC's progress. The VCA method integrates the 14040 and 14044 LCA standards of the ISO [13,14] with the accounting and reporting (A&R) standard for scope 3 of the GHG Protocol [3,5]. The method provides a roadmap for companies that want to gain insights in the 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. When the RC executes the VCA method thoroughly, its results can be used for internal and external purposes. This section continues by describing the six steps of the VCA method alongside a running example regarding an RC that manufactures and sells steel. Figure 2 visualizes the work that is done in each step.

3.1. Step 1: Performing a VCI analysis

The VCA method starts by performing a value chain inventory (VCI) analysis, that combines the value chain analysis as mentioned by the GHG Protocol [3,5] with the LCA's inventory analysis as mentioned by the ISO standards for LCAs [13,14]. Through this VCI analysis, the inputs and outputs of activities within the RC's value chain will be mapped. In this case, the RC is Green Steel, a manufacturer and seller of steel. To acquire a complete overview of the emission and waste streams of Green Steel's value chain, both energy and material flows should be tracked.

To identify and understand the relevant activities in the value chain of Green Steel, the actors present within the value chain must first be grouped and mapped. Actors are grouped regarding the activities they perform. An actor group performs one activity and contains one or more organizations that perform this same activity for Green Steel. The groups are graphically mapped in a presentable overview as a VCI map (Figure 2.1a), representing what is being done in Green Steel's value chain and by who. The VCI map should show all actor groups that are present in Green Steel's value chain as blocks. Green Steel's own facilities determine what happens in the value chain. Therefore, each facility is also depicted as a block. Scope 1 emissions originate directly from these facilities, scope 2 and 3 emissions indirectly. The blocks in the VCI map are connected with arrows and descriptions that indicate the upstream, downstream, and other types of interactions that take place among and between actors and Green Steel's facilities. Identified activities use energy and material inputs, resulting in emission and waste outputs. Each activity that is performed by an actor group should be assigned to one of the 15 scope 3 activity categories of the GHG Protocol [3,5]. Color-coding should be used for the categories present in the VCI map. Each identified actor group possesses data regarding the activity it performs. This data can therefore be assigned to the scope 3 activity categories. The data might be of interest to Green Steel, but is scattered and unorganized (Figure 2.1b). To register all Green Steel's value chain partners that possess possibly relevant data, a list should be composed of all the companies that belong to the identified actor groups.

The next task is to set the boundaries for the collection of data. First, the FU that will be applied during the data collection and rules for allocation must be determined. This FU should be relatable to the business operations of Green Steel in a sense that a multitude of the stated FU is fulfilled in a year. The FU for Green Steel is: "To manufacture and sell 1 ton of steel". For each of the identified actor groups it must be determined whether their performed activity will be included in the VCI. An estimation should therefore be made regarding the total material mass and energy each activity requires to fulfil one FU [14]. Contribution percentages (CPs) can then be determined for mass and energy. An activity is included in the VCI if it contributes significantly to either the total mass or the total energy of all activities. A contribution to mass or energy is deemed significant if the corresponding CP exceeds the limits stated by the ISO 14044 standard [14]. The magnitude of the CPs also determines the level of detail to which an activity's data should be collected. If an activity does not contribute significantly to either effect, it can still be included if Green Steel substantiates that it has a significant EI. Activities that have too low CPs and no expected significant EI can be excluded from the VCI, leaving only the relevant data points (Figure 2.1c).

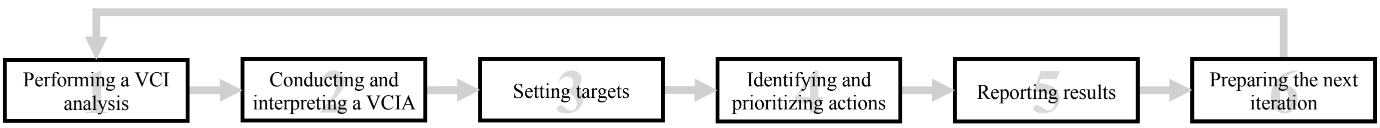

Figure 1. Schematic overview of the six steps of the VCA method.

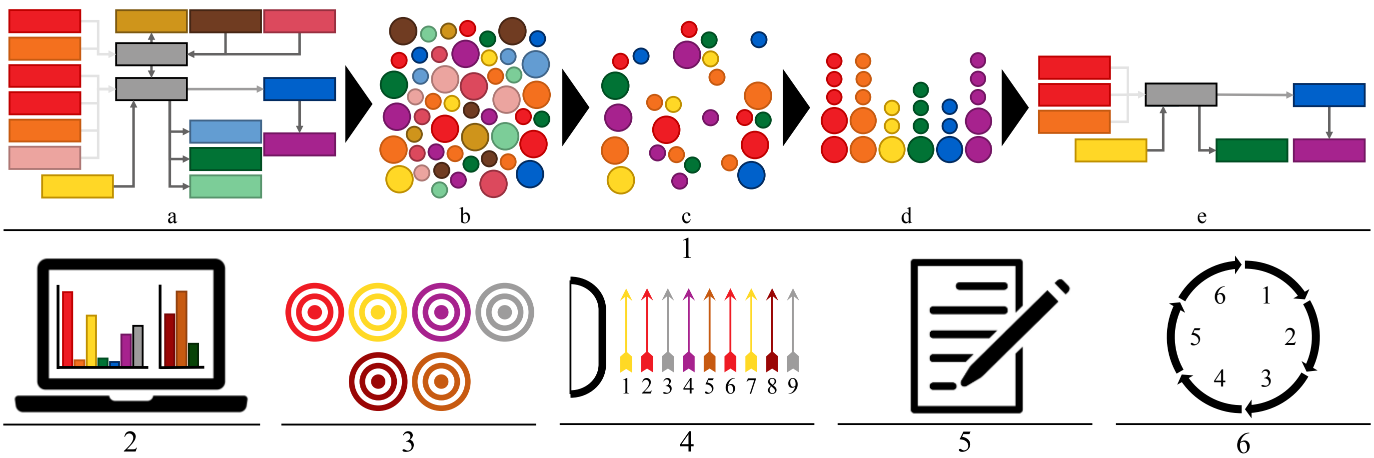

Figure 2. Visualization of the work that is done in each of the six steps of the VCA method. Each color indicates a scope 3 activity category or waste category.

Data must then be collected and organized for the activities that are included in the VCI (Figure 2.1d). The created VCI map can be reduced to only represent the relevant actor groups (Figure 2.1e). Just 7 out of the 15 actor groups were deemed significant for Green Steel's total EI. The reduced VCI map for Green Steel is presented in Figure 3, which shows that only the interactions regarding Green Steel's manufacturing facility were deemed to have a significant impact. The collected data is essential for mapping the input and output flows for activities performed by the relevant actor groups from the reduced VCI map. The first time Green Steel performs the VCA method, data is only gathered for a baseline dataset. For each relevant actor group, this dataset should contain average data or data from a selected actor within that group representing the entire actor group. This way, the outputs resulting from the baseline dataset represent an average of emission and waste streams that flow in the value chain for the fulfillment of one FU. Over time, the final step of the VCA method assures that the data quality is improved, and that the baseline dataset is supplemented with additional data so that it becomes more complete. Based on the initial results from the baseline dataset, future data collection can be prioritized so that a higher level of detail is reached for the most significantly contributing actor groups, assuring a continuous improvement process. Data that should be included in the baseline dataset must be specified before it is collected.

3.2. Step 2: Conducting and interpreting a VCIA

After the VCI has been mapped, the collected data should be assessed in a value chain impact assessment (VCIA) to identify and quantify the EI caused by the VCI. This is similar to profiling in an LCA. The results from the VCIA indicate how actor groups contribute to the EI of Green Steel's value chain. To perform a VCIA, the activities of Green Steel's value chain should first be modelled as processes in LCA simulation software, like GaBi [24]. The LCA model configuration should be based on the created VCI map. However, some components of the VCI map could be presented differently in the LCA model configuration. In the VCI map, transportation processes are shown as arrows, while they are often shown as process blocks in an LCA model configuration. This is because transportation processes are separate processes that are assigned to separate scope 3 activity categories. Note that the categorization of the GHG Protocol states that transportation of operational waste is assigned to the waste generated in operations category [3]. Transportation of end-of-life waste is not required to be included according to the minimal scope 3 boundaries of the GHG Protocol [3].

The next task in quantifying the EI is to determine the inputs and outputs of the processes from Green Steel's LCA model configuration. During the VCIA, the impact assessment method of the IPCC [25] called "IPCC AR6" will be used to present the results regarding the value chain's global warming potential. Discovered emission hotspots offer opportunities to reduce emissions, be more efficient, and save money. Categorization of the inputs and outputs makes it possible to also track the waste that is generated in the value chain. During this categorization, a distinction should be made between "direct waste", which is generated through the strategy of Green Steel and can therefore be eliminated through direct intervention, and "indirect waste", which is generated through the strategies of partner companies and can only be eliminated by strategy adjustments of these companies. As a third waste category, recycled waste can be categorized as "recovered waste". A custom results profile can be made to get insights in the emissions and waste generated in Green Steel's simulated value chain. The processes that are specified in the LCA software should be grouped regarding actor groups, scopes, scope 3 activity categories, and timing to see where and when emissions and waste are generated in the value chain. In the results profile, it can be seen that three scope 3 activity categories and Green Steel's facility (scope 1) had the most significant impact on emissions, while most waste was generated indirectly (Figure 2.2). Green Steel's custom results profile can also be used to document the following results:

- 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, indirect, and recovered waste separately.

The results for one FU can be used to track the efficiency development of Green Steel's value chain processes. However, in order to report Green Steel's yearly generated emissions and waste, the baseline results for the fulfilment of one FU must be upscaled to represent the amount of FUs that were fulfilled in the reporting year. Scaling factors can be used in the LCA simulation software to upscale the results of the created model so that it generates the results of the reporting year. A scaling factor of 10.000 can be used if Green Steel manufactured and sold 10.000 tons of steel. The results of the analysis should be interpreted and evaluated on completeness, accuracy, and sensitivity, before conclusions can be drawn [13,14].

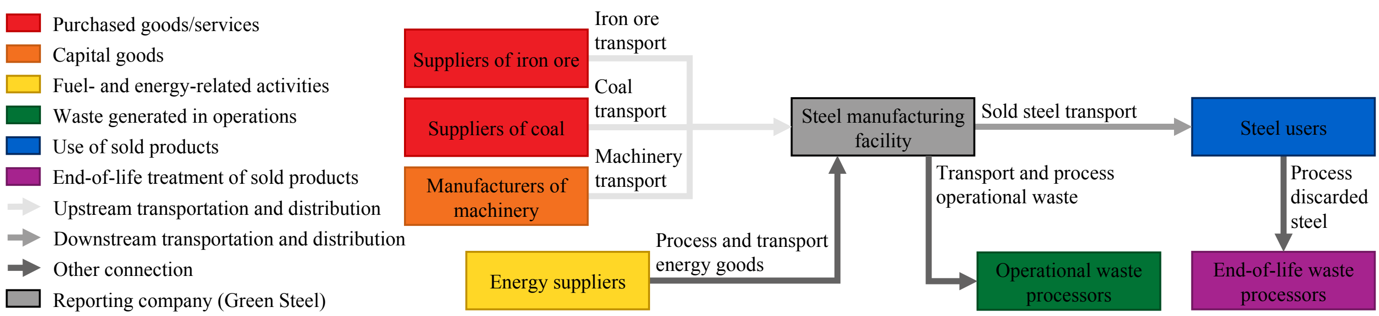

Figure 3. Example of a reduced VCI map for manufacturing steel. The legend indicates the scope 3 activity category and type of interaction for each actor group.

3.3. Step 3: Setting targets

Based on the evaluation of the VCIA results, attainable and trackable targets can be set for impact reduction (Figure 2.3). A distinction should be made between emission and waste targets. Green Steel should decide on how many targets must be set and for which categories. Emission targets can be set for all scopes together, individual scopes, or individual scope 3 activity categories. Waste targets can be set for all accumulated waste, or separately for direct and indirect waste. Emission and waste targets can be set regarding Green Steel's absolute impact, but also regarding the change in magnitude of either the company's financial performance or operational activities [26]. Green Steel set 6 targets, 4 for emissions and 2 for waste.

3.4. Step 4: Identifying and prioritizing actions

Support must be provided for companies to adjust their policies and achieve the set targets. Therefore, actions need to be identified. These are corrective measures for decreasing Green Steel's EI. The value chain model can be analyzed to find the origins of EI. Additional categorization in the model can provide more detail in this analysis. To neutralize the EI, actions should be specified by combining the business policies of Green Steel with the set targets and the results of the VCIA. Targets should be addressed efficiently by first performing the most impactful actions. Actions should be prioritized based on estimations of action aspects such as impact, projected costs, required time, company influence, and social implications. Green Steel identified and prioritized 9 actions, each aiming at a specific target (Figure 2.4). After prioritization, a roadmap can be made based on Green Steel's budget and available time.

3.5. Step 5: Reporting results

Every time Green Steel completes the first four steps of the VCA method, it should document the results such that an independent reader can follow through all the executed steps (Figure 2.5). A progress log should also be updated. This log should contain the estimated base year EI, the history and progress of the set targets, and the history of identified and executed actions. The progress log can therefore be referred to for checking Green Steel's progress regarding its EI reduction.

3.6. Step 6: Preparing the next iteration

After reporting the results, Green Steel can decide to iterate the VCA method to improve and update the study's results (Figure 2.6). To prepare an iteration, each report should conclude with a description of the value and requirements of this next iteration. Directly after completing the VCA method, thoughts about the next iteration can be useful for future reference, even more so when the next iteration could be executed by someone else. A recalculation policy should also be stated to define when Green Steel is required recalculate the base year EI. A report must be created for every iteration. To properly monitor Green Steel's progress, it is recommended that the VCA method is iterated every year or when the most recent results are believed to be significantly inaccurate.

4. Results

To evaluate the applicability of the VCA method, it has been applied in an industry case study in collaboration with Sunrock. Working with many partners, the scope 3 related emission and waste flows of Sunrock are significant. The VCA method enabled the company to report on its emissions and waste. Due to confidentiality, the absolute results of the application cannot be shared. However, the implications of the application, such as the encountered problems and required adjustments, will be discussed per step,

During the first step, the following FU was stated: "To realize and maintain a PV-system of 1 MWp for 25 years". The system boundaries eventually stated that only 14 out of the 32 identified actor groups were deemed to contribute significantly to Sunrock's EI. The composition of the baseline dataset was determined accordingly, and data was collected to compose the VCI. Some of the data came from Sunrock's own database. However, a significant portion of the data could not be provided by the relevant actor groups, as communication with partners and exchange of data were a challenge. Much of the used data therefore originated from the EcoInvent database [21]. In addition, numerous assumptions were required for dealing with data gaps or using acquired data appropriately. Unfortunately, the levels of detail that were stated for the collected data were not reached for all actor groups.

In the second step, a GaBi model of the value chain was used to determine the emissions and waste generated for the fulfilment of one FU. As Sunrock realized a multitude of FUs in its base year, these results were upscaled by using scaling factors. Over 95% of the total EI was caused by just one of the 14 relevant actor groups. Hence, the system boundaries could have been set more strictly through increased CP limits. As the contributions of the actor groups did not all increase linearly with the number of FUs fulfilled, different scaling factors were applied to the results of different actor groups.

In order to facilitate the analysis that was required for setting accurate targets in the third step, the model's processes were grouped in multiple additional categories. The prioritization of actions during the fourth step could have been more accurate if the action aspect estimations were more precise. In turn, this would have improved the feasibility of the generated roadmap.

During the fifth and sixth step, the results and the plans for the next iteration were documented as stated in the method description. Sunrock is still validating its base year results, after which the company plans on publishing an official report.

5. Discussion

5.1. Evaluation

The VCA method's application in an industry case study showed that the method offers a relatively simple roadmap for companies to become more sustainable regarding their energy and material use. The VCA method provides a simple and structured way for a quick estimation of a value chain's generated emissions and waste, and it improves this estimate over time. The method can also be used partially when a company just requires some insights into the impact of its value chain. A company can however only apply the method if it has sufficient in-house experience with LCAs and suitable software that can be used to conduct them. The RC must also be able to accurately gather data, make calculations, and present results properly. Prior knowledge regarding the mentioned standards of the ISO and GHG Protocol would also be convenient.

The VCA method adds value since it presents a generic roadmap that combines the ISO's LCA standards [13,14] with the GHG Protocol's A&R standard [3,5]. However, the limitations of these standards are therefore directly transferable to the VCA method. The accessibility, availability, and quality of relevant data will have a significant impact on the results of the VCA method. An RC should acknowledge these uncertainties and put the results of the VCA method in perspective accordingly.

5.2. Recommendations

Where relevant, the VCA method could be further enhanced by integrating the mentioned standards of the ISO and the GHG Protocol with more detail. The VCA method can also be improved by performing more case studies. The case study at Sunrock revealed issues regarding data collection, upscaling, grouping, and prioritization. Although these issues have been addressed in the current set-up of the method, additional case studies could provide new inputs for improving certain parts of the method. How an RC sets targets and identifies and prioritizes actions depends on the RC's capabilities and priorities. Thus, different case studies might help to develop a more detailed generic way for executing these steps. Insights from additional studies can also help in cases where the required levels of detail are not reached during data collection.

An open innovation environment for sharing insights from different sectors is recommended to make the method universally applicable. The developed VCA method is intended to motivate the initiation of collaboration in the transition towards a more sustainable future.

6. Conclusions

Business operations often go paired with the emission of GHGs and the generation of waste. Companies wish to make the transition to a more sustainable business model. The VCA method was developed for companies to map and eventually neutralize their EI. This method combines renowned standards to map and neutralize the EIs of their value chains. It also supports companies in decision making regarding data collection and processing. The application of the VCA method in a case study showed the practical outcomes it can have.

However, the results of the VCA method are dependent on the quality of the gathered data and the competency and effort of the researcher. As a next step, the method could further improve through more detailed evaluation and application in more case studies. This way, the VCA method might even become a new standard that makes the transition towards sustainability appealing and accessible to all organizations.

Acknowledgements

We would like to thank Sunrock Investments B.V. for allowing us to assess the company's situation for the industry case study that was required for this study.

References

[1] Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard, Revised Edition. 2004.
[2] Schmidt M, Nill M, Scholz J. Determining the Scope 3 Emissions of Companies. Chem Eng Technol 2022;45:1218–30.
[3] Greenhouse Gas Protocol. Corporate Value Chain (Scope 3) Accounting and Reporting Standard (Supplement to the GHG Protocol Corporate Accounting and Reporting Standard). 2011.
[4] Patchell J. Can the implications of the GHG Protocol's scope 3 standard be realized? J Clean Prod 2018;185:941–58.
[5] Greenhouse Gas Protocol. Technical Guidance for Calculating Scope 3 Emissions (Supplement to the Corporate Value Chain (Scope 3) Accounting & Reporting Standard). 2013.
[6] Huang YA, Weber CL, Matthews HS. Categorization of scope 3 emissions for streamlined enterprise carbon footprinting 2009.
[7] Downie J, Stubbs W. Corporate carbon strategies and greenhouse gas emission assessments: the implications of scope 3 emission factor selection. Bus Strateg Environ 2012;21:412–22.
[8] Hertwich EG, Wood R. The growing importance of scope 3 greenhouse gas emissions from industry. Environ Res Lett 2018;13:104013.
[9] Sunrock Investments B.V. Official website Sunrock 2023. https://www.sunrock.com/en/about-us (accessed January 14, 2023).
[10] Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, et al. Recent developments in life cycle assessment. J Environ Manage 2009;91:1–21.
[11] Pattara C, Raggi A, Cichelli A. Life cycle assessment and carbon footprint in the wine supply-chain. Environ Manage 2012;49:1247–58.
[12] Chau CK, Leung TM, Ng WY. A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings. Appl Energy 2015;143:395–413.
[13] ISO. International Standard 14040: Environmental management — Life cycle assessment — Principles and framework, 2nd edition. 2006.
[14] ISO. International Standard 14044: Environmental management — Life cycle assessment — Requirements and guidelines, 1st edition. 2006.
[15] Matthews HS, Hendrickson CT, Matthews DH. Life Cycle Assessment: Quantitative Approaches for Decisions That Matter 2015:82.
[16] De Wild-Scholten MJ. Energy payback time and carbon footprint of commercial photovoltaic systems. Sol Energy Mater Sol Cells 2013;119:296–305.
[17] Kim K, Kim I. The Significance of Scope 3 GHG Emissions in Construction Projects in Korea: Using EIA and LCA. Climate 2021;9:33.
[18] Klaversma E, Van der Helm AWC, Kappelhof J. The use of life cycle assessment for evaluating the sustainability of the Amsterdam water cycle. J Water Clim Chang 2013;4:103–9.
[19] Nijdam D, Rood T, Westhoek H. The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 2012;37:760–70.
[20] Sangwan KS, Bhakar V, Arora V, Solanki P. Measuring carbon footprint of an Indian university using life cycle assessment. Procedia CIRP 2018;69:475–80.
[21] EcoInvent. Official website EcoInvent 2023. https://www.ecoinvent.org/the-ecoinvent-database (accessed January 14, 2023).
[22] Martínez-Blanco J, Inaba A, Quiros A, Valdivia S, Milà-i-Canals L, Finkbeiner M. Organizational LCA: the new member of the LCA family—introducing the UNEP/SETAC Life Cycle Initiative guidance document. Int J Life Cycle Assess 2015;20:1045–7.
[23] Martínez-Blanco J, Finkbeiner M, Inaba A. Guidance On Organizational Life Cycle Assessment. 2015.
[24] Sphera. Official website Sphera 2023. https://www.sphera.com/life-cycle-assessment-lca-software (accessed January 14, 2023).
[25] IPCC. AR6 climate change 2021: The Physical Science Basis. Cambridge Univ Press 2021.
[26] SBTi. Science-Based Target Setting Manual. 2020.