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Puschmann, Thomas ; Quattrocchi, Dario

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DOI: https://doi.org/10.1016/j.jclepro.2023.139575

Originally published at:
Puschmann, Thomas; Quattrocchi, Dario (2023). Decreasing the impact of climate change in value chains by leveraging sustainable finance. Journal of Cleaner Production, 429:139575.
DOI: https://doi.org/10.1016/j.jclepro.2023.139575

Journal of Cleaner Production 429 (2023) 139575

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Decreasing the impact of climate change in value chains by leveraging sustainable finance

Thomas Puschmann [a,*], Dario Quattrocchi [b]

[a] University of Zurich, Swiss FinTech Innovation Lab, Plattenstrasse 32, 8032, Zurich, Switzerland
[b] Im Roggenacher 4, 8306, Bruettisellen, Switzerland

ARTICLE INFO

Handling Editor: Liu Yu

Keywords:
Climate change
Scope 3 greenhouse gas (GHG) emissions
Sustainable finance
Technology

ABSTRACT

Scope 3 greenhouse gas (GHG) emissions are frequently the most relevant element of a company's total emissions since they account for more than eighty percent. However, they are difficult to calculate since many stakeholders in the value chain are involved and emission data are usually not shared among them. Sustainable finance could provide a link to this discussion by providing data, digital data infrastructures and evaluation instruments. However, the existing research today is either limited to analyzing the levels of scope 3 emissions or to calculating them based on different measurement methods. How to implement scope 3 emissions reporting by solving the data sharing challenge remains mainly unexplored. This paper aims to close this gap by developing an approach, which chooses sustainable finance as a connecting element that (1) combines different calculation methods, (2) integrates cross-value chain data from different stakeholders and (3) combines primary and secondary data in a single model. The approach was developed in a prototype that uses real world data from collaboration with the UN-convened Net-Zero Asset Owner Alliance to evaluate its applicability. The findings of the prototype indicate that a digital data infrastructure can improve the calculation of scope 3 GHG emissions by improving data availability, accessibility and reliability and at the same time shows that the calculations are only as good as the data, which fuels this calculation. With this, the paper contributes to the theoretical and practical discussion about scope 3 GHG emission data.

1. Introduction

Climate change is one of the United Nations' (UN) seventeen Sustainable Development Goals (SDGs) which comprehensively describe all economic, social, and environmental challenges for the forthcoming decades. The financial system plays an important role in addressing climate change by providing and evaluating environmentally relevant data which must be disclosed in many countries by companies in value chains across different industries. As the financial sector is a data driven industry, it is said to be a key player in addressing climate change across all industries. For example, climate change is predicted to have an investment gap of an estimated US $5-$7 trillion annually (Vorisek and Yu, 2020), which the financial system could allocate by redirecting assets to sustainable businesses. However, it is estimated that only 5%–25% of all assets globally are invested sustainably today (Eccles and Klimenko, 2019) and most services and products in the financial system are still not aligned with the climate goals. For example, a recent analysis shows that environmental, social and governance (ESG) principles of sustainability are not yet properly integrated into corporate sustainable evaluation (Escrig-Olmedo et al., 2019). Only about 20% do so to some extent and only a few report on climate change risks and opportunities (Schoenmaker and Schramade, 2019) and, in addition, only a few companies' ESG ratings rely more on managers' beliefs than on real data (Clementino and Perkins, 2020). Therefore, the major obstacle to considering sustainability factors in finance is data availability, accessibility, and reliability (Sullivan, 2009; BSR, 2016) which ultimately leads to low transparency which value chains and industries are "green" and which are not.

The reduction of greenhouse gas (GHG) emissions has been discussed in literature in addressing climate change in value chains since many years (e.g. Huang et al., 2009; Hertwich and Wood, 2018). GHGs include carbon, methane, etc. and are typically split up into scope 1, 2 and 3 emissions (WRI and WBCSD, 2015). While scope 1 emissions cover are all direct emissions from an organization (e.g., manufacturing emissions), scope 2 emissions include all indirect emissions like electricity, heat, etc. Scope 3 emissions are all indirect emissions from goods and

* Corresponding author.
E-mail address: thomas.puschmann@uzh.ch (T. Puschmann).

https://doi.org/10.1016/j.jclepro.2023.139575
Received 2 November 2022; Received in revised form 26 September 2023; Accepted 30 October 2023
Available online 6 November 2023

services purchased from suppliers and customers upstream and downstream of a certain value chain, which are required to produce/provide and distribute a certain product or service (Scott et al., 2018). They represent an average of 84% of a company's total GHG emission footprint (Matthews et al., 2008) and thus make up the largest part. However, scope 3 emissions are very hard to calculate since most of them occur outside of a firm's boundaries and require intense data sharing among the stakeholders of a certain value chain since they are part of complex global value chains including all the organizational processes and shipping networks required to manufacture products and bring them from the producer to the final customer (Rolnick et al., 2019).

The fact that these scope 3 GHG emissions are hard to calculate has limited the discussion in literature in the domain of scope 3 GHG emissions to either on how to measure GHG emissions and their reduction targets, which are very often based on secondary data (e.g., Kim and Lyon, 2011; Downie and Stubbs, 2012; Kauffmann et al., 2012; Plambeck, 2012; Wegener et al., 2019; Li et al., 2020; Salzmann et al., 2022; De Stefano and Montes-Sancho, 2023) or on the comparison of different measurement methods, rather than on how scope 3 GHG reporting could be implemented in value chains (e.g. Patchell, 2018; Stenzel and Waichmann, 2023). And the very few research papers in this third category only outline some basic principles for future research rather than concrete concepts for their implementation. But guidelines on how GHG emissions reporting for scope 3 emissions could be implemented in value chains are of major relevance for achieving the reduction targets outlined in the Paris Agreement. Therefore, this paper focuses on the research question: How can scope 3 GHG emissions reporting be implemented by developing an approach which (1) combines the different existing measurement methods, (2) integrates cross-value chain data from different stakeholders and (3) combines primary and secondary data? To achieve this, a Design Science Research Method (DSRM) approach was used which is ideal for developing novel solutions that have a high practical relation (Hevner et al., 2004). The approach, which was developed as a result of this research, is visualized in a prototype. The prototype depicts the emission distributions and their interconnection within the value chain and thus provides financial investors with a better understanding of the environmental performance of its investees and their respective value chain. Based on the prototype's capabilities, further enhancements by financial technologies (fintech) are suggested which may include additional environmental and company data from other data sources. The prototype was developed in collaboration with the UN-convened Net-Zero Asset Owner Alliance and its member companies.

The remainder of this paper is structured in six sections. Section 2 provides an overview on the theoretical background including common goods theory, climate change, GHG data and sustainable finance. Section 3 outlines the research method, while section 4 presents the research results. Section 5 discusses the findings and section 6 summarizes the them.

2. Theoretical background

2.1. Common goods and GHG emissions

A well-known problem in environmental economics is the so-called tragedy of the commons, which refers to a situation within a shared-resource system where individual users act independently, according to their own self-interest behave contrary to the common good of all users by depleting that resource through their collective action. Standard approaches to preserving common goods are applying government instruments, such as taxation or regulation or the vesting of property rights. However, an exclusive regulatory approach toward curbing GHG emissions has been elusive to date (Schoenmaker and Schramade, 2019). Ostrom (1990) looks beyond regulation to govern common resources and offers instead design principles for how these common goods can be governed in terms of sustainability and equitability in a community by creating coalitions in which members spontaneously develop rules to govern the use of common resources, to monitor members' behavior, to apply graduated sanctions for rule violators and to provide accessible means for dispute resolution. Such an approach, however, requires transparency and trust among the involved stakeholders.

According to Thurm et al. (2018), the current sustainability practices of firms fail to take such a coalition approach, because the contributions of individual companies in a value chain are not transparent among the stakeholders and not connected. One of the key connectors is GHG emission data along the value chains, and here especially scope 3 GHG emissions, which contribute the largest part to the overall emissions. Scope 3 emissions were introduced by the GHG Protocol only after scope 1 and scope 2 were released; but due to their complexity, they are often declared as optional (Corporate Standard, 2015). That's why scope 3 GHG emission accounting is not much consistent across companies and may not lend itself well to comparisons between them. In addition, the quality of inventory data is mixed at best and the degree of rigor in the application of these reporting guidelines, however, remains unclear. To the same extent companies are inconsistent in setting reporting boundaries and often do not disclose explicitly what is included or excluded from the scope of their reporting (e.g., how subsidiaries are treated and how geographic subsets of operations are included). But despite its little consideration in practice, for the average company, the environmental impact of its value chain is approximately four times that of its own direct operations (Huang et al., 2009; CDP, n.d.-b). One of the connecting elements might be the use of elements from sustainable finance research which has evolved as a major domain in finance research over the last years.

2.2. Sustainable finance

The intersection of sustainability and finance ("sustainable finance") has gone through different stages of development over the past decades and has evolved as a broader notion of business sustainability (Dyllick and Muff, 2016). The concept that a business activity can simultaneously result in financial, social, and environmental benefits is very much in line with recent developments in sustainability and related concepts such as the circular economy (UN Environment Programme Inquiry, 2019). For this, the focus has been shifting from short-term profit (Friedman, 1970) to long-term value creation (Tirole, 2017). For example, Schoenmaker (2017) distinguishes three phases of development of sustainable finance. Sustainable Finance 1.0 aims at avoiding investing in companies with very negative impacts, such as tobacco or weapons. Sustainable Finance 2.0 incorporates social and environmental considerations in the stakeholder model and firms that are compliant with Sustainable Finance 3.0 consider SDGs in investing and lending decisions (Eyraud et al., 2013). A currently evolving fourth approach considers the SDGs as primary purpose of business models and is at the core of many startups in the field of sustainable digital finance or green fintech (Puschmann et al., 2020). However, this approach is only evolving and in a very early stage of development. For Sustainable Finance 3.0, there are two ways in which financial institutions implement this approach. Either they create "green" financial indices that focus on low-carbon energy, environmental services and/or clean technology (Diaz-Rainey et al., 2017) or they design carbon-neutral investment portfolios that remove under-weight companies with relatively high carbon footprints (Gianfrate, 2018). Another main approach to sustainable finance is climate analytics, which tries to make predictions about the financial effects of climate change (Rolnick et al., 2019). Both approaches are currently being applied by emerging coalitions for sustainable finance, who have only very recently been established and can turn the idea of common goods into action (e.g., investment funds, pension funds and insurance companies). As they manage approx. 65% of all equity holdings, they are the dominant shareholders of companies and can foster sustainable business practices.

However, investors require reliable data on companies and their value chain for decision making. That is the main reason why sustainable finance is still not very well connected to the field of GHG emissions (Khan et al., 2022). Today, only a few companies' sustainability ratings rely on real data (Clementino and Perkins, 2020). This research aims to link both domains through a novel digital data infrastructure which provides the following benefits:

- Sustainability information: Provide information for investors about investments and allocate capital more sustainably.
- Sustainability monitoring: Monitor sustainable investments and exert corporate governance after providing finance.
- Sustainable risk management: Facilitate the trading, diversification, and management of risk according to sustainability principles.
- Sustainable investments: Mobilize and pool savings for sustainable investments.
- Sustainable exchange of goods and services: Ease the exchange of goods and services according to sustainability principles and provide more transparency in value chains.

The following sections describe the research method and the research results for the development of this new digital data infrastructure.

3. Research method

This research is based on the Design Science Research Method (DSRM) ((Nunamaker et al., 1991; Walls et al., 1992; Hevner et al., 2004; Peffers et al., 2007)). DSRM is often used for research that "seeks to create innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, management, and use of information systems can be effectively and efficiently accomplished" (Hevner et al., 2004, 76). In addition to its rigor, DSRM is often used in research with a high practical relation (e.g., the design of a prototype or a new application system). For this, Peffers et al. (2007) propose a DSRM that includes six activities (see Fig. 1).

(1) Identify the problem & motivate (what is the research problem?), (2) define the objectives of a solution (how should the problem be solved?), (3) design and development (create an artifact that solves the problem), (4) demonstration (demonstrate the use of the artifact), (5) evaluation (how well does the artifact work?), (6) communication (communicate the problem, its solution, the utility, novelty and effectiveness of the solution to researchers and other relevant audiences). As part of this procedure, iterations are possible from (5) back to (2) and (3) and from (6) back to (2) and (3). For example, the evaluation process might lead to a redefinition of the design.

Table 1 summarizes the DSRM activities, the description of the activities and the methods used for each single activity of the DSRM process. It comprises the following methods:

- Literature search and analysis: The systematic literature search and analysis are based on five steps (Wolfswinkel et al., 2013): (1) definition of the scope of the analysis, (2) literature search, (3) selection of the final sample, (4) corpus analysis and (5) presentation of the findings. The corpus analysis was conducted by using Grounded Theory for structuring this domain (Glaser and Strauss, 1967), since no one can know the ensuing classes prior to the process (Fisher and Yoo, 1993).
- Interviews with experts: The project was collaboratively developed with the UN Net-Zero Asset Owner Alliance to which organizations like Allianz SE, Caisse des Dépôts, La Caisse de dépôt et placement du Québec (CDPQ), Folksam Group, PensionDanmark, SwissRe, Alecta, AMF, CalPERS, Nordea Life and Pension, Storebrand, Zurich, Aviva, AXA, CNP Assurances, David Rockefeller Fund, Fonds de Réserve pour les Retraites (FRR) and Generali belong. Semi-structured interviews were conducted with experts from the UN Net-Zero Asset Owner Alliance to gather requirements (Strauss and Corbin, 1990). The interviews were not fully structured to leave room for exhibits which seemed appropriate given the different maturity of the involved organizations.
- Development of a prototype: The prototype was developed based on the findings of the literature analysis and the results of the interviews. The prototype itself is based on an Excel tool in which the functionalities were implemented to demonstrate the functionality and data elements.

Table 1 summarizes the DSRM activities, the description of these activities and the methods used in this research to design and evaluate the research artifact. The next sections are structured according to the steps of the DSR methodology and outline the major findings of the

Table 1
DSR methodology and applied methods.

DSRM activities	Activity description	Methods used
1. Problem identification and motivation	What is the problem?	• Literature search • Interviews with experts
2. Define the objectives of a solution	How should the problem be solved?	• Definition of objectives of the potential solution based on the findings of the literature analysis and the interviews with experts
3. Design and development	Create an artifact that solves the problem.	• Development of a prototype
4. Demonstration	Demonstrate the use of the work.	• Demonstration of the prototype to the interviewed experts
5. Evaluation	How well does the artifact work?	• Evaluation of the prototype at the example of the value chain of the company Salzgitter
6. Communication	Communicate the problem, its solution, novelty, and effectiveness of the solution to researchers and other relevant audiences	• Presentation of the prototype to the experts • Paper (this one) which summarizes the problem, its solution, novelty, and effectiveness of the solution

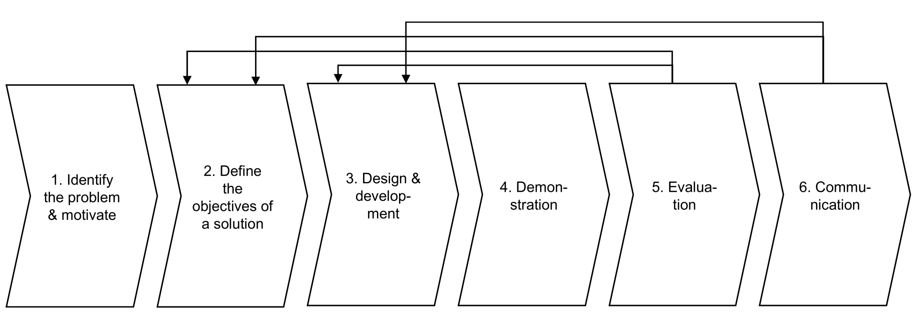

Fig. 1. Design science research methodology (DSRM) process model (according to (Peffers et al., 2007)).

research.

4. Research results

4.1. Problem identification and motivation

To identity and motivate the problem a literature search was conducted, which included the following steps: in a first step, the relevant search terms were defined (see Table 2). In the second step, the online databases were chosen for the academic literature analysis. Once the relevant papers were identified, the selection of the final sample was performed. In a first step, the titles were screened to find out which papers are interesting in the context of the research which led to a selection of 330 papers. In a next step, all papers' abstracts and keywords were analyzed and doubles deleted, ending up discarding another 257 being left with 73. Finally, after analyzing the papers in more detail, 21 papers were classified as being relevant to this research. The selection process only considered papers which included (1) GHG data measurement related approaches and (2) ones which focus on value chains. Table 2 summarizes how the literature search was conducted.

Table 3 summarizes the 21 papers which were selected as relevant for this research in chronological/alphabetical order. The 21 papers identified can be attributed to three groups of research:

- The first category of papers analyzes either the status quo of GHG data disclosures and/or derives emission reduction targets. An example is the research of Schulman et al. (2021) which compares companies in the food and beverage industry regarding their scope 3 emission data. Other examples in this category are (Kim and Lyon, 2011; Downie and Stubbs, 2012; Kauffmann et al., 2012; Plambeck, 2012; Wegener et al., 2019; Li et al., 2020; Salzmann et al., 2022; De Stefano and Montes-Sancho, 2023).
- The second category of research focuses on measurement methods. An example is the paper from Huang et al. (2009) which analyzes scope 3 emissions of U.S. economic sectors by using an organization-oriented approach. Other representatives of this category are (Wiedmann, 2009; Krabbe et al., 2015; Csutora and Dobák, 2019; Kaplan and Ramanna, 2021; Schmidt et al., 2022).
- The third category of papers focuses on how GHG reporting could be implemented. An example is the research from (Braam et al., 2016) which suggests complementing voluntary reporting with mandatory requirements for sustainability reporting in combination with enforcement mechanisms. Another example is from Patchell (2018) who discusses six interdependent factors that inhibit scope 3's ambition of promoting the measurement and management of GHG emissions throughout the value chain. Another representative in this category is (Stenzel and Waichmann, 2023).

Although all existing research in this field highlights the importance

Table 2
Literature search results.

Search Terms Databases	"indirect greenhouse gas emission accounting and reporting" OR "scope 3 greenhouse gas emission accounting and reporting" OR "indirect greenhouse gas emission AND value chain" OR "indirect greenhouse gas emission AND supply chain" OR "scope 3 greenhouse gas emission AND value chain" OR "scope 3 greenhouse gas emission AND supply chain"
AIS Electronic Library	14 (40)[a]
ScienceDirect	26 (101)[a]
Google Scholar	33 (189)[a]
Total Sample	73 (330)[a]
Final Selection	21 (73)

[a] The literature research excluded work in progress papers from conference proceedings, panel introductions, presentation slides, papers not available in English, teaching cases, and pedagogical research papers.

Table 3
Identified literature sources.

No.	Publication Title	Paper Title	Year	Author(s)
1	Corporate Social Responsibility and Environmental Management	The Management of Greenhouse Gas Emissions in large European Companies	2009	Rory Sullivan
2	Environmental Science and Technology	Categorization of Scope 3 Emissions for Streamlined Enterprise Carbon Footprinting	2009	Y Anny Huang, Christopher L. Weber, H. Scott Matthews
3	Ecological Economics	A Review of recent Multi-Region Input–Output Models Used for Consumption-based Emission and Resource Accounting	2009	Thomas Wiedmann
4	Journal of Environmental Economics and Management	Strategic Environmental Disclosure: Evidence from the DOE's Voluntary Greenhouse Gas Registry	2011	Eun-Hee Kim, Thomas P. Lyon
5	Business Strategy and the Environment	Corporate Carbon Strategies and Greenhouse Gas Emission Assessments: The Implications of Scope 3 Emission Factor Selection	2012	John Downie, Wendy Stubbs
6	OECD	Corporate Greenhouse Gas Emission Reporting: A Stocktaking of Government Schemes	2012	Céline Kauffmann, Cristina Tébar Less, Dorothee Teichmann
7	Energy Economics	Reducing Greenhouse Gas Emissions through Operations and Supply Chain Management	2012	Erica L. Plambeck
8	Journal of Cleaner Production	Evaluation of Australian Companies' Scope 3 Greenhouse Gas Emissions Assessments	2013	John Downie, Wendy Stubbs
9	Natural Climate Finance	Aligning Corporate Greenhouse-Gas Emissions Targets with Climate Goals	2015	Oskar Krabble, Giel Linthorst, Kornelis Blok, Wlna Crijns-Graus, Detlef P. van Vuuren, Niklas Höhne, Pedro Faria, Nate Aden, Alberto Carrillo Pineda
10	Journal of Cleaner Production	Determinants of Corporate Environmental Reporting: The Importance of Environmental Performance and Assurance	2016	Geert J. Braam, Lisanne Uit de Weerd, Mara Hauck, Mark A.J. Huijbregts
11	Journal of Cleaner Production	Can the Implications of the GHG Protocol's Scope 3 Standard Be Realized?	2018	Jerry Patchell
12	Biodiversity and Natural Capital Accounting	Accounting for Beyond Scope 3 GHG Emissions	2019	Mária Csutora, Katalin Dobák
13	Journal of Cleaner Production	Unpacking Carbon Accounting Numbers: A Study of the Commensurability and Comparability of Corporate Greenhouse Gas Emission Disclosures	2019	Matthew Wegener, Réal Labelle, Lambert Jerman

(continued on next page)

Table 3 (continued)

No.	Publication Title	Paper Title	Year	Author(s)
14	Environmental Science and Technology	Enabling Full Supply Chain Corporate Responsibility: Scope 3 Emissions Targets for Ambitious Climate Change Mitigation	2020	Mo Li, Thomas Wiedmann, Michalis Hadjikakou
15	Towards User-Centric Transport in Europe 2	Measuring and Allocating Scope 3 GHG Emissions	2020	Beatriz Royo
16	Harvard Business Review	Accounting for Climate Change	2021	Robert S. Kaplan, Karthik Ramanna
17	Cleaner Production Letters	Supply Chains (Scope 3) Toward Sustainable Food Systems: An Analysis of Food & Beverage Processing Corporate Greenhouse Gas Emissions Disclosure	2021	Daniela J. Schulmann, Alexis H. Bateman, Suzanne Greene
18	Corporate Social Responsibility and Environmental Management	Case Study Research of Green Life Cycle Model for the Evaluation and Reduction of Scope 3 Emissions in Food Supply Chains	2022	Muhammad Salman Asif, Henry Lau, Dilupa Nakandala, Youqing Fan, Hilal Hurriyet
19	Chemical Engineering & Technology	Determining the Scope 3 Emissions of Companies	2022	Mario Schmidt, Moritz Nill, Johannes Scholz
20	International Journal of Operations & Production Management	Complex Supply Chain Structures and Multi-Scope GHG Emissions: The Moderation Effect of Reducing Equivocality	2023	M. Christina De Stefano, Maria J. Montes-Sancho
21	npj Climate Action	Supply-Chain Data Sharing for Scope 3 Emissions	2023	Aurel Stenzel, Israel Waichman

and advantages of accounting for and reporting of indirect scope 3 GHG emissions, only a few of them (especially the ones in the category 3) provide solution approaches how to calculate scope 3 emissions in value chains more thoroughly. While the papers that contribute to the discussion about different measurement methods suggest either organization- or product-oriented measurement approaches, they remain ambiguous in providing solutions how to implement them.

However, the implementation of scope 3 emissions faces some major challenges. In general, a product-based and an organizational-based method can be distinguished. While the former places a specific product at the center of the calculation of GHG emissions, the latter one focuses on organizations as the primary calculation target. An example for the product-based method is the ISO 14064-1 standard, whereas an organizational-based standard is described by the GHG protocol. Both the ISO 14064-1 standard and the GHG protocol define relevance, completeness, consistency, accuracy, and transparency as basic principles for reporting GHG emissions (Schmidt et al., 2022). However, both methods also present challenges for their implementation. The organization-oriented approach can be implemented easily for scope 1 and 2 emissions as they can be assigned to a specific organization and location. However, scope 3 emissions are hard to collect and calculate, as they require input from other stakeholders in the value chain like suppliers and customers. Additionally, the organization-centric approach might lead to duplicate counting, as in most cases, none of the stakeholders from a certain value chain share emissions data with other organizations up- or downstream. It is therefore hard to define which organization includes which emissions. On the other hand, for the product-oriented approach, the life cycle of a certain product must be evaluated comprehensively, which requires the quantification of emissions for all kind of materials and services along an entire value chain.

For example, Kaplan and Ramanna (2021) propose a value chain approach called "e-liabilities" at which cost accounting and emission reporting are integrated. While the production of a certain product leads to an asset in a company's balance sheet, it at the same time produces a certain amount of GHG emissions, which can be calculated as an e-liability for the same company. These calculations are added along a certain value chain and can then be used to deduct the organizational GHG footprint based on each organization's value added for a specific product. This product-oriented method eliminates the duplicate counting of emissions that is often embedded in organization-oriented measurement methodologies. But it also faces the same challenges as the organization-oriented approach. It requires data sharing between all relevant stakeholders, which is still a major challenge in most value chains (Li et al., 2020).

Both the organization- and the product-oriented approach outline ideal scenarios where all data is available and comprehensively shared among all involved stakeholders. However, this is not the case today, as empirical data on product life cycles and organizations is not collected nor made available (Stenzel and Waichmann, 2023). That is why methods have emerged, which use estimated GHG emissions. An example is the input-output analysis (Kitzes, 2013; Hertwich and Wood, 2018; Schmidt et al., 2022). Here, purchasing data, which assigns average emission factors to different product groups or economic sectors, is used to estimate the GHG emissions (De Stefano and Montes-Sancho, 2023). Although this approach allows at least approximate calculations, it makes it almost impossible to calculate product emissions or the comparison of different products regarding their different emissions. Table 4 summarizes the different approaches with their individual benefits and challenges.

4.2. Objectives of the solution

Based on the findings of the literature analysis and the interviews with the experts of the UN Net-Zero Asset Owner Alliance, the objectives of the potential solution were defined in a next step. The status quo of existing research shows that especially the implementation of concepts that allow for improved data availability, accessibility and reliability are major success factors. To fill this gap, this research proposes an approach, which (see Fig. 2):

Table 4
Comparison of different GHG measurement methods.

Measurement focus	Data source	Benefits	Challenges
Organization	Real, primary data	- Exact data on a company's emissions - Real-time updates	- Data availability - Accuracy of data –1:1interfaces among different stakeholders due to lack of standards
	Estimated, secondary data	- Estimated data on a company's emissions - Comprehensive emission calculation	- Data availability - Limited data updates - No exact calculation - Product emissions
Product	Real, primary data	- Exact data on a product's life cycle emissions - Real-time updates	- Limited possibilities for comparison of products –1:1interfaces among different stakeholders due to lack of standards
	Estimated, secondary data	- Estimated data on a product's life cycle emissions - Calculation for different product types	- Data availability - Data comparability

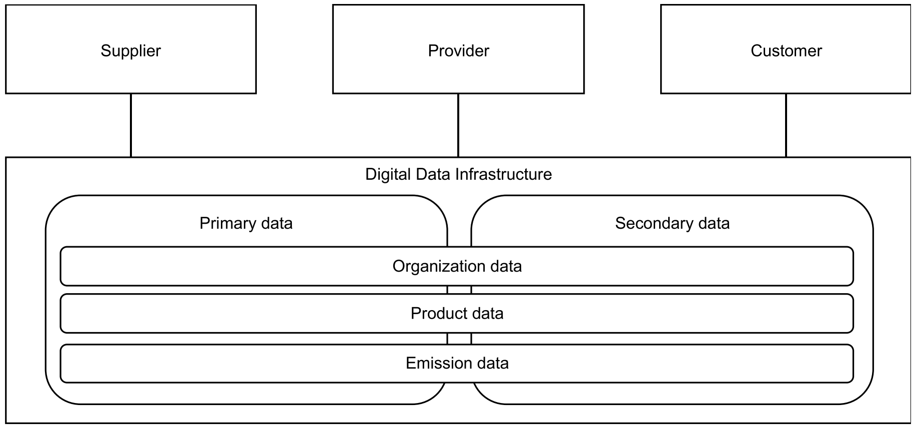

Fig. 2. Scope of the Approach and the Prototype in this Research.

- Combines the organization- and product-oriented measurement methods: Both perspectives are required to overcome the challenges of each of the approaches (see Fig. 2). For example, the organization-oriented approach provides only limited possibilities for measuring scope 3 GHG data along a certain value chain. On the other hand, the product-oriented approach today in most cases requires one-to-one interfaces between the different stakeholders for data exchange. For this, a digital data infrastructure is proposed as a solution approach. However, this requires high levels of data privacy. Companies will be reluctant to share sensitive data with their suppliers, customers or competitors. Another important obstacle is of legal and regulatory stature. Data sharing along an entire, cross-country value chain often includes various legal and regulatory questions such as data ownership, the use of data across different jurisdictions, etc. For this, methods such as homomorphic encryption can be established. Homomorphic encryption allows an organization to reveal data about scope 3 emissions without revealing any information that can be used even for very sensitive health data (Sarkar et al., 2023).
- Integrates primary and secondary data: The comparison of the different approaches shows that the estimated data approaches have many disadvantages regarding data availability, accuracy and comparability. In most cases, they just provide industry averages or proxy data and do not allow for more accurate ways of assigning exact numbers. In contrast to that, approaches that are based on real, primary data have advantages and increase transparency, accountability, cooperation, coordination, and sanctioning on a value chain level as well as the identification of potential cost savings, risk factors, and novel business models on a company level (Stenzel and Waichmann, 2023). Furthermore, this can also have a positive impact on consumers' purchasing decision if they have transparency about the emissions of individual competing products and services. These advantages demonstrate the clear strengths of approaches that are based on primary data.
- Develops a prototype for the sharing of different value chain stakeholders' data: One of today's major challenges is that organizations don't share data among each other, which would be required to establish more transparency along certain value chains. However, these approaches require standards for data sharing among stakeholders in value chains. Today, however, these different standards (e.g., ISO 14064-1 and GHG protocol) are not interoperable and cannot be used to share data across different IT systems from different companies. That's why today one-to-one interfaces between the different involved organizations in a certain value chain are required. However, the complexity of such an approach requires enormous efforts for its implementation. For example, large companies with a revenue of more than $1 billion per year often have between 10,000 and 50,000 suppliers (Schmidt et al., 2022). Such a one-to-one approach could be substituted by a common digital infrastructure for data sharing.

4.3. Design and development of the solution

Based on the definition of the objectives of the potential solution approach, the following requirements were derived:

- Value chain: The solution gives an overview of a specific value chain in scope (i.e., the value chain of the provider in scope) by connecting upstream tier 1 suppliers and downstream tier 1 customers to the target company. The scope of the value chain is focused on business-to-business relationships since the inclusion of consumers is very complex and would require consumer data which is not available on a larger scale yet. With this, scope 3 emissions of an entire value chain can be identified.
- GHG emissions: The solution includes the corresponding GHG emissions reported by the companies along the entire value chain and/or estimated by the data providers, subdivided into scope 1, scope 2 and scope 3 GHG emissions (i.e., for the target provider and each supplier and each customer depicted in the value chain).
- Revenue contribution to suppliers and customers: The solution outlines how much the target company contributes with its purchases to a supplier's total revenue (i.e., the percentage of the supplier's total revenue, marked as "percent revenue") or vice versa in the case of a customer. With this, the solution shows the interlinkages between the target company's scope 3 emissions inventory and the supplier's or customer's emissions (scope 1, scope 2 and scope 3) and their relevance for the overall calculation. In other words, the solution depicts how much of each supplier's and each customer's emissions are attributable to the target company's scope 3 inventory.
- Relevance of suppliers and customers: To identify the importance of a specific supplier, or a specific customer for a target provider in terms of costs and revenues, the solution integrates the target company's expenses related to a specific supplier (stemming from purchases of goods and services) in relation to its total costs ("percent cost") and vice versa in terms of revenues for the customers ("percent revenue"). This is an approximation for the target company's exposure to each supplier and each customer. It then ranks the individual suppliers and customers accordingly (rank 1 for the supplier that is responsible for most of the target provider's total costs, followed by rank 2 and so on; and rank 1 for the customer, which accounts for the biggest share of total revenue of the target company, and so on).
- Market capitalization in relation to emissions: The target provider's, each supplier's and each customer's market capitalization are identified to put their emissions in relation to the company size to shed light on why some companies' emissions are comparably higher to

others'. However, these emission intensity measures should be treated with caution, since first, emission intensities are usually expressed in terms of other metrics (unit of turnover, units produced, etc.). Second, the emissions and the other metrics used to be put in relation to emissions (here market capitalization) are often not necessarily related and thus misleading.

With this solution approach investors (and of course also other relevant stakeholders like auditors, regulators, etc.) can gain a better understanding of how value chains are composed of and how GHG emissions are approximately distributed among the companies in a certain value chain. The goal is to pinpoint any bottlenecks in the value chain to optimize the value chain's emission distribution. Moreover, the reported primary and estimated secondary data and thus, also the data provider can be verified to a certain extent by simply checking if the output of the solution makes sense and, in case it does not, an investor can assess whether this is due to the tool or to the data that served as input.

The solution is designed in a Microsoft Excel prototype application, as this provides an easy-to-use instrument for all kinds of calculations and visualizations. This is because the Net-Zero Asset Owner Alliance consists of a high number of large companies that use different applications within their organizations, and thus Microsoft Excel is the lowest common denominator. The data used for the implementation of the prototype solution are custom data and Bloomberg data. While the custom data has been used as an example only, Bloomberg has developed tools that stakeholders can use to assess climate-related risks and prepare financial disclosures according to the Task Force on Climate-related Financial Disclosures (TCFD). Bloomberg offers ESG data with more than ten years of history for more than 11,700 companies in 102 countries, organized into more than 1300 fields, which is constantly updated and available as a fully integrated feature of the Bloomberg Terminal (Bloomberg (n.d.-b)). In addition, it provides more than 70 data fields corresponding to TCFD-aligned metrics and targets. Policy fields help identify companies addressing climate change risks and opportunities through company governance and operations (Bloomberg (n.d.-a)). The sources of corporate carbon data are annual and sustainability reports of companies as well as information from other data providers, such as CDP and Sustainalytics are included. Along the ESG functions, Bloomberg offers insight into a company's supply chain relationships by mapping a company to its customers, suppliers and competitors and covering supply chain relationships of 35,000 companies from source documents in over a dozen languages. Of course, the tool developed in this research can be complemented with other data sources and providers.

4.4. Demonstration

The following overview (see Table 5) depicts the functionalities and data which the prototype contains. The screenshots of the prototype's interface are described in more detail in the following section. The organization column shows the relevant stakeholder that is in scope, while the organization, product and emission data column outlines the data with which each of the stakeholders is described in more detail. Finally, the data sources column describes where the data originates from.

4.5. Evaluation

The functionality and data visualization defined in the previous section is evaluated at the application example of Salzgitter, a German steel manufacturing group. The following screen shots show the tool that can be applied and what output it generates. To implement the prototype's functionalities', the following visualizations have been used (see Table 6, Table 7):

Table 5
Overview of the Prototype's functionalities.

Organization	Organization, product and emission data (based on organization- and product-oriented method)	Data sources (based on primary and secondary data)
Provider in scope	• raw environmental data • market capitalization • number of tier 1 suppliers • number of tier 1 customers	• Custom data • Bloomberg environmental tab • Bloomberg supply chain
Customer 1, 2, n	• raw environmental data (GHG emissions, water consumption etc.) • market capitalization • % revenue • % cost • rank	• Bloomberg environmental tab • Bloomberg supply chain
Supplier 1, 2, n	same as for the tabs Customer 1, 2, …	same as for the tabs customer 1, 2,
Dashboard customer	• table for reporting years in scope including for each customer in scope its: - name - total emissions - scope 1 emissions - scope 2 emissions - scope 3 emissions - market capitalization - % revenue - % cost - rank - total GHG/market capitalization - scope 3 allocation • table providing an overview of the provider in scope's: - name - total GHG emissions - scope 1 emissions - scope 2 emissions - scope 3 emissions - market capitalization - # tier 1 suppliers g# tier 1 customers • chart total GHG emissions • chart total GHG emissions/ market capitalization • chart scope 3 allocation	• Customer 1, 2, n tab • Sum up scope 1, scope 2 and scope 3 emissions (for total emissions) • Bloomberg raw data
Dashboard supplier	Same as in dashboard customer	Same as in dashboard customer

- Chart total, scope 1, scope 2 and scope 3 GHG emissions of provider in scope
- Chart total, scope 1, scope 2 and scope 3 GHG emissions of tier 1 suppliers in scope
- Chart total, scope 1, scope 2 and scope 3 GHG emissions of tier 1 customers in scope
- Chart percent revenue of tier 1 suppliers in scope
- Chart percent revenue of tier 1 customers in scope

4.5.1. Provider in scope, customers and suppliers

To evaluate the concept, Salzgitter's value chain, i.e., its tier 1 suppliers and tier 1 customers are identified. For this, Bloomberg's supply chain functionality is used. Here, all of Salzgitter's value chain partners are listed by rank. The higher the position on the screen, the more exposure Salzgitter has to the corresponding company. For instance, Salzgitter is more exposed to ArcelorMittal than to Vallourec since the former is responsible for 2.6% of Salzgitter's total costs; opposed to 0.11% of Vallourec. The same holds true for the customers (but here in terms of how much revenue they make up at Salzgitter).

For every supplier and customer in scope its name, market capitalization, rank, revenue percentage, and cost percentage (if applicable) are

Table 6
Provider in Scope Data.

Provider in Scope Data

	A	B	C	D	E	F	G	H	I	J	K	L
1	Name	Salzgitter AG										
2	Market Cap	1020000000.00										
3	#Suppliers (Tier 1)	17										
4	#Suppliers (Tier 2)	13										
5												
6												
7	**Salzgitter AG (SZG GR) - Environmental**											
8												
9	In Millions of EUR except Per Share		FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
10	12 Months Ending		12/31/2010	12/31/2011	12/31/2012	12/31/2013	12/31/2014	12/31/2015	12/31/2016	12/31/2017	12/31/2018	12/31/2019
11	**Environmental Disclosure Score**	**ENVIRON_DIS**	**13.18**	**13.18**	**13.18**	**13.18**	**10.85**	**13.95**	**41.86**	**42.64**	**42.64**	**43.41**
12												
13	Disclosure											
14	GRI Criteria Compliance	GRI_COMPLIAN	No	No	No	No	No	No	No	No	No	No
15	Global Reporting Initiatives Checked	GRI_CHECKED	No	No	No	No	No	No	No	No	No	No
16	Verification Type	VERIFICATION_	No	No	No	No	No	No	No	Yes	Yes	Yes
17												
18	Emissions											
19	**Total GHG Emissions**	**TOTAL_GHG_E**	—	—	—	—	—	—	**9'356.0**	**9'163.0**	**9'310.0**	**8'938.0**
20	GHG Scope 1	GHG_SCOPE_	—	—	—	—	—	—	8'670.0	8'470.0	8'710.0	8'402.0
21	GHG Scope 2	GHG_SCOPE_	—	—	—	—	—	—	686.0	693.0	600.0	536.0
22	GHG Scope 3	GHG_SCOPE_	—	—	—	—	—	—	1'330.0	1'362.0	1'508.0	1'423.0
23												
24												
25												
26												
27	NOx Emissions	NOX_EMISSIOI	—	—	—	—	—	—	4.5	4.7	4.8	5.2
28	SOx Emissions	SULPHUR_OXII	—	—	—	—	—	—	5.1	5.5	4.7	4.6
29	Particulate Emissions	PARTICULATE_	—	—	—	—	—	—	0.2	0.2	0.2	0.2
30												
31	Energy											
32	**Total Energy Consumption**	**ENERGY_CONS**	—	—	—	—	—	—	**8'877.0**	**8'687.0**	**9'061.0**	**8'795.0**
33	Electricity Used	ELECTRICITY_U	—	—	—	—	—	—	2'742.0	2'682.0	2'663.0	2'618.0
34												
35	Water											
36	**Total Water Use**	**TOTAL_WATEF**	—	—	—	—	—	—	**18'773.0**	**18'493.0**	**18'614.0**	**19'482.0**
37	Total Water Withdrawal	TOTAL_WATER	—	—	—	—	—	—	18'773.0	18'493.0	18'614.0	19'482.0
38	Water Discharged	TOTAL_WATER	—	—	—	—	—	—	14'483.0	15'877.0	13'749.0	14'257.0
39	Water Consumption Derived	TOTL_WATER_	—	—	—	—	—	—	—	—	—	—
40												
41	Municipal Water	MUNICIPAL_W	—	—	—	—	—	—	2'647.0	2'693.0	2'523.0	2'346.0
42	Reclaimed Water	RECLAIMED_W	—	—	—	—	—	—	16'126.0	15'800.0	16'091.0	17'136.0
43												

then exported into the corresponding tab in the prototype. For the provider in scope (here Salzgitter), the market capitalization and the number of tier 1 suppliers and tier 1 customers are exported into the corresponding tab (see Table 3). For example, Salzgitter has 17 tier suppliers and 13 tier 2 suppliers. In a next step, the environmental data of Salzgitter as well as its suppliers and customers are exported from Bloomberg. This includes total GHG emissions, scope 1, scope 2 as well as scope 3 GHG emissions (and further environmental data such as electricity consumption and so on) for the reporting years 2010–2019. The provider in scope view is summarized in Table 7.

The same data is captured for all tier 1 suppliers and tier 1 customers. Here, it shows an example for Salzgitter's tier 1 customer Bayerische Motoren Werke (BMW). In general, it contains the same data as Salzgitter's data overview but here for each of the target provider's tier 1 suppliers and tier 1 customers. They are listed according to their importance to the target provider, i.e., the information about the supplier with the highest % cost is in tab "Supplier 1" (here ArcelorMittal), followed by the remaining suppliers with decreasing importance (same procedure for the customers but in terms of % revenue). In addition to the information delivered in the target provider's tab, for each supplier and customer the % cost, % revenue and rank are provided at the top of each sheet.

4.5.2. Dashboard "supplier" and dashboard "customer"

The "Dashboard Supplier" consolidates and links the raw data of the tier 1 suppliers. Moreover, it combines the raw data with the accounting and reporting rules of the GHG Protocol standards. Basically, it provides a table where for each supplier the total, scope 1, scope 2 and scope 3 GHG emissions, as well as the market capitalization, percent revenue, percent cost, rank, total GHG emission in relation to the market capitalization and the scope 3 GHG emissions allocation to the target provider is listed. At the top of the Excel sheet, total GHG emissions, total GHG emission with respect to the market capitalization and the scope 3 GHG emission allocations are summarized in three separate diagrams. Moreover, almost the same information is provided for previous reporting years and for the provider in scope. Fig. 3 shows an excerpt of the Dashboard of Salzgitter's tier 1 suppliers.

Here, ArcelorMittal – Salzgitter's most important supplier in terms of exposure (i.e., percent cost) – emitted 196,000 tCO_2eq of total GHG emissions in the reporting year 2019. 169,700 tCO_2eq is attributable to scope 1 emissions, while 12,600 tCO_2eq and 13,700 tCO_2eq are attributable to scope 2 and scope 3 emissions, respectively. ArcelorMittal's market capitalization amounts to US $16,930,000,000. The revenue generated from Salzgitter relative to ArcelorMittal's total revenues is 0.38%, while these same purchases from Salzgitter make up for 2.60% of Salzgitter's total costs. Since this 2.60% is the highest among all tier 1 suppliers, it is the most important supplier to Salzgitter in terms of financial exposure and is therefore ranked 1. In the second to the last column, one can find ArcelorMittal's total GHG emissions divided by its market capitalization to put the emissions in relation to company size. The last column of this table shows how much of ArcelorMittal's total GHG emissions is approximately attributable to Salzgitter's scope 3 GHG emission inventory giving a hint of the interconnection between the two companies in terms of GHG emissions. This allocation figure is based on the accounting rules of the GHG Protocol standards, which say that for the economic allocation the provider in scope's (here, Salzgitter) upstream or downstream party's emissions must be multiplied by the percent revenue of the suppliers and customers). The percent revenue identifies how much of the downstream party's purchases of the upstream party's goods and/or services make up for the total revenues of the upstream party. Accordingly, in the case of ArcelorMittal – according to the tool's calculation – 744.8 tCO_2eq of ArcelorMittal's total

Table 7
Supplier and Customer Data.

Supplier and Customer Data

A	B
Name	Bayerische Motoren Werke AG
Market Cap	47030000000
% revenue	2.59%
% cost	3.00%
rank	2

Bayerische Motoren Werke AG (BMW GR) - Environmental

In Millions of EUR except Per Share 12 Months Ending		FY 2010 12/31/2010	FY 2011 12/31/2011	FY 2012 12/31/2012	FY 2013 12/31/2013	FY 2014 12/31/2014	FY 2015 12/31/2015	FY 2016 12/31/2016	FY 2017 12/31/2017	FY 2018 12/31/2018	FY 2019 12/31/2019
Environmen	**ENVIRON_DISCLOSURE_SCORE**	**58.14**	**58.14**	**64.34**	**64.34**	**63.57**	**66.67**	**66.67**	**66.67**	**64.34**	**64.34**
Disclosure											
GRI Criteria (	GRI_COMPLIANCE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Global Repor	GRI_CHECKED	No	No	Yes	Yes	Yes	No	No	No	No	No
Verification T	VERIFICATION_TYPE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Emissions											
Total GHG E	**TOTAL_GHG_EMISSIONS**	**1'343.0**	**1'310.0**	**1'346.8**	**1'415.6**	**1'461.0**	**2'008.6**	**2'094.6**	**2'197.5**	**2'121.1**	**2'062.4**
Total Market	TOT_MKT_BASED_GHG_EMISSIONS	—	—	—	—	—	1'459.5	1'430.2	1'136.0	1'120.3	944.8
GHG Scope 1	GHG_SCOPE_1	409.9	451.0	484.6	492.8	494.9	536.2	562.1	625.1	581.7	642.3
GHG Scope 2	GHG_SCOPE_2	933.1	859.0	862.2	922.8	966.1	1'472.4	1'532.5	1'572.4	1'539.4	1'420.2
GHG Scope 2	SCOPE_2_MKT_BASED_GHG_EMISSIONS	—	—	—	—	—	923.3	868.1	510.9	538.6	302.6
GHG Scope 3	GHG_SCOPE_3	618.3	1'405.8	60'256.7	62'604.2	65'452.3	67'532.5	69'388.7	71'714.7	73'093.1	75'042.3
Travel Emissi	TRAVEL_EMISSIONS	48.5	108.5	112.0	113.4	137.6	138.5	142.3	169.2	159.0	129.6
Carbon per U	CARBON_PER_UNIT_OF_PROD	—	—	—	—	0.66	0.57	0.54	0.41	0.40	0.30
Total CO2 E	**TOTAL_CO2_EMISSIONS**	—	—	—	—	—	**1'266.7**	**1'255.0**	**989.1**	**962.5**	**767.6**
NOx Emissio	NOX_EMISSIONS	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7
SO2 Emissio	SO2_EMISSIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VOC Emissio	VOC_EMISSIONS	2.4	2.9	3.1	3.0	2.6	2.6	2.5	2.4	2.1	2.0
CO Emission	CARBON_MONOXIDE_EMISSIONS	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.5
Particulate E	PARTICULATE_EMISSIONS	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Energy											
Total Energy	**ENERGY_CONSUMPTION**	**4'072.2**	**4'278.0**	**4'549.8**	**4'721.2**	**4'867.1**	**5'479.0**	**5'783.8**	**5'852.7**	**5'789.0**	**5'974.6**
Electricity Us	ELECTRICITY_USED	1'832.6	1'973.0	2'090.4	1'910.1	2'141.2	2'485.9	2'584.6	2'588.4	2'513.3	2'439.7
Renewable E	RENEW_ENERGY_USE	299.9	468.4	755.1	916.8	239.0	227.0	238.1	225.4	206.6	166.7

... | Supplier 6 | Supplier 7 | Supplier 8 | Customer 1 | **Customer 2** | Customer 3 | Customer 4 | Customer 5 | Customer 6 | Customer 7

emissions (which equal 196,000 tCO_2eq) are attributable to Salzgitter's scope 3 emissions inventory (which is 1423 tCO_2eq). Or in other words, 744.8 tCO_2eq of Salzgitter's 1423 tCO_2eq scope 3 GHG emissions come from ArcelorMittal. The same logic of reading the figures applies to the remaining suppliers. At the top of the screen, the total emissions are stated, the total emissions relative to the market capitalization and the scope 3 GHG emission allocations of Salzgitter's tier 1 suppliers summarized in three diagrams. Moreover, an overview of Salzgitter's GHG emissions, market capitalization, as well as the number of tier 1 suppliers and tier 1 customers are summarized below the three diagrams. Below the table of supplier data for the reporting year 2019, one can find some more GHG emission data for the same suppliers for previous reporting years. This may be helpful to analyze the evolution of their emissions and thus, to find out if they improved emissions over time. The "Dashboard Customer" contains the same information as the tab "Dashboard Supplier". The same logic for reading the data also applies here for the tier 1 customers.

4.5.3. Visualization

Fig. 4 visualizes all processed data by connecting the relationships between the value chain members, including their GHG emissions and percent revenue (which serves to make the connection between the target provider's scope 3 GHG emissions and the total emissions of each of its suppliers and customers). The "visualization" function basically summarizes the data from the suppliers' and customers' dashboards. On the left, the tier 1 suppliers' GHG emissions are split up into scope 1, scope 2 and scope 3. The same appears on the right for the customers. In the center Salzgitter's scope 1, scope 2 and scope 3 emissions are visualized. In between these 3 diagrams, another chart summarizes the suppliers' and customers' percent revenue data which serves to make the connection between Salzgitter's scope 3 emissions and the emissions of its tier 1 suppliers and tier 1 customers.

The data is used in an additional functionality to prepare Sankey diagrams showing the GHG emission relationship between the target provider and its suppliers and customers in a different format (see Fig. 5). The purple bar in the center represents Salzgitter's scope 3 emissions. On the left and right Salzgitter's tier 1 suppliers and tier 1 customers are listed according to their importance (at the top the most important party followed by the remaining suppliers with increasing rank, i.e., decreasing importance). Each supplier and each customer is represented by a different color. The bars represent their GHG emission allocation to Salzgitter's scope 3 inventory, whereby the size of the bar and the flows in grey between Salzgitter's scope 3 GHG emissions and the suppliers' and customers' bars indicate the relative amount of the allocation compared to the other suppliers and customers. Consequently, this gives an overview of the scope 3 GHG emission allocations of Salzgitter's suppliers and customers to its own scope 3 GHG emission inventory.

4.5.4. Extension by financial technology

One of the core drivers of change towards sustainable finance regarding data availability, accessibility and reliability is technology. As has been shown in the previous sections, the prototype developed in this research depends heavily on data. The digitization of financial services

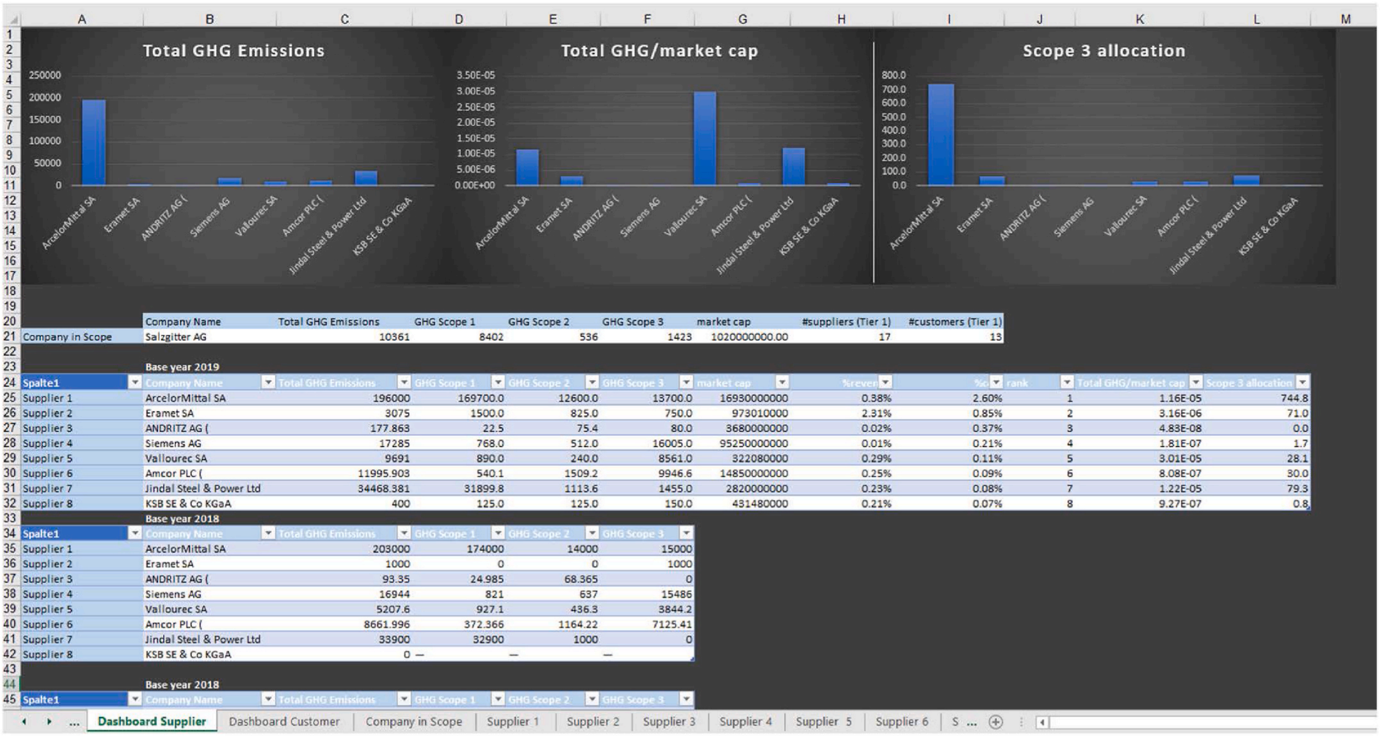

Fig. 3. Supplier dashboard.

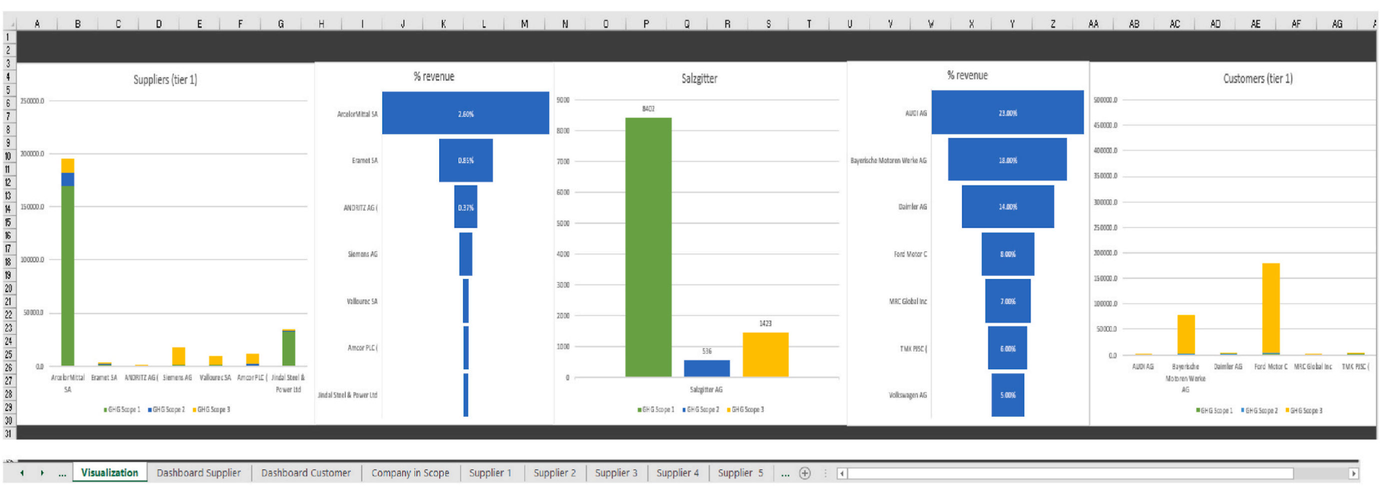

Fig. 4. Visualization of value chain connection.

has just recently culminated in the financial technology (fintech) revolution. Fintech is a term that emerged as a contraction of "financial technology" and is based on at least three areas (Puschmann, 2017; Gomber et al., 2018). These are the evolution of novel technologies such as blockchain or artificial intelligence, the convergence of these different technologies, and their enabling effect on new application areas and business models. An example is a blockchain-based solution for tracking product movements throughout an agriculture supply chain that provides all stakeholders with real-time tracking and financing opportunities as well as transparency of origins of products, concerns over modern slavery, and how to extend sustainable practices and governance up-stream in supply chains.

As the prototype developed in this research strongly depends on data, these technologies may support the benefits and impact of it. For example, if more and more reliable data is available from a company and its suppliers and customers along the value chain, the scope 3 GHG emissions can be calculated more precisely and in real-time. For this, technologies such as blockchain, artificial intelligence or IoT can provide increased benefits. Table 8 lists examples of potentials of these technologies for the different views and functionalities of the prototype.

5. Discussion

5.1. Potentials of the prototype solution

Corporate value chains are responsible for large parts of GHG emissions and, thus a systematic approach to analyze these value chains provides an important element for improvement. A study of (Busch et al., 2018) which investigated the consistency of reported and estimated emissions data among a set of prominent global data providers (e.

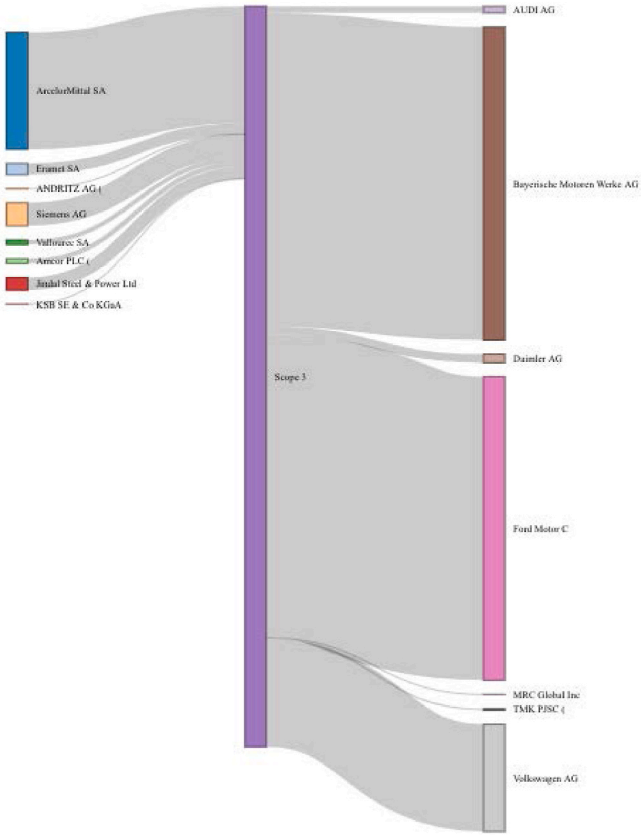

Fig. 5. Sankey diagram.

g., Bloomberg, CDP, ISS, ESG, MSCI, Sustainalytics, Thomson Reuters and Trucost) found that scope 3 GHG emission data reported by similar companies indicate the largest divergence in reported emissions compared to scope 1 and scope 2 data, which in contrast provide a rather homogeneous result. Furthermore, they found that the consistency of estimated data is lower than that of reported data, by which they traced this divergence back to the different estimation methods applied. This is because establishing an inventory for indirect emissions, especially in scope 3 GHG emissions, is still relatively cumbersome and complex requiring substantial resources for many companies. This effect is reinforced by the uncertainties of data gathering and the inconsistency related to different estimation methods applied, number of GHG emission sources reported, and the determination of which sources to include (Downie and Stubbs, 2013; Busch et al., 2018). Accordingly, the GHG Protocol scope 3 standard has been much less successful than the standards for scope 1 and scope 2 GHG emissions reporting and therefore, the lack of success challenges the premise and purpose of the standard – especially, the expectation that the power of multinational companies can be used to leverage reporting and reductions through the value chain (Patchell, 2018). It is, however, the emission scope 3 GHG emissions that makes up for the biggest share of most company's total GHG emissions (Patchell, 2018) and asset owners, investors and even the corporates themselves often do not know where these emissions come from exactly. Therefore, it is of utmost importance to improve the transparency for this type of emissions by providing more comprehensive guidance on how to account for it correctly and consistently. The prototype developed in this paper contributes to this discussion by providing a concept for a digital infrastructure which connects organization- and product-oriented measurement methods, integrating primary and secondary data and allows the sharing of different stakeholder's data along a certain value chain.

Table 8
Potentials of financial technologies.

View	Fintech potentials
Provider in scope, suppliers and customers	• Blockchain enables the traceability of every product and its components along the whole value chain. It automates the collection of high quality data, stores it securely without the possibility of manipulation (also eliminating the possibility of data manipulation and thus, greenwashing, for instance). In addition, novel smart contract-based data exchange models are possible, which, for example, allow companies to pay goods and services only, if a supplier provides GHG emission data before the payment. • IoT enables the collection of new data along the value chain. Examples are environmental data (e.g., from satellites), shipment data, production data. All these data can be stored on a blockchain based infrastructure which ensures that all relevant stakeholders have access to them. With this, all organizations along a certain value chain can, for example, see the GHG emission data from a tier n supplier. • AI enables the collection and analysis of additional data, such as environmental data from other sources like from weather data providers or space data providers or the analysis from payment providers, from which additional GHG emission of suppliers and customers can be identified.
Dashboard supplier and customer	• Blockchain enables effective and trustworthy monitoring, reporting and verification in real-time and therefore, increases transparency, authenticity, traceability, and accountability of data. • IoT allows a tighter cross-organizational data connection of value chain partners by machine-to-machine integration of applications and data. For example, if suppliers and customers are more closely linked by IoT data, GHG data can be exchanged automatically among the participants in real-time. • AI enables more sophisticated clustering, categorizing or predictive analysis. In addition, scenario analyses are possible which can be useful to see how much a specific company must reduce its GHG emissions for meeting its target.
Visualization	• Based on the richer data sets and the tighter integration between the partners in a certain value chain, the visualization becomes more sophisticated allowing for real-time analysis and scenario planning.

5.2. Theoretical implications

The analysis of the existing research in the field of scope 3 GHG emissions revealed that current approaches primarily focus on analyzing scope 3 emission levels and compare them across companies and sectors. In addition, some research developed measurement methods, which show different ways of how to measure scope 3 GHG emissions. However, these approaches vary and provide different benefits and challenges. Finally, only little research addresses the question of how these different approaches could be connected and implemented. This research analyzed the existing approaches and based on additional input from practice derived an approach which addresses the existing challenges and suggests a concept how such an approach could be implemented through a digital data infrastructure. First, it combines the organization- and product-oriented measurement methods by establishing a common data infrastructure that allows organizations to share financial, product and emissions data considering highest levels of data privacy. For this, the different data categories for all suppliers and customers of a certain value chain (e.g., raw environmental data, market capitalization, number of tier 1 suppliers and customers, etc.) are integrated into a dashboard for customers and suppliers. Clearly, many of the technologies required for the implementation are still in an early stage of development (e.g., data privacy). However, with technology developing so rapidly, we can expect to see some of these concepts to be implemented soon. Second, the approach developed in this paper integrates primary (Vuković et al., 2015) and secondary data which addresses the key challenge that either only estimations based on secondary data or the non-accessibility of primary data (because of data privacy concerns) today hinder a more precise scope 3 emission reporting. Such an approach is very promising, as it would allow a more precise measurement of scope 3 GHG emissions data. And third, this research develops a prototype that demonstrates how one-to-one interfaces between the different involved organizations in a certain value chain can be substituted by a common digital data infrastructure, which can foster interoperability across different data and standards like the ISO 12067:2018 standard and the European Commission's Product Environment Footprint (PEF) method by, for example, using mapping tools across different standards' taxonomies.

Overall, this paper contributes to the further development of scope 3 GHG emissions reporting in value chains by developing a digital data infrastructure and advanced financial technologies which may improve the existing approaches. It also contributes to the question how the existing measurement methods could be connected and integrated. In addition, this research strengthens the link between the so far, mostly unconnected fields of scope 3 GHG emission reporting and sustainable finance. Since the financial sector is a strong enabler for providing sustainability information, monitoring, risk management and allocating investments, it can foster the development of novel approaches for scope 3 GHG emission analysis.

6. Practical implications

Companies need to implement solutions for scope 3 GHG emissions reporting, since many public authorities started to draft regulations (e.g., European Commission) for data disclosures. On the other hand, startups in this field also began to address this topic by developing novel solutions to provide more data for sustainability reporting (e.g., Doconomy, Gravity Climate, Living Carbon, etc.). However, these concepts merely address isolated fields and do not extend to more comprehensive solutions.

The prototype developed in this research addresses some of the missing pieces of scope 3 GHG emission reporting up- and downstream of a firm's value chain. By combining (primary and secondary) value chain data and environmental data with scope 3 accounting rules from the GHG Protocol, the prototype maps a specific provider to its suppliers and customers via their GHG indirect emissions. More precisely, the value chain data maps a provider in scope to its suppliers and customers, while at the same time indicating each ones' relative importance to it, i.e., the target provider's exposure to its suppliers and customers (in terms of percent revenue and percent cost). This shows for each supplier and customer how much it contributes with its own emissions to the scope 3 emissions of the provider in scope, thus, improving the understanding of the source and distribution of indirect emissions in value chains. As a result, companies representing bottlenecks in the value chain can be identified, and stakeholders can then engage with them directly and together seek opportunities to reduce their GHG emissions.

7. Conclusion

The financial system plays a major role in achieving the SDGs, given the fact that financial institutions and investors are aligning their short-term profitability goals with long-term sustainability goals in their investment and lending decisions. However, this requires companies to disclose their environmental impact data, thereby increasing the transparency of GHG emission distributions across value chains. But despite the relevance of scope 3 GHG emissions, which in most cases account to a factor 4 of scope 1 and 2 emissions, they are still rather an unexplored area, especially when it comes to implementing concrete solutions. According to Li et al. (2020), under an ambitious carbon mitigation scenario for the year 2035 – which follows a trajectory of 1.75 °C total warming by 2100 – global upstream scope 3 GHG emission intensities must be reduced by an additional 54% compared to a baseline scenario with reference technology. On a sectoral basis, this is equivalent to a 58–67% reduction in energy, transport, and materials, a 50–52% reduction in manufacturing, services and buildings, as well as a 39% reduction in agriculture, forestry and other land use.

However, asset owners and especially institutional investors take up a crucial role in this regard since they wield a great deal of power with respect to driving the movement of the climate change battle. They can influence corporate operations by their investment strategy. By setting up zero-carbon portfolios, they can force companies to reduce their GHG emissions unless they are indifferent to dropping out of investors' portfolio and thus, renounce huge amounts of financing. In this regard, the prototype developed in this research is meant to support financial investors in gaining more transparency of indirect scope 3 GHG emissions in value chains by providing an integrated instrument, which combines different measurement methods (organization- and product-oriented) and data elements (primary and secondary). The purpose of this approach is to assign the correct "ownership" of emissions, differentiating between scope 1, scope 2 and scope 3 GHG emissions, and the shared overlap in these emissions between companies in a certain value chain. It addressed the research question how scope 3 GHG emissions reporting can be implemented by developing an approach which (1) combines the different existing measurement methods, (2) integrates cross-value chain data from different stakeholders and (3) combines primary and secondary data? This is achieved by a solution approach which combines organization- and product-oriented measurement methods into a single model and which integrates primary and secondary data that then can be shared over a joint digital infrastructure that can be accessed by all relevant stakeholders in a certain value chain. Moreover, investors can take up the role of an auditor and verify the data from companies and data providers and thus, promote improvement of this information, thus benefiting also the existing environmental initiatives pleading for more transparent emission reporting (Busch et al., 2018). However, the prototype also showed that the possibilities to identify and analyze scope 3 GHG emission data are only as good as the data it uses. Thus, this research identified possibilities how fintech could increase the access, availability, and reliability of these data. Technologies such as blockchain, AI, and IoT can not only lead to increasing amounts of data but can also lead to an improved integration of value chain data among the involved organizations. This might foster a universally accepted standardized approach to accounting and reporting of corporate scope 3 GHG emissions in the future. Such standards would establish common rules like proposed by Ostrom (1990) and could decrease the impact of climate change. With this, this research contributes to the discussion on how common goods can be protected by using technology and data as key instruments and thus complementing regulation with additional instruments for self-regulation.

Although the prototype developed in this paper provides a novel approach, its maturity is still at an early stage regarding five specific aspects, which could be considered in further research. First, the input data used for the prototype are often incomplete, as much data is still not yet available or of bad quality. Therefore, the data testing plays a major role. Additionally, extending the environmental data by including further data points such as energy consumption, water use, waste management etc., thereby adding more statistical output may also be beneficial for valuable insights. Second, given the small amount of data that was used, the applied allocation method of scope 3 GHG emissions may be under-represented. Third, the interlinkages of scope 3 GHG emissions across value chains can be better approximated by using more specific allocation methods and thus, accounting for product-specific and sector-specific characteristics. Moreover, only GHG emissions related to the products and services purchased by the downstream party should be accounted for. However, this requires a deeper examination of the sector, product or service and activity in scope, as well as assessing the applicability of the allocation methods. It implies assessing the individual circumstances (e.g., characteristics of the activity, product or service, and sector in scope), as well as the categorization of scope 3 GHG emissions of activities identified. However, some of this data might not be available since some companies' data are either not publicly available or accessible. This requires a more intense and more frequent exchange of data between the members of certain value chains. Fourth, it may also be of interest to enrich the prototype's functionalities and output and improving the understanding of the relationships in the value chain and the emission flows across it. Fifth, the use of innovative financial technologies such as AI, IoT or blockchain offers various opportunities to deliver valuable insights that help reduce GHG emissions across specific value chains. But what needs to be emphasized here is that the essential prerequisite for these technologies to work properly is the availability of huge amounts of high-quality data and standards for data definition and exchange.

CRediT authorship contribution statement

Thomas Puschmann: Supervision, Conceptualization, Methodology, Writing. **Dario Quattrocchi:** Data curation, Prototyping, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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