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PCR for ICT: A roadmap for advancing and harmonizing LCA on ICT equipment

Position paper

Karsten Schischke
Erik Poppe
Christian Clemm

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Contact:
Fraunhofer IZM
Gustav-Meyer-Allee 25, 13355 Berlin, Germany
Email: karsten.schischke@izm.fraunhofer.de

Content

Declaration

This paper is a deliverable from a study carried out by Fraunhofer IZM and commissioned by Google. The study was commissioned to arrive at objective and unbiased conclusions. Fraunhofer IZM declares no conflict of interest.

Abbreviations

BOM	Bill of Materials
BSI	British Standards Institution
CD	Committee Draft
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CFP	Carbon footprint of products (sometimes PCF)
CO_2e	Carbon dioxide equivalents
CPU	Central Processing Unit, or: processor
DIN	Deutsches Institut für Normung
DNM	Data Needs Matrix
DPP	Digital Product Passport
DQM	Data Quality Matrix
EC	European Commission
EN	European Standard
EOL	End of life
EPD	Environmental Product Declaration
EPEAT	Electronic Product Environmental Assessment Tool
ETSI	European Telecommunications Standards Institute
EU	European Union
FU	Functional unit
GEC	Global Electronics Council
GHG	Greenhouse gases
GPU	Graphics Processing Unit, or: graphics processor
GWP	Global warming potential
ICT	Information and communication technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
iNEMI	International Electronics Manufacturing Initiative
IS	International Standard
ISO	International Organization for Standardization
ITU	International Telecommunication Union
LCA	Life cycle assessment
LCI	Life cycle inventory
MIT	Massachusetts Institute of Technology
OEM	Original Equipment Manufacturer
PAIA	Product Attribute to Impact Algorithm
PAS	Publicly Available Specification
PCR	Product Category Rule
PEF	Product environmental footprint
PEFCR	Product environmental footprint category rules
PEP	Product Environmental Profiles, typically associated with the PEPecopassport® program
PCF	Product Carbon Footprint (sometimes CFP)

PSF	Product Specific Rule
SCC	Semiconductor Climate Coalition
SDO	Standard Development Organization
SEC	United States Securities and Exchange Commission
SG	Sector Guideline
TC	Technical Committee
TR	Technical Report
WD	Working Draft

1 Introduction

The following paper proposes a roadmap for a unified approach to Life Cycle Assessment (LCA) for information and communication technology (ICT) equipment. Currently, there are several methods and guidelines for conducting LCA on ICT equipment, which leads to a great deal of variation in the results of different studies, making it difficult to compare and interpret the findings. The objective of this roadmap is to identify the main issues to be addressed by a further standardization process and to sketch out a framework for the implementation of a Product Category Rule (PCR) for ICT equipment.

A product category rule (PCR) is a document that provides instructions for conducting an LCA on a specific product category. PCR typically includes comprehensive information on data sources, methodology, allocation rules, and reporting requirements. Depending on the standardization body and program, the procedure to carry out a PCR document can take different forms but is usually developed through a consensus-based process, involving experts from industry, LCA practitioners and other interested parties. The target group for this roadmap proposal are Original Equipment Manufacturers (OEM), as they play a key role in the development of PCRs. They often have extensive knowledge of their products and can provide valuable input into the PCR process. In addition, OEMs can help ensure that the PCR is aligned with industry practices. By participating in the development of PCRs, other relevant stakeholders such as ICT-related associations and independent LCA experts can help to increase the acceptance and adoption of a specific PCR.

The roadmap document is part of an initiative by Fraunhofer IZM and a group of leading industry stakeholders to improve standardization, guidance, and simplification of the LCA process. The results of the initial consultations show a strong commitment across the industry to drive improvements in the accuracy and consistency of product carbon footprints. The proposed roadmap clarifies the next steps in this process. In particular, the roadmap should address the following questions:

- (Why) Do we need a PCR process?
- What methodological issues in ICT LCAs should be addressed, which constitute current shortcomings in light of changing OEMs' expectations, strategic and operational needs and interests?
- What are the options for implementing a PCR for ICT?
- What is the best path forward?

2 Current state assessment

As environmental awareness continues to grow, more and more companies are taking steps to account for their environmental and climate impacts. Product footprints are one way to do this, and they can serve a variety of purposes, from being instrumental in planning for and achieving net-zero sector emissions by 2050 to guiding design decisions in the product development process. In addition, climate transparency is increasingly required by customers and other stakeholders in the electronics supply chain. However, conducting LCAs to obtain product footprints is still a complex and time-consuming process, and there are many different methodologies and approaches that can be used. As a result, there is currently no single "right" way to perform LCA for ICT equipment, and multiple approaches are being employed. The following section aims to show the relevance and need for a dedicated PCR for ICT equipment and how it can improve the consistency and reliability of future carbon footprint studies.

2.1 Carbon transparency – a prerequisite for achieving net zero

As environmental awareness continues to grow, more and more companies are taking steps to account for their environmental and climate impacts. Product footprints are one way to do this, and they can serve a variety of purposes, from being

The Paris Agreement, which came into effect in November 2016, includes the net zero target as a long-term goal. To date, 194 out of 198 countries at the UNCC committed to achieving net zero emissions by 2050[1], including all relevant industries in the ICT sector. From this point of view, net-zero emissions are no longer a question of whether or not, but of when and how the industry takes action.

LCA on a company, product and service level is a necessary tool to account for climate emissions and to move towards net zero goals. In addition to direct measurements at the point of emission, LCA is an elegant way to get an accurate picture of the climate burdens associated with a particular good or service throughout its life cycle. As a result of the effectiveness and acceptance of the LCA method, policymakers and industry initiatives around the world have begun to establish or announce requirements for the reporting of carbon footprints at the product and service level. Product carbon footprints in the ICT sector are supposed to serve with priority following purposes among others:

- **Environmental ratings and benchmarking schemes** such as EPEAT[2], but also policy initiatives to make product carbon footprints comparable (EC 2021).
- Respond to an exponentially increasing number of **customers requests** and demands for more **supply chain transparency** and **decarbonization**.
- **Guide design decisions**, i.e., granularity of the analyses is required where the company has significant influence on design, technology and/or supplier decisions.

[1] https://unfccc.int/process/the-paris-agreement/status-of-ratification

[2] https://globalelectronicscouncil.org/wp-content/uploads/GEC-Criteria-Modules-by-Sustainability-Impacts-Overview-rev8-15NOV2022-.pdf

- Being aligned with **company climate policy**, i.e., product related analyses should guide initiatives needed to realize greenhouse gas reduction targets at the company level, including all scopes.

- In the long run, compliance with upcoming EU ecodesign and battery **regulations** that will require a carbon footprint[1], e.g., as of July 2024, rechargeable industrial and electric vehicle batteries with internal storage will require a carbon footprint declaration to be marketed in the EU.[2]

The product group ICT is very broad and covers at least the product groups listed below. The status of LCA in these market segments is very diverse, ranging from LCA not being common at all to the field of end-user and enterprise computing devices, where LCA is a well-established practice. This broad range of "LCA maturity" has to be kept in mind when discussing LCA in an ICT context. The focus of this PCF roadmap is on those product segments, where LCA is most advanced, i.e. end-user and enterprise computing devices.

Table 1: ICT products overview[3]

Data Centre Devices	
Servers	
Storage	
Networking (switches/routers)	
UPS	
Telecommunication Network	
Broadband communication equipment	
Network in Offices (1GB/10+ GB LAN, WLAN)	
Mobile networks (mobile radio, aggregate/core, satellite TV, TETRA, 2G, 3G, 4G, 5G)	
Cable (fixed, landline) networks (i.e. PSTN/KSDN, TV-cable, ADSL, VDSL, FTTLA, FTTH/B, FTTH)	
End user devices	
Electronic displays	Televisions
	Monitors
Audio/video devices	video players/recorders
	video projectors
	video game consoles
	interactive whiteboards
	video conference systems
	MP3 players

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0142

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32006L0066

[3] adapted from DG JRC ICT Task Force study, Task 2 draft report, 2021

	stand-alone home audio
	network connected home audio
	complex set-top boxes
	digital TV services
Personal ICT Equipment	Desktop PCs
	Workstations
	Notebooks/Laptops
	Tablets/Slates
	Home/Office fixed phones
	Smartphones
Imaging Equipment	Monochrome laser MFD (Multi-Functional Printer)
	Colour laser MFD
	Monochrome laser printer
	Colour laser printer
	Colour inkjet MFD
	Colour inkjet printer
	Professional printer and MFD
	Scanner
	Copier
	3D Printers
Audio Equipment	Loudspeakers
	Radios
	Players/recorders
	Amplifiers
	Receivers
	Tuners
	Microsets
	Wireless speakers
	Smart speakers
	Soundbars
	Network audio players
Home / Office Network Equipment	Home gateway / IoT access devices
	Home routers/gateways, integrated access devices
	Base stations
	Home network equipment
	Office network equipment (servers, routers, switches)

	Home NAS
other ICT	
ICT in public Space	ATMs
	Cash Registers and POS Terminals
	Ticket Machines
	Public WLAN hotspots
	Toll-related ICT
	Security cameras
Building Automation and Control	
Industrial Sensors	
Uninterruptible Power Supply	

As part of this PCR initiative a group of OEMs, representing mainly end-user and enterprise computing devices, and institutions of high relevance for the topic LCA in the ICT sector discussed interest and the need to better harmonize LCA activities and to advance the state of LCA. One way to achieve this is through the use of product category rules (PCRs). PCRs are guidelines that help to carry out LCAs by providing a clear set of rules to be applied for specific product groups, such as ICT equipment. The stakeholder consultation raised a number of important aspects to be considered in the PCR process:

- There is a **clear focus on carbon footprint calculations**; coverage of further environmental impact categories has been done in the past by some case studies, but among the leading OEMs there is a clear trend to remain focused only on carbon footprints.
- It seems, over time, the priority for undertaking LCAs has shifted towards **steering climate policies and targets of the OEMs**. The way LCA is currently implemented does not seem to be the best tool to identify and track measures toward the aim of reducing greenhouse gas emissions.
- For **engaging suppliers** on carbon reduction measures, more specific data on the component level is needed.
- As the regulatory landscape is evolving, there is the risk of multiple regional approaches, which leads to inconsistencies and excessive efforts to comply with the potentially different requirements. Therefore, it is important to counter this risk by agreeing on a common proactive approach, which is also **acceptable for policy makers worldwide**. Explicitly, alignment with the EU development for a Digital Product Passport (DPP) needs to be considered, in case LCA data is required to be reported. In general, EU[1] and SEC rulings can be seen as relevant drivers for defining future standards, but also in China activities regarding carbon footprint calculations are ongoing and should be considered[2].

The ICT sector has complex and far-reaching supply chains that stretch across the globe, as well as the environmental data required for an LCA. Product Category Rules (PCR) are used to address

[1] including potential requirements on Product Environmental Footprints

[2] relevant past activities include the PCF China Standard Project initiated more than 10 years ago and the ICT Product Life-Cycle Assessment Data Service Platform

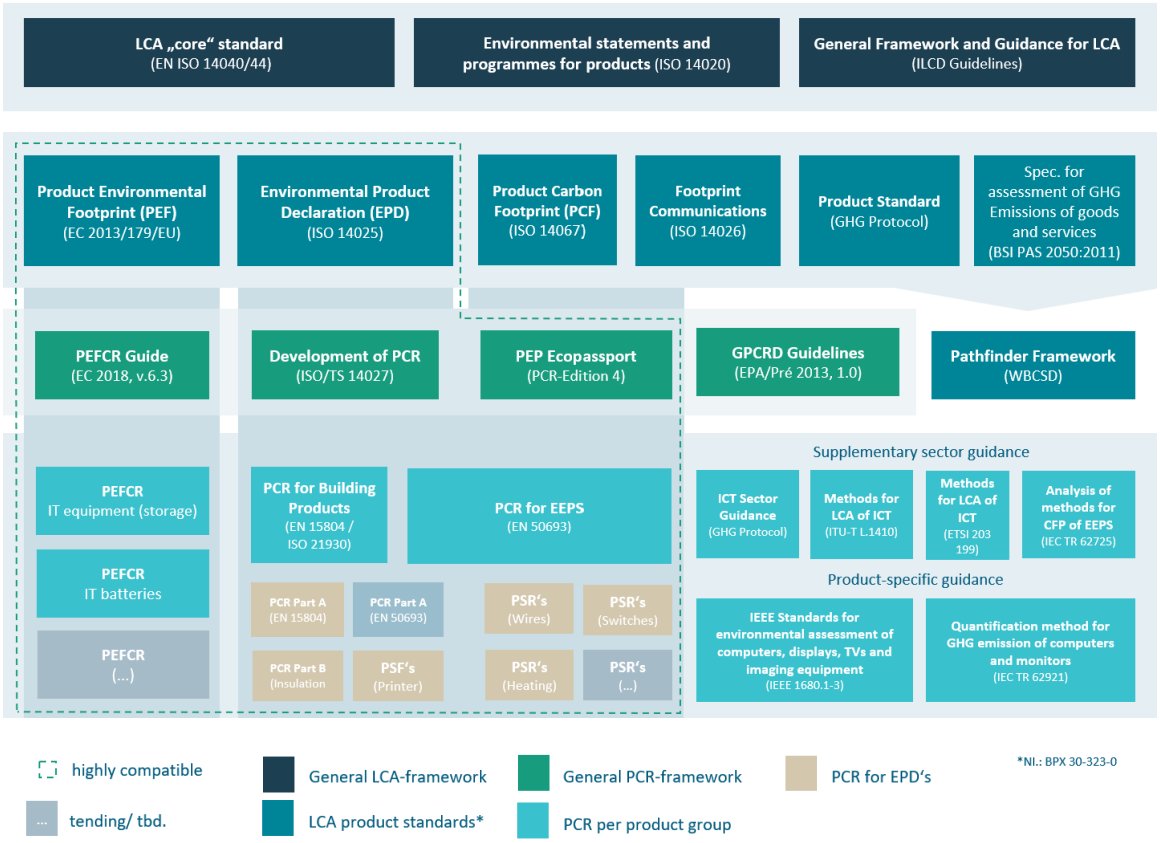
information requirements and bridge gaps if needed. The next sections will explore which standards are already in place and discuss where further collective action is needed.

2.2 LCA and PCR landscape for ICT equipment

During the last decade Life Cycle Assessment (LCA) has seen a wide adoption in research and industry. While international standards such as ISO 14040/44 provide a general framework for conducting LCAs and are complemented by a number of other product-specific standards and sectoral guidelines, which will be addressed in the following section. The research will reveal that much of the groundwork has been done, but practitioners still face many practical problems and lack of comparability of LCA results. The inconsistency problem of LCAs is subject to research for many years (Schaubroeck 2022, Curran 2013) and according to experts an inherent and unavoidable part of LCAs, as standards are always a compromise (Finkbeiner 2021). Although a "one size fits all" solution is unattainable, dedicated PCRs are from a standardization perspective the next step, to close the interpretation gap that higher level standards leave and provide clear guidance on a product specific level.

Figure 1 shows a mapping of existing standards and guidelines relevant to LCA in the ICT sector, which we will refer to here as the "LCA/PCR landscape". A detailed description and specification can be found in the Appendix of this document.

Figure 1: LCA and PCR standards landscape for the ICT sector



Relevant standards were identified through desk research and expert consultations. The order and classification of the various standards and guidelines are a proposal of the project team and do not claim to be complete. However, various stakeholders and experts affirmed the relevance and logic of the landscape (see Figure 1), which is as follows:

- The LCA/PCR landscape has a vertical logic, from more general rules at the top to specific ones at the bottom. ISO 14040/44 standards provide a framework for conducting LCAs for products and services. The ILCD Guidelines provide additional guidance and conventions to perform LCAs (e.g., terminology, data formats etc.). Standard ISO 14020 provides a general framework for the communication of environmental statements for products. Recently, this standard has been complemented by ISO 14026, setting specific requirements for the communication of carbon footprints.
- Depending on the context and objectives, various product standards can be used to perform an LCA, which may include additional vertical requirements in the form of Product Category Rules (PCR) or Product Specific Rules (PSR). For example, the PEF methodology proposed by the European Commission (EC) provides a comprehensive guide for the preparation of PCRs (PEFCR) and has already delivered 26 PEFCRs as pilot studies, covering product groups such as IT equipment, textiles, and various food products. In addition, the international EPD system provides a rich set of PCRs, especially in the building and construction sector, but also for electronic equipment and services by EPD operators such as PEP.
- Alongside more formalized PCR frameworks such as PEF and EPD, there are other highly relevant standards and guidelines on the market that are specifically tailored to the ICT sector

and fulfil a similar function as PCR. Labelled as "supplementary sector guidance" or "product-specific guidance (PSF)", these standards include well-known guidelines such as ITU and ETSI Methodology. Moreover, IEC TR 62921 provides the basis for streamlined calculations with the MIT PAIA Tool, which is the dominant approach for currently published ICT equipment LCAs. Some of the standards and guidelines are also focussed on the specifics of certain market segments, as, e.g., ETSI and ITU naturally focus on telecommunication equipment which leads to nuanced differences compared to approaches for computing equipment.

As can be seen, the current LCA/PCR landscape is characterized by diversity and heterogeneity. In practice, standards exist in parallel and refer to each other, which can cause discrepancy and redundancy at the same time. For example, almost all product standards such as PEF, EPD, PCF and the GHG product standard refer to ISO 14040/44, but also introduce their own specific rules that make a direct comparison of different studies impossible. Key differences include issues such as the reporting of impact indicators, end-of-life scenarios, and the treatment of secondary materials and biogenic feedstocks in LCA. Though some efforts have been made to harmonize different standards (i.e., PEF and Pathfinder Framework), it is unlikely that all the standards and guidelines will ever fully converge. It is therefore important to understand the practical relevance of the various standards and their limitations in the ICT sector, which will be discussed in the next section.

2.3 Industry and market are ready for the next step

In the context of the PCR initiative, 8 OEMs and two high-level institutions in the ICT sector discussed the need to better harmonize and advance the state of LCA. A workshop organized by Fraunhofer IZM took place at the end of 2022. Further insights were gathered through a short survey prior to the workshop, bilateral expert interviews and internal knowledge by Fraunhofer IZM. The section below provides a summarized version of findings, highlighting the key points of relevance for further standardization.

- **Clear focus on carbon footprints:** Almost all stakeholders undertake and prefer single-criteria impact assessments based on CO_2-equivalents (GWP100). In contrast, multi-criteria assessments require the reporting of additional impact categories (e.g., ozone depletion potential, abiotic depletion potential) and increase the complexity and effort of the study, which stakeholders believe adds little value in the current market situation.

- **Priority and limitation to the core standard ISO 14040/44:** Several OEMs investigated the existing standards and PCRs. Some strive for alignment with multiple options, while others restrict their focus solely on ISO 14040/44 as the overarching standard in the field, complementing the ISO standards with in-house methodology guidance to clarify aspects of the LCA approach where the ISO standards leave room for interpretation. Explicitly relevant standards and PCRs for OEMs in the ICT business comprise IEEE 1680, IEC 62921, and with a very occasional mention ISO 14067, PAS 2050, ITU-T L.1410 / ETSI 203 199. The GHG Protocol is essential for some businesses to synchronize product PCFs with corporate reporting requirements. A systematic analysis of applicable LCA standards and PCRs regarding individual needs of the OEMs is not common in the industry, and it seems decisions for one standard / PCR have been made either for historic reasons or indirectly by choosing a tool which seems to fit one's own priorities best.

- **Predominance of PAIA tool in the market:** The Product Attribute to Impact Algorithm (PAIA) is an easy-to-use web-based platform that calculates the carbon footprints of ICT equipment focused on product-level accounting. It was developed by researchers at the

Massachusetts Institute of Technology (MIT) and members of the PAIA consortium in accordance with IEC 62921, was then managed and developed by Quantis and recently came back under leadership by researchers at MIT (Alcaraz et al., 2018). PAIA applies a streamlined LCA methodology, which provides a reasonable estimate of the range of carbon impact of a product class (MIT December 2019). While it comes with some limitations (i.e., simplified assumptions, larger uncertainties, no comparison of results etc.) it is currently the most practical and broadly adopted implementation for doing carbon footprints and a significant share of stakeholders is willing to collaborate to improve PAIA's accuracy and flexibility in future. The current roadmap for PAIA over the next 24 months is to develop PCR-like guidelines by module or component of a ICT products (including integrated circuits, printed wiring boards, and transportation, etc.) and therefore provides further opportunity for collaboration.

- **Strong interest in streamlined and hybrid approaches in the market:** There is an agreement that combining detailed full life-cycle assessment with a streamlined LCA process may be the most effective way to move forward. Some OEMs have already adopted this hybrid approach, although they still acknowledge that there are differences which need to be assessed in more detail. There is agreement to focus on environmental hotspots with more granular data or LCA models where OEMs can demonstrate the impact of their investments to reduce environmental impact. It should be noted that these hot spots are not the same for end-user devices, where PCF results are mainly driven by the manufacturing phase of key components, and enterprise products, where use phase impacts predominate. This difference regarding hot spots might also mean differences in prioritization when it comes to PCR developments.

In addition to our stakeholder consultations, it is also worth noting that various parties have launched initiatives to further enhance the standardization and visibility of product LCAs in the ICT environment. These include key players such as the Global Electronics Council (GEC), which is currently working on a framework that includes standardized component lists and datasets to establish carbon thresholds for the various ICT products covered by the EPEAT ecolabel.[1] iNEMI has been working on an Eco-Impact Estimator, which is meant enhance efficiency and accuracy of LCAs, and developed data models on some key greenhouse gas emissions component categories (Okrasinski 2020). As of now, access to the tool is restricted to iNEMI member organisations. A 4th phase of this Eco-Impact Estimator project is under discussion currently and due for decision early 2023. In addition, new organizations are entering the field. For example, the inter-organisational working group Boavizta provides a comprehensive database of public carbon footprint data for digital equipment.[2] The Sustainable Digital Infrastructure Alliance (SDIA) has established several steering groups to facilitate multi-industry collaboration to calculate and reduce the carbon footprint of digitization.[3] Furthermore, the market development shows an increasing number and diversification of service providers who want to simplify the calculation of carbon footprints for complex products and supply chains with new innovative methods (e.g., BOM-based LCA automation, predictive LCA modelling) and use of artificial intelligence (AI). Overall, the

[1] Visit Website for more information: https://globalelectronicscouncil.org/

[2] https://boavizta.org/en

[3] https://sdialliance.org/

increasing demand and interest in improving and promoting LCA in the ICT industry demonstrates the need for further integration of existing standards and new requirements to simplify the process.

3 Initiating a PCR process: Driving industry consensus and adoption

When initiating a standardization process, it is important to consider both the methodological and organizational aspects, which will be described in more detail in the following sections. From a methodological perspective, key considerations include defining the product scope of the PCR, clarifying the compatibility to related standards, and deciding on data needs and quality when conducting a LCA study. From an organizational perspective, key considerations include developing procedures for implementation and publication of a PCR, ensuring stakeholder buy-in, and establishing a clear governance structure. By taking both perspectives into account, we can increase the likelihood of successful implementation of a standardization initiative. The end of the chapter contains a visualized roadmap showing the necessary steps that need to be taken to further advance the process.

3.1 Methodological considerations

Methodological considerations for the development of a PCR for ICT equipment were explored in advance through desk research and a series of workshop and expert interviews. The study has shown that the ICT sector already has a large number of standards and sectoral guidelines, as well as a corresponding set of software tools to carry out carbon footprints with a different level of detail and granularity. The application of different standards and modelling approaches can lead to inconsistencies when combining or comparing the results of different LCA studies on a component or product level. Among others, major inconsistencies can occur on four levels and should be addressed by a specific PCR:

- **Goal and scope:** The PCR should define and classify the ICT products under consideration. A taxonomy for included groups (i.e., ICT equipment) and types (e.g., Printers, Laptops, Smartphones etc.) of products shall help LCA practitioners to determine if the product is within the scope of the PCR or not. A consistent system boundary approach should be applied across the supply chain. If necessary, the PCR should be supplemented by Product Specific Rules (PSR) at the product type level.

- **Data requirements:** The electronics supply chain is complex and globally distributed. Data from suppliers is sometimes hard to get and assess. The PCR should set the data requirements for building an accurate life cycle inventory (LCI) and enable a quality assessment of the robustness and accuracy of data. The LCI, also known as 'foreground system' is often based on a combination of primary and secondary activity data from manufacturers and suppliers. A Data Needs Matrix (DNM) as proposed by PEF (EC 2013/179/EU) can help define minimum requirements and assess the validity of data. A Data Quality Matrix (DQM) according to PCR EN15804 (Table E.1 or Table E.2) can help to assess the overall quality of the data model.

- **Modelling principles:** The PCR should provide a set of allocation rules with regard to the handling of secondary material and components, the reuse and recycling potential in end-of-life scenarios, multi-output processes, and other multifunctionality issues in LCA (Pelletier et. al., 2014). In the discussion with stakeholders, it became clear that the further standardization should also be sensitive and set requirements for streamlining and simplification techniques that are often used when conducting an LCA study for ICT devices (e.g., parameterized models such as PAIA, BOM-based LCA automation, etc.). Streamlining and simplification techniques

are an integral part of any LCA (Beemsterboer et. al., 2014), but often hinder LCA practitioners in the electronic sectors from striving for full compliance with a particular standard due to the lack of guidelines to what degree simplifications can be made (e.g., use of different background databases, granularity of data, approximated results with parameterized models etc.).

- **Reporting requirements:** A PCR should specify both the modelling requirements as well as the requirements for the documentation of the LCA. According to the core standard ISO 14044, the commissioner and practitioner of an LCA study are obliged to prepare a report for a third party. In practice, however, opinions differ as to the extent to which information must be publicly disclosed (Koffler et. al., 2020). Depending on the standards chosen, the scope of documentation and disclosure of information may vary but should be clearly specified by a PCR. This must include determining which environmental impact categories should be published. Currently, the focus in the industry is clearly on the global warming potential (GWP) of products, also known as the carbon footprint of a product, while more elaborate standards such as the EPD standard require the analysis of up to 13 impact categories and several other indicators (e.g., primary energy, waste, water, etc.).

When developing a PCR standard for ICT equipment, it is important to ensure compatibility with other higher-level standards such as ISO14044, EN50693 and relevant sector guidelines. In some cases, complete compatibility may not be possible or practical. However, every effort should be made to ensure that a new PCR standard is interoperable with as many existing standards as possible. By doing so, we can help to create a more cohesive system that benefits everyone.

3.2 Organizational considerations

There are currently a variety of standards and guidelines for conducting LCA studies, so the question arises under which standardization scheme specific PCRs for ICT devices should be developed and published. The next section should help to answer this question by outlining the different standardization paths and briefly explaining their pros and cons with respect to: speed of implementation, flexibility of adoption and market reach. At the end the authors will make a recommendation for further action.

Box 1: An excursion on standardization

Standards are generally created by a wide array of organizations, companies, professional associations, regulators and government agencies around the world. Many standards are developed by standards development organizations (SDOs) such as ISO, IEEE, ETSI, BSI, DIN etc., which aim to produce, maintain and update technical standards and related documents. In many cases, SDOs work closely with stakeholders to ensure that the needs of all interested parties are taken into account during the standards-setting process. However, it is important to note that there is no clear definition of what a formal standardization is. In general, however, formal standardization processes are characterized by transparency, inclusiveness, and consensus-building.

SDOs use different development models that vary primarily in their consensus-building mechanism. In the best case, a standardization process is open to any interested party and will undertake at least the public consultation for a last revision before publication. In contrast to that, standards can also be developed on the fast track, by an exclusive group of stakeholders with and without the involvement of an official SDO and public consultation process. Depending on the openness of the

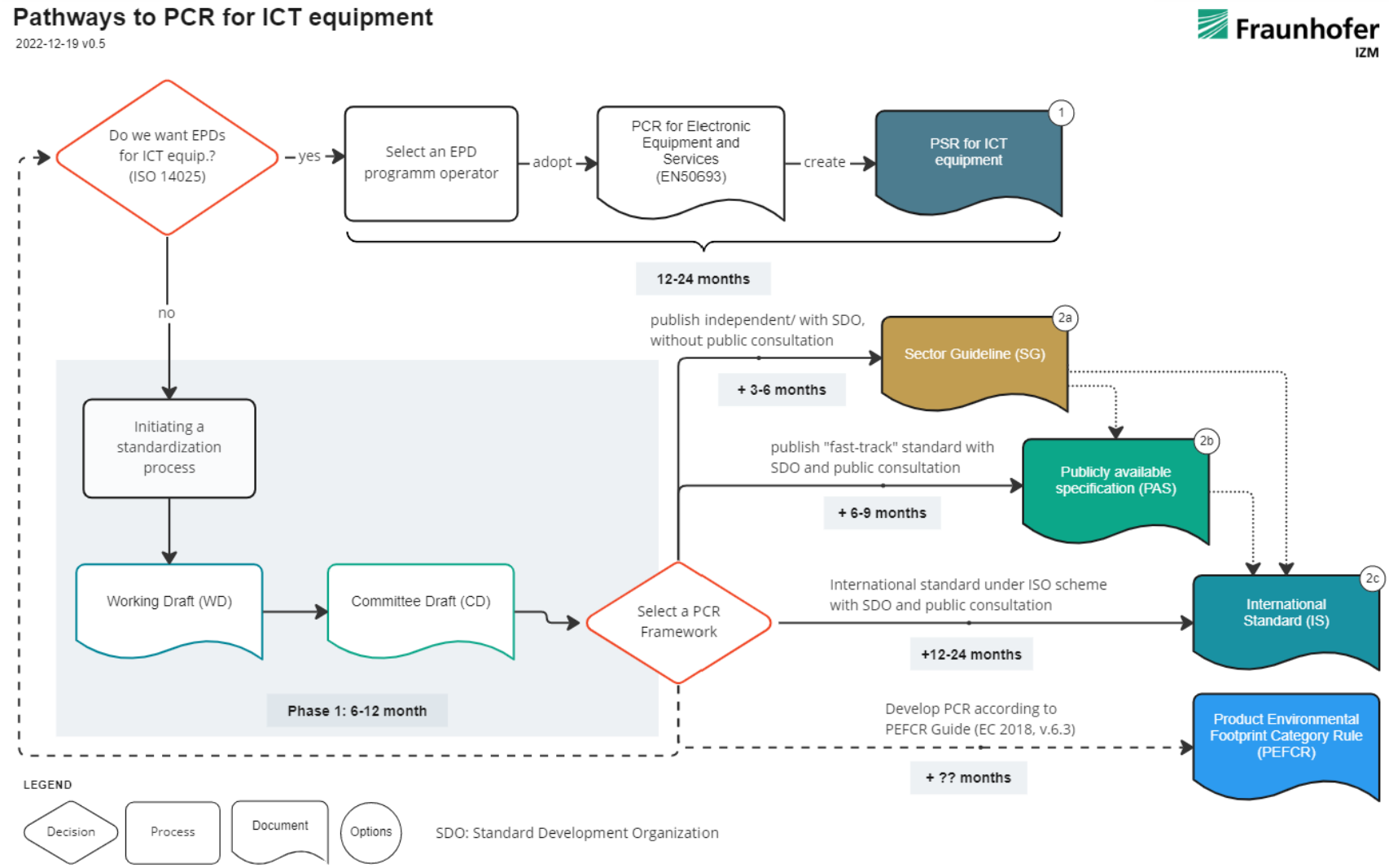
consensus mechanisms, the standardization process can be lengthy and complex, but it is essential to create robust, fit-for-purpose standards that can be used by businesses and other organizations around the world. Once a standard has been finalized, it is typically published by the SDO and made available for purchase or download.

Regarding the current market situation and the organizational perspective, the possibilities for a PCR process for ICT equipment can be boiled down to two main options:

1. Develop a product specific rule (PSR) under the existing EPD framework
2. Develop a product category rule (PCR) outside the existing EPD framework
    a. Develop and publish a PCR as sector guideline (SG) without public participation
    b. Undertake a "fast-track" PCR development within an existing standardization body and publish as publicly available specification (PAS)
    c. Undertake PCR development within an existing standardization body and publish as international standard (IS)

The different pathways and options for developing a PCR for ICT equipment are shown in the next graphic. Possible time frames are estimates of the authors of this paper and may vary in reality. Further explanations can be found below the graphic and a final recommendation on which path to take can be found in the last chapter.

Figure 2: Pathways to PCR for ICT equipment



In terms of speed of implementation, the development of an specific PCR for ICT equipment for an EPD (Option 1) is usually the quickest since it piggybacks on existing work and processes, but it is less flexible and very demanding when it comes to the publication of final EPD studies at a product level. EPD studies require not only that the LCA be conducted according to a specific PCR, but also that all assumptions, modelling aspects, data sources, additional product information and results be fully documented for each product studied. For the environmental impact assessment, 13 environmental impact indicators and another 18 indicators at the inventory level must be reported. The project report is usually non-public and will be verified by an accredited independent verifier along with the public EPD documents. The EPD method is well established throughout Europe and beyond. Several accredited national EPD program operators exist and are usually part of the international steering group ECO Platform[11]. However, while EPDs have been widely used in the construction sector to date, they are less present in the electronics industry. There are several reasons for this, but primarily the cost and duration of their implementation make them unattractive to the ICT industry.

Development of a PCR outside the existing EPD framework (Option 2) leads to additional sub-options, all of which result in better comparability of PCF data, and rather differ in terms of potential acceptance by other stakeholders, but also in a legal context (potential "green claims" issues).

The most straightforward approach is a PCR as a sector guideline (SG) with a less formal and open standardization process (Option 2a). In terms of their openness and inclusiveness, sectoral guidelines focus on industrial sectors rather than specific product groups. They tend to follow a top-down and closed approach, as they are usually developed by experts and key stakeholders in the field without public or open participation. For example, ETSI is a leading international SDO for the ICT sector which also carried out a well-known sector methodology for LCA of ICT equipment (ETSI 203 199). The content and structure of the guideline resemble those of a formal standard, but the development was an exclusive matter of the ETSI members without open public consultation. The advantage here is clearly much faster development and consensus building among stakeholders, as well as greater flexibility with respect to the content of the standard itself. Furthermore, once a sector guideline is published and accepted, it offers great potential for transition to more public standardization schemes.

One of the more open, but also institutionalized options to develop a PCR is Publicly Available Specifications (PAS) (Option 2b), which are marketed by SDOs as fast-track standards. PAS standards are usually developed in response to an urgent market demand or in areas of rapidly evolving technology and are typically designed to be quick to implement. In many cases, PAS standards are initiated by a sponsoring organization and developed by consortia of interested parties within a compressed timescale. PAS can be developed with or without the assistance of an official SDO. In any case, the idea, draft or final PAS must be submitted to an official SDO and follow their specific adoption process. In contrast to fully formal standardization processes, PAS follows an accelerated process with a shorter public consultation phase and is rather flexible in its design. However, in many cases, the PAS can form a starting point for the development of international standards, e.g., ISO standards.

Finally, a PCR can be carried out as an international standard under the framework of the International Organisation for Standardization (ISO) (Option 2c). ISO standards play a critical role in ensuring the quality and safety of products and services around the world, and they have high credibility and acceptance in the marketplace. This can help to increase trust among customers and partners. However, the development of ISO standards is complex, involving experts from all over the world. This

[11] https://www.eco-platform.org/

process can be lengthy and difficult, requiring close coordination among different countries and stakeholders who do not necessarily always share the same interests.

Last but not least, any PCR project should take into account the activities of the European Commission (EC) in the field of its Product Environmental Footprint (PEF) methodology. The EC created PEF to harmonize the existing standards and to allow the comparability of product LCAs (EC 2021). In addition to a comprehensive methodology (EC 2013/179/EU), it also provides a framework for creating category rules (EC 2018, v.6.3), in short PEFCR, and has already published one for IT equipment with a particular focus on storage devices.[12] To date, PEF is still in transition, meaning it is not clear how the method will be adopted in the market and in upcoming product regulations. For example, it is not clear whether PEF will continue to be developed outside of the established standardization frameworks and whether it will remain a methodology or eventually become standard.[13][14]

[12] https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_ITequipment_Feb2020_2.pdf

[13] https://ec.europa.eu/environment/eussd/smgp/pdf/q_a.pdf

[14] according to the EU Ecodesign for Sustainable Products Regulation (ESPR) draft accompanying documents substantial budget is earmarked by the European Commission for PEFCR developments, which indicates a strong political interest to come up with PEF requirements under ESPR

4 Recommendations and Outlook

Since its very beginnings in the 1960s, the LCA method has evolved into a well-established and widely accepted tool for measuring the environmental impacts of products (Owsianiak et al., 2018). It is an essential tool for policymakers to guide sustainable design decisions in the marketplace. Many industries have embraced the idea of using LCA methods throughout product development cycles, working constantly to refine processes and identify areas where sustainability efforts will have the greatest impact. Although a scientific consensus and standards have emerged on the fundamentals of LCA, practitioners in the field of ICT equipment are still faced with a variety of choices and uncertainties that lead to inconsistencies and ambiguities. Product Category Rules (PCR) can help to fill existing methodological gaps and provide guidance to carry out consistent and comparable LCA studies. The following recommendations are part of the PCR initiative led by Fraunhofer IZM and should point to the next steps in this process:

- **Step 1**: Secure sponsorship for further PCR development coordination or putting in place other means of coordinating the process
- **Step 2:** Detailed analysis and comparison of existing standards and PCRs as basis for further methodological discussions (to ensure maximum compatibility and re-use of best practice approaches)
- **Step 3:** Organize a working platform with relevant stakeholders
    - Reconfirming goals of PCF advancements
    - Clarifying methodological considerations (see Section 3.1)
    - Clarifying organizational considerations (see Section 3.2)
    - Reach a consensus with a critical mass of at least 75% of the market to move forward on an agreed path
    - Agreement on how methodological developments complement and/or support PAIA evolution

As stated in previous chapters, there is currently a clear preference for single-criteria impact assessments (i.e., carbon footprints) and streamlined approaches in the market. Therefore, we are not considering initiating a PCR process under the EPD system, as it requires multicriteria impact assessment and extensive documentation of individual studies, which is currently not compatible with more streamlined and simplified approaches. In terms of flexibility, we recommend starting the PCR process independently of an existing standard development organization (SDO) to create a sectoral guideline (Option 2a, Section 3.2) that can still be transitioned into more formalized standards programs later on. In this sense, going for a sectoral guideline would not mean stranded investments in case later on decisions are made to change over to another standardization framework. In any case agreements made under a sectoral guideline can be incorporated by OEMs in internal methodology guidelines, thus also serving the purpose of better harmonization of LCA approaches. Our preliminary analysis has shown that many OEMs are not yet fully aware of the standardization landscape and therefore are hesitant to comply with specific standards. Institutional flexibility is therefore key to ensure maximum stakeholder buy-in.

The PAIA effort will launch a series of working groups by component in the beginning of January 2023 to outline best practices on modeling and data for carbon footprinting efforts covering modules such as integrated circuits, printed wiring boards, transportation, use phase and displays among others. These working groups will provide templates and guidance for the current state of footprinting

modeling by component and identify approaches for regular data updating and assumptions clarification. This effort can be collaborative with step 4 described here and the modeling outputs can be integrated into the efforts pursued here.

- **Step 4:** Setup a working group (WG) and technical committee (TC)
    - Define relevant working areas, such as
        - data acquisition on key components with key suppliers and development of parameterised data models (PAIA effort aligned with activities and interests of OEMs and initiatives outside the PAIA consortium)
            - sub-groups on identified key components, potentially implemented consecutively according to a defined priority list; candidates for such a priority list are CPU, GPU, memory, storage, printed circuit boards as these are relevant for both, end-user devices and enterprise equipment; further candidates, but with relevance for mobile end-user devices only are displays and batteries
        - use phase modelling (PAIA effort aligned with activities and interests of OEMs and initiatives outside the PAIA consortium)
            - sub-groups on end-user devices and, when in scope, enterprise equipment
        - liaison with other industry activities (iNEMI eco-impact estimator project phase 4, if relevant; working groups under the Semiconductor Climate Consortium[15]; consideration of advanced LCA approaches by providers of commercial solutions[16])
        - liaison with policy developments (EPEAT criteria development, SEC reporting requirements, EU PEF, EU DPP, EU Green Claims, China PCF policy developments)
        - implementation of further working areas as needed

- **Step 5:** Compile a methodology paper covering all major elements of a PCR/PSR (Sector guideline)
    - Tentative goal: Compatibility with the PAIA approach and approaches of OEMs not involved in PAIA developments
    - This step is followed by a joint decision, whether the sector guideline shall be advanced towards a standard or PCR or kept as-is with regular maintenance cycles to improve data quality continuously

The overall implementation of the roadmap is illustrated in Figure 3, based on the assumption that consensus is reached to move forward with a sector guideline. In case right from the beginning a formal PCR or standard process is backed by OEMs representing a significant market share, the timeline to reach a final document is extended, but work on the methodology also regarding component modelling can advance in parallel as outlined in the roadmap. It is expected that substantial progress

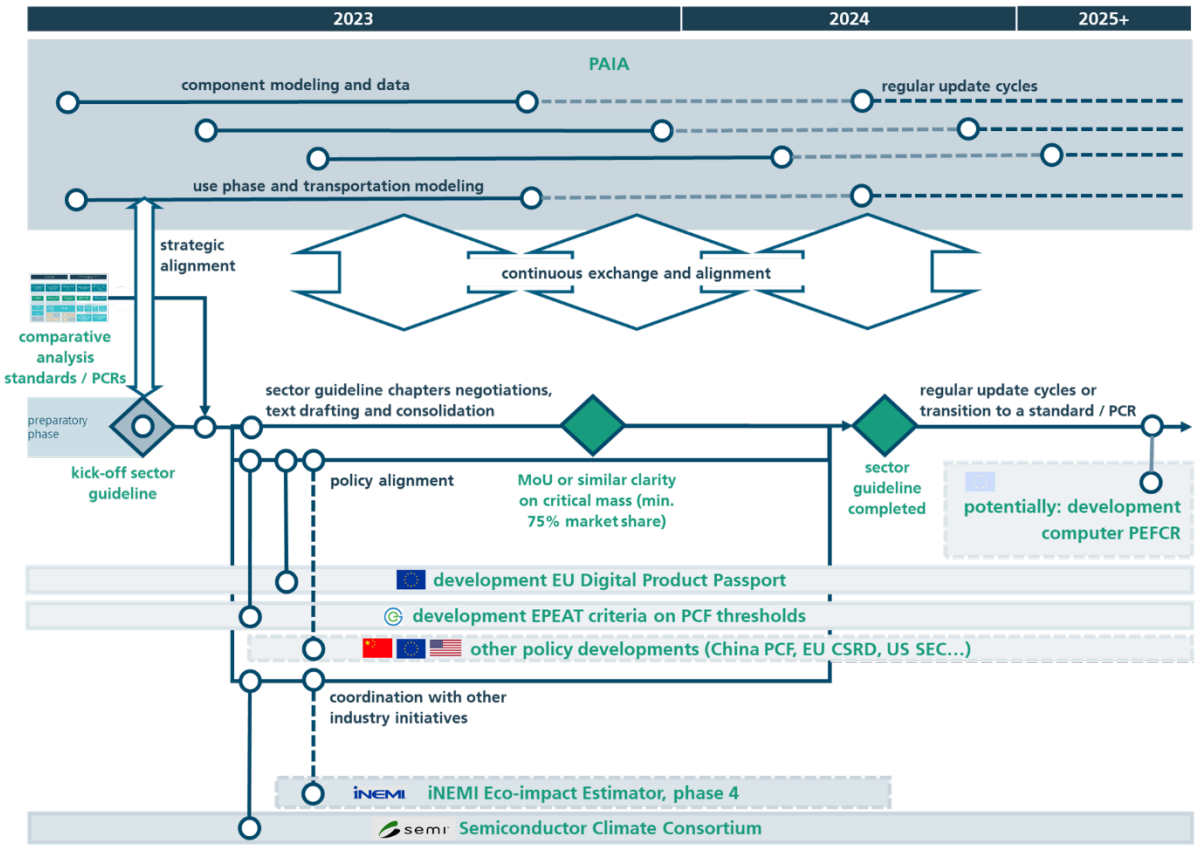
[15] https://www.semi.org/en/industry-groups/semiconductor-climate-consortium

[16] explicitly: Sphera, Makersite

can be achieved in 2023. A final version of the sector guideline is expected to be completed in early 2024.

Given that the aforementioned candidates for priority components (hardware related hot spots) are supplied by a limited number of enterprises, which are also in the process of implementing climate policies and will target at climate neutrality regarding their scope 1 and scope 2 emissions in the mid-term future, the data acquisition and modelling should consider also the scope 3, i.e. the multitude of supplied materials to these key component manufacturers as over time focus of climate related measures has to involve these suppliers and materials as well.

Figure 3: Proposed PCR roadmap



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6 Appendix

A1: LCA and PCR standards and guidelines for the ICT sector

Name	Description	Link
EN ISO 14040	Description of framework and principles for LCA	ISO 14040
EN ISO 14044	Specifies requirements and guidelines for LCA	ISO 14044
ISO 14020	Framework for Environmental statements and programmes for products, which establishes principles and general requirement for four types of product related environmental statements: • Self-declared environmental claim (ISO 14021) • Ecolabel (ISO 14024) • Environmental product declaration (ISO 14025) • Footprint communication (ISO 14026)	ISO 14020
ILCD Guidelines/ handbook	The International Reference Life Cycle Data System (ILCD) is an initiative developed by the European Commission since 2005, with the aim to provide guidance and standards for greater consistency and quality assurance in applying LCA.	ILCD Guides
Product Environmental Footprint (PEF) (EC 2013/179/EU)	The PEF method was initiated by the European Commission to harmonize the existing LCA standards and to allow comparability of product LCAs. Between 2013 and 2019, the European Commission carried out a pilot phase for 26 product categories. The development phase is now entering a transitional phase, where the PEF will be implemented on a large scale, which will determine the further developments.	EC 2013/179/EU
Environmental Product Declaration (EPD) (EN ISO 14025)	An EPD is a standardized way of communicating environmental information of a product, based on LCAs and additional product information. They are verified and published by an international network of EPD program operators (view).	EN ISO 14025

Product Carbon Footprint (EN ISO 14067)	Specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product ● Reporting of carbon footprint only (single criteria)	ISO 14067
Communication of Footprint Information (ISO 14026)	Provides principles, requirements and guidelines for footprint communications for products. The standard focuses on the communication and reporting of footprints and does not address the quantification.	ISO 14026
GHG Product Standard (GHG Protocol)	The Product Lifecycle Accounting and Reporting Standard by the GHG Protocol (referred to as the Product Standard) provides requirements and guidance for companies and other organizations to quantify and publicly report an inventory of GHG emissions and removals associated with a specific product. It is based on LCA and provides additional specifications to report GHG inventories at the product level.	GHG Product Standard
PEFCR Guide (EC 2018, v6.3)	PEFCRs are product category rules that complement the general PEF method by providing further specifications at the level of a specific product category. To date, 26 PEFCR exist as pilot studies including IT storage devices and batteries (view).	EC 2018, v6.13
Development of PCR (ISO/TS 14027)	Provides principles, requirements and guidelines for developing, reviewing, registering and updating PCR within the EPD framework.	ISO/TS 14027
PEP Ecopassport (PCR-Edition 4)	The PEP ecopassport is an EPD program with a particular focus on EPDs for electrical and electronic equipment. Product Environmental Profiles (PEP) are compliant to EPD according to ISO 14025, EN15804 and EN50693.	PEP-PCR-ed4
GPCRD Guidance (EPA/Pré 2013, 1.0)	The guidance aims to provide additional instructions for developing PCRs for product LCAs with the goal of making PCRs more consistent and reducing the need to duplicate PCRs for compliance with multiple standards.	GPCRD Guidance

Pathfinder Framework (WBCSD)	The framework aims to provide guidance for the consistent calculation and simple exchange of verified Product Carbon Footprints (PCFs) between stakeholders across value chains to improve the overall Scope 3 reporting in the market. The framework and accompanying pathfinder network were set up by the WBSCD, which was one of the co-convenor of the GHG protocol.	Pathfinder Framework
PCR for Building Products (EN 15804 & ISO 21930)	Both standards are product category rules that provide the principles, specifications and requirements to develop an environmental product declaration (EPD) for construction products and services, some of which include electrical equipment. ● EN 15804 and ISO 21930 are equivalent in technical content	EN 15804 ISO 21930
PCR for Electronic Equipment and Services (EN 50693)	PCR that provides the principles, specifications and requirements to develop an environmental product declaration (EPD) for electronic equipment and services.	EN 50693
ICT Sector Guidance (GHG Protocol)	Provides guidance and accounting methods for the calculation of GHG emissions for ICT products with a focus on ICT services.	ICT Sector Guidance
Method for LCA of ICT (ETSI 203 199) and (ITU-T L.1410	Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services ● Sector guidelines by ETSI and ITU are equivalent in technical content	ETSI 203 199 ITU-T L.1410
Sustainability Standards (IEEE 1680)	Series of standards for the environmental assessment of the performance of electronic equipment 1. 1680.1 – Standard for the environmental and social responsibility assessment of computers, tablets and monitors. 2. 1680.2 – Standard for the environmental assessment of Imaging Equipment	IEEE 1680.1 IEEE 1680.2 IEEE 1680.3

	(printers, copiers, scanners, fax machines, multifunction devices) 3. 1680.3 – Standard for the environmental assessment of television	
Quantification methodology for greenhouse gas emissions for computers and monitors (IEC TR 62921)	The standard provides specific guidance for the use of streamlining techniques that minimize cost and resources needed to complete greenhouse gas emissions quantifications. ● PAIA meets IEC TR 62921 requirements	IEC TR 62921