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Toward net 0
Digital CO_2 proofs for the sustainable transformation of the European economy

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Executive Summary

With the growing priority of decarbonization and the associated emission reduction instruments, the need for emission data and the obligation to report emissions across sectors have increased. In this context, the administrative burden of collecting, processing, and providing CO_2 information multiplies as national and European regulatory frameworks evolve. Expanding reporting obligations (e.g., in relation to due diligence requirements in the value chain and the introduction of the Taxonomy Regulation), new CO_2 pricing mechanisms (e.g., through the EU ETS II and the CBAM), and further initiatives for the collection of CO_2 information (e.g., a digital product passport) are a few of the reasons for this increased administrative burden. However, the current lack of granularity in the collected CO_2 emissions data prevents CO_2 emissions from being passed on according to their actual origin and use in the value chain and from being uniquely allocated to specific emission reduction measures and CO_2 budgets. Without a unique allocation, however, double counting of emissions cannot be prevented and effective monitoring of economic processes according to CO_2 specifications is not possible. Transparent, reliable, and verifiable emissions data in the form of digital CO_2 proofs provide a solution.

In this context, this study identifies challenges in providing CO_2 information from a business perspective. Based on interviews conducted with experts from various industries, including the automobile industry, the construction industry, and the energy industry, this study analyzes the potential of digital CO_2 proofs of origin and use and derives recommendations for action in climate policy.

Identified Challenges and Requirements

Interviews conducted for this study revealed the following challenges and requirements for companies:

Available Know-How

Since collecting and processing emissions data as well as their publication and communication is a relatively new field of activity for companies, the corresponding know-how for the new processes is often lacking. In the initial years in which a company calculates and publishes emissions data, a considerable amount of personnel is often required to implement and establish the necessary processes for data collection and processing. The difficulties in finding new personnel with the required know-how increase the companies' effort to develop efficient, digital, and suitable processes for emissions data.

Company Management and Controlling

Although emissions data are of increasing importance, there currently is a lack of economic incentives to incorporate CO_2 data as a decisive factor for economic decisions. For example, companies do not know whether investments in better measurement infrastructure will generate a positive return on investment (RoI).

This is mainly the case because it is difficult to assign an exact economic value to emissions and the associated climate damage that can be integrated into business models and investment calculations. Similarly, companies should enable the evaluation and management of investments and emission reduction measures at shorter time intervals with regard to the associated emissions.

Challenges with Data Collection

There are several challenges related to the collection of emissions data. The lack of fine granular data is primarily due to the missing measurement infrastructure at the company and the difficulty in obtaining valid emissions information from process steps outside of the company. Hence, data collection for Scope 3 emissions is particularly challenging, which is why these emissions are only partially collected and aggregated using average calculations and estimates. In the data collection process, potential errors in data transmission and the susceptibility of the collected data to manipulation are essential concerns for companies.

Challenges with Data Processing

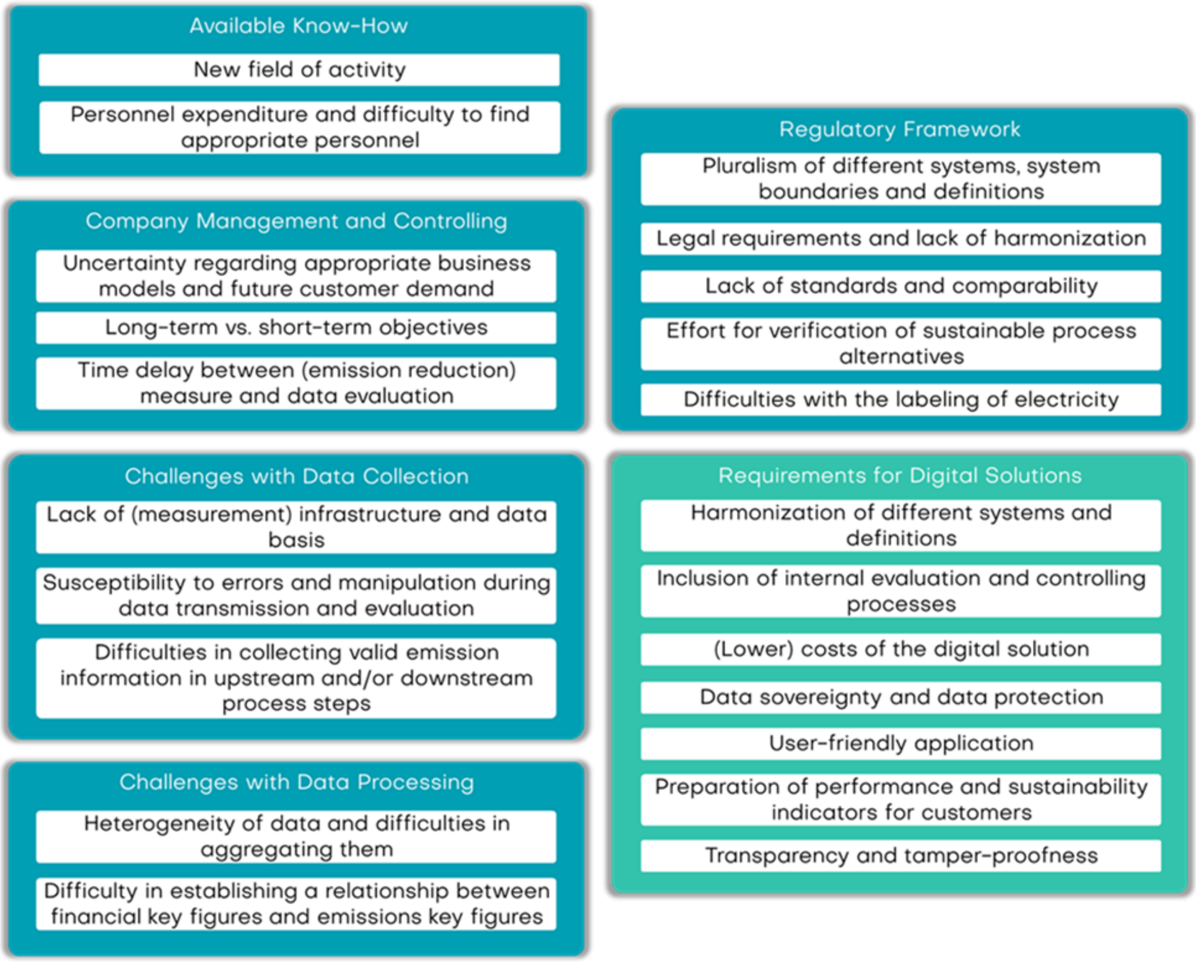
When processing the collected data, difficulties arise in aggregating it to specific key figures, as the data collected is available in different units and temporal resolutions and is, therefore, often heterogeneous. This challenge is intensified when calculated key figures of emissions are to be integrated with financial key figures from other company departments.

Regulatory Framework

The regulatory framework poses challenges, such as the pluralism of different systems, system boundaries, and definitions that companies must observe and communicate due to regulations and voluntarily chosen standards. The pluralism of systems and definitions hinders the comparison of emissions information. In addition to the direct requirements for emissions information for different reports, the effort required to verify sustainable process alternatives (e.g., new production methods and the use of alternative raw materials or primary products) and the regulatory uncertainty of labeling electricity (e.g., in the context of storage and hydrogen) are also challenging.

Requirements for Digital Solutions

The interviewed company representatives derived their requirements for digital solutions from the challenges identified. The following key priorities emerged: The harmonization of the different systems and definitions for mandatory and voluntary standards as well as reports and the inclusion of the company's internal evaluation and control processes should be enabled by digital solutions. Likewise, the necessary investments in digital solutions should be amortized. Furthermore, user-friendly applications for employees are of great importance for the implementation of a digital solution. From a technical point of view, ensuring data sovereignty and sufficient data protection as well as the transparency of the digital processes and the extent to which the data is tamper-proof play a significant role. To communicate emissions information to customers in a suitable manner, digital solutions should enable the preparation of performance and sustainability indicators.



Confirmation of Hypotheses

Based on the results of the interviews, the study confirms the following hypotheses:

Hypothesis 1: Economic and regulatory uncertainty with regard to CO_2 pricing prevents companies from engaging in a long-term, targeted transformation toward climate-friendly processes.

Hypothesis 2: The burden of bureaucratic documentation with regard to CO_2 emissions increases significantly for companies.

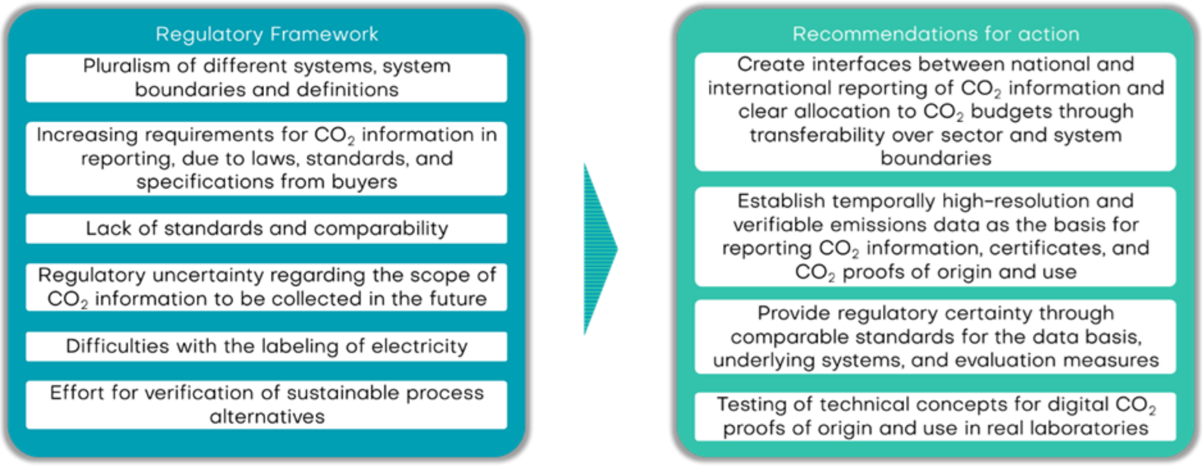
Hypothesis 3: Digital collection and reporting of CO_2 emissions at companies could provide direct incentives for emission reductions and create competitive advantages for companies. *(Partial confirmation)*

Hypothesis 4: If companies want to use high-resolution CO_2 information for economic purposes, the information must be communicated in a verifiable manner. This requires new technological solutions.

Hypothesis 5: Digital and product-specific CO_2 proofs of origin and use enable a high-resolution differentiation of products and, thus, a CO_2 assessment independent of accounting definitions.

Recommendations for Policy Action

Based on the identified challenges, the study derives the following recommendations for policy action:



Recommendation 1: Create interfaces between national and international reporting of CO_2 information and unique allocation to CO_2 budgets through transferability over sector and system boundaries

Due to different system boundaries in assessing and calculating emitted greenhouse gases, double counting of CO_2 emissions can occur. This pluralism of system boundaries currently complicates the specific allocation of CO_2 emissions and reductions to a specific CO_2 budget and, thus, prevents the goal-oriented management of emission reduction measures. The transferability of CO_2 measurements between national and international boundaries, as well as system and sector boundaries, can be enabled by digital CO_2 proofs of origin and use. As a result, digital CO_2 proofs could help utilize the amount of CO_2 emissions as a consistent metric for companies across the value chain to manage the transformation toward climate-friendly processes.

Recommendation 2: Establish temporally high-resolution and verifiable emissions data as the basis for reporting CO_2 information, certificates, and CO_2 proofs of origin and use

To establish CO_2 emissions as a key decision-making factor for companies, emissions must be transmitted in a verifiable, transparent, forgery-proof manner and with a high temporal resolution. From a technical perspective, concepts for digital CO_2 proofs of origin and use can be based on recent developments in relation to a European identity management system as well as promising initiatives such as the development of a secure and transparent European data infrastructure. These concepts rely on purported self-sovereign identities (SSI) and blockchain technologies (tokenization). By increasing the granularity of the data basis, CO_2 proofs of origin and use can be passed on according to their actual *deployment in the value chain. Data at this level of detail is also necessary for initiatives such as a digital product passport, especially if products of the same type are to be differentiated according to their carbon footprint.*

Recommendation 3: Provide regulatory certainty through comparable standards for the data basis, underlying systems, and evaluation measures

There is a need to develop digital solutions that implement existing and future standards and best practices. More standardized frameworks would enable automated emissions data collection and analysis, thereby lean auditing processes. Existing technical concepts such as SSI can be used in combination with zero-knowledge proofs to speed up and make the existing certification and auditing processes more flexible and extend the functionality of current certification and product declarations. Furthermore, life cycle assessment standards should be developed to allow product-specific differentiation. These standards could then provide an incentive for a shift toward a more flexible and differentiated product assessment, for example, in the context of a digital product passport regarding environmental factors.

Recommendation 4: Testing of technical concepts for digital CO_2 proofs of origin and use in real laboratories

It is difficult for companies to quantify, ex ante, the direct added value from investing in systems for CO_2 data collection and monitoring. Therefore, possible technical solutions of digital CO_2 proofs of origin and use as well as their scaling should be evaluated in pilot projects and real laboratories. Implications for regulatory frameworks and legislative proposals as well as impacts on customer demand for products labeled with different carbon footprints can be derived from such pilot implementations.

In summary, the appropriate integration of digital technologies can enhance the visibility, verifiability, and reliability of CO_2 information and, thereby, greatly facilitate the transition to carbon-neutral products. Consequently, CO_2 proofs of origin and use based on technical concepts, such as blockchain and SSI, can form the interfaces between the different CO_2 instruments, such as EU ETS, CBAM, and EU taxonomy, and reduce transaction costs. Policymakers should consequently encourage the development of technical concepts for digital CO_2 proofs and their use and, thus, support their implementation. Furthermore, policymakers should evaluate the potential of digitalization when amending existing and developing new legislative frameworks with regard to emission reduction.

Abbreviations

BEHG	Fuel Emissions Trading Act (Ger. *Brennstoffemissionshandelsgesetz*)
Capex	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CSR	Corporate Social Responsibility
EEG	Renewable Energy Sources Act (Ger. *Erneuerbare-Energien-Gesetz*, EEG)
EHV	Emissions Trading Ordinance (Ger. *Verordnung zur Durchführung des Treibhausgas-Emissionshandelsgesetzes*)
ESG	Environment, Social, and Governance
EU ETS	European Emissions Trading System
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
CHP	Combined heat and power
LCA	Life Cycle Analysis
NDA	Non-Disclosure Agreement
Opex	Operating Expenditures
RED	Renewable Energy Directive
RLM	Recording electricity measurement
RoI	Return on Investment
SMGW	Smart Meter Gateway
SSI	Self-Sovereign Identity
TEHG	Greenhouse Gas Emissions Trading Act (Ger. *Treibhausgas-Emissionshandelsgesetz*)
ZKP	Zero-Knowledge Proof

Glossary

B

Blockchain
Networked computers that reach a consensus on the sequence of executed transactions store this state in self-styled blocks and continuously update them.

C

Cap and Trade
A cap-and-trade emissions trading system defines an upper limit of emissions that may be emitted and traded by participants in a given period. This cap is continuously reduced.

Carbon Border Adjustment Mechanism (CBAM)
Proposal for a border tax equalization system that would price the emissions of products manufactured outside the EU when imported into the EU, thus protecting EU member states from carbon leakage.

Carbon Leakage
Migration of companies to other countries due to stringent climate protection measures and associated costs at current locations.

D

Distributed Ledger Technologies
Technologies such as blockchain which provide decentralized access, validation, and transactions in an immutable manner over a network in which identical copies of the protocols are distributed across multiple locations.

Digital Product Pass
National and European proposals for digitizing product information in which technical and environmental information is recorded and collected in digital form for a product.

Downstream
Emission reduction instruments that target end users of fossil fuels or the actual emitters, i.e., at the end of the value chain.

E

Environment, Social, and Governance (ESG)
Summary of the three assessment areas, environment, social affairs, and (corporate) governance, which can be used to evaluate the sustainability of a company and company activities.

EU ETS I
Existing European emissions trading system for energy-intensive plants and processes beginning at the emitters (downstream).

EU ETS II
Proposal for the further development of the EU ETS I and the design of a second European emissions trading system for the heat and transport sectors beginning at the distributors (upstream).

EUid
Developing digital identity management for EU citizens and businesses that allow identity holders to decide for themselves what data is released and in what cases.

F

Fuel Emissions Trading Act (dt. *Brennstoffemissionshandelsgesetz, BEHG*)
Legal basis for a German national emissions trading system for the heat and transport sectors beginning at the distributors (upstream).

G

Gaia-X
Project to develop a European, secure, and transparent data infrastructure.

Greenhouse Gas (GHG) Protocol
Private standard for accounting greenhouse gas emissions and associated reports for companies, which differentiates emissions according to three different areas (scopes).

L

Life Cycle Analysis (LCA)
Eco-balancing, in which a product's direct and indirect environmental impacts are calculated and evaluated.

R

Renewable Energy Directive (RED)
EU Directive on the promotion of the development of renewable energies, the third major amendment of which is to set higher targets for the share of renewable energies and adjust the framework conditions for issuing guarantees of origin for electricity.

S

Scope 1–3
Areas in a company's global value chain for which emissions are determined in accordance with the GHG Protocol.

- Scope 1: Direct own emissions
- Scope 2: Emissions from purchased energy
- Scope 3: Emissions from upstream and downstream steps in the value chain

Self-Sovereign Identity (SSI)
Secure identity in a decentralized, digital identity management system in which identity information resides with a party itself rather than through a central intermediary.

Smart Meter
Smart (electricity) meter that enables electricity measurements in small time units up to real time and visualizes these consumption values.

Smart Meter Gateway (SMGW)
Communication interface through which readings from a connected smart meter can be automatically transmitted to external parties and which enables these external parties to send incentives or commands for load adjustments to local control systems such as an energy management system.

System boundary
Delimitation of the system to be assessed in a life cycle assessment, i.e., determination of the value chain steps of a product or service to be included in the assessment.

T

Taxonomy regulation
EU regulation that classifies economic activities according to their environmental sustainability and prescribes the corresponding communication of this information for companies.

U

Environmental due diligence
Environmental due diligence requirements for upstream production steps, which are/will be prescribed for companies in global value chains by national and European laws/ legislative proposals.

Upstream
Instruments for reducing emissions beginning with the distributors of fossil fuels, such as producers and importers of fossil fuels, i.e., at the beginning of a value chain.

Z

Zero-Knowledge Proof (ZKP)
Evidentiary mechanism that makes it possible to prove certain (data) attributes of a party under review without the party having to disclose information about itself.

Content

1 Introduction – Hypotheses on Digital CO_2 Proofs

To achieve the goals of the Paris Climate Agreement and, in particular, to keep global warming below 2°C compared to pre-industrial times, a maximum total amount of greenhouse gases still to be emitted must not be exceeded. The maximum total amount of greenhouse gases that we are still allowed to emit into the atmosphere to achieve the 1.5°C target or the 2°C target is called the CO_2 budget. In its latest assessment report, the United Nations Intergovernmental Panel on Climate Change (IPCC) determined, among other things, that 500 Gt of CO_2 may still be emitted globally to achieve the 1.5°C target with a probability of 50%.[1] To not emit more than the determined emissions of the CO_2 budget, the current emissions of CO_2 and other greenhouse gases must be reduced. The success of the European Emissions Trading System (EU ETS) confirms that emissions trading systems can be a cost-effective tool to reduce greenhouse gas emissions at the end of the value chain. For example, CO_2 emissions covered by the EU ETS have been reduced significantly more since 2005 (-29%) than CO_2 emissions outside the EU ETS (-10%).[2]

Overall, political instruments for reducing CO_2 and other greenhouse gases will fundamentally influence business decisions in Europe in the coming years. However, to achieve the climate targets defined at the national as well as the European level within the envisaged time frame, instruments for emission reduction must be continuously evaluated and further developed. Against this background, this study uses interviews with company representatives to identify challenges in the current collection of CO_2 information to evaluate the potential of digital CO_2 verification as a central building block of emission reduction instruments. Based on the current political and regulatory framework for companies, this study hypothesizes the following.

Hypothesis 1: Economic and regulatory uncertainty with regard to CO_2 pricing prevents companies from engaging in a long-term, targeted transformation toward climate-friendly processes.

Particularly, the unclear further development of the multitude of instruments for CO_2 pricing could make it more difficult for companies to plan their long-term transformation toward more climate-friendly processes. For example, it is unclear to what extent government revenues from CO_2 pricing will be targeted to promote sustainable innovation and further emissions reductions. Similarly, with the addition of more sectors to the EU ETS—and, thus, possibly more emissions trading

[1] Cf. IPCC (2021). Summary for Policymakers. Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

[2] Cf. Federal Ministry for Economic Affairs and Energy (2020). Emissionshandel mit Erfolgsbilanz. Retrieved from https://www.bmwi-energiewende.de/EWD/Redaktion/Newsletter/2020/08/Meldung/direkt-erfasst_infografik.html

systems or CO_2 pricing instruments—offsetting along sector or system boundaries is still uncertain. A continuing uncertainty as to whether and how the different CO_2 prices will be prospectively combined into a cross-sector, uniform CO_2 price also promises to reduce the planning certainty further and, thus, the investments of companies with regard to the expected CO_2 costs.

The current political discussions focus on instruments that record the CO_2 emissions of distributors, such as oil and gas producers. Direct economic incentives for industry, commerce, and private (end) consumers, such as CO_2 prices for end products, are less in focus in climate policy. This is mainly due to an emissions trading system with a high number of participants (i.e., companies, (end)consumers) being associated with enormous transaction costs for monitoring, reporting, and verifying CO_2 emissions.[3]

Hypothesis 2: The burden of bureaucratic documentation with regard to CO_2 emissions increases significantly for companies.

It is already foreseeable that the documentation effort for companies concerning CO_2 emissions will increase significantly as a result of the Paris Climate Agreement, the European Green Deal, and the German national CO_2 pricing via the Fuel Emissions Trading Act (BEHG). Especially in the course of the European Green Deal, directly and indirectly effective new legal frameworks are expected on the part of the EU. These include the introduction of an emissions trading system for the heat and transport sectors, which the EU ETS has not yet covered.[4] This means that in the future, companies that have not yet participated in emissions trading and/or have not yet had any reporting obligations with regard to emissions trading for specific sectors will have to record, report, and verify CO_2 data.

Likewise, the EU Commission will further develop an EU directive on mandatory due diligence in the supply chain covering environmental risks and the idea of a European product passport implementing eco-design requirements for products. In addition to the current and future legal framework, the data on CO_2 equivalents will directly influence the business calculations of companies in the medium to long term. In this context, it is foreseeable that the CO_2 reporting currently practiced by companies will become an economic disadvantage: The enormous effort required for additional manual documentation and evaluation duties will lead to high reporting costs. Today, a large part of the transaction costs for companies associated with the EU ETS is related to the measurement, reporting, and verification of emissions. The transaction costs for German companies

[3] Cf. Heindl, P. (2012). Transaction Costs and Tradable Permits: Empirical Evidence from the EU Emissions Trading Scheme. ZEW Discussion Papers, 12. Retrieved from https://ftp.zew.de/pub/zew-docs/dp/dp12021.pdf
[4] Cf. European Commission (2021). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550

participating in the EU ETS amount to an average of approximately 8.7 million euros per year.[5]

Hypothesis 3: Digital collection and reporting of CO_2 emissions at companies could provide direct incentives for emission reductions and create competitive advantages for companies.

To date, European companies report their environmental data primarily to meet legal requirements. Even in the rare voluntary approaches, carbon footprints are not used directly to create value but often for marketing purposes. Both approaches have in common that companies today always publish their environmental indicators ex post. An example of this is the annual non-financial statement based on classic measurement systems and algorithm audits of the previous year. For the environmental indicators in reports, primary data from the companies are usually scaled up or estimated using CO_2 conversion factors.

An alternative approach to the current design of CO_2 reporting is a digital bottom-up approach that captures emissions in real time directly at the company and can be implemented independently of the design of the relevant emissions trading systems. Companies can benefit from combining a digital bottom-up approach with primary data and product-specific CO_2 documentation instead of estimates and averages. On the one hand, companies will be able to automatically transfer the energy indicators and other CO_2 information they need today into their business reports. In the medium term, there is also the option that these CO_2 values can be directly verifiable and continuously transferred to companies' financial accounting. On the other hand, companies can directly influence the production of goods and services through active, real-time CO_2 documentation and control at the process level. In this manner, CO_2 reduction activities no longer just lead to compliance with legal requirements but open up paths for CO_2-adaptive production at the manufacturing level: Input factors can be freely combined according to, for example, CO_2 targets and specifications from customers at the batch size level. This could also increase the willingness to pay for certain products and services on the customer side. Accordingly, the digitization of proofs of CO_2 origin and use should be able to decisively reduce reporting costs by reducing transaction costs in measurement, reporting, and verification and enable lean adaptation and control of production processes with regard to CO_2 emissions.

[5] Cf. Heindl, P. (2012). Transaction Costs and Tradable Permits: Empirical Evidence from the EU Emissions Trading Scheme. ZEW Discussion Papers, 12. Retrieved from https://ftp.zew.de/pub/zew-docs/dp/dp12021.pdf

Hypothesis 4: If companies want to use high-resolution CO_2 information for economic purposes, the information must be communicated in a verifiable manner. This requires new technological solutions.

A decisive prerequisite for achieving competitive advantages through product-specific CO_2 information is that the product-related and process-related CO_2 emissions can also be transmitted to customers validly and at low transaction costs. New digital systems and solution approaches could be used for this validation. In this context, purported self-sovereign identities (SSI) combined with blockchains are a promising basis for high-resolution digital proofs of origin and use. High-resolution digital CO_2 proofs of origin and use can technically prove the origin of CO_2 emissions or, in the case of products such as electricity, their use—resolved according to very small time units up to real time. SSI's technical concept forms the basis of the German government's Digital Identities projects, which aim to enable citizens to digitally manage verifiable information in the future, for example, from their ID cards, and, thus, to make sovereign decisions about the disclosure of their data.[6] Furthermore, the technical concept is directly linked to the framework conditions of the EU's eIDAS Regulation, which regulates the requirements and standards for electronic identification in the European area.[7] Furthermore, SSIs are envisioned to govern access rights to the Gaia-X cloud, which aims to provide a European, secure, and transparent data infrastructure.[8,9] In conjunction with blockchain, SSI relies on decentralized person and machine identities that avoid internet platforms as intermediaries with centralized data storage, enabling high interoperability and, thereby, minimizing the risks of sunk costs and lock-in effects.

Further development of the current CO_2 pricing concept, including recourse to decentralized end-to-end verification with digital identities, thus, promises to make verification machine specific, secure, as real time as possible, interoperable, and dynamically extensible. This technical approach allows Scope 1-3 emissions[10] to be traced unambiguously. Furthermore, digital and individual CO_2 labeling can enable active management at the production level and the use of CO_2 information as a relevant control variable for production and process control. In this manner,

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[6] Cf. Presse- und Informationsamt der Bundesregierung (2021). Okosystem Digitale Identitäten. Von der Testphase zur Markteinführung. Retrieved from https://www.bundesregierung.de/breg-de/suche/oekosystem-digitale-identitaet-1960124

[7] Cf. European Parliament (2014). Regulation (EU) No 910/2014 of the European Parliament and of the Council of 23 July 2014 on electronic identification and trust services for electronic transactions in the internal market and repealing Directive 1999/93/EC https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.257.01.0073.01.ENG

[8] Cf. Gaia-X European Association for Data and Cloud AISBL (2021). Gaia-X Architecture Document, 21.06 Release. Retrieved from https://www.gaia-x.eu/sites/default/files/2021-06/Gaia-X_Architecture_Document_2106.pdf

[9] Cf. Gaia-X European Association for Data and Cloud AISBL (2021). What is Gaia-X. Retrieved from https://www.gaia-x.eu/what-is-gaia-x

[10] Scope 1 to Scope 3 emissions: Direct emissions from the reporting company itself (Scope 1), indirect emissions from the generation of purchased energy (Scope 2), and all indirect emissions arising in the reporting company's value chain (Scope 3).

digital CO_2 proofs could contribute to CO_2-based corporate management and support the transformation toward more sustainable corporate processes. Price leaders who currently ignore CO_2 emissions for CO_2-intensive products will then come under pressure to provide valid information on the CO_2 emissions of their products. Verified and fine granular CO_2 information could help make it more difficult to import or purchase products from countries with lower standards. Moreover, digital and unique CO_2 verification could facilitate the transfer of emission reduction measures from non-EU countries. The digitally verifiable CO_2 proof of origin and use based on decentralized and sovereign identities could, thus, enable a European competitive advantage.

> *Hypothesis 5: Digital and product-specific CO_2 proofs of origin and use enable a high-resolution differentiation of products and, thus, a CO_2 assessment independent of accounting definitions.*

Taking into account CO_2 emissions as well as product-specific end-to-end CO_2 labeling opens up promising possibilities for production: For example, CO_2 emissions associated with consumed electricity can be assessed differently depending on the origin and time of use. This also applies to offsetting digital proofs of origin and use for electricity with other products such as heat and hydrogen. In the case of hydrogen production via electrolysis, it is currently not possible to break down the actual share of renewable electricity in near real time and to a specific product quantity. With digital, shareable, and chargeable CO_2 proofs, the color of hydrogen could be differentiated in a verifiable manner and hydrogen could therefore be traded in many different quality levels.[11]

The hypotheses presented provide an overview of the potential of digital proofs of origin and use and their utilization as future emission reduction tools. In this study, the authors evaluate these hypotheses and investigate the impact of using digital proofs of origin and use for companies and how they could contribute to solving current problems in CO_2 reporting.

[11] The differentiation in different quality levels for hydrogen is particularly necessary because there are currently not yet sufficient capacities of renewable energies to be able to produce exclusively green hydrogen.

2 CO_2 Certificates, CO_2 Proofs, and CO_2 Management

When considering and analyzing digital proofs of origin and use of emissions, especially CO_2, it is necessary to distinguish between different types of proofs and documents that pass on emissions information. In this context, the distinction between CO_2 certificates and CO_2 proofs of origin is particularly relevant. For the rest of the study, it should also be noted that CO_2 is referred to as a greenhouse gas . In the following definitions, however, all other greenhouse gases are also taken into account. These are, however, usually measured in the form of CO_2 equivalents. This means that the effect of a certain amount of a single greenhouse gas in the atmosphere is converted to the effect of CO_2.

2.1 CO_2 Certificates

CO_2 Certificates represent emissions information within the framework of an emissions trading system. The significance of a CO_2 certificate depends on the structure of the emissions trading system.

CO_2 certificates
CO_2 certificates are documents that are created, verified, and traded as part of an emissions trading system.

CO_2 Offsets Generally, there are three different approaches to reducing greenhouse gases. The first approach is offset projects. The objective of these projects is to reduce overall emissions and bind greenhouse gases permanently. Such projects include the reforestation of forests. Investments can also be made in technologies to bind greenhouse gases. These are usually referred to by the abbreviation CCS (carbon capture and storage). Technical CCS processes are designed to capture CO_2 in its gaseous form from the atmosphere and permanently bind and store it in the soil. Companies can use CO_2 offset projects to reduce their emissions on the balance sheet without changing their corporate processes. Certificates can be issued for offset projects and their emission reductions, which companies can, in turn, buy to offset their own emissions. This process is usually referred to as CO_2 offsetting.

CO_2 Tax In addition to investing in such offset projects and in corresponding CO_2 sequestration technologies, two other approaches to emissions reduction can be applied, the operation of which is based on assigning a specific price to the emission of CO_2. The two basic CO_2 pricing models are a CO_2 tax and an emissions trading system. In a CO_2 tax, a price is set for the emission of a certain amount of CO_2. The CO_2 price as a CO_2 tax can be determined, for example, by the CO_2 intensity of energy sources or fuels. This means that the amount of CO_2 emitted during the combustion of an energy carrier per amount of energy produced is taxed with a price. Since this is a tax, government institutions usually set the price for a certain amount of emitted emissions. Therefore, governmental institutions can directly control the (fixed change in the) price of CO_2, for example, by gradually increasing it.[12]

Cap-and-Trade Emissions Trading System In an emissions trading system, in contrast to a CO_2 tax, a certain amount of emissions is fixed. In an emissions trading system, the right to emit a certain amount of CO_2 is designated in certificates or allowances, which, in turn, can be traded on a market. There are different manners of designing an emissions trading system.[13] The differences are based on the right issued via the CO_2 certificate and how the total amount of emissions is reduced in the trading system. In a cap-and-trade emissions trading system, an upper limit of emissions is defined, which may be emitted by the participants in the system.[14] Certificates are issued to the participants in the amount of this cap for a certain period of time. During this defined period, all participants in the trading system can trade their certificates. At the end of the trading period, participants must submit or own the number of certificates corresponding to their emissions. The amount of emissions of a participant and its submission of certificates is controlled by a regulatory authority. To achieve certain emission reduction targets, the upper limit of emissions can be reduced step by step. Trading allows participants who have emitted fewer emissions than the prescribed cap to sell a portion of their certificates. Via the certificates sold, participants receive monetary compensation for the emission reductions they have achieved. Participants that have emitted more emissions than the prescribed cap must buy the right for further emissions via certificates.[13]

Baseline-AND-Credit Emissions Trading System In a baseline-and-credit emissions trading system, a baseline for emissions is defined for the participants. This baseline can be identical to the emissions cap in a cap-and-trade emissions trading system. However, in a baseline-and-credit system, a certificate is not traded for the right to emit a certain amount of greenhouse gases. Instead, a certificate is equivalent to a credit for emission reductions, i.e., for emission levels below the set baseline.[14] If a participant in the trading system reduces its emissions below the baseline, it receives corresponding credits for the amount of emission reduction. These can then be traded with other participants who are above their baseline and therefore need credits to reach the prescribed baseline in the trading period.[13]

Upstream vs. Downstream Emissions Trading System In addition to the way in which certificates are defined and issued in an emissions trading system, they can also be measured at different points in the value chain. A distinction is made between a downstream and an upstream system. This distinction defines which

[12] C.f. Eitze, J.; Schebesta, M. (2019). Comparing Carbon Pricing Models. Retrieved from https://www.kas.de/en/analysen-und-argumente/detail/-/content/comparing-carbon-pricing-models
[13] Cf. Sijm, J. (2004). The impact of the EU Emissions Trading Scheme on the price of electricity in the Netherlands. Energy research Center Netherlands, Petten, The Netherlands, ECN-RX–04-015.
[14] Cf. Rosenzweig, R., Varilek, M., Feldman, B., Kuppalli, R., & Janssen, J. (2002). The Emerging International Greenhouse Gas Market.

participants in an emissions trading system must submit certificates and achieve the emissions targets, i.e., upper limit or baseline. In an upstream system, participants in the upstream steps of the value chain are subject to emissions targets. The participants in an emissions trading system are then, for example, the producers and importers of fossil fuels. In a downstream system, the end users of the fossil fuels or the actual emitters must comply with certain emission targets. Within a downstream system, it is necessary to distinguish whether emissions are assessed directly, as they are emitted, or indirectly. This distinction mainly relates to the consideration of electricity and heat. In a direct system, emissions are attributed to electricity producers directly at the point of emission due to the combustion of the energy sources, while in an indirect system, they are attributed to electricity consumers. For example, the EU ETS implements a direct downstream system, while the German national ETS implements emissions trading using the upstream system. Depending on the choice of emissions trading approach in the value chain, (end) consumers can directly capture the price for a certain amount of CO_2 emissions (downstream approach) or perceive an indirect effect of CO_2 pricing via a price increase of end products (upstream approach).[15]

2.2 CO_2 Proofs of Origin and Use

CO_2 proofs of origin and proofs of use are CO_2 information that, in contrast to CO_2 certificates, are not calculated as quantities for companies or individuals but can be applied to products and/or processes. CO_2 proofs of origin and use are usually based on the principle of life cycle analysis (LCA) of products. In an LCA, the environmental impact of a product is calculated and evaluated. Particularly, emission information from upstream and/or downstream production steps is calculated on a declared unit of the product. This means that emissions associated with the production of raw materials and intermediate products as well as emissions generated during the use and disposal of the product are assigned to a product. When a life cycle assessment calculates only the allocated CO_2 emissions and CO_2 equivalents of other greenhouse gas emissions from a product, it is often referred to as a product's CO_2 footprint, CO_2 label, or CO_2 proof of origin. CO_2 proofs of origin accordingly show which emissions can be attributed to a product through its upstream value-added steps. CO_2 proofs of use, on the other hand, show which emissions are assigned to the product in the downstream value-added steps, for example, in the use phase. Proofs of origin and proofs of use can, however, also prove that a product is emission-free. Green electricity proofs, for example, prove that a certain amount of electricity comes from renewable sources only and that few to no emissions can therefore be attributed to the electricity.[16]

[15] Cf. Matthews, L. (2010). Upstream, downstream: the importance of psychological framing for carbon emission reduction policies. Climate Policy, 10(4), 477-480.
[16] Cf. Styles, A., Werner, R., Maaß, C., 2021. Purpose and Instrumental Scope of Guarantees of Origin – Status quo und Prospects for Further Development. GO4Industry project report (Fundamentals, Part 2), funded by BMU (FKZ: UM20DC003). Hamburg: Hamburg Institut. Retrieved from https://go4industry.com/wp-content/uploads/2022/01/HIC_2021_G2_Purpose_and_instrumental_scope_of_GOs.pdf

CO$_2$ proofs of origin and proofs of use

CO$_2$ proofs of origin and use are documents that show the origin or use of emissions for a specific product in a specific value chain according to the principles of an LCA.

System Boundaries and GHG Protocol Similar to emissions trading systems, life cycle assessments can be designed differently. Analogous to the distinction between an upstream system and a downstream system, a distinction is made in a life cycle assessment as to which steps of the value chain are within the balance calculations and which steps are not included. This decision designates the system boundaries of the LCA. The following distinctions are usually made:

- Cradle-to-gate: The product's environmental impact is assessed starting from the raw materials up to the transport of the finished product to the company.
- Cradle-to-grave: The product's environmental impact is assessed from the raw materials to the disposal of the product after use.
- Cradle-to-cradle: The product's environmental impact is assessed starting from the raw materials through to recycling in a new value-added cycle.
- Gate-to-gate: The product's environmental impacts are only assessed in relation to the production steps within a company.[17]

Moreover, the conventional system boundaries of a life cycle assessment are set similarly to the assessment of direct and indirect emissions under the Greenhouse Gas (GHG) Protocol (see Figure 1):

- Scope 1 refers to the amount of greenhouse gas emissions that a company emits directly into its environment.
- Scope 2 refers to the amount of greenhouse gas emissions that a company emits indirectly through its energy use.
- Scope 3 refers to the amount of greenhouse gas emissions that a company emits indirectly through its upstream and downstream steps in the value chain.[18]

Even though the standard of emissions calculation according to the GHG Protocol refers to companies rather than specific products, the distinction is based on system boundaries within the value chain. Consequently, a life cycle assessment with the system boundaries gate-to-gate covers the emissions according to Scope 1 and Scope 2, while a life cycle assessment within cradle-to-cradle additionally covers Scope 3, both upstream and downstream production steps.[19]

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[17] Cf. Krishna, I. M., Manickam, V. (2017). Life Cycle Assessment. In Krishna, I. M., Manickam, V., Shah, A., & Davergave, N. (Hrsg.), Environmental Management: Science and Engineering for Industry (pp. 57-75). Butterworth-Heinemann.

[18] Cf. World Business Council for Sustainable Development, World Resources Institute (2004). The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard. Retrieved from https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

[19] Cf. World Business Council for Sustainable Development, World Resources Institute (2011). Product Life Cycle Accounting and Reporting Standard. Retrieved from https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

Attributional LCA Life cycle assessments can be calculated from two perspectives. Attributive LCA provides information on the impacts of the manufacturing processes, use phase, and product disposal. However, a purely attributive LCA does not consider the indirect environmental impacts resulting from changes in the production of a product. However, on the basis of the direct environmental impacts of an attributive LCA, products can be compared with one another (based on a functional unit).[20] The attributive LCA is usually calculated based on average values. The LCA of a product follows prescribed standards, notably the ISO 14000 series of environmental standards. In the area of building materials, for example, the LCAs are referred to as Environmental Product Declarations (EPDs). These are based on the ISO 14025 and EN 15804 standards. Furthermore, product category rules are defined for different building materials, which specify in detail which environmental data must be recorded for the product and how the system boundaries of the LCA are defined.

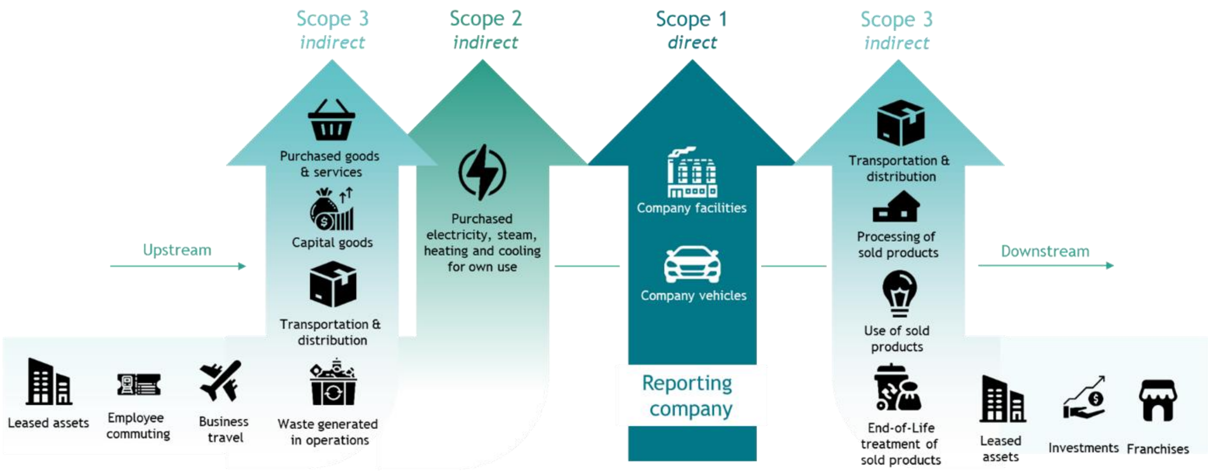

Figure 1: Scope 1–3 according to the GHG Protocol[21]

Consequential LCA A consequential LCA provides information on the environmental impacts of changes in the production process, use, and disposal of a product. The focus of a consequential LCA is the modeling of causal relationships between certain decisions and the change in greenhouse gas emissions attributable to the product.[22] Accordingly, the objective of such LCAs is not to directly compare the environmental impacts of products but to compare measures to reduce emissions from products.

[20] Cf. Brander, M., Tipper, R., Hutchison, C., & Davis, G. (2008). Technical Paper: Consequential and attributional approaches to LCA: A Guide to policy makers with specific reference to greenhouse gas LCA of biofuels
[21] Based on: World Resources Institute, World Business Council for Sustainable Development (2011). Corporate Value Chain (Scope 3) Accounting and Reporting Standard. Retrieved from https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf
[22] Cf. Weidema, B. P., Pizzol, M., Schmidt, J., & Thoma, G. (2018). Attributional or consequential Life Cycle Assessment: A matter of social responsibility. Journal of Cleaner Production, 174, 305-314.

CO_2 Footprint The term CO_2 footprint or CO_2 proof is mostly used in the context of attributive calculations of a life cycle assessment. The distinction between a CO_2 proof of origin and proof of use lies in the aforementioned system boundaries. A proof of origin looks at the CO_2 balance from the beginning of the value chain up to the production site, while the proof of use includes the CO_2 balance of the subsequent downstream steps in the value chain.

2.3 CO_2 Management

When a company engages in CO_2 management, this generally means that CO_2 is regarded as a controlling factor and, thus, as a variable parameter in the company. As a rule, CO_2 management is mainly associated with specific targets for the level of CO_2 and CO_2 equivalents to be reduced.

CO_2 Management
CO_2 management refers to controlling operational performance processes according to the CO_2 factor, which can be measured according to different principles.

Certificate Trading and Certification Companies that actively participate in one or more emissions trading systems require information on their emissions, depending on the framework conditions of the emissions trading system. The company must be able to provide information on the greenhouse gases emitted within the observation period of the emissions trading system. As a rule, external auditors then verify this information such that the responsible regulatory authority can confirm that the emissions reported in the observation period are identical to the emissions measured according to the protocol of the respective emissions trading system.

Publication of Emission Reduction Targets and Annual Reports Many companies voluntarily publish figures on the emissions associated with their business. For example, companies set emission reduction targets independently of political and regulatory requirements, such as in the context of Science Based Targets, an initiative in which companies voluntarily set science-based emission reduction targets.[23] To evaluate the achievement of emission reduction targets and related measures, a company can collect and evaluate information on emissions and communicate it to stakeholders externally. In addition to collecting and publishing emissions data for internal management purposes (according to internal emissions reduction targets), a company may have legal and regulatory reasons to share information about its emissions. For example, a directive in the

[23] Cf. Science Based Targets (2021). Lead the way to a low-carbon future. Retrieved from https://sciencebasedtargets.org/how-it-works

European Union, implemented in German legislation, requires CSR reporting.[24,25] This legal requirement means that companies above a certain size and/or turnover must report sustainability information alongside their annual report.[26]

Process and/or Product-Specific Emission Reduction Targets Besides company-wide emission reduction targets, the emissions of a specific process or a specific product can also be controlled. This control can take place both ex post and in real time. Today, emissions from specific processes and products are usually analyzed ex post. This means that primary data is collected over a certain period of time to determine the emissions. These are then evaluated using the methodology of a life cycle assessment. In this case, CO_2 management refers to the analysis and elaboration of measures to make production processes and products more sustainable in the future. Active CO_2 management in the process or product context, on the other hand, means that emissions are recorded in real time in the same manner as other key production figures and that active intervention in the production process is conducted if the CO_2 variable is not within a prescribed or desired interval.

[24] Cf. Bundesgesetzblatt Jahrgang 2017 Teil I Nr. 20 (2017). Gesetz zur Stärkung der nichtfinanziellen Berichterstattung der Unternehmen in ihren Lage- und Konzernlageberichten (CSR-Richtlinie-Umsetzungsgesetz). Retrieved from http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl117s0802.pdf

[25] Cf. Industrie- und Handelskammer Frankfurt am Main (2021). Was ist die CSR-Berichtspflicht? Retrieved from https://www.frankfurt-main.ihk.de/hauptnavigation/wirtschaftspolitik/csr-und-nachhaltigkeit/csr-berichtspflicht-5284482#:~:text=Laut%20der%20Berichtspflicht%20m%C3%BCssen%20betroffene,thematischen%20Aspekte%20erforderlich%20sind%20(siehe

[26] Cf. Handelsgesetzbuch (HGB) in the version of 10 May 1897 (RGBl., S. 219), which has been amended by Article 51 of the Act of 10 August 2021 (BGBl. I, S. 3436). Retrieved from https://www.gesetze-im-internet.de/hgb/BJNR002190897.html#BJNR002190897BJNG001700306

3 Regulatory Framework

To assess the potential of digital CO_2 proofs of origin and use, it is necessary to explore the current and future policy framework in the European Union. To achieve the emission reduction targets of the European Green Deal, numerous legislative proposals have been put forward in the Fit for 55 package to achieve the goal of a 55% reduction in greenhouse gas emissions by 2030 compared to 1990 levels. This includes several proposed directives that member states would need to implement at the national level.[27] The following section presents the directives and instruments relevant to CO_2 verification that already exist or are currently being drafted. A majority of the directives within the Fit for 55 package is likely to be negotiated by 2022.[28] Responsibility for environmental legislation in the EU is shared between the EU and the member states. Due to the resulting shared legislative competence, member states may exercise their competence as long as the EU has not (yet) exercised its competence in a certain area.[29] Therefore, in addition to the European framework, national laws and initiatives also require or will require the processing of CO_2 information by companies.

3.1 Emissions Trading Systems

At the European level, there is currently an emissions trading system known as the EU ETS. Additional national emissions trading systems supplement the EU ETS in certain European countries. In Germany, for example, a national emissions trading system for sectors not previously covered by the EU ETS (mainly heat and transport) was established by the Fuel Emissions Trading Act (BEHG) in 2021.[30] In addition to the national CO_2-based instruments, emissions trading is being further developed at the European level as part of the Fit for 55 package. However, the interfaces and the transferability of CO_2 prices between European emissions trading and the national CO_2 instruments are still unclear or not yet worked out at present. This includes, among other things, the question of how the already existing national ETS in Germany for the transport and heat sectors is to be transferred to the proposed new EU ETS II for the same sectors.

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[27] Cf. European Commission (2021). Delivering the European Green Deal. Retrieved from https://ec.europa.eu/clima/eu-action/european-green-deal/delivering-european-green-deal_en

[28] Cf. Mathieu, A.; Gläser, A. (2021). Das Fit-for-55-Paket: Startpunkt für die Umsetzung des EU-Klimaziels 2030. Retrieved from https://germanwatch.org/sites/default/files/germanwatch_analyse_ff55_07-10-2021.pdf

[29] Cf. Article 2(2) Treaty on the Functioning of the European Union (TFEU) in the version of 26 October 2012 (Official Journal 2012/C 326/01) Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:12012E/TXT&from=DE

[30] Cf. Brennstoffemissionshandelsgesetz (BEHG) in the version of 12 December 2019 (BGBl. I S. 2728), which has been amended by Article 1 of the Act of 3 November 2020 (BGBl. I S. 2291). Retrieved from https://www.gesetze-im-internet.de/behg/BJNR272800019.html

3.1.1 European Emissions Trading System

EU ETS I In addition to the EU member states, Iceland, Lichtenstein, and Norway also participate in the European emissions trading system EU ETS. The EU ETS operates according to the cap-and-trade system. This emissions trading system currently covers all combustion plants with a thermal capacity greater than 20 MW, including electricity generators, oil refineries, and coke ovens, the production of ferrous metals, cement clinker, wood pulp, glass, and ceramics, as well as European air traffic.[31] This represents approximately 40% of the EU's total greenhouse gas emissions.[32] The emitters of CO_2 and other greenhouse gases are responsible for submitting the emission allowances, i.e., certificates. Accordingly, the EU ETS is designed as a downstream approach, starting with the actors who directly cause the emissions. There is a linear reduction factor to continuously reduce the total amount of emissions traded in the system. This reduction factor results in the removal of 2.2% of the allowances in circulation from the system per year (starting in 2021). Allocation of allowances in the EU ETS is partly free of charge to prevent certain industries from leaving the EU (carbon leakage) and partly by auctioning. Since 2018, the emission allowances of the EU ETS have been considered financial instruments. A penalty of €100/t CO_2 is currently assessed for missing allowances.[33] The member states use the financial revenues from the allowance auctions within the given guidelines. In the future, the use of financial resources from the EU ETS is to be linked more closely to measures or investments to reduce greenhouse gas emissions.[34]

Advancement of EU ETS I The EU ETS is subject to ongoing development. For example, the framework conditions of the EU ETS are being adjusted as part of the European Green Deal and the EU's 2030 Climate Target. The European Commission has proposed the following developments for discussion in the European Parliament –

- Linear reduction factor: The linear reduction factor could be increased from 2.2% per year to 4.2% due to the stricter emission reduction targets.[35]
- One-time withdrawal of allowances: The European Commission proposes a one-time reduction of the number of allowances due to the delayed

[31] Cf. German Emissions Trading Authority (2017). Who participates in emissions trading? Retrieved from https://www.dehst.de/DE/Europaeischer-Emissionshandel/EU-Emissionshandel-verstehen/Ausgestaltung-des-EU-ETS/ausgestaltung-des-eu-ets_node.html

[32] Cf. German Emissions Trading Authority (2021). Auctioning in EU ETS. Retrieved from https://www.dehst.de/SharedDocs/downloads/EN/publications/Factsheet_auctioning.pdf?__blob=publicationFile&v=3

[33] Cf. European Commission (2020). Report from the Commission to the European Parliament and the Council on the functioning of the European carbon market. Retrieved from https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2020)740&lang=en

[34] Cf. European Commission (2021). Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0551

[35] Cf. pages 3-4, 17, 44, European Commission (2021). Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0551

tightening of the linear reduction factor. The number has not yet been discussed at the time of study compilation.[35]

- Market stability reserve: The market stability reserve is an instrument of the EU ETS to prevent a supply surplus of allowances in trading. The parameters according to which the auction volumes are reduced via the market stability reserve are to be reviewed in 2021 and adjusted if necessary.[35]
- Sectors: The shipping sector is to be included in the EU ETS. This would add 79 million new allowances for this sector to the EU ETS.[35]
- Free allocation: The number of industries in which allowances are still freely allocated to protect against carbon leakage is to be reduced.[35]

Carbon Leakage
Carbon leakage refers to companies relocating their production to other countries with less stringent emissions requirements due to increased costs resulting from one country's climate policy. This could lead to an increase in overall emissions globally.[36]

The plans for the further development of the EU ETS by the European Commission mean a strict reduction in the number of allowances in circulation and, thus, in the annual emissions permitted. For companies and their plants that have thus far been covered by the EU ETS, this means that they must specifically identify major levers for reducing emissions. Otherwise, allowances will have to be purchased or penalties paid. Identifying the appropriate places to reduce emissions requires detailed knowledge of the company's emissions. High-resolution emissions and consumption data, for example, in small time units up to real-time recording, can help companies specifically control the use of incinerators and power plants and successively replace energy demand by using alternative technologies at suitable places and times.

EU ETS II The Fit for 55 package includes an additional emissions trading system for the heat and transport sectors, which is to be established alongside the current EU ETS. To distinguish between the two European emissions trading systems, the existing system is referred to as EU ETS I and the new system as EU ETS II. According to the proposal of the European Commission, the EU ETS II shall also be elaborated as a cap-and-trade system. The total quantity of allowances in the EU ETS II has not yet been defined at the time of the study preparation. The total quantity of allowances is to be determined and published based on data from 2024 according to the Effort Sharing Regulation for the heat and transport sectors.[37] The proposal to amend the Effort Sharing Regulation has also yet to be

[36] Cf. European Commission (2021). Carbon Leakage. Retrieved from https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/free-allocation/carbon-leakage_en
[37] Cf. pages 19-20, European Commission (2021). Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability

discussed and finalized. Its objective is to specify for all sectors of the member states which sectors are covered by an EU ETS.[38]

The current proposal implies that the auctions of allowances in 2026 will start with a quantity of 130% of the calculated cap, which will then be deducted from the auction quantities for the period from 2028 to 2030. The increased quantity of 130% is intended to function in a manner comparable to the EU ETS I market stability reserve and ensure that the total quantity has been calculated correctly and that there is no surplus of allowances. Allocation of allowances will be done exclusively through auctions. In the EU ETS II, there will be no free allocation of allowances. Analogous to the EU ETS I, there will be a scarcity factor that annually reduces the number of allowances in the system. This linear reduction factor will initially be 5.15% and will be increased to 5.43% by 2028. Similar to the German national ETS, the EU ETS II is intended to be an upstream system and therefore starts with the distributors of fossil fuels.[39] Since the two EU ETSs begin at different points in the value chain, it is of great importance to avoid double counting emissions. Therefore, it is necessary to accurately track which emissions have already been priced in the EU ETS II at the beginning of the value chain and that those emissions are not repriced at a later point in a value chain. By tracking emissions and, thus, ensuring their traceability along the value chain, it can be ensured that specific emissions are only attributed to one of the two separate CO_2 budgets of the emissions trading systems. Digital CO_2 verification could add significant value to value chains that would fall under both emissions trading systems at different value chain steps by providing verified emissions information. Especially for companies or plants under the EU ETS I, it could be of great importance to prove that specific emissions were already priced at an earlier point under the EU ETS II. This can avoid double pricing for companies by passing on the CO_2 pricing from EU ETS II and the direct pricing from EU ETS I. In addition, digital CO_2 proofs offer the advantage of recording and tracing emissions across sectors. In this manner, emissions can be transferred not only along the value chain but also in parallel along the sector boundaries.

Measurement, Reporting, and Verification In both EU ETSs, member states are responsible for registering installations, accrediting them, and verifying reported emissions. Likewise, member states are responsible for auctioning allowances and sanctioning violations or missing allowances. The monitoring and reporting framework under the EU ETS I is currently governed by the Commission

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reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0551

[38] Cf. European Commission (2021). Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0551

[39] Cf. Stiftung Umweltenergierecht (2021). Das Fit-for-55-Paket: Updates und Neugestaltung des Europäischen Emissionshandels. Retrieved from https://stiftung-umweltenergierecht.de/wp-content/uploads/2021/09/Stiftung-Umweltenergierecht_Das-Fit-for-55-Paket-Updates-und-Neugestaltung-des-Europaeischen-Emissionshandels_Pause_2021-09-28.pdf

Implementing Regulation (EU) 2018/2066. This states that companies or installations under the EU ETS I must submit a monitoring concept that ensures transparent monitoring. Furthermore, the regulation describes the necessary integrity of the emissions data and the basic rules for determining the CO_2 emissions of a plant. However, the detailed design of the reporting requirements, such as whether to use automated systems for data transmission, is left to the verifying member states.[40] The basis for verification and accreditation is defined at the EU level via the Commission Implementing Regulation (EU) 2018/2067. This includes, among other things, the regulations for the national testing and accreditation bodies of facilities that fall under the EU ETS I.[41] At the national level in Germany, for example, the Greenhouse Gas Emissions Trading Act (TEHG) regulates, among other things, the verification of emissions reports, and the Emissions Trading Ordinance (EHV) regulates the verification of verification bodies.[42,43] With the help of digital CO_2 proofs based on decentralized technologies, the necessary data and reports for monitoring the EU ETS can be made available in a directly verifiable or audit-proof manner. This can streamline the verification process.

3.1.2 German Emissions Trading System

Fuel Emissions Trading Act In Germany, emissions in the heating and transport sectors have already been priced since the beginning of 2021 under the Fuel Emissions Trading Act (BEHG), which deals with those emissions "not covered by EU emissions trading."[44] In the first phase, emission allowances will be traded under the BEHG from 2021 to 2025 at defined annually increasing fixed prices per allowance. Subsequently, a price corridor with a minimum price of 55 euros per emission allowance and a maximum price of 65 euros per emission allowance—and only then trading of emission allowances without price regulations and with auctioning procedures—is to be established for the year 2026.[45] Those responsible for acquiring and submitting the allowances, as well as for the associated emissions reports, are the fossil fuel distributors, i.e., those companies that sell, for

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[40] Cf. Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018R2066-20210101

[41] Cf. Commission Implementing Regulation (EU) 2018/2067 of 19 December 2018 on the verification of data and on the accreditation of verifiers pursuant to Directive 2003/87/EC of the European Parliament and of the Council. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018R2067-20210101

[42] Cf. Treibhausgas-Emissionshandelsgesetz (TEHG) in the version of 21 July 2011 (BGBl. I S. 1475), which has been amended by Article 18 of the Act of 10 August 2021 (BGBl. I S. 3436). Retrieved from https://www.gesetze-im-internet.de/tehg_2011/BJNR147510011.html

[43] Cf. Emissionshandelsverordnung 2030 (EHV 2030) in the version of 29 April 2019 (BGBl. I S. 538), which has been amended by Article 19 of the Act of 10 August 2021 (BGBl. I S. 3436). Retrieved from http://www.gesetze-im-internet.de/ehv_2030/BJNR053800019.html

[44] Cf. § 1 Brennstoffemissionshandelsgesetz (BEHG) in the version of 12 December 2019 (BGBl. I S. 2728), which has been amended by Article 1 of the Act of 3 November 2020 (BGBl. I S. 2291). Retrieved from https://www.gesetze-im-internet.de/behg/BJNR272800019.html

[45] Cf. § 10 (2) Brennstoffemissionshandelsgesetz (BEHG) in the version of 12 December 2019 (BGBl. I S. 2728), which has been amended by Article 1 of the Act of 3 November 2020 (BGBl. I S. 2291). Retrieved from https://www.gesetze-im-internet.de/behg/BJNR272800019.html

example, heating oil, gasoline, diesel, natural gas, or coal to consumers.[46] Therefore, national emissions trading in Germany is structured in the sense of upstream emissions trading in which actors at the beginning of the value chain, for example, suppliers of upstream products, are responsible for recording and reporting emissions and acquiring allowances. The functionality of the German national emissions trading is comparable to the European proposal for EU ETS II, which addresses the heat and transport sectors. How the two emissions trading systems will be structured in the future to prevent a double burden for companies and consumers with regard to the same CO_2 emission still has to be worked out. It needs to be reviewed whether the German national ETS should be maintained in parallel with the EU ETS II or directly integrated into the EU ETS II.[47] To prevent the burden of double pricing of a CO_2 emission via EU ETS I and national emissions trading, installations that are already obliged to submit allowances in the EU ETS are exempted from surrendering allowances in national emissions trading under the BEHG.[48] Digital CO_2 proofs can play a significant role, especially in the transition of the individual emissions trading systems into one another. This is especially true when emissions are recorded at different points in the value chain and in different sectors at the European and national levels. In this context, digital CO_2 proofs enable uniquely tracing emission data along these system boundaries. Furthermore, the underlying technical concepts of decentralized technologies and identities can ensure the transparency and integrity of emissions data.

3.2 Relevant Regulatory Framework in the Course of the European Green Deal

In addition to the various emissions trading systems and their future development, other legal frameworks have been and will be developed in the course of the European Green Deal that influence the collection, reporting, and verification of CO_2 information by companies. These are listed below.

Carbon Border Adjustment Mechanism (CBAM) The EU Commission's proposal to introduce a carbon border adjustment system (CBAM), presented in July 2021, is intended to protect EU member states from carbon leakage, i.e., the migration of companies due to climate protection measures. To this end, emissions from products manufactured outside the EU are to be priced when imported into the EU. Since such a border tax adjustment mechanism has an impact on the global trade of products, compatibility with the principles of the WTO is of particular importance. The elaborated proposal of the EU Commission now provides that certificates for the CO_2 emissions attributable to the product must be purchased

[46] Cf. § 2 Brennstoffemissionshandelsgesetz (BEHG) in the version of 12 December 2019 (BGBl. I S. 2728), which has been amended by Article 1 of the Act of 3 November 2020 (BGBl. I S. 2291). Retrieved from https://www.gesetze-im-internet.de/behg/BJNR272800019.html

[47] Cf. Energy and Climate Policy and Innovation Council e.V. (2021). Handlungsprogramm Klima- und Energiepolitik für die neue Legislaturperiode. Retrieved from https://epico.org/uploads/files/EPICO_Handlungsprogramm-Klima-und-Energiepolitik-neue-Legislaturperiode.pdf

[48] Cf. § 7 (5) Brennstoffemissionshandelsgesetz (BEHG) in the version of 12 December 2019 (BGBl. I S. 2728), which has been amended by Article 1 of the Act of 3 November 2020 (BGBl. I S. 2291). Retrieved from https://www.gesetze-im-internet.de/behg/BJNR272800019.html

when non-EU products are imported. The price for the certificates is to correspond to the CO_2 price if the product had been manufactured in an identical manner in the EU. If companies can prove that a price has already been set for the emissions generated outside of the EU, for example, through emissions trading in non-EU countries, this obligation does not apply. The CBAM is to be applied first to the following products with a high risk of carbon leakage: cement, electricity, fertilizers, iron and steel, and aluminum.[49] Digital CO_2 proofs can provide evidence of emissions already priced elsewhere for imports of products into the EU and transparently map offsets or pricing of emissions at the border. In this manner, digital CO_2 proofs could also increase the interoperability of other emissions trading systems with the European one.[50,51,52]

RED III On July 14, 2021, the EU Commission published the proposal to amend Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources (RED III) as part of the Fit for 55 package. This proposal contains new, binding targets for the share of renewable energy in the electricity mix. Under this proposal, a 40% share of renewables is to be achieved by 2030. Furthermore, sector-specific targets for the share of renewable energy are proposed, such as 49% in the buildings sector. Other measures included in the proposal are intended to promote the use of renewable energies. Among other things, the EU Commission's proposal would change the framework conditions for issuing guarantees of origin for electricity. This could mean that the German ban on double marketing in the Renewable Energy Sources Act (Ger. *Erneuerbare-Energien-Gesetz*, EEG) would violate European law.[53] The EEG currently prohibits electricity that is already subsidized via the EEG levy from being marketed twice with payments linked to guarantees of origin for the renewable source.[54] This opens up a new business model for storage operators, as they can remarket electricity stored from renewable sources. However, it must be possible to differentiate when which electricity with which associated emissions is charged and discharged from a storage facility. The technical concepts of decentralized technologies in combination with SSI could expand the existing guarantees of origin for green electricity and ensure their transferability.

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[49] Cf. European Commission (2021). Proposal for a Regulation of the European Parliament and of the Council establishing a carbon border adjustment mechanism. Retrieved from https://ec.europa.eu/info/sites/default/files/carbon_border_adjustment_mechanism_0.pdf

[50] Cf. Kakarott, J., Skwarek, V. (2020). An enhanced DLT-based CO 2 Emission Trading System. In 2020 Fourth World Conference on Smart Trends in Systems, Security and Sustainability (WorldS4) (pp. 435-442). IEEE.

[51] Cf. Macinante, J. D. (2017). A conceptual model for networking of carbon markets on distributed ledger technology architecture. CCLR, 243.

[52] Cf. Franke, L., Schletz, M., & Salomo, S. (2020). Designing a Blockchain Model for the Paris Agreement's Carbon Market Mechanism. Sustainability, 12(3), 1068.

[53] Cf. Erneuerbare-Energien-Gesetz of 21 July 2014 (BGBl. I S. 1066), which has been amended by Article 11 of the Act of 16 July 2021 (BGBl. I S. 3026). Retrieved from https://www.gesetze-im-internet.de/eeg_2014/__80.html

[54] Cf. European Commission (2021). Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. Retrieved from https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf

Taxonomy Regulation EU Regulation 2020/852 classifies economic activities according to their environmental sustainability. The taxonomy establishes four overarching criteria that economic activities must fulfill to be classified as environmentally sustainable. The objective of the taxonomy is to create (financial) incentives for companies to align their activities with sustainability criteria and report these transparently (via publication obligations). In Germany, the taxonomy is particularly relevant for listed companies obliged to a non-financial report. The companies and member states concerned must report the proportion of sustainable financial flows for their capital expenditures (Capex) and operating costs (Opex).[55]

3.3 Environmental Due Diligence of Companies

To oblige companies active in global value chains to comply with due diligence requirements in human rights and environmental protection in upstream production steps, there are laws and draft laws at both the national and the European level. The objective of these laws is to ensure that standards that apply with regard to human rights and environmental protection in Germany and the EU are not fundamentally violated in upstream process steps outside of Europe.

Non-financial Reporting Directive 2014/95/EU of the European Parliament and the Council obliges corporate groups and large companies to report on their activities in the area of corporate social responsibility (CSR). CSR areas include environmental aspects in addition to compliance with human rights, anti-corruption, and other social concerns of employees. The reporting of this information is also referred to as ESG reporting (ESG stands for Environment, Social, and Governance). The companies concerned, mainly listed companies, must consequently address environmental issues, among other things, as part of their reporting obligations in a non-financial statement or integrated with the management report. In this context, a company has to explain the risks to the environment arising from its activities and present concepts that prevent negative impacts on the environment by the company and its value chain.[56] In Germany, the European Directive has been transposed into national law via the CSR Directive Implementation Act.[57] In contrast to the financial statements and management reports, the non-financial statement does not have to be confirmed by an audit. It is only required that the existence of a non-financial statement is verified.[58]

[55] Cf. European Commission (2021). EU taxonomy for sustainable activities. Retrieved from https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities
[56] Cf. European Parliament (2014). Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups Text with EEA relevance. Official Journal of the European Union. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014L0095
[57] Cf. Bundesgesetzblatt Jahrgang 2017 Teil I Nr. 20 (2017). Gesetz zur Stärkung der nichtfinanziellen Berichterstattung der Unternehmen in ihren Lage- und Konzernlageberichten (CSR-Richtlinie-Umsetzungsgesetz). Retrieved from http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl117s0802.pdf
[58] Cf. Federal Ministry of Labour and Social Affairs (2021). CSR-Berichtspflicht für Unternehmen seit 2017.

Moreover, unlike financial information, the reporting within the scope of the non-financial statement is often qualitative and not quantitative. Therefore, the German Institute of Public Auditors (Institut der Wirtschaftsprüfer), for example, calls for greater standardization of the qualitative information in the non-financial statement and better integration with the rest of corporate reporting to increase the comparability of non-financial information. Since this non-financial information becomes increasingly important for shareholders and stakeholders, an audit requirement for the non-financial part of corporate reporting is also advocated.[59] In the event of an audit, the transparent verifiability of the emission indicators in the non-financial statement is essential. Particularly, the traceability of the reported key figures to the primary emission data can be enabled by digital CO_2 proofs.

3.3.1 Environmental Due Diligence of Companies in Germany

The German Supply Chain Due Diligence Act expands the existing reporting obligation for environmental and social concerns of companies to include the execution of due diligence obligations for their supply chain. The Bundestag passed the law in the summer of 2021, and the Bundesrat approved it. From 2023, companies above a specific size will be required to perform due diligence on direct and indirect suppliers. This will strengthen the obligation to analyze risks, for example, in relation to environmental damage, and design proportionate measures to minimize these risks. Information on compliance with corporate due diligence obligations must be reported and will be verified by the German Federal Office for Economic Affairs and Export Control. Fines can be imposed for violations of the law, for example, if no action is taken in the case of violations in the company's business area.[60] However, under the Supply Chain Due Diligence Act, companies do not have to be liable for (foreign) claims in their global value chain.[61] Nevertheless, companies now need valid data on their suppliers' environmental and social conditions. For the suppliers, who then have to prove to the customer that they have complied with certain specified framework conditions, verifiable emissions and consumption data are important, which can be realized with the help of digital CO_2 proofs.

Retrieved from https://www.csr-in-deutschland.de/DE/Politik/CSR-national/Aktivitaeten-der-Bundesregierung/CSR-Berichtspflichten/richtlinie-zur-berichterstattung.html#:~:text=Das%20CSR%2DRichtlinie%2DUmsetzungsgesetz%20legt,mehr%20als%20500%20Besch%C3%A4ftigen%20fest.&text=Die%20Unternehmen%20m%C3%BCssen%20in%20ihren,nichtfinanzielle%20Aspekte%20der%20Unternehmenst%C3%A4tigkeit%20eingehen.

[59] Cf. Institut der Wirtschaftsprüfer (2020). Zukunft der nichtfinanziellen Berichterstattung und deren Prüfung. Retrieved from https://www.idw.de/blob/127008/fe3ecc79b5ff9bfa52b715d7e44f0382/down-positionspapier-zukunft-nichtfinanzielle-be-data.pdf

[60] Cf. Federal Ministry for Economic Cooperation and Development (2021). Das Lieferkettengesetz. Retrieved from https://www.bmz.de/de/entwicklungspolitik/lieferkettengesetz

[61] Cf. Campos Nave, J.A. (2021). Lieferkettengesetz – Haftungsfrage geklärt, Beschluss steht unmittelbar bevor. Retrieved from https://www.roedl.de/themen/lieferkettengesetz-haftung-zivilrecht-geklaert-beschluss-steht-bevor-prozessstandschaft

3.3.2 Environmental Due Diligence of Companies in the EU

Corporate due diligence in global value chains with regard to sustainability is currently also being discussed at the European level. For this reason, the EU Commission has presented a new directive on corporate sustainability reporting. The EU Commission's proposal of April 2021 envisages extending the reporting obligations for sustainability to large companies which have not yet been affected by the CSR Directive.[62] Furthermore, this proposal also significantly expands the information to be published. According to the purported dual materiality perspective, companies would have to publish, among other things, information that does not describe the effects of the company's activities on the environment but is necessary for its understanding. Likewise, the reporting obligation would be expanded to include the disclosure of (environmental) objectives and their implementation and evaluation. Also, the role of management in implementing the sustainability strategy would be specified in more detail.[63] The risks to the environment from corporate activities are to be analyzed for the entire value chain. According to the proposal, ESG information may only be published in the management report. Disclosure in a separate non-financial statement would be excluded under the draft, which is intended to strengthen the integrity in relation to the financial information. Likewise, the draft provides that uniform European standards for reporting the ESG information can be developed and that the report is published in suitable digital formats.[64]

3.4 Digital Product Pass

Another elementary component of the European Green Deal is the Action Plan for the Circular Economy, better known as the Circular Economy Action Plan. The EU Commission launched this action plan in March 2020. The objective of the action plan is to promote the development of sustainable products and services with the help of political and legal measures and establish these on the markets. The action plan should lead not only to a reduction in the amount of waste but also to end products or parts of end products being reintroduced into a product cycle. One component of the action plan is the development of suitable framework conditions for sustainable products. To anchor sustainability principles in products, the EU Commission wants to leverage the potential of digitizing product information, including a digital product passport for products and services.[65] A digital product passport is also being discussed at the national level to provide consumers with

[62] Cf. European Commission (2021). Questions and Answers: Corporate Sustainability Reporting Directive Proposal. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_1806
[63] Cf. Hennrichs, J. (2021). Stellungnahme zum CSRD-Vorschlag der EU-Kommission. Retrieved from https://www.bmjv.de/SharedDocs/Gesetzgebungsverfahren/Stellungnahmen/2021/Downloads/0721_Stellungnahme_AKBR_CSRD.pdf;jsessionid=953D088FF7E663F2DCCEB4FDAA3B178F.1_cid334?__blob=publicationFile&v=2
[64] Cf. European Commission (2021). Proposal for a Directive of a European Parliament and of the Council amending Directive 2013/34/EU, Directive 2004/109/EC, Directive 2006/43/EC and Regulation (EU) No 537/2014, as regards corporate sustainability reporting. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0189
[65] Cf. European Commission (2020). Circular Economy Action Plan. Retrieved from https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

transparent environmental information on products and services.[66] The first prototypes are already being developed and will initially map all product information from the entire value chain for batteries in electric vehicles.[67]

According to the proposals, both from Germany and at the EU level, a digital product passport would record information about the product in one place. This is intended to record environmentally related product information from the entire value chain, which is sometimes only published for individual process steps, especially the last production step before sale to (end) consumers. A digital product passport should therefore contain the following information from the entire life cycle of the product:

- Information on materials and resources, starting with primary raw materials
- Information on the environmentally relevant key figures such as CO_2 equivalents, which are associated with the raw materials and primary products
- Information on the use of the final product
- Information for spare parts and repair of the end product
- Information on the disposal or recycling and/or reuse of the end product.

With a comprehensive design (cradle-to-cradle) of a digital product passport and the recording of the emissions attributable to the product, each product can be assigned a uniquely defined carbon footprint. This could also reduce the variety of different environmental declarations and eco-labels, which provide information on the sustainability of a product based on different measurement, calculation, and evaluation methods to a single point of truth. The transparent and uniform provision of product information can increase the comparability of products and promote sustainable recycling in the sense of a circular economy.[68] Decentralized technologies in combination with SSI could serve as the basis for such a digital product passport. These technical concepts make it possible to add emissions to the product at each step in the value chain without having to disclose the individual consumption and emission data to third parties. Since the individual data entries are verified, the entire carbon footprint of the product is also verified.

[66] Cf. Lell, O., Muster, V., Thorun, C. (2020). Förderung des nachhaltigen Konsums durch digitale Produktinformationen: Bestandsaufnahme und Handlungsempfehlungen. Umweltbundesamt. Retrieved from https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2020_11_17_texte_212_2020_digitalisierung_nachhaltiger_konsum_wirtschaftkonsum.pdf
[67] Cf. Federal Ministry for the Environment, Nature Conversation and Nuclear Safety (2021). Umweltfreundliche Digitalisierung: Bundesumweltministerium treibt Entwicklung des digitalen Produktpasses voran. Retrieved from https://www.bmu.de/pressemitteilung/umweltfreundliche-digitalisierung-bundesumweltministerium-treibt-entwicklung-des-digitalen-produktpasses-voran
[68] Cf. Götz, T., Adisorn, T., Tholen, L. (2021). Der Digitale Produktpass als Politik-Konzept. Retrieved from https://epub.wupperinst.org/frontdoor/deliver/index/docId/7694/file/WR20.pdf

4 Challenges Related to CO_2 Proofs From a Corporate Perspective

Based on the regulatory framework and current developments presented, this study derives the challenges of providing CO_2 information from a business perspective. These challenges were identified through semi-structured interviews of electricity generation and supply companies as well as manufacturing companies. Current challenges in providing, assessing, and verifying CO_2 information are presented below.

4.1 Current and Future Importance of CO_2 Information

In this chapter, the authors present how companies currently prepare their non-financial reports and other CO_2 information and how company representatives assess the current and future relevance of CO_2 information. The term "CO_2 information" is explained in Table 1.

Table 1: Definition of CO_2 information-related terms

Definition of CO_2 information-related terms	
In this study, the term "CO_2 information" is used below as an umbrella term for all relevant information relating to CO_2. The authors distinguish between the following information or data:	
Primary data	In life cycle assessment, primary data is data that is collected directly in the company as annual averages to calculate the allocated emissions. This data is usually consumption data (e.g., electricity consumption and data from purchasing).
Secondary data	In life cycle assessment, secondary data is data that contains the allocated emissions from upstream products and that the company cannot determine itself (e.g., life cycle assessments of upstream products or data sheets).
CO_2 conversion factor	The CO_2 conversion factor is the multiplier that allocates a certain amount of CO_2 emissions to the collected primary data depending on its characteristics. For example, different amounts of CO_2 emissions can be allocated to a kWh of electricity depending on the generation process. The CO_2 conversion factor is usually given in kg CO_2 per unit of quantity.
Emission key figure	An emissions key figure is a figure that aggregates the allocated emissions to a product, a process, or (in the

	most common case) a company.
Emissions data / CO_2 data	Emissions and CO_2 data are data that describe direct emissions or can uniquely allocate consumption to emissions. These data are recorded directly via measuring devices or other technical infrastructure and are highly resolved both locally and temporally (e.g., in 15-minute increments up to real-time recording).

4.1.1 Current Processes for Collecting, Processing, and Publishing CO_2 Information

Set Targets and Internal Controlling

All of the companies interviewed publish both key figures on their emissions and emission reduction targets. A portion of this disclosure comes from the mandatory reporting in the management report or the non-financial statement. The other part is information that the companies publish voluntarily. Depending on the industry and the size of the company, companies have been required to disclose ESG information for a longer time or only for a few years. All companies have set emission reduction targets for themselves. These emission reduction targets are mostly stated in annual increments of about five to ten years up to a target year in which climate neutrality is to be achieved. Depending on the industry, companies also define product-specific emission reduction targets in which the emissions associated with the products are to be reduced by a specified amount in a particular product line.

To achieve the defined emission reduction targets, the companies interviewed have developed strategies and measures at different levels of detail. For the majority of the companies, the CO_2 information provided in their reporting is the starting point for analyzing where the company currently stands in terms of its emissions. As part of the company's own emissions analysis, those components of the company are identified where the company can reduce emissions. The strategies and measures implemented to reduce emissions can also be evaluated and adjusted based on the emissions key figures determined from the mandatory reporting.

In addition to the prescribed CO_2 indicators, the majority of the companies interviewed have also established an internal system for communicating CO_2 information or have developed internal control indicators for their emissions. There is a strong link between the self-imposed targets for emissions reduction and the publication of related information. Additional internal recording and evaluation of CO_2 information serve to check whether the self-defined emission reduction targets can be achieved and how the measures implemented for this purpose have an intended effect.

Current Conduction of Reporting

Since the mandatory reporting of CO_2 information is annual, the data is aggregated as a total over the last annual reporting period. If the relevance of the CO_2 information is high and the CO_2 footprint of products and the company has already been calculated for several reporting years, the interviewed companies already have established processes for aggregating the CO_2 information for reporting. As a rule, the primary data for determining emissions are transmitted from all sites to the responsible department, for example, Controlling, via business management ERP software and aggregated there for the reports. If the CO_2 emissions have to be published in the integrated annual report, they are also part of the annual audit. As part of the audit, extracts from the technical infrastructure, sensors, and emission logs from company facilities are then examined, for example. Even if these are available in digital form, the audit is usually carried out physically on site.

Depending on the industry and the existing measurement infrastructure of the interviewed companies, CO_2 emissions are determined in different manners. Energy producers and utilities usually determine their CO_2 emissions by multiplying the figures from the company's activities (e.g., purchase and sale of electricity, heat, or fossil fuels) by specific CO_2 conversion factors. These indicate how many kg of CO_2 are emitted when generating one kWh of energy from a particular energy source. The CO_2 conversion factors are determined with the help of life cycle assessments for each type of energy source, especially fossil fuels, and their existing energy generation processes, and can be retrieved from life cycle assessment databases, for example. In most cases, the average electricity mix, for example, of a country, then serves as the basis for determining the emissions associated with electricity consumption. CO_2 conversion factors are also used in other industries to assess CO_2 emissions in accordance with the GHG Protocol. For example, manufacturers of engines and vehicles can determine a portion of their Scope 3 emissions using the extrapolated fossil fuel consumption of the vehicles.

Current Use of Information, Communication, and Management Systems to Collect and Process Primary and Secondary Data

The companies use information, communication, and other digital management systems to collect, evaluate, and aggregate the primary data for determining CO_2 emissions in a systematic and most efficient manner for reporting purposes. However, there are significant differences between the companies interviewed with regard to the degree of digitization of processes related to primary and secondary data.

Companies that require emission permits for their plants or that have to monitor their CO_2 emissions due to participation in the EU ETS already have a comprehensive measurement infrastructure and have implemented digital interfaces for data transmission. Since participation in the EU ETS places high demands on the validity of emissions key figures, these companies are particularly challenged to establish a uniform system for collecting primary and CO_2 data. In this case, the primary data collection is extensive, and CO_2 data is partly collected directly. These emissions are then recorded via emission measuring devices installed at the process plants and other measuring points in the plants. Using information systems, the measured data can then be transmitted to the department responsible for preparing the report. According to an interviewed employee, this data transmission already takes place (in part) in real time in his company.

Several companies use ESG performance and ESG risk management software both for mandatory reporting and for calculating carbon footprints and life cycle assessments of products. Another company plans to introduce software for ESG performance and risk management and build digital interfaces for data transfer within the company. The previous data structure was also evaluated and reorganized as part of the software introduction. Data collection and transfer to the accounting software can be done manually via Excel spreadsheets or automatically via interfaces from the corporate control system or process management systems. Compared to data transfer via Excel tables, the control technology is audit-proof since data cannot be changed during transfer via automated control technology.

If the interviewed companies record emissions according to Scope 3, these are usually also queried from suppliers or customers via Excel tables. If the data collection relates to the use of the products, for example, electricity and heat, by private individuals or households, the data is passed on to the interviewed companies anonymized at the plant or building level. Alternatively, as already described, the emissions are also scaled from the purchasing and sales data and calculated using the CO_2 conversion factors.

Scope of Current Reporting

In terms of reporting, the companies interviewed break down their CO_2 emissions into Scopes 1–3 in accordance with the GHG Protocol. However, the preparation of reports and the recording of emissions within a particular scope category vary in scope. For most companies, the focus of reporting is on Scope 1 and Scope 2 emissions. Certain companies determine emissions within Scope 1 and Scope 2 via scaling and conversions using CO_2 conversion factors, while other companies directly report Scope 1 emissions via emissions measurement devices. Regardless of the level of detail and calculation of CO_2 information, Scope 1 and Scope 2 emissions are already extensively to fully disclosed.

Scope 3 emissions allocated to the upstream and downstream steps in the company's value chain are not yet recorded in this respect or only in a specific area. According to the Corporate Accounting and Reporting Standard of the GHG Protocol, information on Scope 3 emissions, in contrast to Scope 1 and Scope 2 emissions, must only be disclosed as an option for companies.[69] Therefore, the companies interviewed have not yet carried out a holistic life cycle assessment of the company's products (cradle-to-cradle) with regard to their emissions. Most of these companies have, however, already identified Scope 3 emissions, particularly in the Scope 3 categories (see Table 2), which the company representatives believe account for a large proportion of Scope 3 emissions. For example, energy producers and utilities record the amount of fossil fuels sold and determine the associated emissions. Similarly, one interviewed company, which manufactures engines and vehicles, has calculated Scope 3 emissions via the projected consumption of fossil fuels by (end) customers. Furthermore, several companies have already identified Scope 3 categories in which they intend to determine and provide CO_2 information in the future. This includes, for example, the evaluation of business travel and employee commuting.

Table 1: Categories of Scope 3 emissions

Categories of Scope 3 emissions[70]	
Upstream process steps	*Downstream process steps*
(1) Purchased goods and services (2) Capital goods (3) Fuel and energy-related emissions not covered by Scope 1 or Scope 2 (4) Transportation (5) Waste (6) Business travel (7) Employee commuting (8) Leased or rented property, plant, and equipment	(9) Transportation (10) Processing of the sold products (11) Use of the products sold (12) End-of-life disposal or treatment of products sold (13) Leased or rented property, plant, and equipment (14) Operation of franchised stores (15) Capital expenditures

4.1.2 Internal and External Relevance of CO_2 Information

Relevance of CO_2 Information for Investments and Purchases

CO_2 information plays an increasingly important role in investments and in purchasing primary products and raw materials by companies. When compiling the investment portfolio of the interviewed companies, ecological parameters are taken into account in addition to economic key figures when making decisions for

[69] Cf. World Resources Institute, World Business Council for Sustainable Development (2011). Corporate Value Chain (Scope 3) Accounting and Reporting Standard. Retrieved from https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf

[70] Cf. World Resources Institute, World Business Council for Sustainable Development (2013). Technical Guidance for Calculating Scope 3 Emissions. Retrieved from https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf

or against projects. For example, a company representative states that, in the past year, the ecological perspective could impact the decision on the investment order. This means that the company identifies which projects can contribute the most to emission reductions in relation to the costs to be spent on them. Depending on the marginal cost of emission reduction, various projects can be prioritized in the investment portfolio. When it comes to an investment, the decision-making factor of emission reductions is also expected to gain importance in the future, besides the economic aspects.

The companies interviewed also pay attention to the emissions associated with the preliminary products and raw materials they procure for their production. In the case of manufacturing companies, for example, the composition of electricity, i.e., the electricity mix, is analyzed particularly in the context of electricity procurement and how the (potential) electricity supplier would like to improve its portfolio from an ecological perspective through the proportion of renewable energies. In the case of energy-intensive manufacturing processes of intermediate products, the electricity mix used for production can also be a decisive factor for or against certain suppliers for the company. For example, a company representative states that a supplier is selected for an energy-intensive intermediate product that produces the intermediate product exclusively with electricity from renewable energies. However, another company representative explains that it is more difficult for strategically relevant suppliers to consider the sustainability of manufacturing processes and products when making purchasing decisions. This is mostly because these suppliers have a monopoly or oligopoly position in the value chain. Therefore, if there is a dependency relationship between the company and a supplier or its products, the corresponding input products cannot be immediately replaced by more sustainable substitutes. In this case, the CO_2 information of the upstream products is still relevant for the company but may not be actively controlled for the selection of the suppliers or their upstream products.

Relevance of CO_2 Information for Process Management

In addition to the relevance of CO_2 information for investments and purchasing, emissions data can be used to control processes. None of the interviewed companies currently controls and optimizes its production according to CO_2 emissions. According to the assessment of a company representative, CO_2 information cannot yet be actively used for process control because specific CO_2 information is only available at the plant level or per product division. Furthermore, emissions other than CO_2 usually play a more significant role for companies with immission control operating permits. For example, the German Ordinance on the Implementation of the Federal Immission Control Act (Ger. *Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes*) specifies minimum values for particulate matter, carbon monoxide, or nitrogen oxide emissions for combustion plants.[71] A company representative, for example, states that there are still no CO_2 limit values for his plants in the context of immission control operating permits. However, active process control according to CO_2 emissions as a decision-making factor becomes particularly relevant in the case of secondary processes. A company with its own combined heat and power (CHP) plants, for example, states that, in the future, these could no longer be controlled exclusively according to key business figures but additionally according to emissions data. Furthermore, other ancillary production processes are being investigated to determine whether they can be replaced by more sustainable processes or optimized in terms of their emissions.

Relevance of CO_2 Information for Managers and Within the Company

Sustainability and emissions reduction as well as related research, development, and technologies have a high priority among the executives of the companies interviewed. A company states, for example, that emissions reduction as a decision-making factor is linked to the executives' individual objectives and, thus, also to their own compensation. Therefore, executives also use CO_2 information and emissions key figures when making strategic decisions. A company states that new executives at the top management level of the company increasingly introduce competencies in the areas of sustainability and digitalization. Several companies also emphasize the high importance of the interface between digitization projects and emission reduction measures for the company's management level. In addition to the increased relevance and competence in the topics addressed, several companies have anchored sustainability more firmly in their organizational structure, for example, by establishing an independent department that coordinates emission reduction strategies. Regarding digital solutions, a company representative also states that digital solutions are developed quickly and straightforwardly in an independent digitization department within the company to counteract that the development of new IT systems is relatively complex in a large company.

External Demand for CO_2 Information

Besides the internal demand for CO_2 information for different business activities of companies, the (end) customers' external demand for this information is also decisive for companies.

In the energy industry, company representatives observe that the demand for more CO_2 information and differentiated energy products increases. The need for higher resolution primary data, for example, an hourly resolution of the consumed electricity mix, is currently not seen, especially among private households. According to the assessment of the interviewed energy producers and suppliers, the green electricity certificates are sufficient for many private customers to prove the origin of the electricity. A company representative perceives, among other

[71] Cf. Verordnung über kleine und mittlere Feuerungsanlagen (BImSchV) in the version of 26 January 2010 (BGBl. I S. 38), which has been amended by Article 1 of the Regulation of 13 October 2021 (BGBl. I S. 4676). Retrieved from https://www.gesetze-im-internet.de/bimschv_1_2010/BJNR003800010.html#BJNR003800010BJNG000300000

things, that (end) customers are not yet willing to pay more for green electricity than for gray electricity. For this reason, the company representative suspects that it may still take a few years before (end) customers demand local and temporary high-resolution information on the amount of energy purchased. In business with large and industrial customers, the requests for information become more specific. In this emerging market, more and more electricity contracts are being signed with industrial customers that require specific physical characteristics, such as electricity from a particular wind farm or a particular share of renewable energy sources.

Proven carbon footprints could be more relevant, especially for consumer goods where consumption is more tangible for the (end) users. However, there is also a high difference in the demand for CO_2 information in a certain level of detail or in a certain temporal resolution in the manufacturing industry. In the case of an interviewed company in whose industry the standardized environmental product declarations are established, customers are very interested in the emissions key figures of the individual product classes. The environmental product declaration, which is compiled ex post based on the average values of a specific operating year for several years, serves as a central source of information for customers. According to the assessment of a company representative, more up-to-date and product-specific emission values could be of interest to customers in this area in a few years. At another interviewed company, which manufactures drive systems, among other things, not many customers have thus far asked about the carbon footprint of the product they buy. However, the company has already provided individual customers with environmental data, such as information on climate-damaging greenhouse gas emissions and water consumption in the production of the purchased product.

In summary, the demand of customers in the manufacturing industry is mainly aimed at an averaged carbon footprint of the desired product category. However, many of the company representatives interviewed suspect that specific information, for example, specific to their purchased product, will be of interest to customers in the subsequent step. Especially for industrial customers, the demand for detailed and verified information could increase.

Future Relevance of CO_2 Information

Although CO_2 information and emissions key figures are already highly relevant to the company representatives interviewed as described above, the authors also asked the interviewees to assess the future importance of this information. All company representatives state that the importance of CO_2 information will increase. The company representatives derive this assessment from different perspectives and areas. From a legal perspective, the requirements for mandatory reporting of CO_2 information have increased. Likewise, new or further developed standards increase the requirements via further specifications outside of accounting. From a product perspective, two company representatives believe that the relevance of calculated emissions increases as, in the future, a CO_2

footprint will no longer be based solely on the company's own production but increasingly on consideration of the entire value chain. As a result, the importance of information on Scope 3 emissions is likely to grow significantly in the future. Likewise, several companies state that substituting precursors with lower-emission alternatives will become more relevant in the future and that information on the carbon footprint of a precursor can therefore become relevant to purchasing decisions. According to the companies interviewed, the differentiation of precursors and raw materials according to their assigned emissions will, generally, become more crucial in the future.

All the companies interviewed have set their own emission reduction targets to achieve climate neutrality. To achieve these targets, emissions key figures will be recorded and evaluated more frequently in the future than in the past. Furthermore, emissions key figures will become relevant control parameters for measures aimed at specifically reducing the company's emissions. For example, measures such as investments in plant modernization will be assessed more closely in terms of the CO_2 emissions saved. Planned emission reduction targets will also be evaluated in the future to determine whether the measures taken to date are sufficient to achieve the next emission reduction target or whether further measures will be necessary. According to these assessments, CO_2 information will become a relevant control parameter for companies in the coming years.

As the importance of directly determined CO_2 data increases, the relevance of information systems for collecting and evaluating this data is also likely to rise in the future. Two companies, for example, state that they are currently looking for suitable software to map CO_2 emissions as a decision-making factor. For this reason, existing IT control systems are to be expanded or provided with the appropriate interfaces to optimize the quality of emissions and other primary data and better integrate them with other control indicators. Several company representatives also address the verifiability of the primary data collected and the key figures calculated from it as part of a potential optimization of the existing information systems.

4.1.3 External Incentives and Future Framework Conditions

Lack of External Incentives

As described, CO_2 information and emissions key figures have gained importance among the companies interviewed. However, several company representatives explain that external incentives are still too low for information on CO_2 emissions to play a central role as a decisive economic factor in investment decisions or the operation of plants. Two company representatives mention the lack of economic incentives in connection with emissions key figures. To use emissions as a control variable in addition to business indicators, it must be possible to better quantify the economic value of emissions or the climate damage they cause. A company representative cites as an example that positive and quantifiable incentives through penalties or CO_2 pricing could encourage investment in measures associated with emissions reductions. This may equally be the case if CO_2 evidence becomes significant in operational business activities, as company assets are relevant to the EU ETS. However, from the perspective of another company representative, the price of these certificates would have to increase significantly to a mid-three-digit amount to reflect the climate damage caused and impact the company's operational business activities.

Environmental Due Diligence

In addition to the lack of incentives for the transformation toward sustainable corporate processes, there are legal regulations and draft laws intended to promote the development of sustainable products and services. These include the German Supply Chain Due Diligence Act and the European draft for tightening environmental due diligence (see Chapter 3.3). The company representatives provided assessments of how they would be affected by these legal changes. For example, a company representative considers it positive that the draft legislation currently under discussion supports the company's plans and investments in a better recording of its carbon footprint.

Since it is currently uncertain how a European directive will be finalized and implemented in the member states, the companies interviewed perceive this uncertainty as a risk factor. Particularly, the companies are uncertain which CO_2 information they will have to record and take into account in their value chain in the future. Expanding data collection to include categories in Scope 3, for example, all supplier emissions, would significantly increase the administrative burden on companies. Two company representatives state that the German Supply Chain Sourcing Obligations Act already poses challenges for their companies, as CO_2 and other ESG information must be recorded and tracked validly across the entire value chain. Even if primary data for determining emissions are easier to collect than other ESG information, such as on-site working conditions, a high level of additional personnel effort would be required to build the necessary (information) systems from the perspective of a company representative. A company representative adds that the time horizon until mandatory implementation by companies may be too short for setting up the necessary (information) systems because one up to a few years would not be sufficient for global corporations to implement such measures. According to the assessment of a company representative, the risk that the effort of collecting emissions data and ensuring further ESG criteria increases significantly could be equally relevant for small to medium-sized companies. In particular, if it is not possible, in parallel, to reduce the effort for the collection through technical tools, stricter regulations could mean a negative development for (especially smaller) companies.

Digital Product Pass

The introduction of a digital product passport is another initiative, both at the German and the European level, intended to lead to the development of more sustainable products and focused on the reuse of end products and their components (see Chapter 3.4). Most of the companies interviewed were not yet aware of the initiatives relating to a digital product passport and have therefore not yet explored a possible design and the impact on company processes. According to a company representative, this is partly due to only averaged CO_2 footprints, calculated using CO_2 conversion factors, used in product markets. Another company representative assumes that the perspective in data collection changes to determining the CO_2 footprint of the end product as it is used. This means that (end) customers of a final product will (have to) be provided with information on the allocated CO_2 emissions, which may be priced directly at the (end) customers.

A company representative considers the impact of a digital product passport as positive, i.e., a legal framework can support the investments in a better recording of the CO_2 footprint that the company has already planned. Another company representative states that the emissions of future products would already be considered in more detail during product development to achieve the company's own emission reduction targets. Similar to the assessments of new requirements for environmental due diligence, several companies interviewed state that new (information) systems would also have to be set up for a digital product passport. This means both high personnel costs and a long implementation period of up to ten years until a digital product passport can map the specific emissions of a product over its entire life cycle.

Carbon Border Adjustment Mechanism (CBAM)

All of the companies interviewed are aware of the current draft of the CBAM (see Chapter 3.2). However, most companies have not yet dealt with the proposed mechanism in detail, as they consider the impact on their own company to be either minor or, in the case of supply dependencies, unavoidable. If there are no alternative suppliers of more sustainable products, the company will continue to purchase the same inputs at higher prices. Since the draft CBAM mechanism starts upstream with raw materials, the company representatives interviewed expect few additional obligations, particularly for manufacturing companies.

4.1.4 Summary of Obstacles Related to CO_2 Information

The current and future importance of CO_2 information results in obstacles outside of the collection and processing (see Chapter 4.2), which are mentioned in Chapter 4.1.1 to Chapter 4.1.3. Figure 2 summarizes these obstacles.

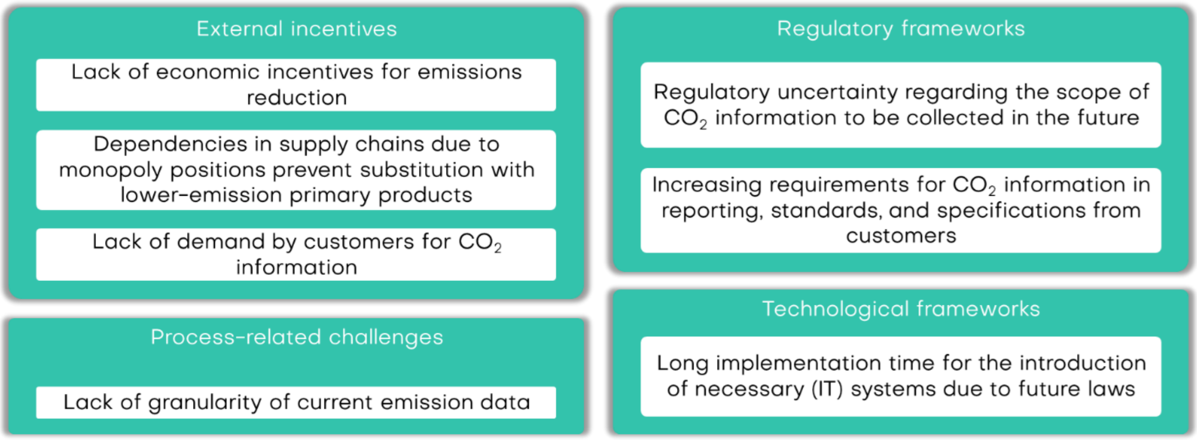

Figure 2: Overview of the identified obstacles from the current and future framework conditions

4.2 Current Challenges with the Collection and Processing of CO_2 Information

Based on how companies currently record and process their CO_2 information, the authors investigated in the interviews with company representatives what challenges companies face. The objective is to identify the central problems and challenges companies face in recording and processing CO_2 information. Figure 3 provides an overview of the challenges identified with the help of the interviews.

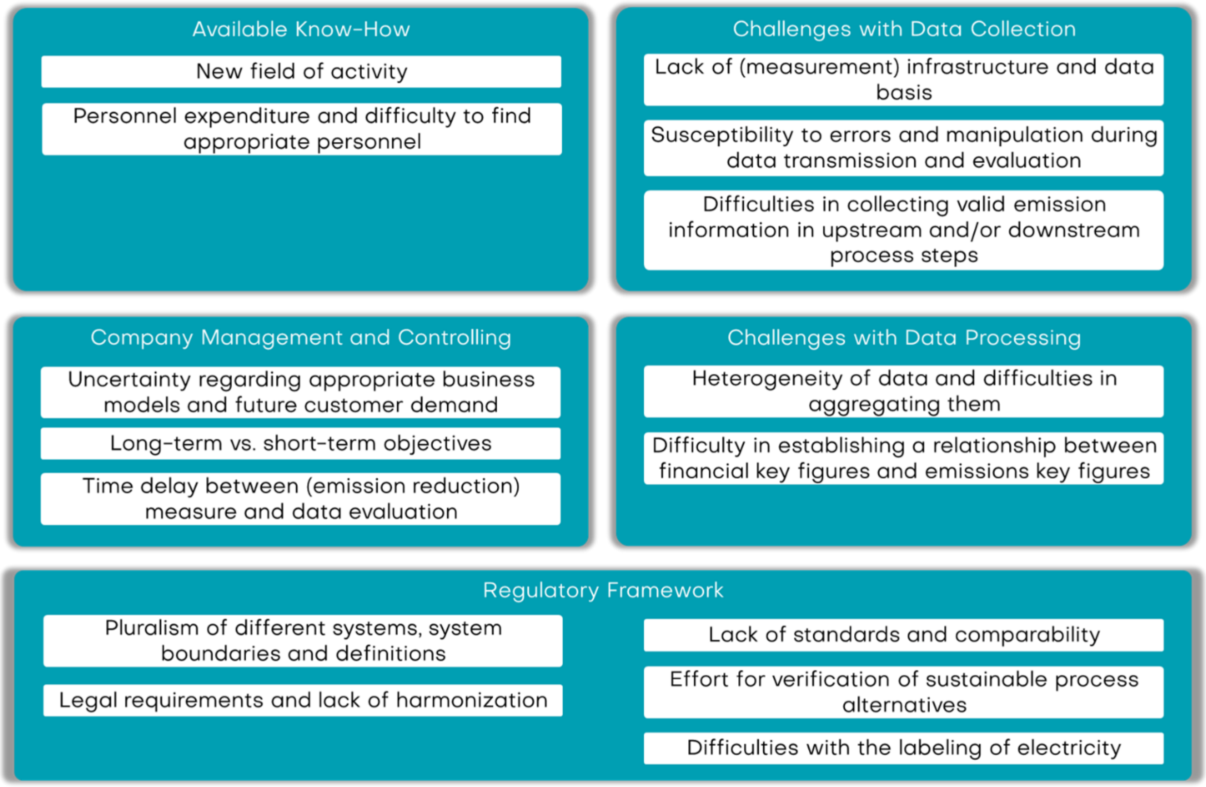

Figure 3: Overview of the identified challenges in the collection and processing of CO_2 information

4.2.1 Regulatory Frameworks

Pluralism of Different Systems, System Boundaries, and Definitions

The existing legal framework increases the effort associated with collecting, aggregating, and accounting of CO_2 information. With the help of the interviews, the authors found that the multitude of different perspectives, system boundaries, and definitions depending on the report or balance sheet make the calculation of CO_2 key figures considerably more difficult for many companies. Several company representatives name the pluralism of methods as a risk for their company, as the different reporting systems increasingly enhance the complexity of data collection and processing.

Different definitions, data collection, and calculation bases may exist for the same issue. For example, different information has to be provided for the annual reports than for the certificate trading according to EU ETS and the evaluation of emissions according to the scopes of the GHG Protocol. Consequently, for several interviewed companies, the effort in report preparation is also related to the different definitions having to be considered very carefully such that one includes the correct primary data for the various definitions and can then put them in relation to each other. As a result, the integrity of the calculated key figures for different audits is highly prioritized among the interviewed companies since performing the calculations several times according to different regulations also involves corresponding costs. The selection of CO_2 conversion factors can also be challenging for the companies, as there are several correct CO_2 conversion factors for many processes and/or intermediate products based on different definitions.

Since each mandatory and voluntary reporting system or standard has different system boundaries in terms of allocations, with the result that a specific CO_2 emission can be allocated differently depending on the reporting system (e.g., non-financial statement, GHG protocol, science-based targets, etc.), parallel data collection systems with parallel calculation tools are necessary for some instances. This also leads to the interviewed companies having to identify the interfaces between the different legal and voluntary reporting systems to transfer data from the different reporting systems into each other.

Legal Requirements and Lack of Harmonization

The legal framework conditions, which, as mentioned, can lead to method pluralism among companies, are being further developed at both the European and the national level. Due to the increasing legal requirements regarding environmental due diligence, it is a challenge for several interviewed companies to keep track of all political and legal developments and to implement them via technology development and products. An example of the increasing effort is the EU Taxonomy Regulation, which companies currently have to implement.

In addition to the increasing requirements, the company representatives interviewed also perceive a lack of harmony between different initiatives and laws at the European and the national level. These inconsistencies in the legal framework increase the effort for companies due to parallel existing assessment bases. For example, a company representative cites the discrepancy in the sustainability assessment of certain technologies, which differs between an elaborated EU strategy and the Taxonomy Regulation. Likewise, the assessment of sustainable business activities under the Taxonomy Regulation is not based on their specific emissions data. With the evaluation of the sustainability of economic activities and products according to various criteria, a further different logic arises from the point of view of the interviewed companies, which is not exclusively based on emissions key figures. This increases the number of assessment options for the sustainability of business activities that need to be reported. Furthermore, in terms of addressing the appropriate point in the value chain, the policy steering elements differ. For example, the current EU ETS takes a downstream approach. Other EU initiatives address consumer choice. However, much of the European framework and legislative proposals associated with the Fit for 55 package focus on process steps early in the value chain. For example, the EU ETS II proposals, the CBAM, and the Taxonomy Regulation focus more upstream on fossil fuel distributors.

Lack of Standards and Comparability

Several company representatives interviewed also state that there is a risk of a lack of transparency and comparability in reporting. They attribute this risk in particular to a lack of standardization. While there are standards for reporting, such as the GHG Protocol, methodologies change. For certain areas, such as data quality and CO_2 conversion factors, there are no (suitable) standards to make primary data more comparable and put companies' external presentation on a consistent basis. In the case of CO_2 conversion factors, for example, there are no legal requirements, which is why companies can refer to different sources when calculating them. For the companies interviewed, it is therefore important that the sources used for reporting and the calculation methods, for example, the CO_2 conversion factors of the energy sources, are communicated transparently.

Suitable standards are also lacking in other areas. According to the company representatives interviewed, there is a lack of comparable, transparent standards with regard to the definition of climate neutrality and the offsetting of certificates, for example, in the case of compensation and offsets. Similarly, there is a lack of standards for automated interfaces between control and other information systems for report generation. For example, a company representative states that only the connections via the control technology are standardized within the company. This standardization, however, is not due to the appropriate recording and processing of CO_2 information but to the uniform maintenance of the technical systems.

Difficulty in Labeling Electricity (in Relation to Storage and Hydrogen)

In the case of the two technologies of energy storage and hydrogen electrolysis, which gain in importance in the context of the energy transition, the companies interviewed see a high relevance in demonstrably differentiating electricity and/or hydrogen according to their associated emissions. The valuation of purchased electricity, for example, via green electricity certificates, is currently mainly decoupled from the electricity mix that the companies and private customers physically use on site. With the help of green electricity certificates, a company can obtain a different electricity mix via the electricity market than it physically receives through the electricity supplied at the grid node. Due to this difference between the characteristics of the traded electricity on the electricity market or in OTC supply contracts and the physical composition, several interviewed companies are uncertain about how renewable electricity can be valued in the future. However, this uncertainty in valuation occurs particularly for energy storage. Company representatives find it difficult to appropriately capture and evaluate the charges and discharges from an energy storage facility. For energy discharged by a storage facility to be considered green, the storage facility would also need to have been fully charged with renewable energy. If the double marketing ban is removed from the EEG due to the development of RED III (see

Chapter 3.2), the evaluation of electricity from energy storage systems could become even more important. At the Policy Accelerator for Climate Innovation organized by EPICO KlimaInnovation and the Konrad Adenauer Foundation, representatives from politics, business, academia, and civil society also discuss the need to map green electricity certificates digitally, transparently, and with higher temporal resolution in the future.[72] The participants of the Policy Accelerator also emphasize that guarantees of origin such as green electricity certificates should be made uniform or more interchangeable within Europe in the future.[72]

In addition to the valuation of electricity in energy storage systems, green electricity certificates and guarantees of origin of renewable energies play an increasing role in the electricity packages offered. For example, the company representative of an energy generator states that an electricity mix with a particular share of electricity from a renewable generation plant and a certain regionality is sold. The energy supplier then makes adjustments, for example, as part of compensation, if the actual share of renewable energies in the electricity mix is too low.

Furthermore, concerning hydrogen, which plays a central role in many strategies for the industrial transformation toward climate neutrality, several interviewed companies lack the standard according to which hydrogen can be evaluated and certified in the future with regard to its sustainability. The companies interviewed as part of the conducted reality check of the National Hydrogen Strategy also indicated that transparent visualization of the CO_2 footprint and uniform international standards for the certification of hydrogen is necessary to strengthen demand as well as the emerging hydrogen production.[73] In Germany, for example, a large share of renewable energy capacity is provided by large wind farms in the north. If hydrogen electrolyzers are now more likely to be located with industry in the south of Germany, it is still unclear to several company representatives how electricity properties and the properties of the hydrogen to be produced are to be allocated. An interviewed company already addresses the correlation between the electricity mix and the emission valuation of hydrogen in several possible use cases. The company also considers using energy storage as a buffer for the periods when the wind farm associated with an electrolysis does not supply energy.

Effort for Verification of Sustainable Process Alternatives

If companies want to replace used raw materials and/or precursors or entire processes with more sustainable alternatives, these are associated with considerable effort through certification processes in several industries of the interviewed companies. Several interviewed companies state that aligning

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[72] Cf. pages 2 – 3 Energy and Climate Policy and Innovation Council e.V. (2021). Policy Accelerator for Climate Innovation – vier Bausteine für eine Innovationsagenda. Retrieved from https://epico.org/de/veroeffentlichungen/vier-bausteine-fuer-eine-innovationsagenda

[73] Cf. Dantine, D., Weber, B., Reh, R. (2021). Reality-Check der Nationalen Wasserstoffstrategie. Konrad-Adenauer-Stiftung e.V., Energy and Climate Policy and Innovation Council e.V. (Hsg.). Retrieved from https://epico.org/de/veroeffentlichungen/reality-check-der-nationalen-wasserstoffstrategie

processes and/or products according to emissions data would be associated with major challenges, as certain processes must be tested according to certain regulations and standards and certified by TUV, for example. If one now wants to change the production process and replace it with more sustainable production methods, this process step must be certified again with all plant specifications. The certification process costs the company significantly more than the pure investment in a changed production operation. This is partly because the production step may not be carried out until sufficiently recertified. For sustainable alternatives, the certification process also involves considerable effort due to the high proportion of manual data collection.

4.2.2 Lack of Know-how

New Field of Activity

Most companies have prepared a report in which they have to disclose CO_2 information and emissions key figures for only a few years or for the first time. Therefore, most companies still have little experience in reporting, collecting, and aggregating CO_2 information. In the case of interviewed companies that have carried out detailed reporting on their emissions for the first or second time, the effort required for the associated processes has been very high.

Personnel Expenses and Difficulties in Finding Suitable Personnel

Almost all of the companies interviewed state that there are not enough employees with the appropriate know-how compared to the effort and the increased requirements for collecting and processing CO_2 information. To cope with the increased effort and the associated requirements, the companies need to hire additional employees with the necessary competencies and justify these hires to the management level. Therefore, most of the interviewed companies state that they currently want to build up expertise in life cycle assessment and (CO_2) data analysis and, consequentially, search for suitable personnel. Since IT skills are increasingly in demand for reporting and calculating LCAs or carbon footprints, the requirement profile for employees has changed in recent years. Two company representatives state that it is particularly difficult to find employees who have the necessary skills for digitization, for example, who can analyze large data sets and derive insights for the company from them. This is due to employees with this skills profile being sought after by many companies in different industries. Therefore, it is a challenge for many of the companies interviewed to find sufficient personnel for topics at the interface of LCA and digitization.

4.2.3 Challenges With Data Collection

Lack of (Measurement) Infrastructure and Data Basis

The first step in determining emissions key figures for reporting or carbon footprints is to collect primary and secondary data. In the case of the companies interviewed, the primary data collected is generally not measured emissions but product and energy consumption data, for example, on electricity and heat consumption. Depending on the company's industry, CO_2 information is more or less relevant to its business activities. In industries where companies are subject to the EU ETS, CO_2 information has been collected for many years, whereas in other industries, it has only been collected for one to a few years. Depending on the industry, the basic measurement infrastructure for primary data collection is already in place or is just being established at the interviewed companies. Data collection is problematic in older plants, for example, where there are no built-in interfaces for data collection. A company representative, therefore, questions whether and how he can collect the necessary data. Another company representative states that the metering infrastructure is in place but is often not connected to the central management system. Yet another company representative points out, for example, that measured consumption data is not yet available at all for small plants.

The basis for sufficient data quality in data collection is formed by the measurement infrastructure in the companies and by the measured data's resolution, for example, the temporal resolution. The level of detail or resolution of the data also depends on the industry and the size of the company. For companies where energy costs form a relevant part of total costs, energy consumption is recorded at a high temporal resolution, for example, in hours, with additional analysis where necessary. Most companies interviewed can fully calculate Scope 1 and Scope 2 emissions. However, most of the CO_2 information comprises conversions from primary data, such as annual consumption, instead of direct collection of emissions data. In the absence of RLM[74]-based metering infrastructure, only annual energy consumption can be measured, and this cannot be broken down by a specific unit of time, such as hours. Smaller and non-energy-intensive companies may therefore not know when energy consumption took place and how much energy was consumed.

Susceptibility to Errors and Manipulation During Data Transmission and Evaluation

All of the company representatives interviewed, however, consider the transfer of data to the system in which the data are to be analyzed as the most significant problem or the highest risk in data collection. Since the majority of the companies read the data manually and, as a rule, transfer it to Excel files, the data collection and transfer are susceptible to unintentional errors. A company representative also emphasizes that many contacts engage in data collection, making the data collection and transmission process prone to errors due to long communication lines. In the case of listed companies, the integrated annual report and the CO_2 key figures it contains are key figures relevant to shareholders. If, for example, a CO_2 key figure needs to be corrected, immediate notification must be sent to all shareholders. Such notification can also lead directly to financial losses in addition to long-term damage to the company's image, which is why unintentional errors in the transmission and calculation of CO_2 information represent a high risk for

[74] RLM = Recording power measurement, in which consumption can be broken down by time units

several of the companies interviewed. Even if the companies are not listed on the stock exchange, interviewed companies state that reputational damage can accompany errors in CO_2 key figures.

Overall, ensuring that data manipulation can be ruled out and guaranteeing data quality have a high priority among the companies interviewed. For this reason, the data stock often has to be subjected to extensive post-processing and multiple checks, such as plausibility checks. A large proportion of the companies interviewed have therefore introduced appropriate controls. To this end, the accuracy of the primary data is checked for conspicuous irregularities at many points within the process. When transferring data from Excel tables to the software used to calculate the emissions key figures, in a number of cases, several employees conduct double checks. Furthermore, for several companies interviewed, the transferred data are compared with data from previous years to identify major deviations. In the event of major deviations, alarm signals are already established in the system in certain cases. Since information reliability cannot yet be proven using data technology within the existing information systems, the transparency and integrity of the data are currently ensured via the measures outlined by the interviewed companies. Several interviewed companies have already planned to upgrade the hardware. This was achieved, for example, by digital meters and by implementing automated interfaces for the energy management system. This approach was followed due to the high risk and effort for data transmission and consolidation. Another company representative explains that the data collection and transmission systems available worldwide in the company are to be merged into a central information system.

For several companies interviewed, a particular challenge in external audits is to be able to transparently demonstrate that manipulation of emission and other primary data can be ruled out. This process begins with the installation and calibration of the measuring instruments. Access to the local computers and (information) systems in which the primary data are stored must also be controlled. Primary data that are read manually and transferred via Excel spreadsheets, for example, is not audit-proof. Errors and possibilities of manipulation must therefore be excluded during the data transfer to the subsequent database systems. Likewise, the process of data collection and processing must be presented in a comprehensible manner to auditors.

Difficulties in Collecting Valid CO_2 Information in Upstream and/or Downstream Value-Adding Process Steps

As shown in Chapter 4.1.2, the relevance of CO_2 information for upstream and downstream value creation steps (Scope 3 emissions) increases. At the same time, the collection of CO_2 information is a major challenge for the interviewed companies. The interviewed companies have limited information on what emissions occur in upstream and downstream steps. Currently, the CO_2 footprint of upstream products at the interviewed companies is mostly assumed via CO_2 conversion factors or, if available, taken from invoices, technical data sheets, or environmental product declarations. Therefore, the data quality or the level of detail of the recorded data is significantly lower for a few of the interviewed companies compared to the documented Scope 1 and Scope 2 emissions. Several company representatives also explain that the return of data from suppliers or customers to the company has been low thus far. As a result, certain interviewed companies plan to invest in measurement infrastructure at customers' sites or on products to increase data response and improve data quality. The expansion of measurement infrastructure outside of the company itself can, however, take several years.

Several interviewees also state that for specific categories in Scope 3, they lack knowledge of how to determine a carbon footprint from existing data, for example, from purchasing. A company representative mentions new technologies from the development department where the associated emissions cannot yet be fully determined and assessed. Furthermore, in the use of secondary raw materials, it is currently unclear how the recyclability of products can be better mapped and recorded for the company.

Furthermore, it is uncertain for the companies how it can be ensured in the future that the data collected on upstream products are valid. This uncertainty is particularly the case if the upstream products originate from non-EU countries and the suppliers have not yet been seriously involved with official regulations on the subject of CO_2 emissions. Moreover, it is unclear to companies according to which definition of climate neutrality a purchased product or service has been assessed as “climate neutral” and how the preliminary products purchased as “climate neutral” should then be assessed by the company itself. There is also uncertainty among several companies interviewed as to how a data transfer of emissions between companies supplying a product can be structured and which side is responsible for financing the digital infrastructure.

4.2.4 Challenges With Data Processing

Heterogeneity of Data and Difficulties in Aggregating Them

Once the data for reporting or calculating life cycle assessments or carbon footprints has been collected, it must be compiled into emissions key figures. According to the interviewed companies, the compilation of primary data and the determination of emissions for reporting are less of a problem compared to data collection, provided that the companies already have access to a suitable (measurement) infrastructure. Since the data collected at the companies from different systems or sources have to be aggregated for a report or a CO_2 footprint, this means another considerable time effort to combine the heterogeneous data into one emissions key figure. The data for determining the CO_2 footprint, for example, comes in part from process control technology and is collected in high temporal resolution. Other data comes from business management systems used in the purchase and sale of products. However, since this primary data is collected to control and monitor company processes, the primary data must first be filtered and checked for its usefulness in calculating emissions key figures. After sorting and processing this primary data, employees must analyze which primary data are multiplied by which CO_2 conversion factors. Several interviewees also state that data consolidation from the plant level to a cross-company emissions key figure is very complex.

Difficulties in Establishing Relationships Between Financial Ratios and Emissions Key Figures

In addition to aggregating the collected data to the required emissions key figures, it is a challenge for the majority of the interviewed companies to establish the relations between financial key figures and emissions key figures. The need to link these key figures and identify their interfaces stems, among other things, from the EU's Taxonomy Regulation (see Chapter 3.2).

Until now, most of the companies interviewed have determined and considered the financial and operational key figures separately from the environment-related key figures. The determination of key figures in the two areas is therefore largely decoupled. According to a company representative, this decoupling is because the key figures serve different purposes and are therefore not used identically. Another company representative states that the calculation of the key figures is based on very different databases, for example, in terms of data granularity, orders of magnitude, and tolerance for errors. For the companies interviewed, the challenge of creating interfaces between different reports and relating the different metrics to each other is new. The complexity of linking the different systems then also depends on how high the data granularity is and will be prescribed for the key figures.

Increasingly, emissions key figures need to be linked to technical indicators, not only for the increased reporting requirements but also for customers. Customers increasingly make their product selection based on a mixture of the products' performance indicators and sustainability indicators. A company representative states that both key performance / use figures and emissions key figures are relevant to customers. These two perspectives may be weighted differently for customers. As a result, the companies are also required to combine and present the separate key figures in a suitable manner from the customers' perspective.

4.2.5 Company Management and Controlling

Uncertainty Regarding a Suitable Business Model and Future Customer Demand

In addition to external conditions, internal decision-making criteria and corporate planning at the interface with customers can also make it difficult for a company to invest in CO_2 information reporting and develop a strategy for dealing with the increasing demands. In this context, the authors learned from a majority of the interviewed companies that there is considerable uncertainty regarding the future demand for CO_2 information.

On the one hand, several companies are uncertain how customer demand for more sustainable products will develop. Therefore, it is still unclear whether it is possible for these companies to build a valid business model with climate-neutral products or production or whether conventional competitors will then be preferred. For example, a company representative explains that certain customers already request specific carbon footprints but are still reluctant to buy new, in this case, more sustainable products. Therefore, the sale of sustainable products with specific CO_2 footprints would currently represent a major challenge for the sales department, as it is still uncertain which information the customers will request.

Second, many of the company representatives interviewed do not yet have an idea of a suitable business model for optimizing the collection and management of emissions data. Since the economic benefits of investing in better measurement infrastructure and corresponding software components are difficult to quantify, the companies interviewed do not give high priority to such investments. Uncertain political conditions reinforce this effect, as it is unknown to the companies at which level of detail they will have to provide CO_2 information in the future. This problem is further exacerbated by collecting and evaluating emissions data not being part of the interviewed companies' core business.

For example, several interviewed companies consider their measurement infrastructure to be not optimally developed, as the company management has thus far not attached great importance to collecting CO_2 information. However, no direct savings can be measured when investing in emission measurement equipment and an associated system. This means that the return on investment (RoI) of an investment in emissions measurement infrastructure is very difficult to quantify. While the investment in measurement infrastructure can be used to better evaluate future emission reduction measures, the company cannot derive a direct effect from the investment. These characteristics make it difficult to justify investments in the better provision of CO_2 information to the management level. A company representative adds that with a higher price for CO_2 certificates, the importance of CO_2 as an economic decision factor increases. When the amount of emissions becomes relevant to the operating results, investments in measurement infrastructure and digital modules for CO_2 monitoring would be given a higher prioritization.

Long-term vs. Short-term Objectives

Several company representatives also explain that decisions for investments, such as in measurement infrastructure, also depend on the term of corporate planning (long-term / short-term) and the company's ownership structure. Particularly in the case of listed companies, it is difficult to push through long-term investments, the monetary equivalent of which will only emerge with future business models.

Time Delay Between Measurement and Data Evaluation

Since the data collection and evaluation of CO_2 information occurs with a delay of approximately one year, there may be a significant time lag between implementing emission reduction measures and their evaluation. As a result, many companies interviewed can only determine and provide associated emissions from primary data ex post. However, if the companies do not have data from the current year of operation, it is more difficult to plan monitoring measures for the future and identify where the greatest leverage for emission reductions is. A number of the interviewed companies, thus, do not have up-to-date information on investment projects and their successes with regard to emission reductions. This is partly because these companies do not currently have CO_2 information in real time or in smaller time units, such as hours. If this CO_2 information is lacking, then the impact of an investment project can only be evaluated with a delay of one or two years. This means that successful and less successful measures cannot be targeted with the desired speed according to their emission reductions.

4.3 Requirements for Digital Solutions

The previous chapter provided an overview of the challenges and increased requirements for companies with regard to the collection, processing, and publication of CO_2 information. Since these requirements increase the effort needed by companies to produce environment-related reports and carbon footprints, digital solutions are a key part of the solution for the identified problems at all companies interviewed. Although certain companies already use software for ESG performance and risk management, all company representatives list additional requirements for digital solutions. Several company representatives state that a holistic digital solution that can meet all of the companies' requirements is still lacking. The following is an overview of the requirements for digital solutions that the company representatives derived from the challenges mentioned.

Harmonization of Different Systems and Definitions

Since, at most companies, the data basis is heterogeneous and the legally prescribed system boundaries also vary depending on how the report is prepared, an information system should integrate the different reporting systems. The companies interviewed, therefore, consider a system to be ideal in which valid CO_2 information is recorded and automatically communicated at all sites via the interfaces and meter infrastructure set up. Furthermore, emissions from upstream and downstream systems should also be recorded via the same system. For this purpose, the CO_2 footprint of a raw material or intermediate product could be automatically transmitted to the central CO_2 management system when it is purchased. This central information system should then store the different system boundaries of the assessment standards such that users can generate different emission key figures from the system for different occasions. The digital solution should, therefore, harmonize the diverse systems and data sets by means of a uniform data ontology.

Inclusion of Internal Evaluation and Controlling Processes

In addition to the integration of the different reporting criteria, the majority of the interviewed companies consider it necessary to set up internal evaluation and controlling processes with regard to emission reductions in the future. Ideally, the monitoring of CO_2 information is integrated into the information system in which the CO_2 information is prepared for external stakeholders. For many of the companies interviewed, it is essential that the effect of emission reduction measures can be monitored at least at the plant level and that the intended target achievement can be made visible. A particular goal could be to break down the emissions key figures to the control variables of the individual company units such that the responsible manager can evaluate their emissions reduction targets with corresponding key figures.

It should also be possible to derive the relevant emissions key figures for investments via a CO_2 monitoring system. Analysis tools, for example, based on machine learning, should be developed that can identify processes and/or process steps with great leverage for reducing emissions within the company. Such findings can supplement the evaluation and prioritization of investments with sustainability criteria.

Costs of the Digital Solution

When deciding for or against implementing a digital solution or a new information system, the costs of the new technical solution must be compared with the costs of the current process. For many companies interviewed, the decision in favor of a new digital solution is therefore dependent on whether the benefits achieved, such as a reduction in personnel expenses, can save more costs than would have to be invested in a digital solution.

Data Sovereignty and Protection

Data sovereignty and data protection are highly prioritized among companies when processing data. Primary and emissions data are already subject to a high level of data protection in relation to the legal framework, for example, GDPR[75], calibration standards, storage of the data, and standards for the associated servers at the measurement infrastructure. If individual customers ask for detailed information on the carbon footprint, this is, for example, only passed on confidentially via non-disclosure agreements (NDAs[76]), according to a company interviewed.

The interviewed companies' data protection requirements for emissions data primarily depend on the conclusions that competitors could draw from the emissions data. Companies therefore specifically investigate which emissions data and emissions key figures can be shared with the public in a meaningful

[75] GDPR = General Data Protection Regulation, which is a regulation of the European Union governing the protection of personal data
[76] NDA = Non-Disclosure Agreement, in which two or more parties agree and contractually record the confidentiality of certain data

manner. For reporting purposes, it is not currently necessary to publish fine granular CO_2 information, for example, at the plant level. If emissions data were published at a higher temporal resolution, the risk of drawing conclusions about production would be more significant. This would result in an increasing need for companies to protect emissions data from access by third parties. The higher resolution data may, however, be relevant for internal management. From the point of view of a company representative, the publication of emissions data as part of a digital product passport would be possible if it is not possible to draw conclusions from the sum of emissions associated with the product as to which proportion of emissions originate from which supplier or primary product. However, especially when collecting emissions data from suppliers or customers for a holistic emissions assessment of products, the requirements for data protection could be high.

User-Friendliness

A central requirement and a decisive criterion for a digital solution for many interviewed companies is the user-friendliness of the information system. Since preparing reports and life cycle assessments is perceived as a complex subject area, a user-friendly interface can increase employees' acceptance of the digital system. A new information system should be comprehensible to existing employees and should be able to be operated without much additional effort. The relevant CO_2 information and emissions key figures should be presented, in particular, for employees without a technical background and for managers. One of the company representatives, for example, states that most of the existing software for energy management and life cycle assessments can display the relevant information. However, these digital systems are often not designed to be operated and used by non-technical employees. Since emissions key figures become increasingly important for executives, intuitive usability for executives is an essential requirement for digital solutions.

Preparation of Performance and Sustainability Indicators for Customers

Since customers increasingly rely on a mixture of technical performance and sustainability indicators when making purchasing decisions, it must be possible to compare the properties of products with one another. Therefore, customers should be able to link relevant product properties with the associated carbon footprint in the future. This is the case, for example, if a product has a particular technical property and a smaller quantity of the product is therefore required. At the same time, the production of this technical property is accompanied by a higher amount of emissions. Then, customers have to weigh up whether the higher allocated CO_2 of the technically better product is outweighed by the lower quantity required. Since such calculations are often very complex and demand data from different sources, digital solution modules are needed that can calculate such information and prepare it accordingly for customers.

Transparency and Tamper-Proofness

Another requirement for digital solutions from the interviewed companies is the security of the technology. With the help of the implemented information systems, the validity of the data should be increased and the risk potential for errors minimized. Since the interviewed companies increasingly need to capture information across their entire value chain, the companies face the challenge of obtaining valid emissions data from suppliers. Accordingly, it would also have to be possible to use a digital system together with partners in the value chain. Due to the increasing number of data points, the system must be able to manage the CO_2 information efficiently and transparently. Furthermore, there is an increasing need for transparent proof that third parties have correctly calculated the emission data and that third parties have also transmitted it in a manner that cannot be falsified.

5 Digital CO_2 Proofs of Origin and Use

The political and legal framework presented here and its possible further development with regard to the collection, analysis, and publication of emissions information will significantly increase the demands on companies. Chapter 4 presents the challenges, problems, and requirements from a corporate perspective. There are, however, also challenges from an economic perspective resulting from the current framework conditions. Since many of the instruments for reducing emissions start at the beginning of the value chain with CO_2 pricing, (end) customers pay different (implicit) prices for the emissions of a certain amount of CO_2.[77]

With the increasing number of instruments for pricing and recording emissions information, there is also an increased risk that due to the different system boundaries and approaches of the CO_2 instruments, specific emissions will be counted more than once, and a particular emission of a greenhouse gas will subsequently be priced more than once. This multiple counting of emissions can result, for example, from emissions trading systems starting at different positions and sectors in global value chains. Therefore, it is increasingly important to be able to trace emissions or emission rights across trade and sector boundaries and transfer them to other systems. Furthermore, with increasing reporting requirements related to the global value chain and origin of products, information on emissions must become traceable along multiple actors in a value chain all the way to the (end) consumers. Article 6 of the Paris Climate Agreement emphasizes the importance of cooperation between parties and the transferability of emission reduction measures, which should be implemented in one country and the results transferred to another.[78]

To reduce the complexity of collecting and verifying emissions information and to keep the costs of the associated processes as low as possible, digital, and decentralized solutions for CO_2 proofs of origin and use may be important. Given the global dimension of emission reduction measures, a globally organized system would otherwise be necessary but would be too bureaucratic and inflexible from the UN perspective.[79] Alternatively, according to Article 6.2 of the Paris Climate Agreement, a decentralized bottom-up approach should be pursued, appropriately linking national CO_2 pricing instruments, such as emissions trading systems, globally without counting emissions multiple times. Under the given framework conditions, information on emissions must be made available in an increasingly transparent, tamper-proof, and verifiable manner along the entire value chain. To avoid double counting emissions, the transferability of emission rights or reductions must also be ensured. Various digital technologies could be

[77] Cf. Bardt, H. (2017). Law of one price. ORDO – Jahrbuch für die Ordnung von Wirtschaft und Gesellschaft, 68(1), 303-322.
[78] Cf. UNFCC (2015). Adoption of the Paris Agreement: Proposal by the President. United Nations: New York, NY, USA.
[79] Cf. Marcu, A. (2017). Governance of Article 6 of the Paris Agreement and lessons learned from the Kyoto Protocol. Fixing Climate Governance Series. 4, 1-28.

used to design such decentralized CO_2 proofs of origin and use.

Article 6.2 of the Paris Agreement[80]

> *Article 6*
>
> *(2) Parties shall, where engaging on a voluntary basis in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards nationally determined contributions, promote sustainable development and ensure environmental integrity and transparency, including in governance, and shall apply robust accounting to ensure, inter alia, the avoidance of double counting, consistent with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to this Agreement.*

5.1 Basics of Possible Technologies for Digital CO_2 Proofs of Origin and Use

In the following, the basics of the technologies addressed for digital CO_2 proofs of origin and use are introduced. These technology proposals address the challenges mentioned by the interviewed companies, as well as their requirements for digital solutions. Depending on the users' requirements, such as companies and individuals, and also the political framework, a digital solution for CO_2 proofs can be designed with the help of the following technologies.

Blockchain Blockchains are networked computers that reach a consensus about the sequence of executed transactions, save this state, and update it continuously. Blockchain technology is a particular distributed ledger technology where data and transactions are stored in blocks linked to each other by a cryptographic value, the hash code. Blockchain technology comprises a wide variety of concepts. The characteristics of redundancy, resistance to a minimum of failures or attackers, and manipulation security represent a wide range of design variants of blockchains. Due to the design property of blockchain technology, it could be applied as basic technology for digital CO_2 proofs.

Decentralized Organization One of the principles of blockchain is that transactions can be carried out without the involvement of an intermediary to ensure trust between interacting parties. Blockchain technology builds on various existing technical solutions, especially cryptography. Thereby, it is possible to prevent double counting and find consensus on the network status to be written in the blocks. This design ensures the pseudonymity of the participants and, at the same time, maximum transparency of the transactions because every transaction

[80] Cf. United Nations Framework Convention on Climate Change (2016). The Paris Agreement. Retrieved from https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf

on the blockchain is visible to all participants. This innovative design of the technology builds manipulation security and trust in a decentralized network. Generally, data can be transmitted and verified bilaterally without blockchain, for example, using digital identities. However, blockchain technology provides the possibility of mapping business logic (by using smart contracts) and transferring values in the digital space in a tamper-proof manner. As a result, a blockchain allows a large number of actors to connect on a decentralized platform without having to agree and rely on an intermediary. Hence, blockchain technology creates a neutral platform for transactions without favoring individual participants. Blockchain technology promises to drive cooperation between national emission reduction measures without benefiting individual companies or countries.

Consensus Mechanisms The principle of the consensus mechanism of a blockchain network ensures that all participating nodes agree on the same state of the blockchain. Furthermore, the participating nodes need to reach a consensus on the new blocks to be added to the chain and that the consensus state is the only valid state. There are various mechanisms to find this consensus within a blockchain. Currently, the largest and most well-known blockchains, for example, Bitcoin and Ethereum, use the proof-of-work mechanism. In this mechanism, the consensus state is determined by solving a cryptographic puzzle for which the participating nodes are rewarded. However, to solve these puzzles as quickly as possible, a large amount of computer power is necessary, which, in turn, results in correspondingly high energy consumption. Alternative consensus mechanisms, therefore, increasingly gain acceptance on other blockchains. Examples of this are proof-of-stake mechanisms and proof-of-authority mechanisms. In proof-of-stake mechanisms, randomly selected network participants are allowed to propose the subsequent blocks. The random selection can be based on the share of each cryptocurrency in the blockchain or on the participation time of each network participant in the network. The proof-of-authority mechanism is mainly used in private blockchains where selected individuals or entities, such as government agencies, are allowed to validate the state of the blockchain. The energy consumption of these alternative consensus mechanisms represents only a fraction of the proof-of-work mechanism.[81]

Redundance and Manipulation Security In a decentralized network, every transaction is distributed among all participants. Thus, all participants need to execute and store every transaction. This design principle of redundancy leads to its high availability and security requirements. In contrast to decentralized systems, centralized systems can be manipulated much more easily by a single instance or can be disabled by targeted attacks. The efficiency and performance of a decentralized blockchain solution are, however, negatively impacted by redundancy in the network.[82] As a result, the time required to process a transaction

[81] Cf. Sedlmeir, J., Buhl, H. U., Fridgen, G., & Keller, R. (2020). The energy consumption of blockchain technology: beyond myth. Business & Information Systems Engineering, 62(6), 599-608.
[82] Cf. Sedlmeir, J., Ross, P., Luckow, A., Lockl, J., Miehle, D., & Fridgen, G. (2021). The DLPS: A New Framework for

or perform complex calculations can be significantly higher than with a centralized solution. Complex calculations that require a lot of computing power should therefore be performed off-chain and only results should be stored on the blockchain. Solutions are currently being developed to link off-chain calculations with blockchain technology. An example of these developments are zero-knowledge proofs (ZKPs), which can be used to prove the correctness of calculation results performed off-chain.[83]

SMART CONTRACTS Smart contracts are programs stored on a blockchain, automatically triggered by an event, and executed when predefined conditions are met.[84] The program code of the smart contract, which means mainly simple programming logic such as if-then conditions, is stored redundantly on the blockchain and executed by all participating network nodes.[85] The execution depends on a triggering event, i.e., an active trigger by another smart contract or a transaction. Automatic execution when the triggering event occurs can reduce transaction costs and ensure that deviations from predefined conditions are nearly impossible. Smart contracts can be designed, for example, to transmit emission rights or emission information safely according to an agreed accounting method at system boundaries.

TOKEN Unlike currencies (coins) that are anchored in a blockchain, tokens are defined on a blockchain and usually managed via smart contracts. Tokens can be defined as a specific digitally guaranteed right that can represent a variety of assets, securities, and rights. For example, a simple asset token represents ownership of an asset. This example illustrates that, unlike currencies, tokens are not necessarily defined by a payment functionality. Specific tokens may, however, be exchanged for currencies or represent such a payment function. Another approach to distinguish tokens is to determine whether the property is fungible or non-fungible. Tokens are called fungible tokens if each token of a category is interchangeable with another token of the same category and if it can be divided into smaller parts. For example, cryptocurrencies such as Bitcoin are fungible. When a certain amount of Bitcoin is transferred to another person, the value of those Bitcoins is independent of the information about which individual Bitcoin it actually is. Tradable emission rights could therefore be represented, for example, by fungible tokens in a blockchain network. In contrast, non-fungible tokens are virtual collectibles with a unique identifier, such as a specific color, and therefore cannot be replicated. Consequently, non-fungible tokens are also not divisible into smaller units.[86]

Benchmarking Blockchains. In: Proceedings of the 54th Hawaii International Conference on System Sciences (HICSS). Kauai, Hawaii, 2021. pp. 6855-6864

[83] Cf. Walfish, M., & Blumberg, A. J. (2015). Verifying computations without reexecuting them. Communications of the ACM, 58(2), 74-84.

[84] Cf. Buterin, V. (2014). A next-generation smart contract and decentralized application platform. White Paper, 3(37).

[85] Cf. Schlatt, V., Schweizer, A., Urbach, N., & Fridgen, G. (2016). Blockchain: Grundlagen, Anwendungen und Potenziale. White Paper, Project Group Business & Information Systems Engineering of the Fraunhofer FIT.

[86] Cf. Oliveira, L., Zavolokina, L., Bauer, I., & Schwabe, G. (2018). To token or not to token: Tools for understanding blockchain tokens. In: International Conference of Information Systems (ICIS 2018).

Self-sovereign Identity Certificate-based digital identities are intended to ensure the forgery resistance of authentication data internationally. In self-sovereign identity management, the owner of the identity information can control his identity and its processing himself, compared to centralized identity management. Self-Sovereign Identity (SSI) is a relatively new collection of paradigms in the field of digital identity management systems, in which identity information resides with a party itself rather than through a central intermediary. The party can maintain control over all components of its identity across different applications where it must identify itself. In an SSI system, digital certificates are used to specify identity attributes. The certificates are issued by third parties or created by self-attestation and can then be stored on a blockchain network, for example. The party can manage the identity via a digital wallet and an associated key. The wallet holder can then decide which parties he wants to release which identity attributes for verification. This verification can be performed with the help of ZKPs, for example.[87,88,89]

Zero-Knowledge Proofs Generally, zero-knowledge proofs (ZKPs) are a proof mechanism in which one party can prove to another party that it possesses a particular piece of information (or knowledge) or that a calculation was performed correctly. Based on cryptographic algorithms, this mechanism makes it possible to prove certain (data) attributes of a party without the party to be verified having to reveal information about itself.[90,91] Therefore, ZKPs allow data to be reviewed without disclosing the underlying data. This evidence mechanism can be of great importance, as emissions information from companies is often sensitive but must be reported to control authorities, such as the German Emissions Trading Authority, which, in turn, verify this data. Combining a blockchain with ZKPs is a promising concept for providing decentrally stored personal data to data owners on a recipient-specific basis.[92] ZKPs can thus ensure the interoperability of self-sovereign identities.[88]

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[87] Cf. Allen, C. (2016). The Path to Self-Sovereign Identity. Retrieved from http://www.lifewithalacrity.com/2016/04/the-path-to-self-sovererign-identity.html
[88] Cf. Strüker, J., Urbach, N., Guggenberger, T., Lautenschlager, J., Ruhland, N., Schlatt, V., Sedlmeir, J., Stoetzer, J.-C., Völter, F. (2021). Self-Sovereign Identity – Foundations, Applications, and Potentials of Portable Digital Identities. Project Group Business & Information Systems Engineering of the Fraunhofer FIT.
[89] Körner, M. F., Sedlmeir, J., Weibelzahl, M., Fridgen, G., Heine, M., & Neumann, C. (2022). Systemic risks in electricity systems: A perspective on the potential of digital technologies. Energy Policy, 164, 112901.
[90] Cf. Ben-Sasson, E., Bentov, I., Horesh, Y., & Riabzev, M. (2018). Scalable, transparent, and post-quantum secure computational integrity. IACR Cryptol. ePrint Arch., 2018, 46.
[91] Cf. Bogensperger, A., Zeiselmair, A., & Hinterstocker, M. (2018). Die Blockchain-Technologie–Chance zur Transformation der Energieversorgung. Berichtsteil Technologiebeschreibung. Forschungsstelle für Energiewirtschaft e.V. (FfE).
[92] Cf. Wang, F., & De Filippi, P. (2020). Self-sovereign identity in a globalized world: Credentials-based identity systems as a driver for economic inclusion. Frontiers in Blockchain, 2, 28.

5.2 Application of Decentralized Information and Secure Identities for CO_2 Proof of Origin and Use

A large part of the contractual relationships used to organize social coexistence requires that the parties confirm their identity to each other and trust the security of underlying data. In practice, various processes have been established to build trust in the authenticity of an identity. Against this background, there is currently widespread testing of blockchain technology in business, academia, and government, all of which are increasingly concerned with the generation of (self-sovereign) digital identities. Especially the reduction of transaction costs and data security are drivers for the application of blockchain-based digital identities in various sectors. In the energy industry, for example, the number of market participants who need to identify their assets to participate in markets increases by increasing decentralization. Besides that, the privacy of service users can be protected by the digital identity. With the help of blockchain-based digital identities, for example, people can be identified without disclosing personal data. Likewise, authorizations and transactions can be documented transparently. Thereby, the personal data of the users can be stored decentrally on the user devices to limit the danger of data theft or misuse.

Despite existing uncertainties, blockchain technology is given high importance in the field of application of this study in the future.[93] The political side thereby recognizes the potential of blockchain technology. By publishing their blockchain strategy, the German government promotes practice-oriented research, development, and demonstration of blockchain applications. Goals have also been formulated at the European level to become a pioneer in the application of blockchain technology. A particular focus of the European strategy is to improve identity management within the framework of the existing guidelines for electronic signatures such as eIDAS. For these electronic signatures, the EU Commission relies on a decentralized approach with self-sovereign identities.[94] The European framework, including the EU's third energy package, supports the smart meter rollout as the foundation for exchanging energy and emission data.[95] By self-styled smart meter gateways (SMGs) both technical as well as identity-relevant security anchors, which ensure a high level of data protection in data communications, can be installed. In this context, blockchain-based digital identities make it possible to ensure the trustworthiness of data and, in particular, to reduce transaction costs.

The majority of blockchain solutions that exist today or are being planned are not for general identity management but are individual forays at a specific use-case level. Thereby, a variety of new use cases, such as tokenization of energy volumes

[93] Cf. Strüker, J. (2019). Technical and economic report in: Blockchain in the integrated energy transition. DENA German Energy Agency.
[94] Cf. European Commission (2021). Blockchain Strategy. Retrieved from https://digital-strategy.ec.europa.eu/en/policies/blockchain-strategy#:~:text=The%20EU%20wants%20to%20be,significant%20platforms%2C%20applications%20and%20companies.&text=This%20'gold%20standard'%20for%20blockchain,be%20sustainable%20and%20energy%2Defficient.
[95] Cf. European Commission (2021). Smart grids and meters. Retrieved from https://ec.europa.eu/energy/topics/markets-and-consumers/smart-grids-and-meters_en

and certifications, are being prepared and evaluated in pilot projects.[96] Thus far, this technology has not been applied for the proof of origin and use of CO_2 and other greenhouse gas emissions. This is partly because such proofs begin at the company level and would, therefore, be applied bottom-up in the value chain. The creation of CO_2 certificates and carbon footprints that start at the end of the value chain often involves higher transaction costs, as significantly more actors have to be considered at this level. Automation and the application of blockchain-based digital identities can reduce these transaction costs. Furthermore, this technical approach can be used to fulfill many required characteristics for the determination of CO_2 footprints according to a holistic digital product passport and for the global trading of emission proofs.

For the use case of green electricity certificates, for example, there are already initial conceptual designs. For example, the project funded by the German Federal Ministry for Economic Affairs and Energy is one of the first projects to elaborate and assess applications of blockchain, SSI, and ZKPs for such certificates. The use case of electricity certificates focuses on the traceability of electricity from renewable energies. To do this, the first step is to collect generation data from a renewable generation plant for a specific period of time. The recorded energy quantities can then be verified. A certificate can then be generated for the recorded period and the uniquely identified plant. Such a certificate thus contains a reference to the generating plant and its identity data, the generation period for which the certificate was issued, and the amount of energy generated by the facility during the period. Decentralized identity management reduces the effort required to inspect the generation plant to issue green electricity certificates. When certificates and asset identities are anchored and linked on a blockchain, the issuance of the certificate for a specific asset identity is stored as a transaction in a tamper-proof and traceable manner.[97]

The trading transactions and the invalidation of the certificates can be made technically traceable and verifiable by anchoring them on the blockchain. Since every transfer and invalidation of a certificate can be stored as a transaction on the blockchain, the certificate can be tracked digitally and tamper-proof by combining it with an identity system. The data of the certificates stored on the blockchain can no longer be falsified. Alternatively, to ensure the scalability of identity management, only the references that confirm the correctness of an issued certificate can be stored on the blockchain. This means that forgery resistance can still be ensured without having to store a large amount of data in a decentralized blockchain infrastructure.

Double sales or invalidations of certificates based on blockchain technology are technically excluded. All transactions can be verified automatically, which, in turn,

[96] Cf. BDEW, PwC (2019). Der PwC BDEW Blockchainradar 2019. Retrieved from https://www.bdew.de/media/documents/blockchain-radar-2020.pdf
[97] Cf. Strüker, J.; Schellinger, B.; Völter, F.; und Wohlleben, J. (2021). InDEED research project investigates the use of blockchain in the energy sector. Retrieved from https://ubtaktuell.uni-bayreuth.de/indeed-research-project

can lean audit processes. Blockchain-based and SSI-based CO_2 proof of origin and use can therefore address many of the identified challenges (see Chapter 4.2) while also meeting the needs of businesses in terms of potential digital solutions (see Chapter 4.3).

5.3 Potential Analysis of Digital CO_2 Proof of Origin and Use

To analyze the potential value created by CO_2 proof of origin and use, the authors asked the company representatives about the potential for the technologies and solution approaches described in the previous chapter. The initial situation at the companies, i.e., the extent to which the recording, reporting, and verification of CO_2 information have already been digitized, is described in detail in Chapter 4.1.1. In summary, a few of the interviewed companies have already digitized several processes to a certain degree, such as data collection via Excel or control technology, but few, if any, processes of collection, reporting, and verification are automated.

Digitization		Automation
Conversion of analog information into clear bits of 1s and 0s, and more broadly, increasing computer assistance, new media, and platforms.[98]	↔	Implementing technology, software, and programs to perform a process with little or no human intervention.[98]

Consideration of the Entire Product Life Cycle

From the perspective of all interviewed companies, there is an increasing need to track the emissions of products over their entire life cycle and thus also to record all emissions that are in the Scope 3 area. There is also an increasing demand for cross-sector consideration in the value chain. As the requirements for CO_2 information in the annual report increase, audit-proof information on emissions from upstream products is of great importance to interviewed companies. Several company representatives, therefore, assume that the digital verification of CO_2 information can create a high added value, especially for suppliers, as they are increasingly asked for valid emission data. It should be noted that the need for digital CO_2 proofs of origin and use is estimated to be significantly higher by manufacturing companies than by electricity generation companies. This disparity could be due, among other things, to the upstream value chain for energy producers being relatively short and emissions being recorded directly during the generation process. Furthermore, a number of the company representatives have not yet dealt with digital CO_2 proofs because they were not yet familiar with the technical concept and its possible applications or because there are no established software or service providers for digital CO_2 proofs yet. Nevertheless, a company representative from an energy producer mentions that they see the

[98] Cf. Schumacher, A., Sihn, W., & Erol, S. (2016). Automation, digitization and digitalization and their implications for manufacturing processes. In Innovation and Sustainability Conference Bukarest.

need to digitally manage the carbon footprint via blockchain and/or digital identities when using energy storage.

Increase in Data Quality

Several companies interviewed realize that increasing data quality through digital CO_2 proofs can help create value. In terms of data quality, several companies still identify a need for optimization within their own organization. However, many company representatives believe that the added value of digital CO_2 proofs of origin can particularly be found in the increased data quality for purchased primary products. Company representatives also hope for more valid data for downstream steps in the value network. This could concern, for example, the amount of CO_2 emissions in the recycling process of a final product.

Ensure Tamper Resistance

Three of the companies interviewed have already investigated blockchain technology in terms of how its use could reduce opportunities for errors and data manipulation. The technical solution addresses both error-proneness within the company and tamper-proofing of emissions data outside of the company. For example, a company representative states that as part of introducing a European carbon border adjustment mechanism (CBAM), CO_2 proofs for each production step must be worked out in a tamper-proof manner but must still be feasible. Technically, these requirements can only be mapped using blockchain logic. In blockchain logic, CO_2 information is attached to a product identity at every step of the process and this information is passed on in the value chain in a traceable and forgery-proof manner.

Risk Reduction Through Automation

Several company representatives see the potential for risk reduction in the automation of data processing. Ideally, primary and emissions data would be automatically transferred to the central system for reporting and be processed depending on the framework of the emissions metric being determined. Automating the data collection and preparation of the non-financial statement would minimize risk due to the size of the processes. The relevance and need for automated processing of emissions data are very high, especially when the plants of the interviewed companies are subject to the EU ETS.

Complexity Reduction Through Automation

Many company representatives interviewed perceive the reduction of complexity in current processes, for example, in reporting, as a major potential. By implementing digital solutions, processes can be made more efficient and would take up less employee time. The use of blockchain technology can make the complex chain of information required to map a product lifecycle transparently traceable. As stated by the company representatives, digital solution approaches must be introduced to reduce complexity in keeping with the approach of a holistic digital product passport. The modular structure of the digital solution modules also makes it possible to harmonize the system landscape when creating reports.

Reduction of Personnel Expenses

The implementation of automated interfaces and the transparent management of CO_2 information by blockchain technology and digital identities will result in potential cost savings in necessary personnel. Several company representatives suppose significantly lower administrative work in evaluating primary data when implementing such a digital solution. The workforce required to verify the primary data collected could also be reduced through verified measurement infrastructure and automated interfaces. A company representative estimates that a number of employees previously tasked with preparing and monitoring primary data could be redeployed to other projects, such as developing and implementing a company-wide sustainability strategy.

Reduction of Costs for Auditors and Audits

Several interviewees assume that audit costs for external verification in the context of audits can be reduced by technical solutions such as blockchain. A company representative interviewed could also envision that the effort of the verification mandate for companies in European emissions trading could decrease if the verification of primary and emissions data could be conducted via technical solutions. In this case, the auditors would only check the implemented processes and the on-site audits could be reduced. This is also connected to the travel costs for the auditors, which is also an advantage because, depending on the production process, access to the plant is severely restricted for outsiders due to safety regulations.

Timely Evaluation of Emission Reduction Measures

According to the assessment of several company representatives, specific and differentiated CO_2 proofs can facilitate the evaluation and control of implemented emission reduction measures. The information systems available thus far usually evaluate ex post primary data based on one reporting year. Emission data with higher temporal resolution and unique allocability offer great potential for targeted planning and control of emission reduction measures. Especially in the case of complex emission reduction measures with several components that are interrelated and interdependent, it must be possible to assess and evaluate the success as a whole. Therefore, it must also be possible to separate emission reduction effects of individual measures. In combination with a user-friendly interface, Blockchain-based identity management can be used to validly assign emissions to individual measures and the associated plants and make them visible to the management level.

In the case of internal or external limits for products, CO_2 information in higher temporal resolution is necessary to plan and transparently implement further measures such as compensation in a targeted manner. For internal management as well as for external communication, it is important to several company representatives that the CO_2 savings associated with a project can be verified. Consequently, digital CO_2 proofs can also be used advantageously at this point.

Product-specific Differentiation of CO_2 Information

Product-specific differentiation of CO_2 information means that emission data is not aggregated at the company level but tracked for individual plants and products. This differentiation can be a key to corporate transformations. This is the case because, on the one hand, it increases flexibility in emission reduction measures if CO_2 information can be specifically allocated. On the other hand, the differentiation of products can affect purchase decisions, as customers have detailed and transparent information on individual products and these, therefore, become comparable with each other in terms of sustainability criteria. An example of product-specific differentiation can be explained using electricity. In electricity, a distinction is currently made as far as possible between gray electricity and green electricity. Due to the increasing lack of green electricity and green hydrogen in the future, there is an increasing need to depict the share of electricity from renewable sources, specifically for grid nodes. Since gray electricity can subsume any electricity mix that is not generated from 100% renewable energy, differentiating the electricity purchased benefits the transformation toward a higher share of renewable energy.

The interviewed electricity generation and supply companies also see potential in digital CO_2 proofs for green electricity and further use via energy storage or hydrogen electrolysis. A company representative also states that digital CO_2 proofs could incentivize investment in renewable energy. Electricity generation and supply companies are, however, uncertain whether digital CO_2 proofs for energy are still necessary when the electricity mix is composed entirely of renewable energy. With the achievement of a complete green electricity mix, the potential of digital carbon footprints in the energy industry also depends on whether marginal carbon footprints are also assigned to renewable energies in the future, for example, due to maintenance and other emissions associated with operation. Likewise, digital CO_2 proofs can continue to play a role in the manufacturing industry, as the energy quantities enter the value chain as intermediate products and, thus, into a digital product passport.

The interviewed company representatives of manufacturing companies mainly distinguish the short-term potential from the long-term potential of digital CO_2 proofs. In the short term, it is important for the companies interviewed to record and manage CO_2 information validly at the plant level and for new technologies such as hydrogen electrolysis. Furthermore, the current focus is on the average carbon footprint of product categories.

The manufacturing companies perceive the long-term potential in product differentiation in many emissions reduction targets having been defined in certain steps and stages. Therefore, tamper-proof emission data and traceability to individual plants and products gain importance. With the valid and specific CO_2 information, the targets can be evaluated via specific CO_2 footprints or via how much it has been reduced. Differentiated and traceable emissions information can also lead to increased comparability between products, which is difficult due to the current lack of transparency and the estimation and scaling included in the calculations. Fine granular digital CO_2 proofs and emissions data are of particular interest to the companies interviewed when comparing products identical in production to establish if they have the same carbon footprint. Traceable emissions data can then help companies analyze internally why certain anomalies in emission levels occur and why, for example, energy consumption differs at certain process points. Digital CO_2 proofs could also support the sustainability transformation of companies in selecting input products from suppliers if companies can use verified emissions data as a basis for decision making in purchasing.

Targeted Incentives for Changing User Behavior

Since the achievement of self-imposed emission reduction targets is also partly dependent on customer demand and user behavior, individual carbon footprints could strengthen the incentive for climate-friendly (purchase) behavior. These incentives through specific digital CO_2 proofs are particularly necessary if the CO_2 pricing at companies at the beginning of the value chain is not consistently and transparently passed on to the (end) customers. This can result in different (implicit) prices for CO_2 emissions for customers.[99] To achieve a steering effect, a company interviewed already investigates individual carbon footprints. This differentiated CO_2 information is to be used to derive measures and incentives for behavioral change. Since the company's own emission reduction measures must be considered holistically together with the behavior of its customers, digital CO_2 proofs can help include the customers in the transformation of the company toward lower emissions.

[99] Cf. Bardt, H. (2017). Law of one price. ORDO – Jahrbuch für die Ordnung von Wirtschaft und Gesellschaft, 68(1), 303-322.

6 Evaluation of the Hypotheses on Digital CO_2 Proofs

The interviews illustrate that the CO_2 factor is gaining importance throughout the industrial value chain. Based on the knowledge gained from the interviews, the authors evaluate their overarching hypotheses on CO_2 instruments, CO_2 reporting, and digital CO_2 proofs of origin and use.

Confirmation of hypothesis 1: Economic and regulatory uncertainty with regard to CO_2 pricing prevents companies from engaging in a long-term, targeted transformation toward climate-friendly processes.

The authors can confirm the first hypothesis to the extent that there are uncertainties in several areas for the interviewed companies. The economic uncertainties include the price development of CO_2 certificates and their relevance as an economic decision-making factor for business operations. Companies are also unsure how to build business models based on valid emissions data and how to use emissions data for economic benefits. Furthermore, there is uncertainty about how CO_2 emissions and sustainability will be defined in the future from a regulatory perspective. The increasing pluralism of introduced calculation methods, standards, and associated system boundaries currently prevents the amount of CO_2 emissions from being used as a consistent key figure across the entire value chain to manage the transformation toward climate-friendly processes.

Confirmation of hypothesis 2: The burden of bureaucratic documentation with regard to CO_2 emissions increases significantly for companies.

All interviewed companies can confirm the second hypothesis. Increasing reporting requirements have increased the administrative burden for collecting and processing CO_2 information. This is, for example, due to diligence requirements in the value chain and the Taxonomy regulation, new CO_2 pricing mechanisms, for example, EUT-ETS II and the CBAM, and further initiatives for the collection of CO_2 information, for example, the digital product passport. According to the companies' estimations, this effort increases, especially when Scope 3 emissions have to be recorded and verified in greater detail. To reduce this effort, the companies interviewed particularly investigate digital solutions. Depending on how much experience the company already has with collecting, transmitting, and aggregating primary data, these solutions start at different points. In the case of companies where data determining emissions has played a rather subordinate role up to now, there is a need to increase data quality by expanding the measurement infrastructure, among other things. Companies that already use information systems to process primary data and determine emissions, on the other hand, explore automating data transfer and report generation.

> *Partial confirmation of hypothesis 3: Digital collection and reporting of CO_2 emissions at companies could provide direct incentives for emission reductions and create competitive advantages for companies.*

The third hypothesis can be partially confirmed by the interviewed companies. They see great potential in the future for making their own products comparable with others through digital CO_2 proofs. However, most companies interviewed estimate that the incentives for emission reduction measures and competitive advantages may not take effect for several years. This is partly because the CO_2 price is currently still too low to be a prioritized decision factor in operations and purchasing decisions. On the other hand, the majority of the interviewed companies must first invest in the (measurement) infrastructure and information systems for digital recording. However, an investment dilemma often arises, as the direct added value from investing in systems for CO_2 data collection and control is difficult to quantify. Furthermore, customer demand currently evolves toward a demand for verifiable and more detailed information on product emissions. In certain industries, this is not yet strongly noticeable. As a result, today, the digital and transparent collection and reporting of CO_2 information still offer few direct incentives for most of the companies interviewed. However, with CO_2 prices expected to rise in the future and increasing customer demand, company representatives see a substantial increase in the importance of digital solutions for implementing emissions reductions.

> *Confirmation of hypothesis 4: If companies want to use high-resolution CO_2 information for economic purposes, the information must be communicated in a verifiable manner. This requires new technological solutions.*

The interviews conducted confirm hypothesis 4. To communicate CO_2 information in a high resolution and in a valid manner to the stakeholders of the company, the information systems currently available at companies are not sufficient. First, most interviewed companies state that specific processes, such as data transmission, involve manual activities that are susceptible to error and manipulation. Therefore, the companies interviewed have introduced controls such as plausibility checks, which are performed either manually or by a software module. With the increasing integration of Scope 3 emissions, the risk increases that companies receive data from third parties that they cannot evaluate and/or classify as valid. As a result, several companies have already explored digital solutions such as blockchain, which can technically establish tamper resistance and track Scope 3 emissions in a transparent manner via decentralized identity management, without companies having to publish their emissions data underlying the calculations for all to see.

Confirmation of hypothesis 5: Digital and product-specific CO_2 proofs of origin and use enable a high-resolution differentiation of products and, thus, a CO_2 assessment independent of accounting definitions.

The interviews with the company representatives can also confirm the last hypothesis. A central challenge for the interviewed companies is the pluralism of methods, which requires aggregating emission indicators according to different system boundaries and definitions. This pluralism of different systems makes it challenging to take a holistic view of emissions and emission reduction measures in the value chain. Many of the companies interviewed, therefore, call for an end-to-end CO_2 assessment that enables companies to monitor and, if necessary, control their products and processes according to the CO_2 factor, irrespective of the assessment limits of the respective systems.

7 Recommendations for Policymakers

CO_2 information and emission indicators are highly relevant to the company representatives interviewed. -At the same time, all the companies interviewed have set their own emission reduction targets to achieve climate neutrality in their business. As a result, emission indicators will not only be recorded and evaluated more frequently in the future but will also increasingly become a relevant control variable for a company's investments. On the other hand, legal requirements regarding the collection, reporting, and verification of CO_2 information increase due to further development of existing laws and standards (e.g., emissions trading systems) as well as new regulatory frameworks and standards (e.g., the proposed EU Taxonomy Regulation). Different challenges arise for companies when collecting, reporting, and auditing CO_2 information. Digital CO_2 proofs of origin and use can help address these challenges and support transformations toward sustainable economic processes.

Based on the confirmed hypotheses and the statements of the company representatives, political implications are derived below and recommendations for action are formulated for policymakers. Figure 4 provides an overview of the challenges companies face associated with regulatory frameworks and the recommendations for action derived.

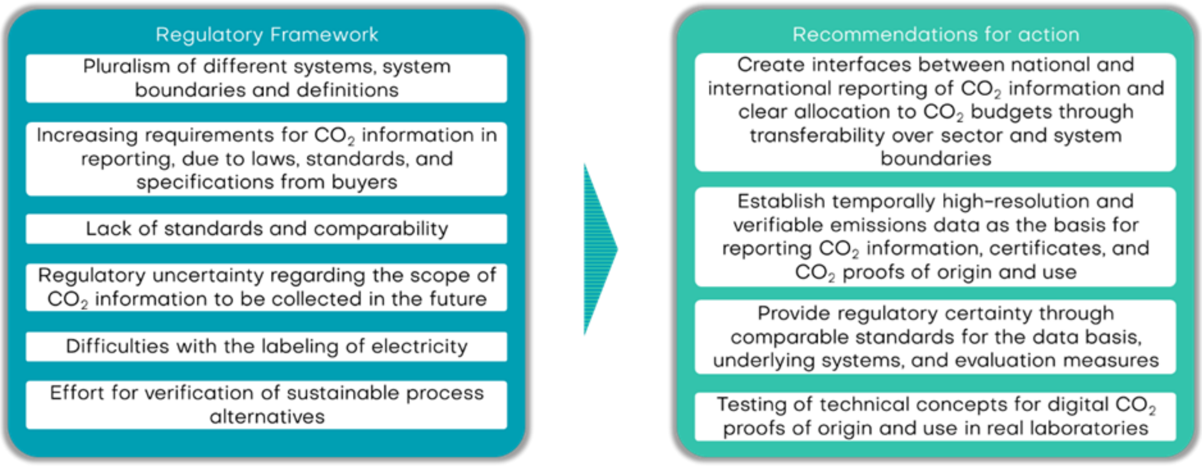

Figure 4: Overview of the challenges posed by regulatory frameworks and the recommendations for action by policymakers

> *Recommendation 1: Create interfaces between national and international reporting of CO_2 information and unique allocation to CO_2 budgets through transferability over sector and system boundaries.*

With the increasing number of instruments for pricing and recording emissions information, such as the parallelism of national (e.g., BEHG) and international (e.g., EU ETS I and EU ETS II) trading systems, there is an increasing risk that due to the different sector and system boundaries, specific emissions will be counted more than once and consequently also priced more than once. To prevent double counting of CO_2 emissions in Article 6.2 of the Paris Agreement, decentralized bottom-up approaches that can link the different CO_2 pricing instruments while avoiding double counting, should therefore be pursued. However, the interviewed companies state that different definitions as well as collection and calculation bases can exist for the same product or process. For example, different information must be provided for the statutory standards in annual reports and the non-financial statement than for certificate trading under EU ETS I or the emissions assessment under voluntary standards such as the GHG Protocol or Science-Based Targets. This means that companies (have to) provide different emission indicators and aggregated data, which, in turn, include various parts of a value chain. These different system boundaries for statutory and voluntary standards lead to increased efforts for companies in determining key figures and make it difficult to compare them with other companies.

To reduce or even eliminate uncertainties due to a multitude of different sector and system boundaries, it is necessary to establish a uniform perspective across the different CO_2 instruments and enable offsetting at the system boundaries. Otherwise, the increasing pluralism of system boundaries due to the different approaches could prevent the amount of CO_2 emissions from being used as a consistent key figure across the value chain to manage the transformation toward climate-friendly processes. An example of the need for offsetting at system boundaries is the objective of the German government to establish a CO_2 border adjustment not only at the EU level but also in parallel with international climate clubs.[100] It remains to be seen whether a CO_2 border adjustment of an international climate club should be developed in parallel with the proposal of the European CBAM and how CO_2 information within these different systems can be verified and transferred into each other.

Information on emissions must be made available in an increasingly transparent, tamper-proof, and verifiable manner along the entire value chain. This helps avoid double counting emissions. At the same time, decentralized CO_2 proofs of origin and use can ensure the transferability of emission rights or reductions. This can help ensure that emission volumes and pricing can be controlled in a differentiated and target-oriented manner. Since allocated CO_2 emissions can be recorded flexibly at different points in the value chain, these emissions can be uniquely allocated to the CO_2 budgets of CO_2 instruments, such as emissions trading systems, and emission reduction targets can be better controlled and monitored within CO_2 budgets. Strengthening this holistic approach to tracking CO_2 emissions independent of system boundaries will enable calculations and planning of CO_2 instruments in CO_2 budgets. Transparent traceability of a product's emissions

[100] Cf. Social Democratic Party of Germany, Alliance 90/The Greens, Free Democratic Party (2021). Koalitionsvertrag 2021 – 2025 zwischen der Sozialdemokratischen Partei Deutschlands (SPD), Bündnis 90/Die Grünen und den Freien Demokraten (FDP). Retrieved from https://www.spd.de/fileadmin/Dokumente/Koalitionsvertrag/Koalitionsvertrag_2021-2025.pdf

using blockchain and SSI-based digital CO_2 proofs also means that offsets for CO_2 emissions can be uniquely accounted for.

In addition to the unique allocation to CO_2 budgets, the harmonization of existing directives and laws at both the European and the national level also plays a role. Due to different system boundaries, perspectives, and definitions, it is difficult for companies to manage according to a determined key performance indicator. Therefore, it may be useful to improve the offsetting of CO_2 emissions at system boundaries—both between different emissions trading systems and in other CO_2 instruments, such as CBAM—and thus, also to uniquely allocate CO_2 emissions to the CO_2 budget of emissions trading systems. The use of digital CO_2 proofs of origin and use would allow the system boundaries to be set flexibly and individual calculations and allocations to be carried out automatically based on the data. The tamper-proof transfer of CO_2 information along the value chain can also extend the system boundaries, as companies can access verifiable data from suppliers.

Recommendation 2: Establish temporally high-resolution and verifiable emissions data as the basis for reporting CO_2 information, certificates, and CO_2 proofs of origin and use.

From the perspective of all interviewed companies, there is an increasing need to track the emission of products over their entire life cycle and thus also to record all emissions that are in the Scope 3 area according to the GHG protocol. Furthermore, the demand for product-specific CO_2 information, which can be used to uniquely allocate the CO_2 footprint of individual products and services, will increase in the future. As the demand for detailed CO_2 information increases, so does the auditing effort. This means that the different calculated emission key figures must also be able to be traced back to the CO_2 information on which the calculation is based.

To reduce the certification burden as the number of CO_2 control instruments and their system boundaries expand; the collection, reporting, and verification of emissions data must be made more efficient and decentralized. Verifiable emissions data with a high temporal resolution allow for reducing the effort of verifying data from third parties as well as verifying own data by auditors. The key figures determined for reporting can also be uniquely traced back to the associated data basis. Furthermore, a fine granular and verifiable data basis forms the foundation for the unique allocation of emissions to calculated CO_2 budgets and the avoidance of double counting and double pricing of CO_2 emissions. Digital CO_2 proofs and SSI identity management offer a technical solution to reduce the transaction costs for the increasing number of certifications required. New approaches to certification should be pursued, especially in the context of new certification processes, for example, for green hydrogen. These new approaches to certification will reduce the administrative burden on both the company and the audit side and can be designed in a flexible way through digital applications.[101,102]

Recommendation 3: Provide regulatory certainty through comparable standards for the data basis, underlying systems, and evaluation measures.

Several interviewed company representatives state that there is a risk in CO_2 reporting of a lack of transparency and comparability of the emissions figures determined. They attribute this risk in particular to a lack of standardization. Likewise, for several companies interviewed, there is uncertainty about how electricity from renewables as well as hydrogen will be assessed in the future in terms of their carbon footprint. This uncertainty exists in particular with regard to the valuation of electricity that has been temporarily stored in energy storage facilities and the extent to which CO_2 proofs of origin can be passed on in the future or how such educts can be assessed. There is also a lack of appropriate standards and clear regulations for the declaration of products. This is especially the case for the term and definition of "climate neutrality," which is now often used for products and services. However, different assessment methods may underlie a product (or service) declared as "climate neutral." These can differ, for example, in the range of emissions included (Scope 1–3) and the instruments used to reduce emissions (e.g., compensation through the purchase of carbon offsets, genuine emissions reduction, or removal of greenhouse gases from the atmosphere).

Policymakers should therefore develop standards for the calculation of the different indicators and labels as well as for the necessary (IT) systems that simplify the implementation of reporting for companies. These standards should set identical requirements for the data used in calculation and reporting and, thus, increase the comparability between carbon footprints and emission indicators. Ensuring transparency and verifiability could play a significant role in this process. Technical concepts, such as decentralized technologies and identity management, can meet these data requirements. Stricter specifications for data collection and the IT systems that process the data could also significantly improve the data basis. Consequently, this would also mean that introducing further standards for converting annual averages of purchasing and consumption figures into emission values would be obsolete, as these can be recorded directly via measurement infrastructure, for example.

The requirements for the data basis and the underlying technical properties, such as verifiability, transparency, and granularity, could be gradually increased,

[101] Cf. Energy and Climate Policy and Innovation Council e.V. (2021). Policy Accelerator for Climate Innovation – vier Bausteine für eine Innovationsagenda. Retrieved from https://epico.org/de/veroeffentlichungen/vier-bausteine-fuer-eine-innovationsagenda

[102] Cf. Energy and Climate Policy and Innovation Council e.V. (2021). Handlungsprogramm Klima- und Energiepolitik für die neue Legislaturperiode. Retrieved from https://epico.org/uploads/files/EPICO_Handlungsprogramm-Klima-und-Energiepolitik-neue-Legislaturperiode.pdf

especially in the case of the draft laws yet to be prepared. This could allow companies, for example, to first set up technical systems for exchanging data with suppliers and then transfer these to the downstream value creation step. Policymakers could also support companies in optimizing their data processing systems by encouraging the development of digital solution systems and advising on the targeted and cross-standard use of these digital solution systems.

Recommendation 4: Testing of technical concepts for digital CO_2 proofs of origin and use in real laboratories.

There is currently no economic incentive for the companies interviewed to invest in digital measurement infrastructure to collect primary and emissions data and to differentiate the carbon footprints of products and/or services. This is primarily the case because the added value of verifiable and temporally high-resolution CO_2 information is difficult to quantify. Furthermore, existing software programs for managing CO_2 information are usually based on an ex post approach in which average emissions are aggregated into key figures. However, the emissions are then no longer clearly traceable to the respective cause of the emission. To reduce the investment dilemma in CO_2 detection and control systems, targeted technical applications could be conceptualized and tested in publicly funded pilot projects and real laboratories together with industrial partners. An example of this is the project ID-Ideal, which, among other things, assesses the transparent trading of electricity using SSI-based CO_2 proofs within the example of electromobility.[103] With the help of pilots of the technical bottom-up approach, which starts directly with individual companies, both the costs and the economic added value can be analyzed and evaluated. Moreover, pilot projects can be used to precisely investigate the impact of available and verified emissions data on purchasing decisions and customers' willingness to pay. Testing technical concepts and their scalability can also deduce which regulatory framework conditions may need to be adapted to enable such technical solutions. It is also possible to find out how specific properties (e.g. data protection) can be ensured during implementation such that they can be introduced within the current regulatory framework.

To establish CO_2 emissions as a central decision-making factor for companies, emissions must be transmitted in a verifiable, transparent, and tamper-proof manner. CO_2 proofs of origin and use based on technical concepts, such as blockchain and SSI, have great potential to be interoperable at the interfaces between different CO_2 instruments and to reduce related transaction costs. Therefore, policymakers should promote the development and implementation of technical approaches to digital CO_2 proofs of origin and use and evaluate their use to strengthen and improve carbon instruments.

[103] Cf. Dresden University of Applied Sciences (2021). About the project. Retrieved from https://id-ideal.de/en/about/

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