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CARBON MITIGATION APPROACHES
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Towards more accurate, timely, and granular product-level carbon intensity metrics

A scoping note

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Inclusive Forum on Carbon Mitigation Approaches Papers

Towards more Accurate, Timely, and Granular Product-Level Carbon Intensity Metrics

A Scoping Note

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Inclusive Forum on Carbon Mitigation Approaches (IFCMA) Papers

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The IFCMA Papers series brings together outputs from the initiative's work to take stock of different carbon mitigation approaches, map policies to the emissions they cover, and estimate their impact on greenhouse gas emissions, as well as its work on analysing methodologies for computing the carbon intensity of goods and sectors. Comments on IFCMA Papers are welcome at IFCMA@oecd.org.

Background

The Inclusive Forum on Carbon Mitigation Approaches is the OECD's flagship initiative to help optimise the global impact of emissions reduction efforts around the world through better data and information sharing, evidence-based mutual learning, and inclusive multilateral dialogue.

By taking stock of different carbon mitigation approaches, mapping policies to the emissions they cover, and estimating their comparative impact in terms of emissions reductions, the IFCMA is enhancing understanding of the comparative impact of the full spectrum of carbon mitigation approaches deployed around the world and their combined global impact. The IFCMA is also identifying and addressing challenges related to the calculation of sector- and product-level carbon intensity metrics, relevant to the design and evaluation of mitigation policies, and to steer firms' and consumers' decisions towards lower-emission products. This work supports better international coordination to avoid the proliferation of different standards, help minimise compliance costs for business, and avoid disruptions to trade.

To advance its technical work, the IFCMA brings together delegates from the climate, tax, and structural economic policy communities from more than 55 IFCMA members and numerous countries participating as Invitees around the world.

Abstract

This scoping note presents a high-level overview of the main approaches to, and challenges faced when, calculating product-level carbon intensity metrics, including those applicable to collecting and verifying information across the supply chain. Though the analysis focuses on approaches used in emissions-intensive trade-exposed sectors (EITE), the findings also have broader relevance to other sectors. As part of the analysis, challenges relating to computing sector-level carbon intensity metrics are also considered, particularly as inputs to product-level metrics.

A full report, due by the second half of 2024, will analyse these aspects in more detail. The work for the report, as outlined in this scoping note, seeks to identify approaches to minimise duplication among various initiatives, minimise compliance and reporting costs for firms, and avoid disruptions to trade. This can provide a foundation for developing basic principles and considerations to support the widespread calculation and use of carbon intensity metrics globally.

Keywords: Climate Change, Climate Change Policies, Carbon Intensity, Carbon Footprint, Industrial Decarbonisation

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Table of contents

Acknowledgements 3

Executive Summary 7

1 Introduction 9

2 Sector-level carbon intensity metrics 12

- Calculation approaches 12
  - Calculations of sector-level carbon intensities by international bodies 13
  - Calculation of sector-level carbon intensities for national reporting 14
  - Carbon intensity metrics to underpin climate policy analysis 16
- The role of installation-level data as a basis for sector-level carbon intensity metrics 17
  - Government reporting frameworks for collecting installation-level carbon intensity data 18
  - Industry bodies initiatives to compute sector-level carbon intensity metrics 19
  - Novel approaches for improving the granularity and timeliness of carbon intensity metrics in conjunction with the development of product-level metrics 20

3 Product-level carbon intensity metrics 21

- Motivation 21
- Scope and boundaries 22
- Trade-offs between calculation methods 23
- Challenges in verifying and assuring the quality of the data 25
- Challenges in sharing emission data across the supply chain 26
- Overcoming the challenges of sharing emissions data 28
  - Initiatives to overcome methodological interoperability challenges 28
  - Initiatives to overcome technical interoperability, data confidentiality, and regulatory challenges 29

4 Conclusion and next steps 31

References 33

Tables

Table 1. Main use cases of carbon intensity metrics 10

Figures

Figure 1. Disclosure of emissions data and the share of audited disclosures 26

Figure 2. Relative use of actual data vs. proxies for the measurement of Scope 1- 3 emissions 26
Figure 3. Current climate-related disclosures by US companies 27

Boxes

Box 1. IEA methodology for calculating emissions intensity of electricity and heat generation 14
Box 2. An overview of the 2006 IPCC guidelines 16
Box 3. World Steel Association and carbon intensities computation 19
Box 4. Firm-level carbon intensity metrics 24

Executive Summary

This scoping note presents a high-level overview of the main approaches to, and challenges faced when, calculating product-level carbon intensity metrics, including those applicable to collecting and verifying information across the supply chain. Though the analysis focuses on approaches used in emissions-intensive trade-exposed sectors (EITE), the findings also have broader relevance to other sectors. As part of the analysis, challenges relating to computing sector-level carbon intensity metrics are also considered, particularly as inputs to product-level metrics. A full Inclusive Forum on Carbon Mitigation Approaches (IFCMA) Carbon Intensity Workstream report, due by the second half of 2024, will analyse these aspects in more detail, put forward possible solutions to the technical and policy challenges faced when calculating carbon intensity metrics across an increasing number of products and sectors and outline areas for possible future work.

The work for the report, as outlined in this scoping note, seeks to identify approaches to minimise duplication among various initiatives, minimise compliance and reporting costs for firms, and avoid disruptions to trade. This can provide a foundation for developing basic principles and considerations to support the widespread calculation and use of carbon intensity metrics globally. Whilst the work does not delve into sector-specific or product-specific issues, it builds on the relevant literature that does so.

The main messages of this scoping note are the following:

- Existing approaches to compute product-level carbon intensity metrics often use default values and make limited use of primary data. Novel data collection methods can improve the timeliness and quality of carbon intensity metrics. Choosing between computation methods involves considering trade-offs between accuracy, costs, and the ability to generalise across sectors or products. Combining methods can reduce costs, though at the cost of reduced comparability.
- Carbon intensity metrics have several use cases. These include helping governments to design policies to deliver the ambitious mitigation goals countries have set, and guiding businesses and consumers towards making less carbon-intensive choices. However, newer use cases require timelier and more comparable carbon intensity metrics than are currently available. Whilst sector-level metrics are already well established and used for policy making, they are produced with a non-negligible time lag and at too of an aggregate a level to support targeted policy interventions. Product-level metrics are still underdeveloped because of challenges relating to methods, data collection, and data sharing. Consequently, consumers and firms have little reliable information on the climate impacts of their consumption and investment decisions.
- The proliferation of product-level carbon intensity standards, initiatives, and methods that vary across sectors and regions can increase firms' reporting costs and fragment global value chains. This variation may encourage firms planning to produce and sell low-carbon goods to source more locally, forsaking the benefits of international trade. Ensuring technical and operational interoperability among different standards and methods is challenging but necessary to preserve open markets and avoid raising firms' reporting costs.

The scoping note also proposes additional areas of research and analysis that could be included in the 2024 report. Priorities, guided by comments from IFCMA delegates, are:

- Outlining selected sources of data to compute carbon intensity metrics as well as potential empirical approaches for analysing product-level carbon intensity metrics for key basic products in EITE sectors.
- Reviewing policy levers that can promote the calculation and sharing of carbon intensity metrics.
- Developing principles and guidelines that governments can consider as they design policies requiring product-level carbon intensity metrics to help ensure international comparability.

Suggestions from delegates for work beyond the 2024 report are also noted in Section 4 of the scoping note. This includes considering additional data sources for the computation of carbon intensity metrics, performing empirical analyses and identifying scalable and reliable methodologies as a common basis for further convergence of carbon intensity methodologies.

1 Introduction

1. **Climate change is an existential threat.** To avert it, rapid progress needs to be made to decarbonise economies, including the industry sector, which accounts for about a third of global greenhouse gas emissions (Ritche, Roser and Rosado, 2020[1]; IEA, 2021[2]; IPCC, 2022[3]; Calvin et al., 2023[4]).

2. **Carbon intensity metrics can enable the tracking of the carbon emissions associated with producing outputs (either at country, sector, or product-level), supporting efforts to decarbonise economies**. Lowering carbon emissions while increasing outputs, employment and living standards implies reducing the carbon intensity of production. Carbon intensity metrics are defined in this analysis as the ratio between the greenhouse gasses (GHG) emitted (measured in tonnes of CO_2-equivalent) in the production of an output and the total output produced (measured in physical volume or economic value). They can be calculated at different levels of aggregation, including at the sector and product-level, depending on the specific purpose for their use. Carbon intensity metrics have also been calculated and used at country-level as, in the UNFCCC context, some countries have set carbon emission targets in terms of carbon emissions intensity per GDP unit (UNFCCC, 2022[5]). Reporting can also take place at the installation-level (i.e. plant-level), firm-level and for financial portfolios (Noels and Jachnik, 2022[6]).

3. **This scoping note sets out the main points to be fully developed in a report on product-level and sector-level metrics scheduled for the second half of 2024.** The report will focus on how the Inclusive Forum on Carbon Mitigation Approaches (IFCMA) can work towards more accurate, timely and granular product-level carbon intensity metrics. As part of the analysis, challenges relating to computing sector-level carbon intensity metrics are also considered, including how novel data sources and approaches for estimating product-level intensities can also lead to better and timelier sector-level metrics. The possible use and improvements of economy-wide (or country-level) carbon intensity metrics are beyond the scope of this analysis. This scoping note presents the main topics the report could deal with, which cover key use cases of carbon intensity metrics, methodologies for calculating them and issues relating to carbon emissions data collection, verification and sharing.

4. **Carbon intensity metrics have many use cases that can help to deliver a reduction in global emissions to net zero while supporting growth and improvements in living standards.** (Table 1). In general, carbon intensity metrics can be useful in designing, implementing, and evaluating mitigation policies and strategies. They can help steer firms' and consumers' decisions towards lower-emission products and provide investors with objective information on the GHG emission performance of firms' activities, thus diminishing the risk of "greenwashing" (Noels and Jachnik, 2022[6]; Deconinck, Jansen and Barisone, 2023[7]). Producers can use them to clearly signal to consumers, investors and other stakeholders the intention to undertake actions to decarbonise their activities and measure progress in a more objective way than current metrics, such as Environmental, Social and Governance (ESG) scores, allow for (D'Arcangelo et al., 2023[8]; Boffo, Marshall and R., 2020[9]). At the sector-level, carbon intensity metrics can be used to track the progress towards net zero emissions targets, for instance, via the IEA Tracking Clean Energy Progress report (IEA, 2023[10]). Moreover, sector-level carbon intensity metrics can be used as the basis for default values to be employed in carbon intensity computations at the product-level if the collection of primary data is too costly.

5. **Carbon intensity metrics are crucial to inform discussions on carbon leakage risks and how to manage them** (IEA, 2022[11]). Internationally uncoordinated decarbonisation policies can create spillovers inhibiting the delivery of global climate goals. Carbon leakage is one such spillover, which may arise from asymmetric mitigation policies across countries resulting in production and emissions shifting to jurisdictions with less stringent mitigation policies and higher carbon intensity of production (HM Treasury (United Kingdom), 2021[12]). Sector and product-level carbon intensity metrics can help to pinpoint where and how carbon leakage risks may manifest, thus helping to prioritise and guide policymaking (Yamano and Guilhoto, 2020[13]; OECD, 2023[14]). Additionally, policy tools such as mandatory product emission standards and border carbon adjustment mechanisms rely on the use of product-level carbon intensity metrics to enable the mitigation of carbon leakage risks (OECD, 2020[15]).

6. **Sector-level metrics can complement product-level information, for example, when tracking the overall impacts of border measures.** Used in conjunction with input-output tables, sector-level carbon intensity metrics can be used to compute production and consumption-based emissions to evaluate the contribution of international trade (Yamano and Guilhoto, 2020[13]). The demand for more timely and granular carbon intensity metrics to serve these use cases is growing. The 2024 report will outline existing use cases currently served by sector-level carbon intensity metrics and emerging ones that could be better served by product-level metrics.

Table 1. Main use cases of carbon intensity metrics

Governments Developing and measuring the impact of climate policies	Product-level metrics used as a basis for public procurement, tax incentives and explicit subsidies to support the growth of the market for low carbon and carbon-neutral goods
	Product-level metrics used in trade policy to increase the comparative advantage of low-carbon goods
	Product and sector-level metrics to identify, quantify and mitigate carbon leakage risks through multilateral and unilateral solutions
	Product and sector-level metrics to underpin policy design and granular analyses of the impact of policies on emissions
	Sector-level metrics to help governments drive change, set high-level targets, and compare progress across sectors
Firms Managing the carbon intensity of production and communicating to investors and consumers	Product, firm, and sector-level metrics to help industry make better decisions and help firms to compare themselves against sector-, firm -, and product-specific benchmarks
	Firm-level metrics (or product-level metrics linked to firms) to help investors allocate capital to firms better able to manage climate transition risks
	Product and firm-level metrics to help improve Environmental pillar of ESG scores by providing quantifiable and objective information on the carbon intensity of production and progress towards reducing it
	Product-level metrics to help strengthen incentives to innovate and commercialize low carbon intensity products
Households Guiding the carbon intensity of consumption	Product-level metrics to inform consumers' purchases and investment decisions
	Product-level metrics as a basis for taxes to shift consumption decisions towards low carbon and carbon-neutral goods

Source: OECD.

7. **The analysis will highlight common challenges across products and sectors in computing reliable and timely product-level carbon intensity metrics and seek to highlight potential ways forward to overcoming them.** The work will build on sector and product specific analyses already available seeking to infer common problems among various sectors and products (IEA, 2023[16]; WBCSD, 2023[17]; Greenhouse Gas Protocol, 2011[18]; OECD, 2023[19]). The work will discuss the trade-offs associated with different metrics, including their impact on SMEs and developing countries, timeliness, accuracy, and robustness to gaming. The work will not focus on sector or product specific issues as doing so requires in-depth expertise in specific production processes and supply chains. Some of these more in-depth analyses are already taking place across the OECD and relevant new work could be the considered for extensions to this IFCMA workstream. To maintain a reasonable scope, the analysis for both the

scoping note and the 2024 report will focus on approaches taken in emissions-intensive trade-exposed sectors (EITE), though the findings have broader relevance as well.

8. **The data and information requirements for granular carbon intensity metrics are high**. This scoping note presents the trade-off between flexibility in accounting and reporting methodologies, and accuracy of the resulting data whilst considering the costs required to produce carbon intensity metrics. As underlined in Section 2, methods to compute sector-level carbon intensity metrics relying on default values and limited primary data can be useful in a transitional phase towards product-level metrics. This can allow time for capacity to be developed, primary data to be collected and definitions to be agreed for the use of product-level metrics, discussed in Section 3. Novel emissions data collection methods at the installation-level, for example using satellite and machine learning technologies, aim to improve the timeliness and completeness of data. They can complement conventional data sources and ensure better consistency between sector and product-level metrics.

9. **Fragmentation of public and private initiatives, guidelines, standards, and infrastructure supporting the computation product-level carbon intensity metrics could have harmful implications for global value chains.** Section 3 provides an overview of some recent public and private initiatives that are developing guidelines, emissions accounting standards, and infrastructure to facilitate product-level carbon intensity computations. Some of these initiatives also focus on mitigating the economic, technical, legal, and regulatory obstacles that have hindered the collection and verification of data across supply chains. All these initiatives are a welcome addition to the data and evidence base, but the proliferation of standards and methods varying across sectors, regions, and country blocs also present risks in terms of fragmentation (WTO, 2023[20]). The section underlines the importance of ensuring the technical and operational interoperability among different initiatives so as to prevent disproportionate transaction costs. This scoping note outlines options for governments' action to build on such initiatives, which the 2024 report will explore in more detail.

10. **The final section of the scoping note proposes additional areas of research and analysis that could be included in the 2024 report in line with IFCMA delegate priorities**. These proposals comprise of additional work exploring the issues highlighted in this scoping note. Additional proposals are also included focusing on policy aspects, such as reviewing the range of policy levers to promote the development and sharing of carbon intensity metrics, and developing basic principles and guidelines governments might consider as they design policies requiring carbon intensity metrics while ensuring international consistency and comparability. The aim of these principles will be to promote synergies, avoid duplication, minimise compliance and reporting costs for firms, and pave the way towards better interoperability and comparability of national or regional systems to compute product-level carbon intensities.

11. **Section 4 also notes suggestions from IFCMA delegates for work beyond the final report.** This includes reviewing the availability of data to enable the calculation of carbon intensity metrics and, if data allows, providing illustrative computations of product-level carbon intensity metrics for key basic products in EITE sectors, and identifying scalable, widely used, and reliable methodologies to provide a common basis for further convergence of carbon intensity methodologies.

2 Sector-level carbon intensity metrics

12. **This section outlines the main approaches for computing sector-level carbon intensity metrics in energy intensive sectors, highlighting their strengths and outstanding challenges, and their uses to facilitate carbon intensity computations at the product-level**. Sector-level carbon intensity metrics are better established than product-level metrics due to the availability of national emissions and output data at sectoral levels. Sector-level metrics are provided at high levels of aggregation and are often not based on primary emissions measures. For this reason, sector-level metrics can be easier to implement than product-level metrics, used as fall-back values where product-level metrics are not yet developed and primary data are missing.

13. **The measurement and use of sector-level carbon intensity metrics can help governments to make public policy decisions, international bodies to monitor global progress, and industry bodies to set benchmarks.** To be fit-for-purpose, carbon intensity metrics need to be accurate, sufficiently up-to-date and detailed. There is no silver bullet for measuring carbon intensities at the sector-level, but rather a collection of approaches that serve different purposes, including supplementing for product-level metrics where they are not yet developed. The 2024 report could describe a range of these methodologies in more detail, highlight their different use cases and point to the need for greater granularity of sector-level metrics and more timely updates to better support the transition to net-zero. Progress in these areas can also ease the computation of product-level metrics by providing reliable and timely fall-back values when primary product-level data are not available. At the same time, product-level metrics can be used to improve sector-level estimates by providing information on the distribution of carbon intensities within a sector that go beyond the simple average, which can support better policy making.

14. **Current approaches to calculating sector-level carbon intensity metrics lack timeliness and granularity.** This is a challenge as the public and private sectors have increasingly begun to demand more precise and timely carbon intensity metrics in the pursuit of carbon emissions mitigation targets. This section first presents the motivations for improving sector-level metrics and the main methodological approaches available to date. It then provides an overview of the main data sources and the guidelines for computing carbon emissions using nationally reported sectoral carbon emissions and output data. Next, the section explores the carbon intensity metrics used by governments for public policy analysis and by industry bodies for tracking progress. The section concludes by noting some limitations of traditional data sources and approaches, and points to some novel approaches that could complement them. It concludes by emphasising the need for developing product-level metrics as a tool to improve and as a complement to sector-level metrics.

Calculation approaches

15. **Computing sector-level carbon intensities requires information on both greenhouse gas emissions (GHG) (the numerator) and output (the denominator).** The denominator at the sector-level is more standard as output metrics are well-established within accepted and common frameworks for countries' national accounts. There is still misalignment, however, among carbon intensity approaches with

some defining output in terms of volume (i.e. units of production) and others in terms of value (i.e. monetary value). In addition, some rely on gross output while others on value added. The numerator, i.e. emissions, in contrast, opens several conceptual issues where a common methodology for emissions accounting has not been established, and varies between government and industry.

Calculations of sector-level carbon intensities by international bodies

16. **Sector-level carbon intensity metrics can be at the centre of efforts to understand and accelerate the global shift of sectors towards net-zero**. This requires combining information on the evolution of total emissions and output over time and tracking the possible impacts of policies and technology shifts. These metrics can be decomposed to account for changes due to efficiency gains or fuel switching. For example, the IEA's annual Tracking Clean Energy Progress report (IEA, 2023[10]) measures progress made in key sectors towards achieving climate mitigation goals using sector-level carbon intensity metrics. The IEA report distinguishes between total emissions and emissions intensity, pointing, for example in the aluminium subsector, to increases in total emissions but a modest decrease in the carbon intensity in the past decade. This implies that efficiency gains leading to lower carbon intensity have not been sufficient to offset the increase in total emissions due to higher output. The IEA report also highlights that the decrease in emissions intensity achieved to date is mostly attributable to improvements in the efficiency of the aluminium production process and that fuel switching can play a larger role in further reducing the carbon intensity of the sector. The 2024 report of the IFCMA carbon intensity workstream could analyse in more detail the availability of and data requirements for this type of analyses to highlight data gaps and possible actions to overcome them.

17. **There are two main approaches to calculating emissions at the sector-level.** The first approach is based on energy and on non-energy use related emissions by a sector (or subsector) and its associated emissions factors. The second approach is based on verified emissions data at the installation level that are subsequently aggregated to the sector-level. The latter being the approach undertaken for instance by the Environmental Protection Agency in the United States under its Greenhouse Gas Reporting Program (GHGRP). The IEA adopts the first approach whereby it calculates emissions intensity for a variety of sectors combining the IEA's World Energy Balances (IEA, 2023[21]) with the IPCC's default emissions factors corresponding to the different energy carriers (IPCC, 2006[22]) such as for electricity generation (see Box 1).[1] This approach allows for a relatively simple way of computing carbon intensities at the sector-level without direct measurements at the installation-level. The accuracy of the carbon intensity metrics, however, ultimately depends on the quality of data provided by the submitting country and the treatment of missing data. Inconsistencies in these two dimensions may undermine comparability of carbon intensity metrics at the sector-level across sectors and countries. Collecting emissions data at the installation-level is a way to overcome these problems (as discussed below). However, such primary emission data collection poses its own challenges in terms of consistency across sectors and countries – due to differing methodologies, resource capacity and technical expertise in measuring, verifying, and reporting emissions.

18. **Overall, approaches based on energy and on non-energy use related emissions by sector and its associated emissions factors impose fewer data requirements and lower costs than measuring and verifying emissions at the installation level**. However, these remain estimates based on a level of aggregation that does not reflect the different challenges sectors face in improving production efficiency or switching to less carbon-intensive fuels. As a result, identifying tailored policies within and across sectors is difficult with highly aggregated sector-level metrics as they can lump together subsectors that have different production process and barriers to decarbonisation. In addition, such sector-level

[1] These data sources are discussed further in the following sections.

metrics can differ based on methodological decisions made in the estimation process (e.g. what data sources and default values to use) and the frequency in which they are updated.

19. **The 2024 report could outline the advantages and disadvantages of a range of these methodological approaches for computing sector-level carbon intensity metrics**. Issues to be explored in more detail include the usefulness and limitations of using default values (and how these are calculated based on and energy use and emissions factors) rather than direct measurements, data availability, and costs associated with primary data collection and reporting. Shedding light on these issues and identifying trade-offs can guide choices towards improving methodological approaches. This can help to create comparable and more accurate sector-level carbon intensity metrics that can also act as fall-back values for when product-level carbon intensity metrics cannot be calculated.

Box 1. IEA methodology for calculating emissions intensity of electricity and heat generation

The methodology for computing IEA emissions intensities for electricity and heat generation (CO_2 per kWh) uses the IEA World Energy Balances for total emissions by energy source in each sector and country (IEA, 2023[21]) and 2006 IPCC Guidelines default values for emission factors (IPCC, 2006[22]). There are some adjustment factors such as for traded and lost energy (i.e. emissions that are transferred to another process or lost due to inefficiencies). In addition, for fuels that are combusted directly in production processes (rather than used for electricity generation), the IEA uses direct combustion factors, which contain specific product, sector, and country coefficients for emissions by input into a process. The IEA use Net Calorific Values for determining these factors (i.e. the physical amount of emissions contained in a fuel source).

CO_2kWh for electricity and heat generation =

$$\frac{\sum_{fuels} \langle (Input_{\ Electricity\ plants} + Input_{CHP\ plants} + Input_{Heat\ plants} + Own\ use_{Plants}) \times EF_{fuel} \rangle}{Ele_{Inland} + Heat_{Inland}}$$

Where:

- CO2kWh: Carbon intensity (in CO2/kWh) calculated at the generation point
- $\sum fuels$: Sum over the fuels.
- $Input_{plants}$: Fuel input into the plants expressed in energy unit.
- EF_{fuel}: Default emission factors as provided in the 2006 IPCC Guidelines.
- $EleInland + HeatInland$: For the total emissions factor: includes the generation from all sources (i.e. as well the non-emitting sources). For the emissions factors by fuel (oil, coal, gas, non-renewable waste, and Memo: biofuels): includes only the electricity and heat generated by the corresponding fuel.

Source: (IEA, 2022[23])

Calculation of sector-level carbon intensities for national reporting

20. **Sector-level carbon intensity metrics are useful in monitoring progress towards international climate goals.** Some countries use carbon intensity metrics as part of their reporting for Nationally Determined Contributions (NDCs) targets under the Paris Agreement. The NDCs are reported with a range of metrics. These include absolute emissions reduction targets (37% of countries choose this metric), relative emissions reduction targets such as comparisons with business-as-usual (46% of countries), and other reporting including emissions intensities expressed as emissions per unit of GDP or emissions intensity of sectoral ‘business as usual’ levels (17% of countries) (UNFCCC, 2022[5]; Jeudy-Hugo, Lo Re and Falduto, 2021[24]).

21. **Carbon intensity metrics at sector-levels can be useful to analyse to what extent reductions in emissions are being driven by lower output, higher energy efficiency, changes in fuel use or other factors such as production efficiency gains**. Reducing emissions while promoting growth in some sectors requires lowering economy-wide and sector-level carbon intensities. To this end, sector-level carbon intensity metrics can be useful in tracking progress and helping to design policies. However, sector- and economy-wide carbon intensity metrics should be used judiciously as declines in carbon intensity may mask increases in absolute emissions, if output rises faster than emissions (Rodriguez, Pansera and Lorenzo, 2020[25]).

22. **Sector-level carbon intensity metrics can be calculated using emissions from national inventories reported to the UNFCCC, which commonly use sector estimates for energy use and default emissions factors**. The national inventories use the IPCC Guidelines (IPCC, 2006[22]), which allow countries a flexible approach for estimation with minimum standards (see Box 2). The minimum standards, or the Tier 1 approach, primarily requires the use of internationally available data such as the IEA's World Energy Balances (IEA, 2023[21]) and applies default values for emissions factors that are provided by the IPCC without direct measurement of emissions being required. This allows the flexibility for all countries to be able to report on emissions and calculate emissions. The higher tier methods, such as Tier 3, require the use of more sophisticated and direct measurement approaches to calculating emissions, such as that reported at the installation-level to comply with an emissions trading system. Developing countries may need technical assistance to build the capacity and expertise necessary to implement direct measurement approaches.

23. **The 2024 report could explore in detail the main datasets and methods governments use to compute sector-level carbon intensity metrics**. In doing so, it will highlight their strengths and weaknesses and point to ways to address shortcomings. This can include a discussion of how to achieve fit-for-purpose metrics by improving the comparability of economy-wide and sector-level carbon intensity metrics while striking a balance between accuracy and data collection costs. The report could also identify synergies in data collection efforts between sector-level and product-level metrics so as to enhance consistency of carbon intensity metrics at different level of aggregation.

Box 2. An overview of the 2006 IPCC guidelines

The 2006 IPCC Guidelines (IPCC, 2006[22]) are intended to be used by all parties to the UNFCCC. They provide guiding principles for measuring carbon emissions, provide default data and methods, and allow flexibility for more sophisticated methods if countries have the desire and capability to use them. The 2019 Refinement to the 2006 Guidelines provides additional information to be used in conjunction with the 2006 Guidelines (Calvo Buendia et al., 2019[26]). This includes supplementary information on sources and sinks of emissions and to account for the development of new technologies and production processes that have emerged recently or were previously not well-covered (such as the production of hydrogen, rare earth metals, and alumina). The 2019 refinement also provides updated emission factors and other parameters based on more recently available scientific information, where significant differences to the existing emission factor values were identified. The most basic method takes activity data and multiplies it by an emissions factor. The guidelines include high level emissions factors as well as more detailed ones for ‘key sectors’ within a country.

Principles

The IPCC’s pragmatic approach allows for cross-country and cross-sector differences in data availability and quality. The approach concentrates on the key sectors or categories for a particular country by providing more detail. The guidelines aid in:

- The identification of key sectors;
- Defining minimum standards for data;
- Providing flexibility for inclusion of better data;
- Establishing guidelines for industries that require a greater detail where more complex data and calculations are needed to yield accurate results.

A tiered approach

These guidelines allow for a pragmatic approach to estimating emissions at the national level, broken down by sectors, by using a ‘tiered’ approach based on an increasing level of accuracy and granularity. There are three tiers:

1. Simple first order approach: default values corresponding to large spatial regions of the world and based on globally available data are used, allowing the calculations to be done by any country;
2. A more accurate approach: similar calculation method to Tier 1 but using country and region-specific data;
3. Higher order methods: involving the use of countries’ own detailed modelling, inventory measurements systems and data at a greater level of granularity.

Carbon intensity metrics to underpin climate policy analysis

24. **Sector-level metrics can enhance industry and policy analyses when paired with other sector-level data such as input-output (IO) tables, but challenges around data aggregation and timeliness remain**. IO tables depict how much of a sector’s output is used as an input into production processes in another sector, consumed domestically or exported. IO analysis can therefore be used to estimate the impact of an intervention in a sector by modelling the flow of inputs and outputs across all sectors of the economy that have economic linkages to the initial sector. This technique has been used for policy analysis to model the effects of government climate change mitigation policies through linking IO

tables with emissions data. Changes in in sectoral output and emissions due to the policy intervention can affect the sector-level carbon intensity.

25. **Intercountry input-output tables, when paired with emissions data, can be used to compute consumption-based emissions at the sector-level**. Traditionally, emissions are measured taking a territorial approach – accounting for emissions within a country's jurisdiction, as in countries' national GHG inventories – or a production approach – accounting for Scope 1, 2 and 3 emissions resulting from economic entities based within a country, as in air emission accounts. In contrast, a consumption-based approach quantifies emissions embodied in the final demand of countries. The calculation of consumption-based carbon intensity metrics starts with emissions intensity by value of output and traces emissions throughout the production of final and intermediate goods using input-output analysis. This allows for an aggregated and relatively simple method for taking into account Scope 1, 2 and 3 emissions in sector-level carbon intensity metrics and can provide a comprehensive view of emissions embodied in countries' trade to inform international dialogues. The IMF (2022[27]) and the WTO (2022[28]) both use the OECD's Trade in embedded CO2 (TeCO_2) database to analyse and support dialogue on the decarbonisation of international trade.[2]

26. **However, the coarse granularity of the sectoral classification used in this type of analyses can provide only a blunt assessment of the change in sector-level carbon intensities and may be insufficient to identify the main drivers of changes in key sectors.** For example, the OECD Inter-Country Input-Output (ICIO) database and the OECD's global input output tables use 45 sector classification groups (OECD, 2022[29]). Ceramic, stone, and clay products are subsumed under a single sector despite cement's emissions intensity being more than 20 times that of glass (Hasegawa, Kagawa and Tsukui, 2015[30]). As the use of input output tables for climate policy has increased, so has the demand for more granular data to help with this issue. Moreover, due to the high data requirements for IO tables, there is a significant time lag between data collection and publication. For example, the OECD's IO tables are published every three years, which risks that the economic linkages between sectors used in IO analysis may become outdated, particularly in sectors with rapid technological developments. Challenges also arise in the matching of data on emissions and economic activity at the sector level. The classification of sectors used for emission sources under common frameworks such as the IPCC Guidelines cannot be directly matched to classification frameworks used for economic activity. Differences in sector definitions and concordance between emissions and economic data can add to methodological discrepancies between countries. It is therefore desirable to complement this type of analyses with more granular approaches being developed in the context of product-level carbon intensity metrics (see Section 3). The 2024 report could explore the merits and limitations of using sector-level information for modelling and analysing climate policy, including as complements and inputs to product-level metrics, based on IO analysis and computable general equilibrium models (Yamano and Guilhoto, 2020[13]; Château, Dellink and Lanzi, 2014[31]; Niamir, Ivanova and Filatova, 2020[32]).

The role of installation-level data as a basis for sector-level carbon intensity metrics

27. **Installation-level data can be aggregated to deliver more detailed and timelier sector-level carbon intensity metrics**. This bottom-up approach produces alternative and complementary estimates to sector-level carbon emissions provided by national bodies (using sources such as IEA World Energy

[2] National governments also have in-house models for policy evaluation, such as Finland with the ENVIMAT-model developed by the Finnish Environmental Institute.

Balance data) while remaining consistent with the IPCC Guidelines.[3] In some cases, they can also be used to compute product-level carbon intensity metrics (see Section 3). Thus, installation-level data and metrics sit at the intersection of sector and product-level metrics.

28. **The 2024 report could explore opportunities for increasing the use of installation-level data in sector-level carbon intensity metrics.** Two main means exist to gather installation-based emissions: industry bodies that collect data from their members and public authorities that collect data from firms (i.e. installations' owners) for regulatory reasons. Collecting and reporting installation level data can be highly resource- and cost-intensive for small- and medium-sized enterprises (SMEs) and developing countries that still lack the infrastructure to monitor, report and verify primary emission data. These constraints may justify the adoption, at least in an initial phase, of a lower-tier approach based on default values (referring to the IPCC Guidelines) as countries gradually build the resource and capacity to monitor, report and verify installation-level data and address the specific challenges SMEs face. These challenges and possible solutions could be discussed in more detail in the 2024 report. The report could also explore the growing number of public and private sector-level initiatives to collect data through novel approaches using, for example satellite and machine learning technologies. In addition, the limitations of these methods could be explored, including issues with incomplete and biased data that arise from self-selection and regulation that often only includes large installations.

Government reporting frameworks for collecting installation-level carbon intensity data

29. **There is a range of environmental reporting that can provide complementary emissions data and may lead to better carbon intensity metrics for sectors**. This includes mandatory reporting of emissions to government agencies as well as supranational bodies. For example, the United States Environmental Protection Agency (US EPA, 2023[33]) requires reporting of the emissions from cement production and related emissions, which have been used to calculate a distribution of emissions intensities for the sector (US EPA, 2019[34]). This reporting was restricted to only the direct measurement approach using Continuous Emissions Measurement Systems (CEMS) under which the flow and carbon content is measured directly at the installation. The EU Emissions Trading System and Carbon Border Adjustment Mechanism also require reporting of emissions for a range of EITE sectors (in accordance with rigorous monitoring and reporting, and accreditation and verification regulations), which can also be used to calculate sector-level carbon intensity.[4] Further examples of reporting frameworks will be explored in the report.

30. **Reporting systems under emissions trading schemes are a source of data underpinning sector-level carbon intensity calculations**. The emissions data at the sector-level can be used to inform national inventories reporting but can also be used directly for sector analysis. For example, Mura (2021[35]) provides a dataset that reports emissions per unit of GDP in detailed EU regions, using only installation-level data and GDP statistics. These sector-level carbon intensities are used as a proxy for industrial sustainability transition pathways.

31. **Governments can use carbon intensity metrics to benchmark emissions.** Most emissions trading systems utilise free allocations of pollution permits to industry where they may be at risk of carbon leakage. To do this, benchmarking is often used to allocate allowances to those firms that perform below

[3] Estimates of industrial process emissions are based on production data for iron and steel, clinker for cement, aluminium, and chemicals (OECD, 2023[79]).

[4] Sectors covered by the EU Emissions Trading System include power, heavy industry and civil aviation as well as buildings, road and other industry, as of 2023 under EU Emissions Trading System 2 (European Commission, 2023[81]). Sectors covered by the EU Carbon Border Adjustment Mechanism include cement, aluminium, fertiliser, electricity and iron and steel and will be expanded to additional sectors in later phases (European Commission, 2023[82]).

the benchmarked carbon intensity (Lo Re et al., 2019[36]). This approach incentivises early action and a reduction in carbon intensity without stifling total output (through a benchmark on total emissions, for example). The benchmark can be set at the 'best achieved level' to reward firms with low carbon intensities and encourage those with high intensities to perform similarly. This leads to governments and firms being able to recognise where in the sector they are positioned and can provide strong incentives to decarbonise. As the method for calculating the carbon intensities and therefore benchmarks can have a significant effect, it is important that these methodologies are accurate to provide strong incentives to decarbonise.

Industry bodies initiatives to compute sector-level carbon intensity metrics

32. **Industry bodies provide an alternative source of sector-level carbon intensity metrics, but often only have partial coverage**. These are most commonly emissions and energy use per unit of output split by process type. For example, the World Steel Association, a global steel industry body covering 85% of global steel production across 60 countries, reports on emissions intensity of the industry (World Steel Association, 2022[37]). This facilitates industry benchmarking and comparison as well as demonstrating the progress of the industry in lowering carbon intensity (see Box 3).

Box 3. World Steel Association and carbon intensities computation

The World Steel Association has created its own methodology guidelines using a combination of standards from the ISO, the GHG Protocol and the IPCC Guidelines (Worldsteel Association, 2022[38]). The emissions data is collected from firms using the ISO 14404 international standard – the calculation method of carbon dioxide emission intensity from iron and steel production that allows for the comparison between sites, firms and regions and includes Scope 1, 2 and 3 emissions. The emissions measured at the installation-level are then aggregated along with output of tonnes of crude steel cast to calculate the sector emissions intensity of steel. In addition, energy intensity and material efficiencies are reported, which help with the interpretation of the emissions intensity. For example, a reduction in emission intensities can come from productivity improvements (less inputs used) or from a change in fuel type (hydrogen instead of coal). The sector-level emissions intensity is then disaggregated by plant type such as blast furnace and scrap-based electric arc furnace global steel production routes based on weights. In 2022, this included 104 steel companies that contributed to the data, covering 56% of global crude steel production.

33. **Although computations from industry bodies allow for comparison over time and within the industry and utilise common guidelines, they may not cover all firms and are heavily biased towards some countries.** For example, the World Steel Association collects self-reported data and some firms in large steel producing countries do not report to the initiative at all. In addition, the different methodologies for reporting emissions to different bodies and government agencies can lead to a greater reporting burden (see Section 3).

34. **Industry bodies producing sector-level average carbon intensity metrics can help firms assess how much progress they have made in decarbonising their activities and their potential for improvement**. This can inform decisions in investing in cleaner technology to improve their environmental performance and potentially reduce their capital cost. The same information can help investors to make decisions about where to invest and the environmental and financial risks associated with a firm.

35. **The 2024 report will aim to assess a range of methodologies by industry bodies representing certain emissions-intensive and trade-exposed sectors.** The report will seek to review and determine whether the sector-level carbon intensity metrics provided by industry bodies are adequate

in achieving their goals by considering their granularity, timeliness and costs. The report also could investigate how such metrics can be used as inputs towards the estimate of product-level metrics.

Novel approaches for improving the granularity and timeliness of carbon intensity metrics in conjunction with the development of product-level metrics

36. **The increasing need for more precision and granularity in policy evaluation and emissions data analysis warrants more robust, timely and detailed sector-level metrics**. Despite their long-standing history in informing policy analysis, current frameworks for providing sector-level metrics may not always be fit-for-purpose due to these limitations.

37. **Novel approaches have been emerging for estimating sector-level carbon intensity metrics.** Often, installation and granular sector-level data are not available due to privacy concerns around revealing trade secrets or misusing these data (see Section 3). In addition, data from energy use reported by governments often comes with lags of two to four years and from sources that may not be independent or lack common methodologies. Novel approaches to carbon intensity metrics can help to tackle challenges in addition to easing the calculation of product-level carbon intensity metrics. These approaches come with limitations, when not relying on primary data, but could ensure more consistency between sector and product-level metrics.

38. **The 2024 report will describe some novel approaches that utilise objective but indirect measurements, which can lead to quicker and more granular reporting than traditional approaches**. This includes approaches across a range of economies with differing capacities and resources available for measuring and reporting carbon intensity data. For example, Climate Trace uses satellites with infrared technology and machine learning to measure output by installations and then apply emission factors to estimate carbon intensities and total emissions. Data are then aggregated at the sector-level and, in the case of steel, can be produced with a one-month lag. Climate Trace collects only minimal data from firms (Ben m'barek, Phillpott and De Daniloff, 2022[39]). Instead, it makes use of several public datasets including from the World Steel Organisation's estimates of emissions intensities, IEA Energy Balance data, and various sector-level emissions data sources for calculation and validation. Novel approaches, such as that of Climate Trace, feature their own limitations as a result of indirect measurements. However, they can offer faster and cheaper alternatives to compute carbon intensity metrics than primary data collection methods. Comparing metrics from both methods, when available, can shed light on the reliability and cost-accuracy trade-off between direct and indirect measurements, and provide information on the desirability for extending the use indirect measurements.

39. **Although novel approaches attempt to fill some problems at the sector-level, ultimately, more granular, and timelier product-level data is needed.** Sector-level metrics remain essential, but installation or product-level metrics can provide information on the distribution of carbon intensities within a sector beyond the simple average. Such information can help policy design and implementation given that the average sector-level carbon intensity may poorly represent the carbon intensities of products within the same sector. They can also provide more accurate and timely data to inform sector-level metrics. To this end, the 2024 report could focus on improvements with regards to product-level metrics.

3 Product-level carbon intensity metrics

40. **This section discusses key challenges associated with computing product-level carbon intensity metrics and identifies areas that would merit an in-depth assessment.** It first provides motivations for using such metrics. It then discusses scope and boundary issues that need to be resolved to compute comparable metrics that can inform policy makers, producers, and consumers. The section also introduces the main methods to calculate product-level carbon intensity metrics, highlighting that their use will be guided by data constraints and cost-benefit considerations. It then turns to the challenges related to verifying emissions data, before discussing the challenges in sharing these data along the supply chain.

Motivation

41. **Product-level carbon intensity metrics are important for both information provision and policy making.** Information on products' carbon intensity can help businesses and consumers to make less carbon-intensive choices in several ways. First, they can help people to shift consumption towards lower-emissions product categories. Wood buildings material can, for instance, to some extent replace steel and concrete (Churkina et al., 2020[40]). Second, within each product category, such metrics can support the shift to lower-emissions producers (e.g. from higher- to lower-emissions producers of a certain type of steel). Third, they can provide incentives to producers to invest in lower-emissions techniques (Deconinck, Jansen and Barisone, 2023[7]).[5] Product-level carbon intensity metrics enable governments to select, for instance, products eligible for public support, decide if additional regulation or support is needed to speed up clean-technology innovation or deployment, and evaluate the effectiveness of past policies (Rajagopal, Vanderghem and MacLean, 2017[41]). Carbon intensity metrics can also be used to determine the level of a tax or subsidy for a given product.

42. **However, various challenges have meant product-level metrics are not yet as systematically available as sector or country-level metrics.** Reasons include data limitations, challenges in sharing information along the supply chain due to "data silo-ing" (Industrial Deep Decarbonisation Initiative, 2023[42]), and, historically, a lack of use cases to motivate action to overcome those limitations. However, the transition to net zero is providing impetus in some countries to develop product-level carbon intensities to track progress and, in some cases, to establish border carbon adjustments or mandatory product emissions standards. The report will highlight the relevant use cases for new and improved product-level carbon intensity metrics (see e.g. Box 4).

43. **In recent years, a variety of regional and international approaches have emerged to improve the measurement of product-level metrics.** Initiatives extend across public and private sector actors and seek to address many of the issues related to carbon emissions accounting, including scope and

[5] By contrast, economy wide and sector-level metrics (Section 2) do not in themselves lead to incentives for firms to adopt cleaner-than-average technologies and consumers to pivot towards cleaner products.

boundary-related considerations, calculation methods, verification, reporting and data sharing challenges.[6] While these initiatives are a welcome addition to the data and evidence base, their multiplicity also presents risks of value chain fragmentation due to a proliferation of standards and methods for measuring product-level carbon intensity (WTO, 2023[20]).

44. **The development of standards and methods for carbon intensity metrics that differ across countries and regions could have damaging implications for global value chains**. Specifically, if carbon intensity standards are incompatible, firms seeking to produce or sell low-carbon goods may choose to source locally or regionally, forsaking the benefits from international trade.[7] The report could discuss the main regional and international initiatives, analyse commonalities and differences among them, and seek to identify policy options to avoid or reduce fragmentation. It will cover both private sector initiatives, such as the Pathfinder Network (WBCSD, 2023[17]) and public-sector-led initiatives, such as the Industrial Deep Decarbonisation Initiative (2023[42]).

Scope and boundaries

45. **Product-level carbon intensity metrics draw on lifecycle assessment (LCA) methods to quantify the GHG emissions associated with a product throughout its lifecycle**. The traditional approach is Attributional LCA (ALCA), which attributes a share of observed emissions to an individual product. An alternative approach is a Consequential LCA (CLCA), which uses economic models to estimate the emissions caused by the production and use of the product (Rajagopal, Vanderghem and MacLean, 2017[41]). ALCA-based methods are more easily applicable to a large set of individual products than CLCA-based estimates as these require economic model simulations for each individual product, generating additional uncertainty due to the assumptions required (Rajagopal, 2013[43]). CLCA has been used to carry out impact assessments of biofuel policies inter alia accounting for indirect land use change, e.g. to determine feedstock eligibility for biofuel production in the context of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (Prussi et al., 2021[44]). The report aims to discuss the limitations and the appropriate uses of both types of LCA methods (Plevin, Delucchi and Creutzig, 2013[45]; Ekvall, 2020[46])

46. **Product category rules (PCRs) provide product-specific instructions for conducting life-cycle assessments (LCA) and reporting results in a comparable way across products.** They can be used in the context of environmental product declarations (EPD), which include but are not limited to climate impacts, and product carbon footprints (PCF).[8] They complement general product standards such as the Product Lifecycle Accounting and Reporting Standard (Greenhouse Gas Protocol, 2011[18]) by providing detailed rules, requirements and guidelines at the level of a specific product category or sector.[9] The report could compare selected product-level carbon emissions accounting standards against common

[6] For example, novel work of the European Commission's Joint Research Centre (JRC) estimates product-level carbon intensities based on the definitions of the monitoring and reporting rules of the EU CBAM, adapting the approach to publicly available information (Vidovic et al., 2023[80]).

[7] OECD analysis carried out in the context of COVID-19 shows that such a re-localisation would make the economy in most countries both less efficient and less resilient to shocks (Arriola et al., 2020[64]).

[8] This scoping note uses the term PCR, as in ISO 14025. Note that PCRs are referred to as Product Rules in the GHG Protocol Product Life Cycle Accounting and Reporting Standard and as Supplementary Requirements in PAS 2050 standard.

[9] In the European Union, for instance, environmental footprint methods provide harmonised rules for the evaluation of carbon footprints and other life cycle environmental impacts both at the level of products/services (Product Environmental Footprint, or PEF) and organisations/sectors (Organisation Environmental Footprint).

criteria, such as their geographic focus and product specificity, and seek to identify complementarities, duplications, and gaps.

47. **Whether a full lifecycle assessment or more limited approaches are appropriate depends on the circumstances.** Full lifecycle (i.e. cradle-to-grave) approaches can help to design products in a way that reduces their end-of-use emissions by considering products' end-of-life issues such as recycling. However, they require strong assumptions particularly for downstream emissions (Meinrenken et al., 2020[47]). Metrics calculated based on lifecycle standards therefore often take a more limited approach, e.g. the 'cradle-to-gate' approach using ACLA methods to focus on Scope 1, Scope 2, and upstream Scope 3 emissions. This differs from 'cradle-to-grave' approaches because it does not include downstream emissions from the use of the product, nor includes emissions involved in the products' disposal. Domestic carbon pricing systems, and policy instruments addressing carbon leakage and competitiveness concerns, such as border carbon adjustment mechanisms, typically do not take a full lifecycle perspective (OECD, 2020[15]).[10] The report intends to discuss the trade-offs associated with each approach.

48. **The temporal scope of the assessment can have material implications for carbon intensity metrics as emissions intensities may vary significantly over time across facilities**. Calculating carbon intensity metrics involves choosing a time horizon. Greenhouses, for instance, tend to require more heating in the cold season, but seasonal differences are averaged out when using annual data for heating-related emissions. Another example is the carbon intensity of electricity inputs, which can vary depending on weather conditions (e.g. wind, sunshine) and time of use. To date, metrics are typically calculated annually. Increasing the granularity of the time horizon brings greater precision, which can be useful in some contexts but not in others and whose benefits need be compared with the higher costs the data collection will entail. The report could investigate these issues in more depth and provide concrete examples.

49. **Even when emissions are perfectly measured, comparing individual products is challenging.** For instance, a new processing technique may enhance a material's strength, thus lowering the amount of it needed to produce a certain product relative to the conventional processing technique (US Department of Energy, 2022[48]; Roychand et al., 2023[49]). In this case, the less material-intensive and stronger product could also be the less carbon intensive choice even if it were to have higher emissions per declared unit (i.e. its physical quantity, such as tonnes of steel). Expressing emissions relative to a product's functional unit, such as the amount of steel, in kg, needed to produce an automotive B-pillar that meets all relevant structural and safety requirements over a vehicle lifetime of 200 000 kilometres travelled, would allow for comparing such partial substitutes (Rajagopal, Vanderghem and MacLean, 2017[41]). The report intends to reflect on ways forward to improve the comparability of carbon intensity information with a view to ensuring that firms and consumers have sufficient information and incentives to evaluate cleaner products.

Trade-offs between calculation methods

50. **When selecting a calculation method for computing product-level carbon emissions, there is a trade-off between accuracy and resource requirements.** This implies that there is not a single method that fits all applications and contexts, and practitioners may use a combination of these methods.[11] There are three main types of methods. First, the spend-based method, which involves multiplying

[10] The EU CBAM is more limited in scope than the 'cradle-to-gate' approaches as it, for example, does not apply to upstream transportation emissions, which also facilitates the work of customs authorities.

[11] Practitioners, may, for instance, reserve more resource intensive methods for those inputs that have large impacts on the overall carbon intensity of the product. Less resource intensive methods can also be useful in a transitional period while capacity is being developed for using primary data and where resource intensive methods would pose an undue burden on certain groups, such as SMEs and firms from developing countries.

company expenditures on a given product or input by an emission-intensity factor of these activities (WBCSD, 2023[17]), e.g. based on environmentally extended input-output (EEIO) models discussed in the context of input output tables in Section 2 (Steubing et al., 2022[50]). Second, the average data method relies on multiplying primary activity data (e.g. on material weight, fuel consumption) with activity-specific emission factors based on industry averages when preparing carbon intensity estimates (Finnveden et al., 2009[51]; Ben m'barek, Phillpott and De Daniloff, 2022[39]). Third, the primary data method draws on data directly measured, collected, calculated, and shared along the supply chain (WBCSD, 2023[17]). The report could assess each of these methods in greater detail and highlight trade-offs, e.g. related to (i) administrative costs, which may mean that certain approaches are not realistic across countries and firms with heterogenous capabilities, and (ii) decarbonisation incentives that could be compromised by using less accurate methods that mask the performance of individual producers

51. **Allocation rules for product-level carbon emissions are key for primary data methods as plants may produce a variety of products**. A major source of primary data is installation-level data that can be collected for a variety of reasons beyond the computation of carbon intensity metrics, such as complying with data collection and reporting requirements in emissions trading systems (Section 2). However, as many installations produce more than one product, allocation methods are needed to arrive at product-level estimates. The 2024 report could aim to review different allocation methods (such as those used for the calculation of product-specific benchmarks used for the allocation of free allowances in emissions trading systems).

52. **Using supplier-specific data to measure product-level carbon intensity metrics involves the verification and sharing of data across the supply chain.** The subsequent subsections first outline the challenges related to verifying emission data. They then discuss the challenges in sharing these data along the supply chain, including costs associated with fragmented reporting standards, and the private and public initiatives that have emerged to address these challenges. These initiatives are focussed on the firm-level but can serve as a first step to achieving the data and procedural requirements for product-level carbon intensity metrics (see Box 4). Standardised reporting of accurate and verifiable product carbon intensity metrics that take into account data across the supply chain are central to a myriad of applications. These include trade policy adjustments, carbon leakage mitigation, green procurement and providing exhaustive information to consumers, firms and governments.

Box 4. Firm-level carbon intensity metrics

There is growing demand for firms to measure and report the carbon intensity of their business activities to support their alignment with international and national greenhouse gas emissions reduction targets. A consistent framework for firm-level carbon intensity metrics can help firms compare themselves to others within relevant sectors and strengthen their incentives to innovate and commercialize low-carbon products. By collecting detailed information on emissions, firms can also improve the transparency and credibility of their Environmental, Social and Governance (ESG) commitments for stakeholders such as investors and consumers of end-products. Importantly, reporting of firm-level metrics can serve as a first step to achieving the data and procedural requirements for product-level carbon intensity metrics.

Calculation methods

At the firm-level, there are various methodologies to calculate carbon intensity, depending on the scope of emissions and business activity measured. Regarding emissions, firms may measure direct emissions at the installation, or combine activity data (e.g., on energy consumption, vehicle use or fugitive gasses) with default emission factors provided by public bodies or private databases. For example, the United States Environmental Protection Agency and the United Kingdom Department for Energy Security and Net Zero both publish emission factors for such processes for public use (Tarleton, 2023[52]). As for product-level metrics, the scope of emissions also determines the extent and focus of data collection.

Regarding business activity, firms may choose to express their emissions denominated in units of output, revenue from sales, or enterprise value. The revenue methodology is most widely accepted as it provides a proxy of production irrespective of the units of output, which can vary widely across sectors for firms of a similar size in terms of revenue. Using revenue to normalise carbon intensity, however, tends to favour firms with higher prices. Hence, it be more insightful to compare a single firm across time, rather than with other firms that vary by size, organisational structure, and business activities.

As an alternative to the revenue methodology, firms may denominate their carbon intensity in terms of enterprise value, which better reflects a firm's total activities and assets, especially stranded assets. This methodology, however, is sensitive to changes in firms' market capitalization and can inherit equity market volatility, leading to misinterpretation of carbon intensity metrics. For both within and across firm comparisons over time, it can reward a firm's market performance over emissions reductions efforts.

Both the measurement of emissions and business activity are subject to how a firm defines its business entity, which is relevant, in particular, to firms embedded in larger, more complex organisational structures. Taking the equity share approach, a firm reports its emissions and output, sales revenue, or enterprise value according to the firms' share of equity in the operations of its larger organization. Taking the control approach, a firm reports carbon intensity for the business activities over which it has control, which can be financial or operational. Accordingly, the scope of emissions included in a firm's inventory and the scope of business activity that is considered can vary.

Challenges in verifying and assuring the quality of the data

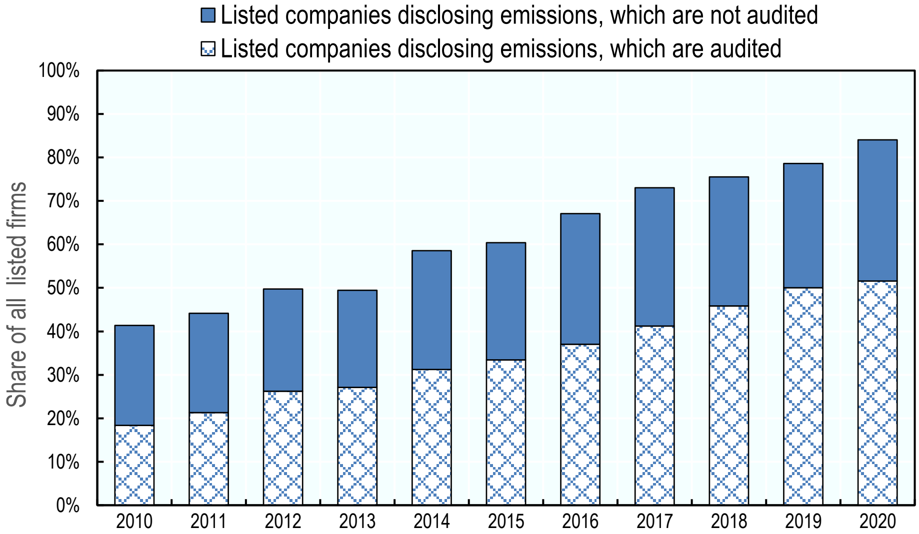
53. **In contrast to firms' financial reporting, the assurance and verification of sustainability reporting remains optional, with country-specific practices reflecting the absence of a common international standard**. Verification of emissions data has increased in recent years, particularly among the biggest companies within the European Union and the United States, which are likely most exposed to public scrutiny (Figure 1). However, this practice is not yet widespread, and even within this group of companies, only half of the companies verify their emission data. Furthermore, recent research on the oil and gas sector highlights considerable misreporting of emission data among companies, including those that voluntarily assure their reported emissions (Garcia Vega et al., 2023[53]). Misreporting may jeopardize the accuracy of ESG scores or broader risk assessment reporting, hindering efforts to steer capital towards firms better able to manage climate transition risks (D'Arcangelo et al., 2023[8]; Boffo, Marshall and R., 2020[9]).

54. **The lack of an assurance requirement threatens the credibility of the emissions data shared or disclosed by firms.** This is thwarting efforts to compute reliable carbon intensity metrics for their products also incorporating Scope 3 emissions. The absence of an international standard also breeds uncertainty about the quality and scope of verification processes across different countries. Recognising these issues, the European Union proposed a common EU-wide standard for mandatory sustainability reporting assurance as part of the Corporate Sustainability Reporting Directive (CSRD). The European Commission is also developing guidelines for the Carbon Border Adjustment Mechanism's assurance and verification process.[12] The 2024 report could discuss this type of initiatives in detail and assess their implications for product-level carbon intensity metrics.

[12] Verification of declared embedded emissions by an external independent body will only be mandatory from 2026 onwards. The specific rules for this including accreditation of the verifiers will be detailed in an implementing act.

Figure 1. Disclosure of emissions data and the share of audited disclosures

Companies listed in the S&P 500 (US) and STOXXX 600 Europe (EU), percentages



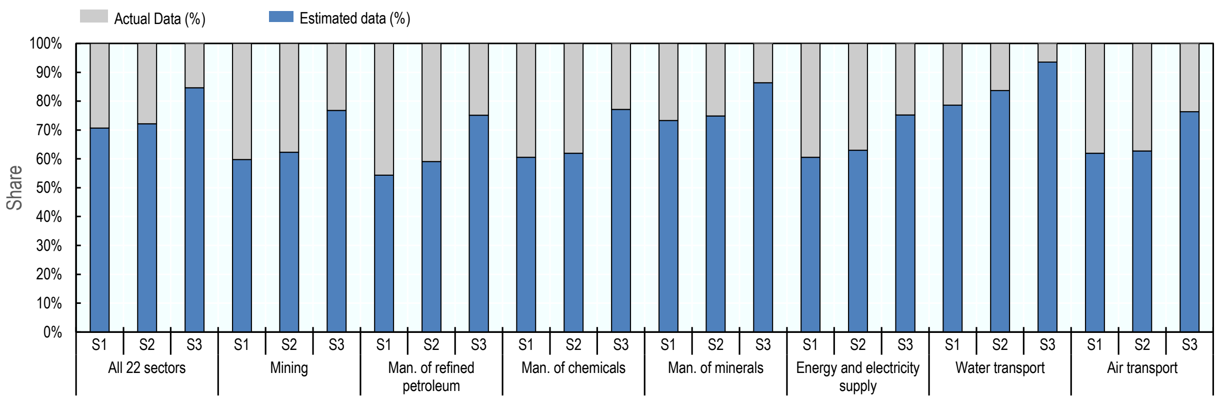
Note: Emission disclosure of one of the three emission scopes.
Source:. (ECB, 2022[54])

Challenges in sharing emission data across the supply chain

55. **Measuring Scope 3 emissions, and including them in carbon intensity calculations, requires a firm to collect information on processes (i.e. GHG emissions and activity data) not directly owned or controlled by them.** This is because Scope 1 and 2 emissions for one firm are the Scope 3 emissions of another firm downstream in the supply chain. There exist a range of economic, technical, legal, and regulatory challenges that firms are likely to encounter in this process (Stenzel and Waichman, 2023[55]). Consequently, the bulk of Scope 3 emissions' measurement currently relies on estimations or proxies rather than actual data (Figure 2). However, the use of proxies versus actual data varies across sectors, indicating sector-specific differences in the severity of these challenges.

Figure 2. Relative use of actual data vs. proxies for the measurement of Scope 1- 3 emissions

European banks' use of proxies for Scope 1- 3 emissions of their customers



Source: ECB (2022[56]).

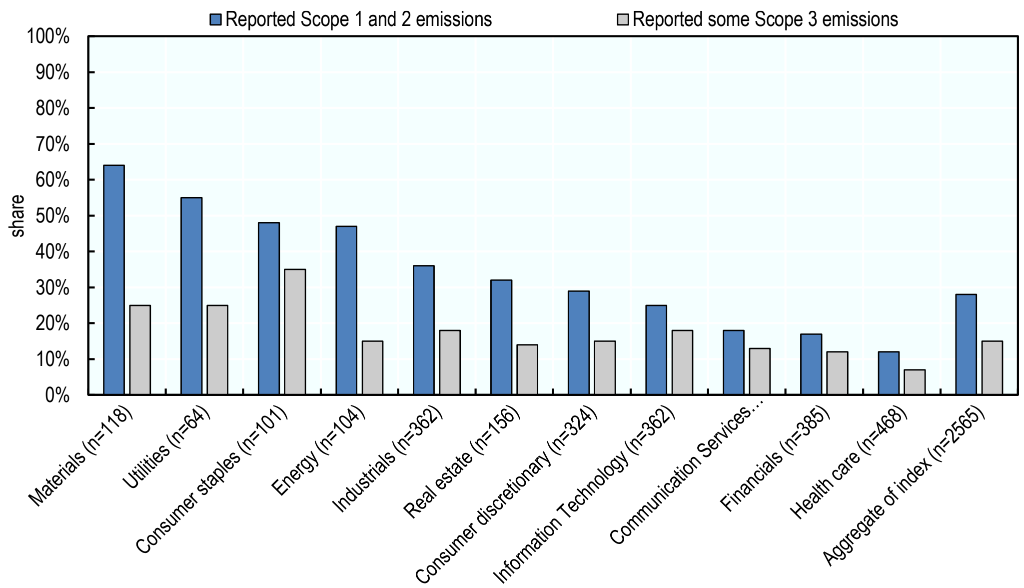
56. **Companies may be reluctant to share carbon intensity information due to potential adverse impacts on their competitive advantages and the risk of divulging trade secrets**. In the manufacturing sector, for instance, revealing emissions could hint at energy usage, cost structures and other production details. The severity of this problem may differ across sectors. The full paper could discuss in more detail how the perceived competitiveness risk from sharing emission data differs across sectors and the solutions being developed to overcome this problem.

57. **Legal and regulatory barriers may also be significant obstacles to sharing emission data**. Firms could, for instance, encounter contractual restrictions when re-sharing data received from their suppliers. Additionally, OECD (2022[57]) shows that the number of data localisation measures (i.e. an explicit requirement that data be stored or processed within the domestic territory) is increasing and becoming more restrictive. These measures can restrict cross-border flows of emission data, with particularly severe implications for value chains spanning different countries. Furthermore, data sharing among firms can be impeded by competition law, as Scope 3 emissions data could include competition-relevant information (OECD, 2019[58]).

58. **The absence of a mandatory requirement for Scope 3 emissions reporting in many countries may generate a wait-and-see attitude on the part of companies to measure Scope 3 emissions**. The GHG Protocol requires firms to report their Scope 1 and Scope 2 emissions, while reporting on Scope 3 emissions is optional. Consequently, corporate reporting on Scope 3 emissions is generally sparse and varies by industry with higher disclosure rates in emission-intensive sectors (Figure 3). This lack of mandatory reporting may also create incentives for firms to allocate emissions to Scope 3, for instance by outsourcing carbon-intensive production that is currently part of their Scope 1 emissions. Unclear messages from governments or standard setters on future regulations or requirements may discourage companies from investing in a reporting infrastructure (e.g. information-gathering processes) (Kauffmann, Tébar Less and Teichmann, 2012[59]). Recent research shows that climate policy uncertainty discourages investment, especially in pollution intensive sectors (Berestycki et al., 2022[60]). The full paper might provide a more detailed analysis on how Scope 3 disclosure rates vary across industries, reporting region, and specific Scope 3 reporting categories.

Figure 3. Current climate-related disclosures by US companies

Scope 1-3 disclosure of US-listed companies in the MSCI USA Investable Market index as of March 2022



Note: The MSCI USA Investable Market Index (IMI) is designed to measure the performance of the large, mid, and small cap segments of the United States market. With 2,470 constituents, the index covers approximately 99% of the free float-adjusted market capitalization in the United States
Source: (MSCI ESG Research LLC, 2022[61])

59. **Initial analyses also point towards significant interoperability issues hampering effective emissions data sharing**. The lack of harmonised GHG accounting and reporting standards (methodological interoperability), coupled with an absence of a common technical infrastructure for data exchange (technical interoperability), entails high transaction costs and operational inefficiencies (e.g. filling in different surveys or spreadsheets). This issue may be especially burdensome for firms operating within global value chains and SMEs. The latter often lack the financial resources needed for the upfront investments in a data collection and sharing system, and the in-house expertise to prepare the Scope 3 emissions data (OECD, 2019[58]).

Overcoming the challenges of sharing emissions data

Initiatives to overcome methodological interoperability challenges

60. **Several private and public sector initiatives have emerged to promote and enhance consistency in GHG accounting (i.e. data collection and measurement) and GHG disclosures**. Efforts to promote GHG disclosure are often part of broader sustainability disclosure initiatives that encapsulate a broad spectrum of firm-level environmental issues, including proposals to mandate the disclosure of Scope 3 emissions. While existing reporting initiatives do not primarily focus on promoting disclosure of product-level carbon intensities, the obligation to disclose firm-level Scope 3 emissions could reinforce corporate accountability. Progress in this area is a precondition for greater cooperation with supply chain partners to decrease Scope 3 emissions, and to collect and disseminate the data needed for calculating product-level carbon intensities.

61. The initiatives covering GHG accounting and sustainability disclosure fall broadly into two categories:

- **Sustainability reporting and GHG accounting standards**: Often developed by governments or standard setters, they define formal requirements or specifications to consistently measure (at the product-level) and report (at the firm-level) emissions data. These efforts can enhance market efficiency by reducing information barriers and transaction costs.
- **Sustainability frameworks**: Provide more flexible guidelines, including best practices and tools (e.g. ESG software, a reporting platform, etc.) to help companies identify, measure and report their emissions.

Sustainability reporting and GHG accounting standards

62. **There is a growing consensus towards harmonising sustainability reporting standards.** However, ongoing efforts in this area target diverse adopter groups, vary in focus on environmental, social, or economic aspects, and propose diverse requirements for Scope 3 emissions and carbon intensity metrics. The Task Force for Climate-related Financial Disclosures (TCFD) set the stage in 2017 with recommendations for clear, comparable, and consistent sustainability information. Building on this groundwork, the International Sustainability Standards Board (ISSB) issued in June 2023 standards on general sustainability-related disclosure and climate-related disclosure to support a comprehensive global baseline. Moreover, individual jurisdictions are currently either establishing or plan to establish disclosure requirements, which may align or diverge from the previously mentioned initiatives (NGFS, 2021[62]). For instance, the European Union and the United States are progressing towards mandatory Scope 3 emission

reporting and harmonizing related standards. Both proposals draw significantly on the TCFD's recommendations but show differences in some key areas, including their scope and materiality definitions (i.e. the level of importance an organization should attribute to specific environmental or social factors). The full paper could provide more details on the various (proposed) standards, their differences and assess prospects for further harmonisation.

Sustainability frameworks

63. **Numerous frameworks with different scopes have recently emerged to provide flexible guidelines to help companies identify, measure and report their emissions.** For instance, the non-profit organisation Carbon Disclosure Project (CDP) provides training services to upskill suppliers (e.g. emission accounting support) and a standard framework for reporting emission data (Scope 1-3) through an online questionnaire. The questionnaire is structured along several Scope 3 emission categories (as set out by the GHG protocol) but leaves it to participants to identify relevant categories. Notwithstanding these efforts, preliminary analysis that could be developed in the 2024 report suggests that companies tend to underreport their Scope 3 emissions.

64. **Similarly, the PACT Pathfinder Framework takes a cross-sectoral approach to assist organisations in developing and exchanging product carbon intensity metrics across the value chain.** The Pathfinder Framework, which was established in 2022 through a collaboration between the World Business Council for Sustainable Development (WBCSD) and multiple industry groups, issues guidance on data collection, verification, measurement, and reporting. A growing number of companies across industries have been adopting the Pathfinder Framework. The full paper will provide additional insights into these and other prominent initiatives and evaluate how these efforts connect and can build synergies with sustainability reporting and GHG accounting standards.

Initiatives to overcome technical interoperability, data confidentiality, and regulatory challenges

Private-sector initiatives

65. **Several private sector initiatives have emerged to solve the issue of technical interoperability while addressing governments and companies' concerns over data sovereignty and confidentiality**. The target group of these initiatives vary, with some having cross-sectoral memberships and an industry-agnostic focus, while others concentrating on specific industries. Furthermore, some initiatives prioritise accessibility by lowering entry barriers, while others seek to foster trust among participants by setting demanding requirements, which act also as entry barriers. This illustrates the trade-offs between creating trust and ensuring accessibility in designing data sharing platforms.

66. **The PACT Pathfinder Network aims to establish a global network for the secure peer-to-peer exchange of product-level carbon intensity data.** It was developed as the technological counterpart of the PACT Pathfinder Framework (discussed above) by the World Business Council for Sustainable Development (WBCSD) and the SINE foundation - in collaboration with different stakeholders like technology companies, various industries, and standard-setting bodies. At the core of the PACT Pathfinder Network is an open-source technology to connect organizations across diverse technology solutions (e.g. emission accounting software), allowing for scalability of the network and minimising transaction costs for new joiners.

67. **Catena-X seeks to develop an agile, secure data-sharing platform across the automotive value chain.** It was initiated by a consortium of prominent automotive companies and employs a decentralized, peer-to-peer data exchange approach similar to the PACT Pathfinder Network. Its technical foundation rests on a data connector that must be installed at each participant's site, serving as a

gatekeeper for incoming and outgoing data. This design enables automated negotiations on data usage between participants, safeguarding private ownership of data. To join Catena-X, companies must pass an audit verifying compliance with platform standards. While this audit and the required data connector raise entry barriers, it also strengthens trust and transparency within the platform. The full paper could offer an in-depth look at the design features of these and other prominent initiatives, with the view to exploring options to balance trust and accessibility, among other considerations.

Public-sector initiatives

68. **Some governments have developed regulations to facilitate the free exchange of data along supply chains and across borders.** The European Union, for example, has introduced several legislative initiatives, informed by its February 2020 European strategy for data, which could address the legal and regulatory challenges companies face in sharing emission data along their supply chain and across borders. Some of these initiatives also assess possibilities of embedding carbon intensity data into eco-design requirements or products to improve transparency about products' environmental sustainability.

69. **While these legislative initiatives do not explicitly focus on emissions data, they create a supportive framework for data sharing in general.** They also offer a means to navigate around issues like digital security, intellectual property rights, national security, and competition law that may pose challenges to sharing emissions data. A more complete analysis could appear in the full paper, including a more detailed discussion of the various legislative initiatives and the need, if any, for international coordination.

4 Conclusion and next steps

70. **Carbon intensity metrics are a vital part of the transition to net zero**. These metrics can help governments develop climate policies in a way that mitigates carbon leakage risks, help firms lower the carbon intensity of production, and guide households' consumption choices towards lower carbon-intensive products. However, numerous challenges have so far thwarted the widespread calculation and use of carbon intensity metrics. The IFCMA Carbon Intensity Workstream Report scheduled for 2024 could elaborate on the use cases of sector and product-level metrics and the specific obstacles hampering their calculation and use.

71. **The 2024 report could explore the current methods and data collection requirements, and additional challenges in computing timely and sufficiently disaggregated sector and product-level carbon intensity metrics**. As outlined in Section 2, sectoral carbon intensities metrics are well established and have already been used extensively, but they face challenges in enabling consistent and timely cross-sector comparisons. As discussed in Section 2 and 3, methodologies for computing sector and product-level carbon intensity metrics allow for a degree of flexibility, which however results in less accurate estimates across countries, across sectors, and products. Going forward, the report could explore in detail the main datasets and methods used to compute these carbon intensity metrics. It could also point to ways to fill data gaps to improve the comparability of carbon intensity metrics while striking a balance between accuracy and data collection costs, and ensuring consistency between sector and product-level metrics. More granular and timely sector-level metrics are also key to providing reliable fall-back values to compute product-level metrics when primary data are not available.

72. **The 2024 report could also explore how to support and facilitate the calculation of product-level carbon intensity metrics building on the numerous and already ongoing private and public sector initiatives**. Recently, a number of regional and international initiatives have emerged that seek to improve the measurement of product-level metrics. The report could analyse and compare some of the most relevant initiatives and identify policy options to build on them in ways that avoid fragmentation (due to a proliferation of different standards), limit trade distortions and encourage innovation. The report might compare selected product-level emissions accounting standards against common criteria, such as their geographic focus and product specificity, and seek to identify complementarities and duplications. Based on this, the report could propose ways forward to improve the reliability and comparability of product-level carbon intensity metrics.

73. **The verification, reporting, and sharing of carbon intensity information across the supply chain entail significant economic, technical, legal, and regulatory challenges.** The report could analyse these issues and assess private and public initiatives that are seeking to address them. Prominent private-sector endeavours have emerged to assist companies in measuring and reporting carbon intensity metrics, along with overcoming related technical challenges. The report could scrutinize these private sector initiatives in the context of ongoing public initiatives to harmonise and enhance sustainability disclosure, such as those led by the International Sustainability Standard Board, the European Union, and the United States. The aim would be to identify differences and commonalities and assess prospects for further harmonisation. Regulatory efforts promoting the free exchange of data along supply chains and across borders would also merit greater attention. Recent data localisation requirements (implemented

ostensibly for data sovereignty and security reasons) risks undermining efforts to share detailed emission data across borders.

74. **Various mitigation policies rely on carbon intensity metrics.** Carbon intensity metrics can be used by governments to guide policy (e.g. highlighting sectors and products where the decarbonisation challenge is the greatest) and as a basis for policies themselves (e.g. taxes based on the carbon intensity of a product). Under these two categories exist a wide range of policy levers such as carbon taxes, emissions trading schemes, energy efficiency laws or standards, tax incentives and government procurement initiatives, among others. The report could explore this range of policy levers and outline selected examples of such policies that have already been implemented across the IFCMA membership. Understanding this range of policy instruments can support efforts to make the calculation and use of carbon intensity more widespread.

75. **International dialogue is key to identifying and implementing common approaches in supporting the widespread calculation and use of product-level carbon intensity metrics**. Product-level carbon intensity metrics can add significant value to mitigate climate change, design policies and track progress, but they could also distort international trade and supply chains (White et al., 2021[63]). Accordingly, the report could explore ways to promote "sufficient" international consistency of product-level carbon intensity metrics, including under the umbrella of the IFCMA, or how to encourage the technical and operational interoperability of different national and regional systems being designed to compute product-level carbon intensity metrics. It could also propose ways to improve sector or sub-sector-level metrics through the use of granular data at installation level. As part of this, the report may then put forward basic principles and considerations that governments and stakeholders may wish to consider when designing policies or specific standards for the computation of product-level carbon intensity metrics.

76. **Finally, the 2024 report could highlight areas of potential further work to be taken forward in the workstream after the completion of the 2024 report**. Such work, as suggested by IFCMA delegates, could include: a review of data availability to enable the calculation of carbon intensity metrics and, if data allows, providing illustrative computations of product-level carbon intensity metrics for key basic products in EITE sectors as well as identifying scalable, widely used, and reliable methodologies to provide a common basis for further convergence of carbon intensity methodologies.

References

Arias, P. et al. (eds.) (2023), *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.*, Intergovernmental Panel on Climate Change (IPCC), https://doi.org/10.59327/ipcc/ar6-9789291691647. [4]

Arriola, C. et al. (2020), "Efficiency and risks in global value chains in the context of COVID-19", *OECD Economics Department Working Papers*, No. 1637, OECD Publishing, Paris, https://doi.org/10.1787/3e4b7ecf-en. [64]

Ben m'barek, B., M. Phillpott and C. De Daniloff (2022), *Manufacturing sector methodology*, Climate Trace, https://github.com/climatetracecoalition/methodology-documents/blob/main/Manufacturing/Manufacturing%20sector-%20Steel%20Methodology.pdf. [39]

Berestycki, C. et al. (2022), "Measuring and assessing the effects of climate policy uncertainty", *OECD Economics Department Working Papers*, No. 1724, OECD Publishing, Paris, https://doi.org/10.1787/34483d83-en. [60]

Boffo, R., C. Marshall and P. R. (2020), *ESG Investing: Environmental Pillar Scoring and Reporting*, OECD, http://www.oecd.org/finance/esg-investing-environmental-pillar-scoring-and-reporting.pdf. [9]

Calvo Buendia, E. et al. (2019), *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. [26]

Château, J., R. Dellink and E. Lanzi (2014), "An Overview of the OECD ENV-Linkages Model: Version 3", *OECD Environment Working Papers*, No. 65, OECD Publishing, Paris, https://doi.org/10.1787/5jz2qck2b2vd-en. [31]

Churkina, G. et al. (2020), "Buildings as a global carbon sink", *Nature Sustainability*, Vol. 3/4, pp. 269-276, https://doi.org/10.1038/s41893-019-0462-4. [40]

D'Arcangelo, F. et al. (2023), "Corporate cost of debt in the low-carbon transition: The effect of climate policies on firm financing and investment through the banking channel", *OECD Economics Department Working Papers*, No. 1761, OECD Publishing, Paris, https://doi.org/10.1787/35a3fbb7-en. [8]

Deconinck, K., M. Jansen and C. Barisone (2023), "Fast and furious: the rise of environmental impact reporting in food systems", *European Review of Agricultural Economics*, Vol. 50/4, pp. 1310-1337, https://doi.org/10.1093/erae/jbad018. [7]

Deconinck, K. and L. Toyama (2022), “Environmental impacts along food supply chains: Methods, findings, and evidence gaps”, *OECD Food, Agriculture and Fisheries Papers*, No. 185, OECD Publishing, Paris, https://doi.org/10.1787/48232173-en. [66]

ECB (2022), “2022 climate risk stress”, *2022 climate risk stress*, https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm.climate_stress_test_report.20220708~2e3cc0999f.en.pdf (accessed on 2023). [56]

ECB (2022), *Climate-related risks to financial stability*, https://www.ecb.europa.eu/pub/financial-stability/fsr/special/html/ecb.fsrart202205_01~9d4ae00a92.en.html. [54]

Ekvall, T. (2020), “Attributional and Consequential Life Cycle Assessment”, in *Sustainability Assessment at the 21st century*, IntechOpen, https://doi.org/10.5772/intechopen.89202. [46]

European Commission (2023), *Carbon Border Adjustment Mechanism*, European Commission, https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en (accessed on 26 September 2023). [82]

European Commission (2023), *EU Emissions Trading System (EU ETS)*, https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en (accessed on 26 October 2023). [81]

European Commission (2018), *Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs)*, https://eplca.jrc.ec.europa.eu/permalink/PEFCR_guidance_v6.3-2.pdf. [73]

European Parliament and Council of the European Union (2022), *Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting*, https://eur-lex.europa.eu/eli/dir/2022/2464/oj. [78]

Finnveden, G. et al. (2009), “Recent developments in Life Cycle Assessment”, *Journal of Environmental Management*, Vol. 91/1, pp. 1-21, https://doi.org/10.1016/j.jenvman.2009.06.018. [51]

Franzen, A. and S. Mader (2018), “Consumption-based versus production-based accounting of CO2 emissions: Is there evidence for carbon leakage?”, *Environmental Science & Policy*, Vol. 84, pp. 34-40, https://doi.org/10.1016/j.envsci.2018.02.009. [69]

Garcia Vega, S. et al. (2023), “Abominable Greenhouse Gas Bookkeeping Casts Serious Doubts on Climate Intentions of Oil and Gas Companies”, *SSRN Electronic Journal*, https://doi.org/10.2139/ssrn.4451926. [53]

Greenhouse Gas Protocol (2011), *Product Life Cycle Accounting and Reporting Standard*, https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf. [18]

Grubb, M. et al. (2022), “Carbon Leakage, Consumption, and Trade”, *Annual Review of Environment and Resources*, Vol. 47/1, pp. 753-795, https://doi.org/10.1146/annurev-environ-120820-053625. [68]

Hasegawa, R., S. Kagawa and M. Tsukui (2015), “Carbon footprint analysis through constructing a multi-region input–output table: a case study of Japan”, *Journal of Economic Structures*, Vol. 4/1, https://doi.org/10.1186/s40008-015-0015-6. [30]

Hellweg, S. and L. Milà i Canals (2014), "Emerging approaches, challenges and opportunities in life cycle assessment", *Science*, Vol. 344/6188, pp. 1109-1113, https://doi.org/10.1126/science.1248361. [65]

HM Treasury (United Kingdom) (2021), *Net Zero Review: Final Report*, https://www.gov.uk/government/publications/net-zero-review-final-report. [12]

IEA (2023), *Emissions Measurement and Data Collection for a Net Zero Steel Industry*,, IEA, Paris, https://www.iea.org/reports/emissions-measurement-and-data-collection-for-a-net-zero-steel-indust. [16]

IEA (2023), *Tracking Clean Energy Progress 2023*, https://www.iea.org/reports/tracking-clean-energy-progress-2023,. [10]

IEA (2023), *World Energy Balances*, International Energy Agency, https://www.iea.org/data-and-statistics/data-product/world-energy-balances (accessed on 12 June 2023). [21]

IEA (2022), *Achieving Net Zero Heavy Industry Sectors in G7 Members*, https://www.iea.org/reports/achieving-net-zero-heavy-industry-sectors-in-g7-members. [11]

IEA (2022), *Emissions Factors 2022*, https://www.iea.org/data-and-statistics/data-product/emissions-factors-2022. [23]

IEA (2021), *Global CO2 emissions from fuel combustion by sector with electricity and heat reallocated, World*, https://www.iea.org/data-and-statistics/data-tools/greenhouse-gas-emissions-from-energy-data-explorer. [2]

IMF (2022), *CO_2 Emissions embodied in Domestic Final Demand, Production, and Trade*, IMF, https://climatedata.imf.org/datasets/7ba962035bb548bb9893add2b5491896_0/about (accessed on 25 October 2023). [27]

Industrial Deep Decarbonisation Initiative (2023), *Summary of progress and outlook*, https://www.cleanenergyministerial.org/resource/industrial-deep-decarbonisation-initiative-summary-of-progress-and-outlook/. [42]

IPCC (2022), *Global Warming of 1.5°C*, Cambridge University Press, https://doi.org/10.1017/9781009157940. [3]

IPCC (2006), *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1 : General Guidance and Reporting*, IPCC, https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html. [22]

Jeudy-Hugo, S., L. Lo Re and C. Falduto (2021), "Understanding countries' net-zero emissions targets", *OECD/IEA Climate Change Expert Group Papers*, No. 2021/03, OECD Publishing, Paris, https://doi.org/10.1787/8d25a20c-en. [24]

Kauffmann, C., C. Tébar Less and D. Teichmann (2012), "Corporate Greenhouse Gas Emission Reporting: A Stocktaking of Government Schemes", *OECD Working Papers on International Investment*, No. 2012/1, OECD Publishing, Paris, https://doi.org/10.1787/5k97g3x674lq-en. [59]

Koolen, D. and D. Vidovic (2022), *Greenhouse gas intensities of the EU steel industry and its trading partners*, https://publications.jrc.ec.europa.eu/repository/handle/JRC129297?mode=full. [71]

Lo Re, L. et al. (2019), "Designing the Article 6.4 mechanism: Assessing selected baseline approaches and their implications", *OECD/IEA Climate Change Expert Group Papers*, No. 2019/05, OECD Publishing, Paris, https://doi.org/10.1787/59feca56-en. [36]

López González, J., F. Casalini and J. Porras (2022), "A Preliminary Mapping of Data Localisation Measures", *OECD Trade Policy Papers*, No. 262, OECD Publishing, Paris, https://doi.org/10.1787/c5ca3fed-en. [57]

Lyubich, E., J. Shapiro and R. Walker (2018), "Regulating Mismeasured Pollution: Implications of Firm Heterogeneity for Environmental Policy", *AEA Papers and Proceedings*, Vol. 108, pp. 136-142, https://doi.org/10.1257/pandp.20181089. [70]

Meinrenken, C. et al. (2020), "Carbon emissions embodied in product value chains and the role of Life Cycle Assessment in curbing them", *Scientific Reports*, Vol. 10/1, https://doi.org/10.1038/s41598-020-62030-x. [47]

Misch, F. and P. Wingender (2021), "Revisiting Carbon Leakage", *IMF Working Papers*, https://www.imf.org/en/Publications/WP/Issues/2021/08/06/Revisiting-Carbon-Leakage-462148. [74]

MSCI ESG Research LLC (2022), , https://www.msci.com/www/blog-posts/companies-may-not-be-ready-for/03092675115. [61]

Mura, M. et al. (2021), "The role of geographical scales in sustainability transitions: An empirical investigation of the European industrial context", *Ecological Economics*, Vol. 183, p. 106968, https://doi.org/10.1016/j.ecolecon.2021.106968. [35]

NGFS (2021), *Progress report on bridging data gaps*, https://www.ngfs.net/sites/default/files/medias/documents/progress_report_on_bridging_data_gaps.pdf. [62]

Niamir, L., O. Ivanova and T. Filatova (2020), "Economy-wide impacts of behavioral climate change mitigation: Linking agent-based and computable general equilibrium models", *Environmental Modelling & Software*, Vol. 134, p. 104839, https://doi.org/10.1016/j.envsoft.2020.104839. [32]

Noels, J. and R. Jachnik (2022), "Assessing the climate consistency of finance: Taking stock of methodologies and their links to climate mitigation policy objectives", *OECD Environment Working Papers*, No. 200, OECD Publishing, Paris, https://doi.org/10.1787/d12005e7-en. [6]

OECD (2023), *CO2 Emissions in 2022*, OECD Publishing, Paris, https://doi.org/10.1787/12ad1e1a-en. [79]

OECD (2023), *The Heterogeneity of Steel Decarbonisation Pathways*, OECD Publishing, Paris, https://doi.org/10.1787/fab00709-en. [19]

OECD (2023), "Trade in value added", *OECD Statistics on Trade in Value Added* (database), https://doi.org/10.1787/data-00648-en (accessed on 31 August 2023). [14]

OECD (2022), *OECD Inter-Country Input-Output Database*, https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm. [29]

OECD (2020), *Climate Policy Leadership in an Interconnected World: What Role for Border Carbon Adjustments?*, OECD Publishing, Paris, https://doi.org/10.1787/8008e7f4-en. [15]

OECD (2019), *Enhancing Access to and Sharing of Data: Reconciling Risks and Benefits for Data Re-use across Societies*, OECD Publishing, Paris, https://doi.org/10.1787/276aaca8-en. [58]

OECD (2013), *THE OECD ENV-LINKAGES MODELLING FRAMEWORK*, http://www.oecd.org/environment/modelling. [75]

People's Republic of China (2021), *China's Achievements, New Goals and New Measures for Nationally Determined Contributions (Unofficial Translation)*, https://unfccc.int/sites/default/files/NDC/2022-06/China%E2%80%99s%20Achievements%2C%20New%20Goals%20and%20New%20Measures%20for%20Nationally%20Determined%20Contributions.pdf. [67]

Plevin, R., M. Delucchi and F. Creutzig (2013), "Using Attributional Life Cycle Assessment to Estimate Climate-Change Mitigation Benefits Misleads Policy Makers", *Journal of Industrial Ecology*, Vol. 18/1, pp. 73-83, https://doi.org/10.1111/jiec.12074. [45]

Prussi, M. et al. (2021), "CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels", *Renewable and Sustainable Energy Reviews*, Vol. 150, p. 111398, https://doi.org/10.1016/j.rser.2021.111398. [44]

Rajagopal, D. (2013), "Consequential Life Cycle Assessment of Policy Vulnerability to Price Effects", *Journal of Industrial Ecology*, Vol. 18/2, pp. 164-175, https://doi.org/10.1111/jiec.12058. [43]

Rajagopal, D., C. Vanderghem and H. MacLean (2017), "Life Cycle Assessment for Economists", *Annual Review of Resource Economics*, Vol. 9/1, pp. 361-381, https://doi.org/10.1146/annurev-resource-100815-095513. [41]

Ritche, H., M. Roser and P. Rosado (2020), *CO_2 and Greenhouse Gas Emissions*, https://ourworldindata.org/emissions-by-sector#energy-use-in-industry-24-2. [1]

Rodriguez, M., M. Pansera and P. Lorenzo (2020), "Do indicators have politics? A review of the use of energy and carbon intensity indicators in public debates", *Journal of Cleaner Production*, Vol. 243, p. 118602, https://doi.org/10.1016/j.jclepro.2019.118602. [25]

Roychand, R. et al. (2023), "Transforming spent coffee grounds into a valuable resource for the enhancement of concrete strength", *Journal of Cleaner Production*, Vol. 419, p. 138205, https://doi.org/10.1016/j.jclepro.2023.138205. [49]

Schneider Electric (2022), *2022 Climate Report: Digital an Electric for a sustainable and resilient future*, https://www.se.com/ww/en/assets/564/document/396656/2022-climate-report.pdf. [72]

Simmons, J. et al. (2022), *Mind the gaps: Clarifying corporate carbon*, FTSE Russell, https://www.lseg.com/en/ftse-russell/research/mind-gaps-clarifying-corporate-carbon. [83]

Stenzel, A. and I. Waichman (2023), "Supply-chain data sharing for scope 3 emissions", *npj Climate Action*, Vol. 2/1, https://doi.org/10.1038/s44168-023-00032-x. [55]

Steubing, B. et al. (2022), "How do carbon footprints from LCA and EEIOA databases compare? A comparison of ecoinvent and EXIOBASE", *Journal of Industrial Ecology*, Vol. 26/4, pp. 1406-1422, https://doi.org/10.1111/jiec.13271. [50]

Stowe, L. (2023), *Accounting to Address “Carbon Leakage”*, https://silverado.org/news/governments-must-lead-on-trade-tailored-ghg-accounting-to-address-carbon-leakage/. [76]

Tarleton, A. (2023), *ecoact*, How to calculate a carbon footprint for your business, https://eco-act.com/carbon-reporting/how-to-calculate-a-carbon-footprint-for-your-business/ (accessed on 18 September 2023). [52]

UNFCCC (2022), *Nationally determined contributions under the Paris: Synthesis report by the secretariat*, https://unfccc.int/documents/619180. [5]

US Department of Energy (2022), *Defining functional units for LCA and TEA*, https://www.energy.gov/eere/iedo/life-cycle-assessment-and-techno-economic-analysis-training#functionalunit. [48]

US EPA (2023), *Greenhouse Gas Reporting Program, Emission Calculation Methodologies*, https://www.epa.gov/ghgreporting/ghgrp-methodology-and-verification (accessed on 2023). [33]

US EPA (2019), *U.S. Cement Industry Carbon Intensities (2019)*, https://www.epa.gov/system/files/documents/2021-10/cement-carbon-intensities-fact-sheet.pdf. [34]

Vidovic, D. et al. (2023), *Greenhouse gas emission intensities of the steel, fertilisers, aluminium and cement industries in the EU and its main trading partners*, Publications Office of the European Union, https://publications.jrc.ec.europa.eu/repository/handle/JRC134682. [80]

WBCSD (2023), *Pathfinder Framework: Guidance for the Accounting and Exchange of Product Life Cycle Emissions*, https://www.wbcsd.org/PFV2.0. [17]

White, L. et al. (2021), “Towards emissions certification systems for international trade in hydrogen: The policy challenge of defining boundaries for emissions accounting”, *Energy*, Vol. 215, p. 119139, https://doi.org/10.1016/j.energy.2020.119139. [63]

World Steel Association (2022), *Sustainability Indicators 2022 Report*, https://worldsteel.org/wp-content/uploads/Sustainability-Indicators-2022-report.pdf. [37]

World Trade Organization (2022), *World Trade Report 2022: Climate change and international trade*, World Trade Organization, https://www.wto.org/english/res_e/booksp_e/wtr22_e/wtr22_e.pdf (accessed on 25 October 2023). [28]

Worldsteel Association (2022), *CO2 Data Collection User Guide*, https://worldsteel.org/wp-content/uploads/CO2_User_Guide_V11.pdf (accessed on 17 August 2023). [38]

WRI and WBCSD (2023), *Greenhouse Gas Protocol*, Corporate Standard, https://ghgprotocol.org/corporate-standard (accessed on 18 September 2023). [77]

WTO (2023), “Decarbonization standards and the iron and steel sector: how can the WTO support greater coherence?”, *Trade and Climate Change Information brief* 7, https://www.wto.org/english/tratop_e/envir_e/trade-climate-change_info_brief_no7_e.pdf. [20]

Yamano, N. and J. Guilhoto (2020), "CO2 emissions embodied in international trade and domestic final demand: Methodology and results using the OECD Inter-Country Input-Output Database", *OECD Science, Technology and Industry Working Papers*, No. 2020/11, OECD Publishing, Paris, https://doi.org/10.1787/8f2963b8-en. [13]

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