npj | climate action

www.nature.com/npjclimataction

REVIEW ARTICLE OPEN

Check for updates

Supply-chain data sharing for scope 3 emissions

Aurel Stenzel[1] and Israel Waichman[2]✉

This paper deals with data sharing among firms along a supply chain for the calculation of Scope 3 emissions. Scope 3 emissions are indirect emissions produced along a firm's supply chain. They represent the majority of most firms' carbon footprint. Current estimations of Scope 3 emissions are largely based on industry averages and other approximations, which leads to several disadvantages. By contrast, primary data sharing along the supply chain would provide firms with precise measures of Scope 3 emissions (that are eventually necessary for decarbonizing supply chain emissions beyond industry averages). For that, firms need access to data and information from their suppliers that are not under their control. We review the benefits of and three main obstacles to such data sharing: legal and regulatory challenges, missing interoperability, and data privacy concerns. Finally, we discuss initiatives and approaches for overcoming these obstacles.

npj Climate Action (2023)2:7 ; https://doi.org/10.1038/s44168-023-00032-x

INTRODUCTION

Reducing greenhouse gas (GHG) emissions is among the momentous and most urgent challenges humanity is facing[1,2]. The problem is that mitigating climate change is essentially a global social dilemma, where mitigation efforts are very costly for individual countries (or firms), but the benefits are shared globally and would be realized in the future[3–9]. An additional barrier for successful mitigation stems from the considerable heterogeneities between countries regarding wealth, projected loss from climate change, historical emissions, etc[1,10–16].

We are in the midst of a digital revolution in production[17]. With the Internet of Things and an increasing number of connected devices, raw data are often created as by-products of firms' daily operations at very low costs; for example, logistic data from a company (such as volumes of truckloads, GPS truck positions, truck routes, etc.). Following Varian's[18] definition, *data* are raw alphanumeric values that need to be organized and contextualized to be turned into *information*. Knowledge is the conclusions and insights learned from that information. Data-based knowledge allows firms to gain better control over their production and supply chains, and the opportunity to reduce their costs and emissions. While firms are hesitant to share confidential information and knowledge with other firms, they are more willing to share encrypted data[19].

This paper deals with data sharing among firms along a supply chain for the calculation of product-level Scope 3 emissions; e.g., data on all material and energy inputs, purchased product components, transportation, and their direct emissions. It answers the following questions: What are the benefits of primary data sharing for Scope 3 emissions? What are the barriers for successful emission data sharing along the supply chain? And what are the current developments in overcoming these obstacles? Before answering these questions, we provide some background on Scope 3 emissions and their importance.

Effective data sharing became possible due to recent technological developments (e.g., digitalization in production and processes, increase in computer power, new encryption technologies, etc.). As mitigating climate change is a social dilemma, data sharing can increase the transparency of the situation and the accountability of the actors[20], and can even transfer the social dilemma to a coordination game[21]. Thus, the overarching motivation in sharing primary data for Scope 3 emissions is to optimally mitigate GHG emissions. In particular, by sharing company data with other firms, data are contextualized and turned into information. Latest innovations in cryptography allow the computation or analysis of shared data without requiring the parties to reveal their private inputs. The encryption reduces the risk for data owners to reveal sensitive data or lose control over it, and thus increases the willingness of firms to engage in data sharing[19]. With information derived from their data-sharing activities, firms can conclude (i.e., gain knowledge) about parts of the supply chain (e.g., emission reduction potentials).

We focus on Scope 3 emissions along the upstream supply chain ("cradle-to-gate"). In this regard, an important distinction is between "cradle-to-gate" and "cradle-to-grave". The former includes all upstream emissions in the production process (i.e., along the supply chain up to the reporting firm), whereas the latter also includes downstream emissions from the consumption of the good. Currently, much of Scope 3 data estimates are calculated based on industry averages, financial information, and approximations[20,22]. Such approximations sometimes yield close estimates to the actual emissions of a product, but other times the derived values are much less accurate. For instance, Downie & Stubbs[23] find that when conversion information is not available, there are wide discrepancies in reported emissions for the same activities among Australian firms. In this respect, corporate environmental performance (CEP) rating schemes do not yet provide a sufficiently good measure for emissions, and current CEP rating databases lack consistency[24]. The problem of using industry averages is that they may lead to insufficient incentives for firms to adopt cleaner-than-average technologies. By contrast, primary emission data that is shared along the supply chain can provide exact emissions on product- and firm-level. Thus, it allows firms to tackle emissions reduction at the most effective point on the supply chain, and also provides incentives for the adoption of cleaner technologies beyond the industry average.

The structure of the paper is as follows: In the next section, we introduce the notion of Scope 3 emissions. Section 3 reviews the main obstacles for sharing primary data for Scope 3 emission

[1]Department of Economics, University of Kiel, Olshausenstrasse 40, 24118 Kiel, Germany. [2]Department of Economics, Bard College Berlin, Platanenstrasse 24, 13156 Berlin, Germany. ✉email: i.waichmann@berlin.bard.eu

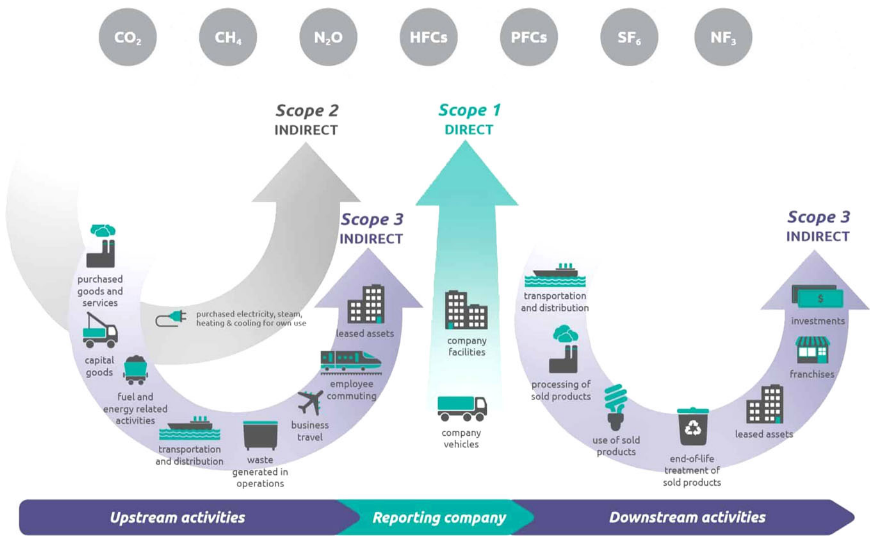

Fig. 1 Scope 1, 2 and 3 emissions (Source: ref. [28], Fig. 1.1, p. 5).

reporting. Section 4 explains what is required to overcome the main data sharing obstacles and discusses the current development in overcoming these obstacles. Finally, Section 5 concludes.

SCOPE 3 EMISSIONS: INTRODUCTION AND CURRENT ESTIMATION

Emissions generated in the production process can be classified as direct or indirect emissions. Direct emissions are those created by the reporting entity itself, whereas indirect emissions are embodied in products as raw materials are transformed along the supply chain[25]. In this respect, the GHG Corporate Protocol[26] provides a standardized definition for direct and indirect emissions in the production process. It classifies emissions as follows: Scope 1 emissions are direct emissions from owned or controlled sources, while Scope 2 and 3 emissions are indirect emissions. Scope 2 are emissions from the generation of acquired and consumed electricity, steam, heat, or cooling[27]. Scope 3 emissions include all other emissions along the supply chain, both upstream emissions related to the purchased goods and services, and downstream emissions related to sold goods and services (ref. [28], pp. 31–32). In this paper, we focus on upstream Scope 3 emissions consisting of emissions from purchased goods and services, capital goods, transportation of goods and services, waste generated in operations, business travel, employees commuting, and leased assets – see Fig. 1.

Under the corporate standard, firms are required to quantify and report Scope 1 and 2 emissions. However, to date, the reporting of Scope 3 emissions is recommended, but optional[22,29]. This is especially problematic because according to Matthews et al.[30], Scope 3 emissions represent, on average, 84% of a firm's total carbon emission footprint (whereas the remaining 16% are Scope 1 and 2). Moreover, in nearly two-thirds of all economic sectors, Scope 3 emissions represent more than 75% of their carbon emission footprint[30]. Similarly, Huang et al.[31] find that Scope 3 emissions are responsible for 70–80% of firms' total analyzed footprint for most manufacturing industries. Moreover, Hertwich & Wood[32] find that while direct (Scope 1) emissions increased by 47% between 1995 and 2015, indirect emissions grew considerably more: Scope 2 emissions increased by 78% and Scope 3 emissions by 84%.

To assess its Scope 3 emissions, a firm must map its total value chain (i.e., cradle-to-gate) and identify all emission sources. Often, a firm does not have access to the emission data from other firms along the supply chain (especially when firms are further away in the supply chain)[33]. The data used to calculate Scope 3 emissions should ideally be primary data. Primary data are data on actual emissions that are directly collected by firms (e.g., meter readings, purchase records, utility bills, engineering models, direct monitoring, etc.). With digital production processes, such data are produced as by-products or at very low costs. When we refer to data sharing, we refer to sharing of such primary data. When primary data are not available or shared along the supply chain, it becomes necessary to use secondary data to calculate Scope 3 emissions. Secondary data are not directly collected by the firms and are, e.g., industry average data, financial data, proxy data, and other generic data (ref. [34], p. 21). Such data could be used with so-called "environmentally extended input output (EEIO) models"[30–32,35,36]. EEIO models attribute emissions to final demands, providing a method of accounting for the embodied emissions in different sectors and regions for different products.

The potential benefits of accurately calculating and reporting Scope 3 emissions

To overcome climate change, governments, firms, and consumers need to reduce GHG emissions. Reporting of Scope 3 emissions increases transparency as it reveals the emissions in production processes, i.e., it allows firms to identify emissions as well as the most promising intervention points. Moreover, reporting leads to (at least some) accountability. Increasing accountability could increase cooperation through the actions of "conditional cooperators"[37–39]. Additionally, reporting opens the possibility for various types of sanctioning that have been shown to overcome social dilemmas[40,41] and could facilitate coordination between firms along the supply chain. However, when firms report their Scope 3 emissions, the overall emissions along the supply chain may become a liability for the firms, as they may be forced to reduce those emissions (e.g., by adopting low-pollution technologies, switching to "cleaner" suppliers, and improving material efficiency[25,42]). Yet, for the individual firms, emission reporting helps in identifying potential cost savings, potential and future climate change-related risk factors, and in seeking new business opportunities[43].

Scope 3 reporting based on primary data (i.e., representing the actual production technologies of the individual firms instead of industry averages) is also useful for investors seeking to assess a firm's strengths and reduce uncertainties. In fact, Matsumura et al.[44] find "that the markets penalize all firms for their carbon emissions, but a further penalty is imposed on firms that do not disclose emissions information”. Moreover, if consumers are aware of the embodied emissions of competing products, they may consider this information in their purchase decisions[45,46]. This would put pressure on firms to reduce emissions along the supply chain that could result in switching to low-emission suppliers, provide incentives for adopting low-pollution technologies, increasing material efficiency, etc. However, if Scope 3 emissions are reported based on secondary data of industry averages, then firms do not have an incentive to improve their processes beyond the industry average.

The current situation, where only Scope 1 and 2 emissions must be reported, may lead to a re-allocation of emissions to industries with stronger lobbies (i.e., with a lower chance to be regulated), or to “carbon leakage” to regions with less strict environmental standards. Since GHG emissions matter globally, this may impair the fight against climate change. In this context, Mytton[29] reports that when firms deploy information technology to the cloud, they switch their emissions from Scope 1 and 2 to Scope 3 emissions. Given the current reporting policy, firms may avoid reporting their Scope 3 emissions and thus brand themselves as “cleaner” (as they have now lower Scope 1 and 2 emissions), although they did not reduce emissions along the supply chain. Another point is that for emission trading institutions (e.g., EU ETS) to work efficiently, firms need to be aware of their actual emissions. Precise reporting (which can only be attained by sharing primary emission data along the supply chain) will also increase the efficiency of the emission permit trading systems.

Therefore, the overall consequences of not reporting Scope 3 emissions based on primary data (i.e., using secondary data that may or may not be close to the true values) may lead to a distorted climate policy[32], in particular to a less-than-optimal emission mitigation. Finally, firms that share data with each other may establish partnerships and also generate new business models, more efficient supply chains, and revenue from the monetization of their data[47].

OBSTACLES TO PRIMARY DATA SHARING

Today’s value chains are complex networks that include multiple tiers of different suppliers across the globe[48,49]. To (precisely) calculate Scope 3 emissions based on primary data, firms need access to data that are not under their control; all suppliers (in all tiers) need to measure and share relevant data with each other. However, some firms lack the in-house knowledge and personnel to prepare the required data for Scope 3 in a sharable way and would need to make significant up-front investments[50]. This is especially problematic for small and medium-sized firms with smaller operations, less personnel, and smaller budgets. And since sharing such data could also lead to a competitive disadvantage, as it might reveal confidential information on the production processes (e.g., costs, technology), firms are often hesitant to make the required investments[51].

In our analysis, we do not reflect on questions of data measurement. In fact, FERF[52] has estimated that the internal costs of accounting constitute between 1 (for large firms) and 3 percent (for smaller firms) of the revenues (see ref. [49], p. 949). Instead, we focus on the obstacles to sharing available emission data and review the following issues: lack of legal clarity and regulatory concerns, lack of data and action interoperability (allowing two or more IT systems to exchange data which is understood and can be re-used by the other system), and high risk in sharing sensitive data[22,47,50,53–55].

Legal and regulatory challenges

The rapid growth of global data volumes raises multiple legal and regulatory questions, for example with regard to data ownership, access to, and re-use of data[56–59]. For Scope 3 emissions, currently, firms do not have access to all the data they need and face (contractual) limitations when they re-share received data as part of their own emission footprint to the next tier in the supply chain. In addition, individual countries have started to protect data for local value creation by implementing an increasing amount of data localization measures[60]; i.e., measures that limit data flows across borders to not lose control over the data. An example for such a data localization measure is article 27 of the Data Act by the European Commission: It requires cloud computing providers to prevent the international transfer of non-personal data where such transfer might create a conflict with Union law. (Retrieved November 8, 2022 from https://digitalstrategy.ec.europa.eu/en/library/data-act-proposal-regulationharmonized-rules-fair-access-and-use-data) A review of different regulations and their impact on non-personal data sharing in general is offered in ref. [61,62]. For example, data sharing between firms may infringe anti-competition law, e.g., by fixing prices[50]. In particular, Scope 3 emissions data could include competition-relevant information such as production capacity, truck routes, etc[22]. Contrary to information and knowledge, data and their specific use regarding Scope 3 calculations are not covered by existing laws. For example, the Copyright DSM Directive by the European Commission grants copyright protection to information and knowledge representing a creative expression, but not to non-creative factual data[61]. Therefore, firms must decide on a case-by-case basis which data can be shared for what purpose[47]. Furthermore, “[u]nclear messages from governments on future regulations or major changes in reporting methodology may discourage early movers from investments in a specific reporting [(and data sharing)] infrastructure and generate a wait-and-see attitude [among firms]” (ref. [43], p. 25). In particular, the regulatory body should commit to a clear strategy for future emission reporting requirements (e.g., regarding precision and timing), as without clear legal commitments firms may be hesitant to report Scope 3 emissions and rather opt to “let sleeping dogs lie”, fearing that reporting might lead to legal implication without urgency (see ref. [43], p. 29). In sum, these legal and regulatory challenges lead to high uncertainty and costs for supply-chain data sharing.

Interoperability

A study by the European Commission[47] identifies missing interoperability as one of the main obstacles for more data sharing across firms in general. Interoperability can be defined as “a measure of the degree to which diverse systems, organizations, and/or individuals are able to work together to achieve a common goal” (ref. [63], p. 2). In particular, the lack of interoperability regarding Scope 3 emissions is twofold: First, a lack of harmonized standards to measure GHG emissions, and second, the absence of a common infrastructure to technically exchange emission data across IT systems. Existing standards (e.g., ISO standards, GHG Protocol standards) and sector guidelines (such as the Product Category Rules or Product Environmental Footprint method) leave room for interpretation[22,53,64]. Scope 3 emission footprints build up on top of the emission data input of different suppliers, but lack an overarching harmonization and integration[33]. With missing data interoperability, i.e., when suppliers within a supply chain use different calculation standards or interpret certain inputs differently, the resulting Scope 3 emission footprint is inconsistent and insufficient. But even if all firms along a supply chain agree to a certain calculation standard, they still face a lack of action interoperability, i.e., most IT systems cannot exchange data with other systems across company boundaries. In a global value chain including very small producers, a variety of IT systems are used. Current data exchange is realized with high manual efforts and surveys or spreadsheets leading to high costs[22].

Data privacy

Another major obstacle for data sharing is the risk of sharing sensitive data. Product-level emission data can enable reverse engineering to conclude insights into production processes (e.g., information about product composition and supplier networks) and is therefore considered to be competitively relevant[33]. Firms are very hesitant to share such data. For example, a survey among producing firms revealed that 42% fear losing innovative or competitively relevant knowledge if data are shared or locked into one data platform[65]. Moreover, Pauer et al.[66] conducted a survey with executives from large enterprises as well as small and medium-sized firms throughout Germany: 57% of the respondents stated that "[a]nxiety about core data and business secrets being exposed" is a "very big [or] rather big obstacle" for data and information sharing, 51% expressed that "[s]haring competitive information is dangerous because it might create advantages for competitors". Furthermore, 59% of the respondents stated that it is a "very big [or] rather big obstacle" that "we cannot check who is going to read our data if they are uploaded to the platform" (ref. [66], p. 25). Those data privacy concerns sum up to a significant obstacle to sharing primary data and thus enabling other firms to calculate their emission footprint.

OVERCOMING THE OBSTACLES TO PRIMARY DATA SHARING

There is already a large (and constantly increasing) number of initiatives seeking to address the obstacles reported in the previous section and thus promote successful sharing of emission data along the supply chain. In this section, we discuss different initiatives and their approaches (focusing on the obstacles as categorized above rather than on individual initiatives).

Overcoming legal and regulatory challenges

Private firms have only limited possibilities to influence legal and regulatory environments. It is the task of policy makers and regulators (e.g., international bodies such as the United Nations and its subsidies, European Commission, national governments) to remove legal and regulatory barriers to data sharing. First, they could make Scope 3 emission reporting obligatory (regional attempts have been made, e.g., the Corporate Sustainability Reporting Directive of the European Union, and the Enhancement and Standardization of Climate-Related Disclosures of the U.S. Securities and Exchange Commission). Second, policy makers and regulators have the task to ensure "that information provided by [firms] is timely, reliable and relevant" (ref. [43], p. 24). The more the precision requirement is emphasized, the more important it becomes to share primary emission data (as it is the only means to provide actual numbers rather than estimates). For example, under the UK Carbon Reduction Commitment Program, the Environment Agency conducts third-party audits of 20% of the participants every year. In Japan, entities that submit false reports or fail to meet the reporting criteria can be fined (ref. [43], p. 38). In May 2022, the U.S. Securities and Exchange Commission fined the Bank of New York Mellon USD 1.5 million for misstatements in its sustainability reporting. (Retrieved November 7, 2022 from https://www.sec.gov/news/press-release/2022-86) Third, when governments commit to a future date where Scope 3 emission reporting would be mandatory, they could provide incentives for first movers. Fourth, to meet the global dimension of supply chains, regulatory bodies could create regulations to enable free movement of data across borders (e.g., regulation on the free flow of non-personal data by the European Commission).

Overcoming missing interoperability

Interoperability in emission data sharing brings a twofold challenge: First, to create a harmonized standard to measure GHG emissions, and second, to create a common infrastructure to technically exchange emission data across IT systems. To address the first challenge of interoperability, standard setters (e.g., Greenhouse Gas Protocol, ISO, European Commission) strive to establish one harmonized standard on how to measure Scope 3 emissions within supply chains in a consistent way. The ISO developed and is still working on various standards to measure emission data (e.g., ISO 14067:2018 defines requirements and guideline for measuring the carbon footprint of products). Additionally, the European Commission published the Product Environmental Footprint method (PEF), quantifying the environmental impact of products, and the Product Environmental Footprint Category Rules (PEFCR), defining guidance at the level of specific product categories. Private coalitions or public-private partnerships (e.g., World Business Council for Sustainable Development (WBCSD), SME Climate Hub, CEO Alliance, We Mean Business Coalition) can use their market reach to facilitate overarching conversations and to establish a harmonized standard across industries. For example, the WBCSD has initiated the Partnership for Carbon Transparency (PACT), that brings together leading firms from a range of industries, technology players, industry-focused initiatives, standard-setting organizations, reporting bodies and regulators seeking to define an overarching standard for Scope 3 emissions. PACT launched a coordinated and open approach to calculate product carbon footprints (PCFs) along the whole value chain. The partnership published a methodology of standards for the calculation of PCFs that leverages and aligns with existing methods and standards, e.g., GHG Protocol, PEF and PEFCR, and removes the room for interpretation and inconsistency[24,26–28,34].

To solve the issue of action interoperability, i.e., the ability of different IT systems to exchange information, PACT, together with the non-profit SINE Foundation, launched a technical infrastructure for data sharing based on open-source technology. This infrastructure defines rules for data sharing such as data formats and standards describing how to connect the different IT systems used by firms across the value chain[22]. PACT initiated a collaborative process in which large corporations and software providers developed technical core components of the network together. With the standards defined in the methodology, the infrastructure is open and interoperable, connecting different IT systems. Another example for an open-source infrastructure for sustainability data sharing is OS-Climate, an open-source project backed by the Linux Foundation, building technology and data platforms focusing on data availability, comparability, and reliability. The goal is to provide data about climate change impact and incorporate that data into global financial decision-making and risk management.

As a non-profit organization consisting of 122 firms from the automotive industry, the Catena-X Automotive Network e.V. created a uniform standard for data exchange along the entire value chain. It connects all members in the automotive supply chain without lock-in effects, provides a sustainable solution for the digitalization of supply chains, especially for small and medium-sized firms, and supports the cooperation and collaboration of market participants and competitors. Catena-X allows for different kinds of data sharing including emission data. Finally, the Smart Freight Center was established in 2013 as a non-profit organization and works with the global logistics community to drive transparency and industry action. To harmonize the calculation and reporting of the logistics emission footprints, the Smart Freight Center published the Global Logistics Emissions Council Framework which can be implemented by shippers, carriers and logistics service providers.

To overcome the obstacle of interoperability, the different initiatives need to remain open and collaborative to establish one harmonized standard across countries and industries for consistent data measurement and the exchange of emission data.

Table 1. Obstacles to data sharing and current approaches.

	Legal clarity and regulatory concerns	Missing data and action interoperability	High risk in sharing sensitive data
Description	Firms not having access to supply-chain data and facing (contractual) limitations to use and re-share (e.g., anti-trust); data localization measures limiting cross-border data flow; high levels of uncertainty leading to high regulatory costs for firms to report emissions.	Lack of harmonized standards to measure Scope 3 emissions – existing standards and sector guidelines leave room for interpretation; absence of a common infrastructure to technically exchange emission data across IT systems.	Risk of exposing data and enabling reverse engineering (e.g., product composition, supplier networks).
Current approaches	Move to mandatory and Scope 3 reporting; move to timely, reliable, and verifiable emission data; commitment to future reporting policy; regulations for the free flow of non-personal data.	Coalitions consisting of companies from a range of industries, technology players, industry-focused initiatives, standard-setting organizations, reporting bodies and regulators to define overarching standards and technical infrastructures.	Neutral data trusts to empower data holders and provide a technical environment for data processing and analysis while holding everyone accountable for his or her actions; decentralized data storage combined with homomorphic encryption technologies; cybersecurity firms will protect confidential data and information.

Overcoming data privacy concerns

Ensuring data privacy is a necessary condition for successful data sharing between firms. One promising possibility to enable data sharing while protecting the firms' privacy are data trusts; neutral stewards that manages a firm's or person's data on their behalf. A data trust "works within the law to provide ethical, architectural and governance support for trustworthy data processing" (ref. [67], p. 6). A data trust has two key functions: First, providing data holders the possibility to execute their rights and to set limitations on who can do what with their data. Second, providing a technical environment in which data processing and analysis can take place while holding everyone accountable for his or her actions. Organizations such as the SINE Foundation, OS-Climate or Catena-X were established as non-profit organizations to be able to function as data trusts for the exchange of sustainability data. Besides a data governance, data trusts also need to provide technical tools such as encryption technologies to protect the data.

Academic research on so-called 'homomorphic encryption technologies' has now become possible in practice due to the increase in computing power[68,69]. Without homomorphic encryption technology, data need to be revealed to be utilized (leading to a decrease in privacy of the sharing party, i.e., the privacy-personalization paradox[70]). Examples for homomorphic encryption are "zero-knowledge proofs" and "secure multi-party computing". With "zero-knowledge proofs"[71], a party can prove that it meets certain criteria (e.g., proving that a product carbon footprint is below a certain threshold) without revealing any other information. "Secure multi-party computing"[72] is a protocol that allows computation or analysis of combined data without the different parties revealing their private input[73]. A large pool of data is always a security risk and will be luring cyber attackers. One solution (used e.g., by PACT) is to allow the firms to keep their data decentralized and share it peer to peer which decreases the attractiveness for hackers. Data trusts and homomorphic encryption technologies in combination with decentralized data storage enable firms to overcome the privacy-personalization paradox and thus solve the data privacy concerns as an obstacle for emission data sharing.

Finally, whenever a firm holds confidential data or information, there are issues of cybersecurity involved. Cybersecurity refers to "the set of technologies, processes, and practices designed to protect networks, computers, programs, and data from attack, damage, or unauthorized access, in accordance with the common information security goals: the protection of confidentiality, integrity, and availability of information" (ref. [74], p. 105). The global cybersecurity market is constantly increasing. Fortune Business projected it "to grow from USD 155.83 billion in 2022 to USD 376.32 billion by 2029" (Retrieved from https://www.fortunebusinessinsights.com/industry-reports/cybersecurity-market-101165) and private cybersecurity firms will be part of securing the data and information.

Summary

Table 1 presents a short summary of the three main obstacles to primary data sharing, and current approaches to overcome them.

CONCLUDING REMARKS

This article underlines the benefits of and the obstacles to sharing primary data for the calculation of Scope 3 emissions along the supply chain. We started by defining Scope 3 emissions, their relevance in sustainability reporting, and why their precise calculation (beyond industry averages) requires data sharing among firms. While the ongoing digitization of production is reducing the costs of data measurement, data sharing among firms requires overcoming three main obstacles: legal and regulatory challenges, missing interoperability, and data privacy concerns. The paper reviewed these obstacles and discussed the current progress in overcoming them.

Nowadays, the production of goods is a global and complex process involving several suppliers. The number of sustainability start-ups focusing on the measurement of Scope 3 emissions is increasing every day. Many of them provide estimates based on industry averages. While such data cannot provide precise emission values, they may serve as starting points. However, only primary data sharing provides actual emission numbers and thus has the potential to accelerate the decarbonization of the economy. Primary data sharing may also provide additional benefits to individual firms and enable new business models within digitized supply chains. For example, to account for transportation emissions, a firm needs to share data on the mode of transportation (e.g., road, rail), distance covered, and load specifications[22]. If these data are shared in real-time, firms could use them to coordinate collective logistic optimization. For example, Procter & Gamble (P&G) and Tupperware shared their logistics data and identified significant potential for load consolidation. They used similar routes, and their truckloads were complementary and thus offered substantial potential gains from coordination: Tupperware's trucks were filled to around 80% of the maximum volume of the vehicle but only 30% of its weight—while P&G's trucks were at 50% of the maximum volume of the vehicle but 95% of its weight. With real-time data sharing, they coordinated a consolidation of their loads, saving 17% of the transportation costs and more than 200 Mt CO2. (Retrieved March 27, 2022, from https://www.eknowit.eu/the_case_studies/case_study02.pdf) In addition, Pedreira & Melo[75] suggest a possible reduction of CO2 emissions of up to 23% if all firms sought similar arrangements as described above. Irannezhad et al.[76] conducted a study at the Port of Brisbane showing an emission reduction potential of up to 40% if the logistic firms operating at the port would share their data to coordinate their activities (e.g., to reduce the number of empty trucks).

Thus, the potential benefits of data sharing among firms (e.g., logistic consolidation) are even larger than the mere benefits of calculating Scope 3 emissions. In order to utilize the sharing of primary data for the calculation of Scope 3 emissions and beyond, different stakeholders—including regulatory bodies, standard setters, climate initiatives, research institutes, and private firms—need to take a systemic and global perspective to overcome the three major obstacles for data sharing along supply chains.

Received: 15 July 2022; Accepted: 9 December 2022;
Published online:

REFERENCES

1. IPCC. *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Pörtner, H.-O. et al.) (Cambridge University Press, 2022).
2. Tosun, J. Addressing climate change through planning. *Climate Action* **1**, 1–4 (2022).
3. Barrett, S. *Why Cooperate? The Incentive to Supply Global Public Goods* (Oxford University Press, 2007).
4. Hauser, O. P., Rand, D. G., Peysakhovich, A. & Nowak, M. A. Cooperating with the future. *Nature* **511**, 220–223 (2014).
5. Battersby, S. News feature: can humankind escape the tragedy of the commons? *Proc. Natl Acad. Sci. USA* **114**, 7–10 (2017).
6. Nordhaus, W. Climate change: the ultimate challenge for economics. *Am. Econ. Rev.* **109**, 1991–2014 (2019).
7. Buchholz, W. & Sandler, T. Global public goods: a survey. *J. Econ. Literature* **59**, 488–545 (2021).
8. Lohse, J. & Waichman, I. The effects of contemporaneous peer punishment on cooperation with the future. *Nat. Commun.* **11**, 1815 (2020).
9. Boon-Falleur, M., Grandin, A., Baumard, N. & Chevallier, C. Leveraging social cognition to promote effective climate change mitigation. *Nat.Climate Change* **12**, 332–338 (2022).
10. Heyward, M. Equity and international climate change negotiations: a matter of perspective. *Climate Policy* **7**, 518–534 (2007).
11. Lange, A., Löschel, A., Vogt, C. & Ziegler, A. On the self-interested use of equity in international climate negotiations. *Eur. Econ. Rev.* **54**, 359–375 (2010).
12. Burton-Chellew, M., May, R. & West, S. Combined inequality in wealth and risk leads to disaster in the climate change game. *Clim. Change* **120**, 815–830 (2013).
13. Brown, T. C. & Kroll, S. Avoiding an uncertain catastrophe: climate change mitigation under risk and wealth heterogeneity. *Clim. Change* **141**, 155–166 (2017).
14. Waichman, I., Requate, T., Karde, M. & Milinski, M. Challenging conventional wisdom: experimental evidence on heterogeneity and coordination in avoiding a collective catastrophic event. *J. Environ. Econ. Manage.* **109**, 102502 (2021).
15. Bathiany, S., Dakos, V., Scheffer, M. & Lenton, T. M. Climate models predict increasing temperature variability in poor countries. *Sci. Adv.* **4**, 5 (2018).
16. Mendelsohn, R., Dinar, A. & Williams, L. The distributional impact of climate change on rich and poor countries. *Environ. Dev. Econ.* **11**, 159–178 (2006).
17. Bojanova, I. The digital revolution: what's on the horizon? *IT Professional* **16**, 8–12 (2014).
18. Varian, H. *The Economics of Artificial Intelligence: An Agenda* (eds Agrawal A., Gans J., & Goldfarb A.) 399–419 (University of Chicago Press, 2018).
19. Jones, C. I. & Tonetti, C. Nonrivalry and the economics of data. *Am. Econ. Rev.* **110**, 2819–2858 (2020).
20. Li, M., Wiedmann, T. & Hadjikakou, M. Enabling full supply chain corporate responsibility: scope 3 emissions targets for ambitious climate change mitigation. *Environ. Sci. Technol.* **54**, 400–411 (2020).
21. Barrett, S. & Dannenberg, A. Climate negotiations under scientific uncertainty. *Proc. Natl Acad. Sci. USA* **109**, 17372–17376 (2012).
22. WBCSD. Pathfinder Framework: Guidance for the Accounting and Exchange of Product Life Cycle Emissions (World Business Council for Sustainable Development (WBCSD), Geneva, 2021).
23. Downie, J. & Stubbs, W. Corporate carbon strategies and greenhouse gas emission assessments: the implications of scope 3 emission factor selection. *Business Strategy Environ.* **21**, 412–422 (2012).
24. Rekker, S. A., Humphrey, J. E. & O'Brien, K. R. Do sustainability rating schemes capture climate goals? *Business Society* **60**, 125–160 (2021).
25. Scott, K., Roelich, K., Owen, A. & Barrett, J. Extending European energy efficiency standards to include material use: an analysis. *Climate Policy* **18**, 627–641 (2018).
26. WRI/WBCSD. *GHG Protocol Corporate Accounting and Reporting Standard, Revised Edition* (World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), Washington DC, 2004).
27. WRI/WBCSD. *GHG Protocol Scope 2 Guidance (Author: Sotos M.)* (World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), Washington DC, 2015).
28. WRI/WBCSD. *Corporate Value Chain (Scope 3) Accounting and Reporting Standard: Supplement to the GHG Protocol Corporate* (World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), Washington DC, 2011).
29. Mytton, D. Hiding greenhouse gas emissions in the cloud. *Nat. Clim. Change* **10**, 701–701 (2020).
30. Matthews, H. S., Hendrickson, C. T. & Weber, C. L. The importance of carbon footprint estimation boundaries. *Environ. Sci. Technol.* **42**, 5839–5842 (2008).
31. Huang, Y. A., Weber, C. L. & Matthews, H. S. Categorization of scope 3 emissions for streamlined enterprise carbon footprinting. *Environ. Sci. Technol.* **22**, 8509–8515 (2009).
32. Hertwich, E. G. & Wood, R. The growing importance of scope 3 greenhouse gas emissions from industry. *Environ. Res. Lett.* **13**, 104013 (2018).
33. Jaeger, F. A. et al. Challenges and requirements of exchanging Product Carbon Footprint information in the supply chain. In *E3S Web of Conferences 10th International Conference on Life Cycle Management (LCM 2021)*, 349, 07005 (2022).
34. WRI/WBCSD. *Technical Guidance for Calculating Scope 3 Emissions: Supplement to Corporate Value Chain (Scope 3) Accounting and Reporting Standard* (World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), Washington DC, 2013).
35. Wiedmann, T. A review of recent multi-region input–output models used for consumption-based emission and resource accounting. *Ecol. Econ.* **69**, 211–222 (2009).
36. Kitzes, J. An introduction to environmentally-extended input-output analysis. *Resources* **2**, 489–503 (2013).
37. Keser, C. & Van Winden, F. Conditional cooperation and voluntary contributions to public goods. *Scand. J. Econ.* **102**, 23–39 (2000).
38. Fischbacher, U., Gächter, S. & Fehr, E. Are people conditionally cooperative? Evidence from a public goods experiment. *Econ. Lett.* **71**, 397–404 (2001).
39. Rustagi, D., Engel, S. & Kosfeld, M. Conditional cooperation and costly monitoring explain success in forest commons management. *Science* **330**, 961–965 (2010).
40. Fehr, E. & Gächter, S. Altruistic punishment in humans. *Nature* **415**, 137–140 (2002).
41. Tyran, J. R. & Feld, L. P. Achieving compliance when legal sanctions are non-deterrent. *Scand. J. Econ.* **108**, 135–156 (2006).
42. Liu, G., Bangs, C. E. & Müller, D. B. Stock dynamics and emission pathways of the global aluminium cycle. *Nat. Clim. Change* **3**, 338–342 (2013).
43. Kauffmann, C., C. Tébar Less. & Teichmann D. *Corporate Greenhouse Gas Emission Reporting: A Stocktaking of Government Schemes, OECD Working Papers on International Investment* (OECD Publishing, Paris, 2012).
44. Matsumura, E. M., Prakash, R. & Vera-Munoz, S. C. Firm-value effects of carbon emissions and carbon disclosures. *Account. Rev.* **89**, 695–724 (2014).
45. Korkala, E. A., Hugg, T. T. & Jaakkola, J. J. Awareness of climate change and the dietary choices of young adults in Finland: a population-based cross-sectional study. *PloS one* **9**, e97480 (2014).
46. Jürkenbeck, K., Spiller, A. & Schulze, M. Climate change awareness of the young generation and its impact on their diet. *Clean. Responsible Consump.* **3**, 100041 (2021).
47. European Commission. Study on emerging issues of data ownership, interoperability, (re-)usability and access to data, and liability: final report (author: Directorate-General for Communications Networks, Content and Technology; Wauters, P., Siede, A., Cocoru, D., et al.) https://op.europa.eu/en/publication-detail/-/publication/74cca30c-4833-11e8-be1d-01aa75ed71a1/language-en (2018).
48. Hearnshaw, E. J. & Wilson, M. M. A complex network approach to supply chain network theory. *Int. J. Oper. Prod. Manage.* **33**, 442–469 (2013).
49. Patchell, J. Can the implications of the GHG Protocol's scope 3 standard be realized? *J. Clean. Prod.* **185**, 941–958 (2018).

50. OECD. *Enhancing Access to and Sharing of Data: Reconciling Risks and Benefits for Data Re-use across Societies*. (OECD Publishing, 2019).
51. Kraemer, J., Stüdlein, N. & Zierke, O. Data as a public good: experimental insights on the optimal design of B2B data sharing platforms. *Available at SSRN 3970821* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3970821 (2021).
52. FERF (Financial Executives Research Foundation). *Benchmarking: The Accounting and Finance Function* (Financial Executives Research Foundation, Morristown N.J., 2014)
53. European Commission. Commission recommendation of 16.12.2021on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations (author: Directorate-General for Environment) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM%3AC%282021%299332 (2021).
54. Martens, B., De Streel, A., Graef, I; Tombal, T. & Duch Brown, N. Business-to-business data sharing: An economic and legal analysis. In *JRC Digital Economy Working Paper, No. 2020-05* (European Commission, Joint Research Centre (JRC), Seville, 2020).
55. Bertin, M., De Streel, A., Graef, I., Tombal, T. & Duch-Brown, N. Business-to-business data sharing: an economic and legal analysis. In *JRC Digital Economy Working Paper, No. 2020-05* (European Commission, Joint Research Centre (JRC), Seville, 2020).
56. Drexl, J. Designing competitive markets for industrial data: between propertisation and access. *J. Intell. Property, Inform. Technol. Electron. Commerce Law* **8**, 257–292 (2017).
57. Wiebe, A. Protection of industrial data–a new property right for the digital economy? *J. Intell. Property Law Pract.* **12**, 62–71 (2017).
58. Hummel, P., Braun, M. & Dabrock, P. Own data? Ethical reflections on data ownership. *Phil. Technol.* **34**, 545–572 (2021).
59. Asswad, J. & Gómez, J. M. Data ownership: a survey. *Information* **12**, 465 (2021).
60. Wu, E. *Sovereignty and data localization*. Report: Belfer Center for Science and International Afiairs, Harvard Kennedy School. Retrieved November 5, 2022, https://www.belfercenter.org/sites/default/files/2021-07/SovereigntyLocalization.pdf (2021).
61. SCDS. Analytical report on EU law applicable to sharing of non-personal data, SMART 2018/1009 v2.0 Support Centre for Data Sharing (2020).
62. Leistner, M. & Antoine L. *IPR and the Use of Open Data and Data Sharing Initiatives by Public and Private Actors* (Study commissioned by the European Parliament's Policy Department for Citizens' Rights and Constitutional Affairs at the request of the Committee on Legal Affairs, 2022).
63. Ide, N. & Pustejovsky, J. What does interoperability mean, anyway? Toward an operational definition of interoperability for language technology. In *Proceedings of the Second International Conference on Global Interoperability for Language Resources* Hong Kong, China (2010).
64. ISO. *Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification*. International Organization for Standardization (ISO 14067:2018). Retrieved from https://www.iso.org/standard/71206.html (2019).
65. EFI (Expertenkommission Forschung und Innovation). *Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands*. Retrieved April 24, 2022 https://www.e-fi.de/publikationen/gutachten (2022).
66. Pauer, A., Nagel, L., Fedkenhauser, T., Yvonne, F.-S. & Resetko, A. *Data exchange as a first step towards data economy*. https://www.pwc.de/en/digitale-transformation/data-exchange-as-a-first-step-towards-data-economy.pdf. Accessed: 13.04.2022 (2018).
67. O'Hara, K. *Data Trusts: Ethics, Architecture and Governance for Trustworthy Data Stewardship (WSI White Papers, 1) Southampton* (University of Southampton, 2019).
68. Royal Society. *Protecting Privacy in Practice: The Current Use, Development and Limits of Privacy Enhancing Technologies in Data Analysis*. Retrieved April 24, 2022, from https://royalsociety.org/-/media/policy/projects/privacy-enhancing-technologies/privacy-enhancing-technologis-report.pdf (2019).
69. WEF. The Next Generation of Data-Sharing in Financial Services: Using Privacy Enhancing Techniques to Unlock New Value. Retrieved April 24, 2022, from https://www3.weforum.org/docs/WEF_Next_Gen_Data_Sharing_Financial_Services.pdf (2019).
70. Kaaniche, N., Laurent, M. & Belguith, S. Privacy enhancing technologies for solving the privacy-personalization paradox: Taxonomy and survey. *J. Netw. Comput. Appl.* **171**, 102807 (2020).
71. Goldwasser, S., Micali, S. & Rackoff, C. The knowledge complexity of interactive proof systems. *SIAM J. Comput.* **18**, 186–208 (1989).
72. Yao, A. C. How to generate and exchange secrets. In *27th Annual Symposium on Foundations of Computer Science* 162–67 (1986).
73. Bogdanov, D., Talviste, R. & Willemson, J. Deploying secure multi-party computation for financial data analysis. In *International Conference on Financial Cryptography and Data Security* 57–64 (Springer, 2012).
74. Dunn Cavelty, M. From cyber-bombs to political fallout: threat representations with an impact in the cyber-security discourse. *Int. Stud. Rev.* **15**, 105–122 (2013).
75. Pedreira, H. B. & Melo, T. Supply chain coopetition: A simulation model to explore competitive advantages in logistics. Capstone submitted to the program in supply chain management in partial fulfillment of the requirements for the degree of master of applied science in supply chain management at the Massachusetts Institute of Technology. Retrieved March 27, 2022, from https://ctl.mit.edu/pub/thesis/supply-chain-coopetition-simulation-model-explore-competitive-advantages-logistics (2020).
76. Irannezhad, E., Prato, C. G. & Hickman, M. The effect of cooperation among shipping lines on transport costs and pollutant emissions. *Transport. Res. Part D: Transport Environ.* **65**, 312–323 (2018).

ACKNOWLEDGEMENTS

We are grateful to Nicolas Duvoisin, Yasha Tarani, and Francesco Vogelezang for their invaluable comments and discussion. We would like to thank the editor and three anonymous referees for their invaluable suggestions and comments.

AUTHOR CONTRIBUTIONS

The review was written by A.S. and I.W.

FUNDING

Open Access funding enabled and organized by Projekt DEAL.

COMPETING INTERESTS

The authors declare no competing interests. Aurel Stenzel is a PhD candidate in Quantitative Economics at Kiel University and a co-founding member and co-chairman of the SINE foundation. SINE is a nonprofit think tank combining academics and technology entrepreneurs to promote data sharing for the common good. SINE is a technology partner in the Partnership for Carbon Transparency. Israel Waichman is a professor of Economics at Bard College Berlin and a co-founding member of the SINE Foundation.

ADDITIONAL INFORMATION

Correspondence and requests for materials should be addressed to Israel Waichman.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.