GLOBAL ELECTRONICS COUNCIL

Sustainability for a Connected Future

EPEAT – ULCS – 2023

Criteria for the Assessment of Ultra-Low Carbon Solar Modules

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Foreword

The Global Electronics Council (GEC) is a mission driven non-profit working to create a more sustainable and just world, focused on supporting institutional purchasers in procuring only credible sustainable and circular technology products and services. GEC owns and operates EPEAT™, a comprehensive voluntary sustainability ecolabel. GEC ecolabel criteria address priority impacts throughout the life cycle of the product, based on an evaluation of scientific evidence and international best practices.

Criteria are developed in balanced, voluntary consensus processes consistent with:

- ISO 14024 *Environmental labels and declarations – Type 1 environmental labelling – Principles and procedures*[1], and
- U.S. Executive Office of the President, Office of Management and Budget, OMB Circular A-119: *Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities*[2].

A summary of GEC's Criteria Development Process (P74) and procedures governing the process are publicly available on the EPEAT Registry (https://www.epeat.net/). Public stakeholder consultation occurs throughout the criteria development process. Stakeholder comments on criteria are considered by the Technical Committee as part of the Voluntary Consensus Process. Detailed policies for the EPEAT Program and criteria implementation are available in the EPEAT Policy Manual, also found on the EPEAT Registry (https://www.epeat.net/). The EPEAT Program may issue temporary policy addenda to this document, EPEAT Policy Manual (P65), to address unforeseeable and extraordinary circumstances that are beyond the control of manufacturers. Such circumstances include but are not limited to natural disasters, acts of war or terrorism, significant labor strikes, devastating accidents to a supplier facility, epidemics, or pandemics.

These Ultra-Low Carbon Solar (ULCS) Criteria were developed with funding from the Ultra Low-Carbon Solar Alliance (ULCSA) and GEC. Anthesis LLC provided technical support and managed the criteria development process, in alignment with GEC's criteria development process. On the following page is a list of stakeholders participating on the Technical Committee and Expert Ad Hoc Group.

[1] Available at: https://www.iso.org
[2] Available at: https://www.whitehouse.gov/wp-content/uploads/2020/07/revised_circular_a-119_as_of_1_22.pdf

Participants

The following stakeholders were members of the Technical Committee:

Annick Anctil, Michigan State University
Carsten Rohr, NorSun
Dustin Mulvaney, San Jose State University
France Jonathan, PINK by Solystyce
Garvin Heath, National Renewable Energy Laboratory (NREL)
Holly Elwood, U.S. Environmental Protection Agency (EPA)
James Higham, Scatec
Jen Snook, Clean Energy Buyers Institute (CEBI)
Lindsay Cherry, Hanwha Q CELLS America Inc.
Lisa Booth, Dominion Energy
Lucas Weiss, Voltec Solar
Parikhit (Ricky) Sinha, First Solar
Rob Steeman, CubicPV
Steve Heim, Boston Common Asset
Steven Holty, Hemlock Semiconductor Operations LLC (HSC)
Trude Nysæter, REC Solar Norway
Wolfgang Storm, Wacker Chemie AG

Stakeholders from the following organizations participated in criteria drafting as participants in the Expert Ad Hoc Group:

Clean Energy Buyers Institute (CEBI)
CubicPV
First Solar
Global Electronics Council
Hanwha Q CELLS America Inc.
Hemlock Semiconductor Operations LLC
Michigan State University
National Renewable Energy Laboratory
NorSun
REC Solar Norway
The Fraunhofer Society
U.S. Environmental Protection Agency
Wacker Chemie AG

1.0 Purpose

The purpose of the Ultra-Low Carbon Solar (ULCS) Criteria (herein referred to as "Criteria") is to establish a framework, standardized methodology, and performance objectives to incentivize manufacturers and suppliers to design and manufacture low embodied carbon photovoltaic (PV) modules. For purchasers, these Criteria provide a consensus-based definition of low-embodied carbon to aid in identifying and procuring low embodied carbon PV modules. These Criteria are used within EPEAT™, a global Type 1 ecolabel that helps purchasers identify and select sustainable electronic products and provides market recognition for conforming products.

The ULCS Criteria are developed based on the principle that manufacture and procurement of low-embodied carbon solar PV modules are critical for achieving net-zero emissions. These Criteria will be continually maintained and periodically reviewed to ensure that the definition of low embodied carbon solar progresses with the evolution of technology and services and sustainability/environmental improvements in the product sector.

The ULCS Criteria are expected to be reviewed two years after initial publication to determine if updates are necessary. All elements of the criteria will be considered. After the initial revision, the Criteria are expected to be considered for review as per the general EPEAT Criteria revision schedule.

1.1 Product Scope

The Ultra-Low Carbon Solar Criteria are based on the Life Cycle Inventory (LCI) completed by the International Energy Agency's Technology Collaboration Programme on Photovoltaic Power Systems (PVPS) Task 12: PV Sustainability. To maintain alignment with this LCI, the specific scope of these Criteria includes the Standard Value table approach ("Path A", as further defined in section 4 and Annex A) and the Additional LCA Data approach ("Path B") for the following module technologies.

- Crystalline silicon-based PV, including mono- and multi-crystalline silicon
- Thin-film PV based on Cadmium telluride (CdTe)

Other module technologies can also be considered using these Criteria but will depend substantially on the Path B Additional LCA Data approach.

1.2 ULCS Criteria in EPEAT Ecolabel

The EPEAT ecolabel addresses multiple sustainability issues, including climate change, sustainable use of resources, chemicals of concern and supply chain due diligence. These ULCS Criteria are added to the requirements for PV modules to achieve the EPEAT ecolabel. To be awarded the EPEAT ecolabel, PV module manufacturers must conform to these ULCS Criteria and the EPEAT Criteria in *NSF 457 – Sustainability Leadership Standard for Photovoltaic Modules and Photovoltaic Inverters*.[3]

EPEAT is a tiered ecolabel designed to recognize the top 25 - 30% of the market. EPEAT Criteria are identified as either Required or Optional. Required Criteria must be met for a product to become EPEAT-registered (Bronze). Depending on the number of Optional Criteria met, a product may achieve an EPEAT rating of Silver or Gold.

[3] https://globalelectronicscouncil.org/wp-content/uploads/NSF-457-2019-1.pdf

Products recognized as Silver must meet over 50% of total available optional points, while products achieving Gold recognition must meet over 75% of total available optional points.

Products that meet EPEAT Criteria are identified in the public facing website called the EPEAT Registry. Before becoming EPEAT-registered, an independent GEC-approved Conformity Assurance Body (CAB) must confirm the product's conformance with EPEAT Criteria, which are identified in the Verification Requirements of each criterion.

2.0 Normative References

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. European Union Directives, which contain the adoption date in their title, are not treated as "dated references" (as described above). Unless explicitly indicated otherwise, when a European Union Directive is referenced in this document, a new or updated European Union Directive shall apply upon its enforcement date unless otherwise noted in the criteria.

Ecoinvent[4]

IEC 61215 Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements[5] -- Requirements for the design qualification of terrestrial photovoltaic modules suitable for long-term operation in open-air climates.

IEC 61730 Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction[6]

International Energy Agency, PVPS Task 12 – Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems, and Guidelines on Life Cycle Assessment of Photovoltaic Electricity[7]

International Accreditation Forum (IAF) Multilateral Arrangement (MLA)[8]

IPCC2013-GWP100a method[9]

ISO 14067 Greenhouse gases — Carbon footprint of products[10]

ISO 14040 Environmental management — Life cycle assessment — Principles and framework[11]

ISO 14044 Environmental management — Life cycle assessment — Requirements and guidelines[12]

[4] www.ecoinvent.org
[5] https://webstore.iec.ch/publication/61345
[6] https://webstore.iec.ch/publication/25674
[7] https://iea-pvps.org/wp-content/uploads/2020/12/IEA-PVPS-LCI-report-2020.pdf
[8] https://iaf.nu/en/about-iaf-mla/
[9] https://www.ipcc.ch/2013/01/30/ipcc-publishes-full-report-climate-change-2013-the-physical-science-basis/
[10] https://www.iso.org/standard/71206.html
[11] https://www.iso.org/standard/37456.html
[12] https://www.iso.org/standard/38498.html

ISO/IEC 17020 Conformity assessment – Requirements for the operation of various types of bodies performing inspection[13]

ISO/IEC 17021-1 Conformity assessment – Requirements for bodies providing audit and certification of management systems

ISO 17025 General requirements for the competence of testing and calibration laboratories[14]

ISO/IEC 17065 Conformity assessment – Requirements for bodies certifying products, processes and services[15]

3.0 Definitions & Acronyms

3.1 Definitions

Manufacturer[16]: Refers to any natural, legal person or entity who:

- manufactures a product, or
- has a product designed or manufactured, or
- places a brand label on a ready-made product; and
- places it on the market under their own name or trademark.

Process steps: The subsequent manufacturing processes required to produce a multi-process manufactured product. In the case of silicon PV modules, the process steps include the production of metallurgical-grade silicon, production of solar-grade silicon, production of ingot (including bricking and pulling), wafering, cell manufacture and module manufacture.

Product data sheet: A technical data sheet from a PV module manufacturer that details performance specifications including module size, design power output and performance warranty.

Renewable electricity: electricity generated from renewable sources that meet the definition of such sources under the RE 100 Technical Criteria[17].

Supplier: Entity that provides goods or services, usually in context of an end-product manufacturers supply-chain.

3.2 Acronyms

CAB: Conformity Assurance Body

CdTe: cadmium-telluride

[13] https://www.iso.org/standard/52994.html
[14] https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html
[15] https://www.iso.org/standard/46568.html
[16] For the purposes of the ULCS Criteria, 'Manufacturer' refers to the company making the PV module registered to EPEAT, not any separate company supplying components into that PV module
[17] https://www.there100.org/sites/re100/files/2022-10/20221024_RE100%20technical%20criteria%2Bappendices.pdf

CIS/CIGS: copper-indium-selenide / copper-indium-gallium-selenide

c-Si: crystalline silicon

EAC: Energy Attribute Certificate

EPD: environmental product declaration

ESL: estimated service life

FU: functional unit

GWP: global warming potential

HJT: heterojunction technology

IEA: International Energy Agency

ISO: International Organization for Standardization

kWp: kilowatt peak

LCA: life cycle assessment

LCI: life cycle inventory

LCIA: life cycle impact assessment

Micro-Si: micromorphous silicon

Mono-Si: monocrystalline silicon

Multi-Si: multicrystalline silicon

PCR: product category rules

PV: photovoltaic

PVPS: Photovoltaic Power Systems (in context of the IEA)

RSL: reference service life

Si: silicon

SoG-Si: solar grade silicon

ULCS: ultra-low carbon solar

VCF: Verified Carbon Footprint

Wp: watt-peak

4.0 Criteria

4.1 Required – Low Carbon Solar

The embodied carbon of the PV module, including the frame[18], shall be equal to or less than 630 kg CO_2e / kWp.

The manufacturer shall calculate the embodied carbon of the PV module, including the frame, using the Verified Carbon Footprint (VCF) method detailed in Annex A. The VCF can be calculated using either Path A, which utilizes standard data tables for carbon contribution coefficients, or Path B, which allows for supplier specific Life Cycle Assessment (LCA) data to be used to calculate carbon contribution coefficients.

Only national-level location-based electricity emission factors, as defined in Annex A section A2.3 and shown in Table 3, are allowed in the VCF calculation for this criterion.

Manufacturer shall have the VCF verified by an independent third-party(ies) as per the requirements below for Path A and Path B.

The VCF shall be valid for one year after issue, after which time the manufacturer shall submit revised supporting data to the independent third-party(ies) to ensure the VCF is still valid. Upon request, the manufacturer shall be able to provide a revised verification statement(s) and supporting documentation, as per the verification requirements, from the independent third-party(ies). The independent third-party(ies) is subject to audit within twelve months of completion of each verification.

If the photovoltaic module is based on technologies other than crystalline Silicon and CdTe thin film, independent third-party verification must also include verification of comparable life span and reliability (e.g., 25-year lifespan during which it demonstrates no more than 20% performance degradation).

Independent third-party verification for Path A:

Manufacturer shall have the VCF and accompanying Table 1 in Annex A verified by an independent third-party that is accredited to ISO/IEC 17020, ISO/IEC 17021, ISO/IEC 17025 or ISO/IEC 17065. For ISO/IEC 17020, ISO/IEC 17021, or ISO/IEC 17065, accreditation shall be issued by an accreditation body that is a signatory to the International Accreditation Forum (IAF) Multilateral Arrangement (MLA). For ISO/IEC 17025, accreditation shall be issued by an accreditation body that is a signatory to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA). The independent third-party must also demonstrate prior experience in the PV industry.

The independent third-party shall verify the following information in Table 1 from Annex A:

1) Process steps (Column 1) and quantities (Column 2).

    - Manufacturer shall provide a product data sheet, report from testing the PV module against IEC 61215 and IEC 61730, and a physical sample of the PV module.

[18] PV modules without frames can also be included in these criteria if they are designed and installed in a manner that never adds a frame.

- A laboratory analysis of a physical example of a whole PV module meeting all requirements to make it suitable for sale must be performed to determine that the density and dimensions of components match those specified in the material product data sheet and IEC 61215 / IEC 61730 test report(s).Laboratory analysis shall be performed by a laboratory that is accredited to ISO 17025 with the accreditation issued by an accreditation body that is a signatory to the ILAC MRA.

2) Process steps (Column 1) from each manufacturing site (Columns 3 and 4) used to produce the number of PV modules required to produce 1 kWp of generating capacity as identified in Table 1.

    - For each manufacturing site identified in Table 1, manufacturer shall provide the supplier's name and contact details (name and email address), a list of orders made from each site over the timeframe used to develop the VCF, and the amount delivered by the site over the timeframe used to develop the VCF.

    - Verification shall confirm the quantities of materials used in the process steps by review of additional supporting documentation (e.g., invoices, purchase orders, delivery receipts).

    - Verification shall confirm that the quantities of materials used in the process steps (Column 1) conform with expectations based on losses and breakages shown in Table 2, by review of additional supporting documentation as per the examples above, and, at the discretion of the independent third-party, interviews with suppliers.

3) Process steps (Column 1) and the location of each manufacturing site (Columns 3 and 4).

    - Manufacturer shall provide a facility inspection report for each supplier manufacturing site identified in Table 1. Each facility inspection report shall be performed during the VCF valid period or up to 1 year prior to the start of the VCF valid period and identify at a minimum:

        - Name and employer of the independent facility inspector,

        - Date of inspection,

        - Manufacturing site address,

        - Manufacturing site layout diagram, and

        - Product type for the relevant process steps (i.e., Column 1 in Table 1).

    - Verification shall confirm that each facility inspection was conducted within the previous twelve months by an independent inspector, and that the facility is performing activities necessary for the process steps identified for that site.

4) Use of correct Global Warming Potential (GWP) contribution coefficients (Column 5), taken from Table 3 in Annex B, for each process step (Column 1).

5) Calculations used to determine GWP value (Column 6) for each process step and for the overall GWP for the PV module, including the frame.

A manufacturer can create an alternative GWP coefficient from Path A values that represents more than one process step in Table 1, i.e., it can represent a "cradle-to-gate" value for the preceding process steps in Table 1. Such an alternative coefficient must be verified by the Designated Expert (see LCA REVIEW STEP 2 below) who will issue a verification statement that the alternative GWP coefficient has met the requirements and can be used for calculation within the criteria.

The independent third-party verifier must issue a summary certificate (called a Verified Carbon Footprint or VCF) that summarizes the information listed above including the final Path A VCF value.

Independent third-party verification for Path B:

Manufacturer shall meet the requirements identified above for Path A for those aspects of the VCF calculated using GWP contribution coefficients taken from Table 3 in Annex B, for the calculations used to determine the GWP value for each process step and for the calculation to determine the overall embodied carbon for the PV module, including the frame.

For those aspects of the VCF calculated using alternative GWP contribution coefficients resulting from an LCA, the LCA shall have been conducted within the previous three years and been verified via the two review steps listed below.

The independent third-party verifier must issue a summary certificate (called a Verified Carbon Footprint or VCF) that summarizes the information listed above including the final Path A VCF value and Path B VCF value.

For Path B, the summary certificate must also verify that the following two review steps for the LCA have been completed:

LCA REVIEW STEP 1 – Critical Review

The LCA shall have been the subject of an independent critical review assuring conformance to the requirements listed in Section A2.3, including specific additions and exceptions. The critical review shall be conducted in accordance with the requirements of ISO 14044, ISO 14067 and NPCR 029 2021, and performed by an individual or organization meeting the requirements of ISO 14044 Section 7.3.2.

LCA REVIEW STEP 2 – Review of Alternative Coefficient by GEC Designated Expert

GEC will designate one or more Designated Experts to verify proposed alternative GWP coefficients. To qualify, a Designated Expert must have at least 10 years experience in conducting and/or reviewing technical LCAs and experience in engineering processes related to PV module manufacturing. A Designated Expert shall be independent of individuals and organizations calculating the alternative GWP contribution coefficient.

For each GWP contribution coefficient resulting from an LCA, the supplier or manufacturer shall have the underlying LCA data and resulting alternative GWP contribution coefficient verified by a GEC Designated Expert. The Designated Expert shall verify the following:

1) The LCA has addressed the specific requirements of Section A2.3.

2) The LCA data for process steps with GWP contribution coefficients resulting from an LCA (Column 1 in Table 1) from each manufacturing site (Columns 3 and 4 in Table 1) used to produce the GWP contribution coefficient are accurate, with special attention to records provided demonstrating that the aluminum frame is modelled with appropriate assumptions (e.g., correct secondary datasets applied based on actual aluminum supply).

3) Verification shall confirm that energy assignment methods (e.g., total site consumption, total site production) meet the requirements of Section A2.3, with special attention to how electricity usage is assigned to production at a manufacturing site level and evenly distributed across the entire electricity use of the named site.

4) Verification shall confirm that the LCA representing production of silicon ingot includes the pulling, bricking or squaring, and scrap recycling processes, with no reduction of solar-grade polysilicon demand due to scrap recycling.

5) If the LCA and resulting GWP contribution coefficient includes self-generated renewable electricity from generation assets owned by the reporting entity (e.g., manufacturer and/or supplier), verification that the Energy Attribute Certificates (EACs) are tracked and redeemed, retired or cancelled by or on behalf of the reporting entity, and are not sold to any entity other than the reporting entity.

An alternative GWP coefficient can represent more than one process step in Table 1, i.e., it can represent a "cradle-to-gate" value for the preceding process steps in Table 1, if all unit processes represented in the LCA are modelled with data specific to the product, rather than values referenced from LCA databases.

Upon completion of the review, the GEC Designated Expert will issue a verification statement that the alternative GWP coefficient has met the requirements and can be used for calculation within the criteria.

Verification requirements:

a) A VCF that shows the embodied carbon of the photovoltaic module, including the frame, meets the criterion threshold for the time period of module production covered by the EPEAT registration.

b) For Path A:

   i. Verification statement from the independent third-party that is dated and identifies successful validation of items (1) through (5) for Path A, as per the criterion.

   ii. Supporting data summary document from the independent third-party that identifies all documents and records submitted by the manufacturer and reviewed for verification, any interviews conducted with suppliers, and results from analysis of the physical sample of the photovoltaic module.

   iii. Completed Table 1 as per Annex A.

   iv. Accreditation certificate(s) for the independent third-party that performed the verification.

c) For Path B:

i. For use of GWP contribution coefficients taken from Table 3 in Annex B (Standard Value Table), verification requirements identified above for Path A.

ii. For each GWP contribution coefficient resulting from an LCA:

a. Summary of the LCA including at a minimum, the key LCA inputs and calculations[19], the input and output masses and energies including sources for all process steps, and the methods and rationale for allocating energy.

b. Copy of the independent critical review of the LCA identifying at a minimum, name of the critical reviewer, date of the review, results of the review, and the standard(s) against which the review was performed (i.e., ISO 14044 and/or ISO 14067, and inclusion of NPCR 029 2021).

c. Contact information, credentials and qualifications of the party conducting the independent critical review of the LCA (e.g., number of years' experience in the field of LCA and carbon footprinting, number of LCAs or carbon footprints reviewed, number of LCAs or carbon footprints conducted).

d. Verification statement from the GEC Designated Expert that is dated and identifies successful verification of items (1) through (5) for Path B, as per the criterion.

e. Supporting data summary document from the independent third-party that identifies all documents and records submitted by the manufacturer and reviewed for verification and any interviews conducted with suppliers.

f. Completed Table 1 as per Annex A.

4.2 Optional – Ultra Low Carbon Solar

The embodied carbon of the PV module, including the frame, shall be equal to or less than 400 kg CO_2e / kWp.

The manufacturer shall calculate the embodied carbon of the PV module, including the frame, using the Verified Carbon Footprint (VCF) method detailed in Annex A. The VCF can be calculated using either Path A, which utilizes standard data tables, or Path B, which allows for customization of LCA data.

Manufacturer shall meet all requirements outlined in Criterion 4.1, except that location-based (either National-level in Table 3 or Sub-National level in Table 4) or market-based electricity emission factors, as defined in Annex A section A2., are allowed in the VCF calculation for Criterion 4.2 - Ultra Low Carbon Solar (ULCS).

Point value: 4 points

Verification requirements:

a) All verification requirements from Section 4.1 must be satisfied.

[19] See IEA PVPS Task 12 LCA Guidelines for additional guidance

b) A VCF that shows the embodied carbon of the PV module, including the frame, meets the criterion threshold.

c) If electricity emission factors from sub-national locations are used, the location of the facilities consuming electricity must be verified as per the facility inspection report, as defined in part (3) of "Independent third-party verification for Path A".

d) If the LCA and resulting GWP contribution coefficient includes renewable electricity purchases that produced EACs, verification of the following:

   i. The LCA quantified energy consumption for relevant manufacturing sites.

   ii. The EACs have been retained, retired or cancelled on behalf of the reporting entity and for the benefit of the relevant manufacturing sites. Verification shall include review of the contractual instruments or ownership/retirement documentation indicating the financially responsible counterparty.

   iii. The EACs meet the requirements of RE 100 Credibility Claims (RE100). Verification shall include review of documentation that shows participation in RE100 or independent verification that the EACs meet the requirements of RE100 or ISO 14067.

   iv. The contractual agreement that provides qualifying EACs is for the full time-period of the ULCS VCF certification.

   v. Adjustments to electricity emission factors via renewable electricity purchases is limited to 25% across the cradle-to-gate product life cycle (i.e., including energies from each required process step)[20].

   vi. Assignment of qualifying EACs is transparently communicated on the VCF certificate and on the program operator website, including the unique tracking number, electricity amount, and time basis.

4.3 Optional – Publicly Available LCI Data in IEA PVPS Task 12 Format

Primary life cycle inventory data underlying alternative GWP_{ij} coefficients (e.g., those generated for Path B) shall be publicly available in the IEA PVPS Task 12 Life Cycle Inventory format.

Point value: 1 point

Verification requirements:

a) Internet address (URL) for Life Cycle Inventory data in the format defined by IEA PVPS Task 12.[21]

[20] Use of purchased renewable electricity emission factors limited to protect against misrepresentation. This limit will be reviewed for potential change during each review of the criteria as required in Section 1.

[21] LCI format is defined in the 2020 LCI report (https://iea-pvps.org/wp-content/uploads/2020/12/IEA-PVPS-LCI-report-2020.pdf) and may be updated by GEC and/or PVPS Task 12 in the future.

Annex A (Normative): Verified Carbon Footprint Method

To minimize burden to PV manufacturers and build on existing methodologies, the Verified Carbon Footprint (VCF) method is based on the French national government specification for solar and wind power facility tenders ("Cahier des charges de l'appel d'offres portant sur la réalisation et l'exploitation d'Installations de production d'électricité à partir de l'énergie solaire - AO PPE2PV Sol," referred to in this document as "French Tender"). Changes made from the French Tender process are intended to ensure global applicability of the ULCS Criteria.

The VCF can be calculated in one of two ways: Path A and Path B.

- Path A implements the VCF Method using Standard Value Tables that provide the Global Warming Potential (GWP) contribution coefficients based on standard values. This methodology is intended to be simpler to calculate but likely to be more conservative and/or less accurate for a specific module producer because it is based on market average LCA studies, and primarily dependent upon verified production locations for the PV supply chain.
- Path B builds on the Path A approach and allows manufacturers to include supplier specific data. Manufacturers can substitute GWP contribution coefficients for specific process steps that are derived from supplier-specific LCA data. Path B requires additional verification steps to ensure comparability of LCA results.

The following sections provide an overview of the VCF method (Section A1) and a detailed explanation of how to calculate the VCF (Section A2).

A1. Method Overview

The VCF method determines embodied carbon based solely on the greenhouse gas (GHG) emissions assessment related to the manufacturing process of the framed[22] PV module. Any GHG emissions related to balance of system components of the PV system (e.g., racks, cables, inverters including micro-inverters) are not considered - only the module and frame (if a frame is used) is to be considered. The embodied carbon footprint boundaries and calculation approach is based on the IEA PVPS Task 12 LCI from 2020.[23]

For crystalline silicon products, the following process steps or components including transportation are included:

- Production of basic silicon

[23]R. Frischknecht, P. Stolz, L. Krebs, M. de Wild-Scholten, P. Sinha, V. Fthenakis, H. C. Kim, M. Raugei, M. Stucki, 2020, "*Life Cycle Inventories and Life Cycle Assessment of Photovoltaic Systems*", International Energy Agency (IEA) PVPS Task 12, Report T12-19:2020. Available online from: https://iea-pvps.org/wp-content/uploads/2020/12/IEA-PVPS-LCI-report-2020.pdf. Thermal energy inputs for solar grade silicon are taken from the IEA PVPS Task 12 LCI update from 2022, available online from: https://iea-pvps.org/fact-sheets/fact-sheet-environmental-life-cycle-assessment-of-electricity-from-pv-systems-2022-update/.

    - Metallurgical-grade silicon (Task 12 LCI Table 6)
    - Solar-grade polycrystalline silicon or polysilicon including transportation (Task 12 LCI Table 7-8)
- Production of crystalline silicon ingot (ingot as brick, inclusive of pulling, bricking or squaring, and recycling of scrap)
    - Mono-crystalline silicon ingot (Task 12 LCI Table 9)
    - Multi-crystalline silicon ingot (Task 12 LCI Table 10)
- Production of the silicon wafer including transportation (Task 12 LCI Table 12-14)
- Production of the photovoltaic cell, laminate and aluminum framed modules
    - Cell including transportation (Task 12 LCI Table 16-18)
    - Laminate and aluminum framed modules including transportation (Task 12 LCI Table 19-25)

For thin film products, the VCF is based on a single integrated unit process including CdTe photovoltaic cell, laminate, and framed module production.

The GHG emissions from other stages of the life cycle of the solar PV module are not considered (e.g., transportation to site, commissioning and operation, installation, use, end of life). It is therefore limited to the assessment of GHG emissions related to the production of the module, the process equipment, buildings and utilities (excluding administrative and R&D). Energy used for manufacturing and operating buildings and utilities equipment is considered in the calculation of emissions.

The VCF method is a summary of individual PV module components that are calculated via standard tables, or a combination of standard tables and LCA calculated values. Mathematically, the method applies the following Equation 1:

$$G = \sum_{module\ components} G_i \qquad \textit{(Equation 1)}$$

Wherein:

- G is obtained by the addition of G_i, representing the values of GHG emissions of each component i of a PV module per kilowatt-peak (kWp).
- G_i is expressed in the same unit as G (kWp). Each G_i is obtained by Equation 2.

$$G_i \left[\frac{kgCO_2}{kW_p}\right] = \sum_j (GWP_{ij} \times X_{ij}) \times Q_i \qquad \textit{(Equation 2)}$$

Wherein:

- G [kg CO_2e / kWp] represents the amount of GHG emissions generated during the manufacture of one kWp.

- Q_i represents the amount of component i (in units defined in column 2 of Table 1) required for the manufacture of a PV module kWp, including losses and breakages.
- X_{ij}, is used only when the module components are manufactured in multiple locations. It is unitless and represents the proportion of the total mass of module component manufactured for each manufacturing site j of the i component (as determined in step 2 below). This coefficient is averaged over a year's supply from the most recent fiscal year.
- GWP_{ij} expressed in kg CO_2e, represents the global warming potential impact associated with the manufacture of component i per unit of production for that process step (e.g., m^2 for the module) in the j manufacturing site. This value is either determined by geographic location of manufacture (Path A) or via LCA derived values (Path B), in which case it may be referred to as an 'alternative GWP coefficient'.

A2. Calculating the Verified Carbon Footprint

Calculation of the VCF requires access to materials and energy information across the PV module supply chain, as depicted in Figure 1 and Table 1, and described in the sections below.

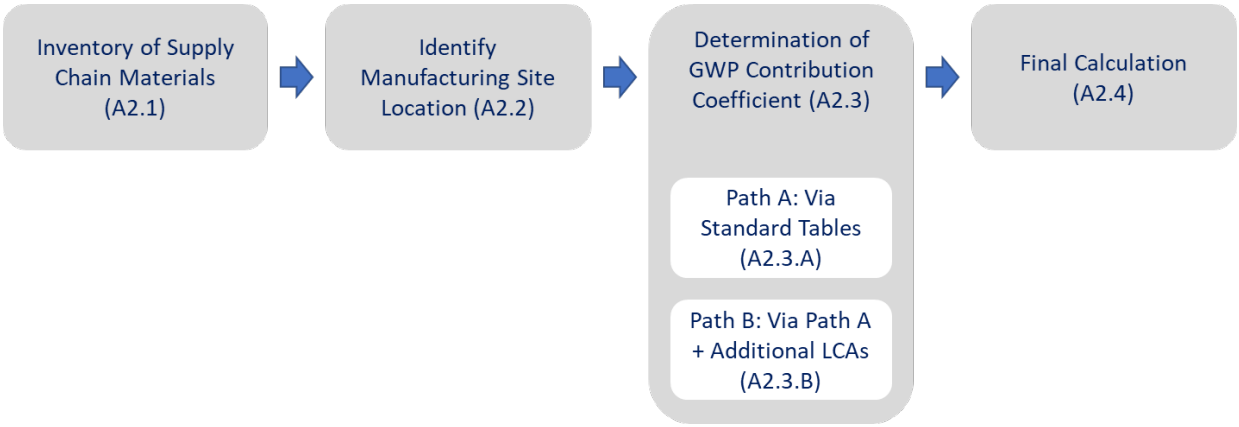

Figure 1. The process required for calculating the VCF

A2.1 Inventory of Supply Chain Materials

Calculation of the VCF for a PV module requires identification and quantification of the subsidiary components normalized to a one kilowatt-peak functional unit. The coefficients in Table 2 are applied relative to the amount of materials and components needed to manufacture each subsidiary component, and to account for losses and breakage during module manufacturing processes.

The process steps to be included for silicon PV modules are as follows:

1) Metallurgical-grade Silicon (in kg). This value is adjusted to the weight of silicon required for the production of one module kWp. Values shall incorporate losses and breakages.

2) Solar-grade Silicon or polysilicon (in kg). This value is adjusted to the weight of silicon required to produce one module kWp. Values shall incorporate losses and breakages.

3) Ingots of Silicon (in kg). Ingots within the IEA PVPS Task 12 LCI are inclusive of the pulling, bricking or squaring, and recycling of scrap processes. This value is adjusted to the weight of silicon required for the manufacture of one module kWp. Values shall incorporate losses and breakages.

4) Wafers (in number of wafers). This amount is adjusted to the number of wafers required for 1 kWp. Values shall incorporate losses and breakages.

5) Cells (in number cell). This value is the number of cells needed to produce 1kWp. Values shall incorporate losses and breakages.

6) Framed Modules (in m2 of modules). This value is the unit area required to produce 1 kWp electricity. A product with no frame can be included in this calculation if it is designed to be installed without a frame.

A2.2 Identify Manufacturing Site Location

The calculation of the VCF requires knowledge of the manufacturing site location for each PV module component, allowing the calculation of GHG emissions that vary by geographic electricity grid emissions. If one component (i) come from different manufacturing sites (j), the proportion of the total module component manufactured for each manufacturing site (x_{ij}) (averaged over a year's supply) must be indicated in column 6 of Table 1. (For each component i, the sum over j of x_{ij} equals 1.) The site and each component manufacturing location are required to be reported in Table 1.

A2.3 Determination of GWP Contribution Coefficient

Module component GWP contribution (GWP_{ij} units from Formula 2 above) may be determined using two approaches referenced as Path A and Path B.

A2.3.A – Path A - Calculation Method via Standard Value Tables

GWP_{ij} units are determined using the contribution coefficient values provided in Annex B (Normative): Table 3, which shows the carbon emission coefficients for the manufacturing steps for each type of PV module component depending on the country of manufacture. The values in Annex B (Normative): Table 3 are calculated based on the IEA PVPS Task 12 LCI and ecoinvent 3.8 electricity emission factors.

If manufacturing country is known, verifiable and shown in the table, the value of specific emission of CO_2e of the corresponding column should be used. If manufacturing country is known but is not listed in Annex B (Normative): Table 3, a conservative specific emission value in the world will be used (i.e., row "Others" in Table 3).

For VCF calculations at the Section 4.1 LCS threshold, national-level locations must be used.

A2.3.B – Path B - Calculation Method via Additional LCA Data

Path B shall be applied in the case where the process step manufacturer would like the value of GWP_{ij} associated with a specific manufacturing step to be different from those shown in Annex B (Normative): Table 3 based on independent LCA results. VCF calculations using Path B must adhere to the following requirements:

1) The new value used for the process step(s) must be from a recent LCA, conducted within the previous twenty-four (24) months.
2) The LCA must also have been the subject of an independent critical review according to the requirements of ISO 14040, ISO 14044, ISO 14067 and NPCR 029 2021 (with specific additions or exceptions listed in this section).
3) The resulting alternative GWP coefficient must also be verified by a GEC Designated Expert.
4) The LCA report must detail
    a. origin of data,
    b. time periods of inventories,
    c. detailed description including locations of the flow of materials and energy,
    d. assumptions concerning material, energy and environmental inputs and outputs,
    e. the Life Cycle Impact Assessment methods applied to calculate GWP, and
    f. other applicable requirements from the Reporting & Communication section of the IEA PVPS Task 12 LCA Guidelines.
5) Any use of self-generated renewable electricity from generation assets owned by the reporting entity must include supporting evidence that Energy Attribute Certificates (EACs) are not sold to any entity other than the reporting entity, i.e., the EACs are tracked and redeemed, retired or cancelled by or on behalf of the reporting entity.
6) The LCA representing production of silicon ingot must include the pulling, bricking or squaring, and scrap recycling processes, with no reduction of solar-grade polysilicon demand due to scrap or kerf recycling.

A2.3.B.1 – Requirements for Electricity Emission Factors within Path B Life-cycle Assessments

For VCFs pursuing section 4.1, Low Carbon Solar:

1) Path B life-cycle assessments must apply electricity emission factors[24] that are location-based (at a national level via Table 3).

[24] Emission factors from sources such as Ecoinvent should be contrasted from "contribution coefficients" listed in Tables 3 and 4, which are used within the context and assumptions of Path A and the values aggregated in Table 1.

2) Emission factors must be from Ecoinvent 3.8 or later and calculated using IPCC2013-GWP100a method or later.

For VCFs pursuing section 4.2, Ultra Low Carbon Solar:

1) Path B life-cycle assessments can apply electricity emission factors that are location-based (at a national or sub-national level), or emission factors that are accounting for renewable electricity purchases (i.e., market-based factors) within the limitations listed below.

2) Adjustments to electricity emission factors via renewable electricity purchases is limited to 25% across the cradle-to-gate life cycle, i.e., up to 25% of the cradle-to-gate life cycle GWP from electricity consumption is calculated via the purchased renewable electricity emission factor, with the remainder of electricity usage GWP is calculated based on the appropriate national or sub-national location-based emission factor. Purchased renewable electricity emission factors should consider upstream life cycle impacts (i.e., should be cradle-to-gate).

3) Renewable electricity purchases through market-based mechanisms must satisfy section 6.4.9.4.4 of ISO 14067. Renewable electricity purchases must apply contractual instruments that result in Environmental Attribute Certificates (EACs). The EACs from the contractual instrument shall (adopted from ISO 14067):

    a. convey the information associated with the unit of electricity delivered together with the characteristics of the generator,

    b. be assured with a unique claim,

    c. be tracked and redeemed, retired or cancelled by or on behalf of the reporting entity,

    d. be generated as close as possible to the reporting period to which the contractual instrument is applied,

    e. be produced within the country, or within the market boundary where consumption occurs if the grid is interconnected[25].

4) Additionally, the EACs must:

    a. meet RE100's Technical Criteria[26], which aligns with ISO 14067 and provides greater specificity for credible claims,

    b. be tied to a contractual agreement that provides qualifying EACs for the full time-period of the ULCS VCF certification whose vintage falls within a 21-months of the reporting period as referenced in part 5.iv above,

    c. be exclusively and equitably assigned at a manufacturing site level and evenly distributed across the entire electricity use of the named site. That is, EACs cannot be assigned preferentially to a

[25] See Appendix B in the RE 100 Technical Criteria for additional guidance on market boundaries
[26] https://www.there100.org/sites/re100/files/2021-08/RE100%20Technical%20Criteria%20Aug%202021.pdf

specific site or to a sub-set of a site's production.

5) If available in the manufacturing site region, use of leadership certification programs such as Green-E to demonstrate retirement of EACs on behalf of the reporting entity is encouraged.

6) Assignment of qualifying EACs must be transparently communicated on the VCF certificate and on the program operator website, including the unique tracking number for the EAC, number of EACs purchased, and the temporal alignment of the EACs to the manufacturer's consumption.

7) The VCF must include results from all methods applied: from Path A, from Path B (if it is applied), and from Path B with adjustments for renewable electricity purchases (if it is applied).

A2.4 Final Calculation of GWP

The final calculation of G is done through the addition of G_i for all i components of the module via Table 1.

Table 1. Summation Method for Calculating the Verified Carbon Footprint of PV Modules

Column 1 Process Step[27]	Column 2 Quantity used to quantify amounts for 1 kWp	Column 3 Supplier Name[28] and Site of Manufacture (Address)	Column 4 Manufacturing Country	Column 5 GWP contribution coefficients (from Table 3)	Column 6 GWP_{ij} value (Column 2 * Column 5)
Si Module Steps					
Silicon Metallurgical-grade Silicon	kg kg (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)
Silicon Solar-grade	kg kg (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)
Mono-Si Ingot	kg kg (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)
Multi-Si Ingot	kg kg (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)
Si Wafers [designate mono- or multi-]	kg kg (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)
Si PV Cells [designate mono- or multi-]	m^2 m^2 (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)
Si PV Modules (with frame) [designate mono- or multi-]	m^2 m^2 (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)
CdTe PV Module step					
CdTe PV Modules (with frame)	m^2 m^2 (...)	Site 1: Site 2: (...)	Country 1: Country 2: (...)	$X_{11:}$ X_{12} (...)	kg CO_2e kg CO_2e (...)

[27] Process steps can be aggregated if completed at a single location

[28] Manufacturer may be their own supplier, in which case indicate as such.

Table 2. Coefficients of losses and breakages for intermediates (From IEA PVPS Task 12 LCI, Table 11 and Table 15)

	unit	mono-Si	multi-Si
Gross silicon demand	g	15	16
Length	mm	158.75	158.75
Width	mm	158.75	158.75
Area	cm^2	252	252
Thickness	µm	170	180
Kerf loss	µm	65	65
Additional losses [1])	µm	20.5	27.5
Silicon content	g/m^2	**396.1**	**419.4**
Silicon losses	g/m^2	**199.1**	**215.5**
Total silicon demand	g/m^2	**595.2**	**634.9**
Electricity demand	kWh/m^2	4.92	5.69
Diamond wire demand [2])	m/m^2	52.6	52.2
Diamond wire demand [3])	g/m^2	1.56	1.55
Water demand	litre	57.4	56.9

	unit	mono-Si	multi-Si
Wafer area	cm^2	252	252
Wafer weight	kg/m^2	0.396	0.419
Wafer thickness	µm	170	180
Cell weight	kg/m^2	0.470	0.498
Electricity demand	kWh/m^2	17.7	17.7
Metallization paste, front	g/m^2	3.37	3.37
Metallization paste, back	g/m^2	1.11	1.11
Metallization paste, back, Al	g/m^2	57.2	56.8
Silver demand	g/m^2	3.70	3.67
Aluminium demand	g/m^2	46.2	45.9

Annex B (Normative): Table 3 — Standard National Values for GWP Contribution Coefficients

The values in Table 3 represent the Global Warming Potential (GWP) Contribution Coefficients (in kg CO_2-eq per reference flow unit) as calculated per Annex A, based on the IEA PVPS Task 12 Life Cycle Inventory (2020) for life cycle stage material & energy flows, and Ecoinvent 3.8 for location-based cradle-to-gate electricity emission factors (which uses IPCC2013 GWP100a v1.02 impact assessment methods).

	Silicon Metallurgic Grade	Silicon Solar Grade	Mono-Si Ingot	Multi-Si Ingot	Mono-Si Wafer	Multi-Si Wafer	Mono-Si PV Cell	Multi-Si PV Cell	Mono-Si PV Module (w frame)	Multi-Si PV Module (w frame)	CdTe PV Module (w frame)
Reference Flow	Kg	kg	kg	kg	m2	m2	m2	m2	m2	m2	m2
Albania	10.495	18.044	11.464	1.548	3.128	3.283	7.958	8.940	39.543	39.543	44.814
Armenia	11.963	17.367	15.736	2.482	3.771	4.025	10.321	11.303	42.323	42.325	36.285
Australia	19.534	51.092	37.760	7.300	7.047	7.852	22.503	23.485	51.958	51.960	61.244
Austria	12.488	23.057	17.261	2.816	3.990	4.290	11.165	12.147	42.080	42.080	42.789
Azerbaijan	15.231	31.921	25.240	4.562	5.185	5.677	15.578	16.560	46.481	46.483	48.320
Bahrain	14.726	29.672	23.771	4.240	4.966	5.421	14.765	15.748	45.838	45.840	46.145
Bangladesh	17.547	42.239	31.978	6.036	6.187	6.847	19.305	20.287	49.429	49.431	51.435
Belarus	15.917	31.683	27.237	4.998	5.474	6.024	16.682	17.664	46.444	46.444	52.612
Belgium	11.784	21.287	15.215	2.369	3.686	3.935	10.032	11.015	41.184	41.184	36.552
Bosnia and Herzegovina	18.346	37.793	34.303	6.544	6.525	7.251	20.591	21.573	49.536	49.536	18.346
Brazil	11.370	12.160	14.010	2.105	3.506	3.725	9.366	10.348	41.568	41.569	37.668
Brunei Darussalam	15.839	34.633	27.011	4.949	5.448	5.984	16.557	17.540	47.256	47.258	49.205
Bulgaria	14.919	29.173	24.335	4.364	5.042	5.519	15.077	16.059	45.174	45.174	49.352
Cambodia	14.995	30.870	24.554	4.412	5.083	5.557	15.198	16.181	46.181	46.183	53.587
Canada	11.103	11.256	13.232	1.935	3.391	3.590	8.936	9.918	41.227	41.229	30.916
China	20.193	54.025	39.675	7.719	7.324	8.185	23.562	24.544	52.776	52.798	62.649
Croatia	14.174	27.299	22.167	3.889	4.720	5.143	13.878	14.860	44.226	44.226	44.282
Cyprus	20.026	42.019	39.190	7.613	7.252	8.100	23.294	24.276	51.674	51.674	62.222
Czechia	18.459	38.077	34.631	6.616	6.574	7.308	20.772	21.755	49.679	49.679	61.411
Denmark	11.980	21.780	15.784	2.493	3.770	4.034	10.347	11.330	41.433	41.433	39.158
Estonia	18.509	38.202	34.776	6.648	6.595	7.334	20.853	21.835	49.743	49.743	59.312
Finland	11.768	21.246	15.167	2.358	3.678	3.926	10.006	10.988	41.163	41.163	38.711

	Silicon Metallurgic Grade	Silicon Solar Grade	Mono-Si Ingot	Multi-Si Ingot	Mono-Si Wafer	Multi-Si Wafer	Mono-Si PV Cell	Multi-Si PV Cell	Mono-Si PV Module (w frame)	Multi-Si PV Module (w frame)	CdTe PV Module (w frame)
France	9.810	16.320	9.470	1.112	2.831	2.937	6.855	7.837	38.671	38.671	34.543
Georgia	10.254	17.437	10.761	1.394	3.023	3.161	7.569	8.552	39.236	39.236	10.254
Germany	15.081	29.579	24.804	4.466	5.112	5.601	15.337	16.319	45.38	45.38	51.393
Gibraltar	19.242	40.046	36.909	7.114	6.913	7.704	22.032	23.015	50.676	50.676	59.695
Greece	17.672	36.097	32.341	6.115	6.233	6.911	19.506	20.488	48.677	48.677	59.075
Hong Kong	18.107	44.736	33.609	6.392	6.430	7.131	20.207	21.189	50.142	50.144	59.837
Hungary	13.778	26.303	21.016	3.638	4.548	4.943	13.241	14.223	43.722	43.722	43.407
Iceland	9.494	15.525	8.551	0.911	2.694	2.777	6.347	7.329	38.269	38.269	30.128
India	24.161	71.703	51.220	10.245	9.049	10.191	29.948	30.930	57.847	57.849	73.738
Indonesia	21.366	59.254	43.090	8.466	7.840	8.778	25.451	26.433	54.290	54.292	65.875
Iran (Islamic Republic of)	16.110	35.837	27.797	5.121	5.565	6.121	16.992	17.974	47.600	47.601	49.898
Iraq	19.321	50.142	37.139	7.165	6.955	7.744	22.160	23.142	51.687	51.689	61.325
Ireland	13.295	25.088	19.610	3.330	4.339	4.698	12.463	13.446	43.107	43.107	46.614
Israel	16.703	38.480	29.523	5.499	5.822	6.421	17.947	18.929	48.355	48.357	55.738
Italy	13.308	25.120	19.647	3.338	4.345	4.705	12.484	13.466	43.123	43.123	46.430
Japan	16.291	36.645	28.325	5.236	5.644	6.213	17.284	18.266	47.830	47.832	55.812
Jordan	14.856	30.252	24.150	4.323	5.023	5.487	14.975	15.957	46.004	46.006	47.427
Kazakhstan	19.967	53.020	39.019	7.576	7.234	8.071	23.199	24.181	52.509	52.511	61.320
Korea, Democratic People's Republic of	11.006	13.102	12.950	1.873	3.357	3.541	8.780	9.762	41.104	41.106	36.264
Korea, Republic of	16.606	38.050	29.243	5.437	5.780	6.372	17.792	18.774	48.232	48.234	51.399
Kosovo	23.441	50.610	49.126	9.787	8.730	9.827	28.790	29.772	56.020	56.020	72.981
Kuwait	17.339	41.313	31.374	5.903	6.097	6.742	18.970	19.953	49.164	49.166	56.505
Kyrgyzstan	10.125	17.114	10.388	1.313	2.968	3.096	7.363	8.345	39.073	39.073	32.274
Latvia	14.965	29.287	24.466	4.392	5.062	5.542	15.150	16.132	45.232	45.232	42.347
Lebanon	19.441	50.678	37.489	7.241	7.007	7.805	22.353	23.335	51.840	51.842	59.951
Lithuania	14.140	27.212	22.066	3.867	4.705	5.125	13.822	14.805	44.182	44.182	41.880
Luxembourg	14.319	27.664	22.589	3.982	4.783	5.216	14.112	15.094	44.411	44.411	49.418
Malaysia	18.094	44.675	33.569	6.384	6.424	7.124	20.185	21.167	50.125	50.127	55.440
Malta	13.488	25.571	20.169	3.452	4.423	4.796	12.773	13.755	43.352	43.352	44.885

	Silicon Metallurgic Grade	Silicon Solar Grade	Mono-Si Ingot	Multi-Si Ingot	Mono-Si Wafer	Multi-Si Wafer	Mono-Si PV Cell	Multi-Si PV Cell	Mono-Si PV Module (w frame)	Multi-Si PV Module (w frame)	CdTe PV Module (w frame)
Mexico	15.187	25.069	25.114	4.534	5.158	5.655	15.508	16.490	46.426	46.428	51.039
Moldova, Republic of	15.353	30.265	25.597	4.640	5.230	5.739	15.775	16.758	45.727	45.727	47.991
Mongolia	22.350	63.634	45.951	9.092	8.266	9.275	27.033	28.016	55.542	55.544	69.095
Montenegro	15.585	30.847	26.271	4.787	5.330	5.856	16.148	17.130	46.021	46.021	69.095
Myanmar	11.952	17.317	15.703	2.475	3.766	4.020	10.303	11.285	42.308	42.310	37.701
Nepal	14.552	28.898	23.266	4.130	4.891	5.334	14.486	15.468	45.617	45.619	45.570
Netherlands	15.374	30.317	25.657	4.653	5.239	5.749	15.809	16.791	45.753	45.753	51.323
New Zealand	10.144	9.260	10.441	1.324	2.984	3.105	7.392	8.374	40.006	40.008	51.323
North Macedonia	17.720	36.218	32.482	6.146	6.254	6.935	19.584	20.566	48.739	48.739	59.132
Norway	9.185	14.749	7.653	0.714	2.561	2.621	5.850	6.832	37.876	37.876	31.490
Oman	15.662	33.842	26.494	4.836	5.371	5.895	16.272	17.254	47.030	47.032	48.695
Pakistan	14.557	28.922	23.282	4.133	4.894	5.336	14.495	15.477	45.624	45.626	46.410
Philippines	17.090	40.203	30.648	5.745	5.989	6.616	18.569	19.552	48.847	48.849	52.510
Poland	19.891	41.679	38.797	7.527	7.194	8.032	23.077	24.059	51.502	51.502	61.264
Portugal	13.274	25.034	19.547	3.316	4.330	4.688	12.429	13.411	43.080	43.080	47.797
Qatar	14.658	29.372	23.575	4.197	4.937	5.387	14.657	15.639	45.753	45.754	45.953
Romania	13.633	25.938	20.593	3.545	4.486	4.869	13.008	13.990	43.537	43.537	43.780
Russia	16.797	33.896	29.796	5.558	5.855	6.468	18.098	19.080	47.564	47.564	52.219
Saudi Arabia	20.007	53.197	39.135	7.601	7.252	8.091	23.263	24.246	52.560	52.562	62.141
Serbia	18.736	38.774	35.438	6.792	6.694	7.449	21.219	22.201	50.032	50.032	60.446
Singapore	13.970	26.304	21.572	3.759	4.639	5.039	13.549	14.531	44.876	44.878	44.127
Slovakia	14.158	27.259	22.121	3.879	4.713	5.135	13.853	14.835	44.206	44.206	45.631
Slovenia	13.276	25.040	19.554	3.318	4.331	4.689	12.433	13.415	43.083	43.083	42.106
South Africa	20.830	56.864	41.529	8.125	7.608	8.507	24.588	25.570	53.608	53.609	37.668
Spain	12.430	22.912	17.094	2.780	3.965	4.261	11.072	12.054	42.006	42.006	43.762
Sri Lanka	15.634	33.718	26.413	4.818	5.359	5.881	16.227	17.209	46.994	46.996	53.274
Sweden	9.426	15.354	8.353	0.868	2.665	2.743	6.237	7.220	38.182	38.182	32.139
Switzerland	9.367	15.208	8.183	0.83	2.64	2.713	6.143	7.126	38.108	38.108	34.219
Syrian Arab Republic	16.709	38.508	29.542	5.503	5.825	6.424	17.957	18.939	48.363	48.365	51.954

	Silicon Metallurgic Grade	Silicon Solar Grade	Mono-Si Ingot	Multi-Si Ingot	Mono-Si Wafer	Multi-Si Wafer	Mono-Si PV Cell	Multi-Si PV Cell	Mono-Si PV Module (w frame)	Multi-Si PV Module (w frame)	CdTe PV Module (w frame)
Taiwan, Province of China	17.277	41.037	31.193	5.864	6.070	6.711	18.871	19.853	49.085	49.087	54.522
Tajikistan	10.179	17.249	10.545	1.347	2.991	3.123	7.450	8.432	39.141	39.141	31.163
Thailand	17.064	40.087	30.573	5.728	5.978	6.603	18.528	19.510	48.814	48.816	51.945
Turkey	15.823	34.558	26.962	4.938	5.441	5.976	16.530	17.513	47.234	47.236	48.464
Turkmenistan	16.765	38.756	29.704	5.538	5.849	6.452	18.047	19.029	48.434	48.436	52.404
Ukraine	14.799	28.870	23.983	4.287	4.990	5.458	14.883	15.865	45.021	45.021	45.869
United Arab Emirates	14.769	29.865	23.897	4.268	4.985	5.443	14.835	15.817	45.893	45.895	46.340
United Kingdom	12.342	22.689	16.836	2.723	3.927	4.216	10.929	11.911	41.894	41.894	42.575
United States of America	14.439	22.539	22.938	4.058	4.834	5.277	14.305	15.287	45.474	45.476	47.485
Uzbekistan	15.896	34.884	27.175	4.985	5.473	6.013	16.648	17.630	47.327	47.329	50.585
Viet Nam	15.127	31.460	24.939	4.496	5.140	5.624	15.411	16.393	46.349	46.351	43.239
Yemen	20.279	54.409	39.926	7.774	7.369	8.228	23.701	24.683	52.906	52.908	58.825
Others (if country is not present in table)	16.530	37.708	29.019	5.388	5.747	6.333	17.668	18.651	48.134	48.136	28.581

Annex C (Normative): Table 4 — Standard Sub-National Values for GWP Contribution Coefficients

The values in Table 4 represent the Global Warming Potential (GWP) Contribution Coefficients (in kg CO_2-eq per reference flow unit) as calculated per Annex A, based on the IEA PVPS Task 12 Life Cycle Inventory (2020) for life cycle stage material & energy flows, and Ecoinvent 3.8 for location-based cradle-to-gate electricity emission factors (which uses IPCC2013 GWP100a v1.02 impact assessment methods).

	Silicon Metallurgic Grade	Silicon Solar Grade	Mono-Si Ingot	Multi-Si Ingot	Mono-Si Wafer	Multi-Si Wafer	Mono-Si PV Cell	Multi-Si PV Cell	Mono-Si PV Module	Multi-Si PV Module	CdTe PV Module
Reference Flow	kg	kg	kg	kg	m2	m2	m2	m2	m2	m2	m2
Brazil, Mid-western grid	10.509	9.248	11.505	1.557	3.134	3.290	7.981	8.963	40.472	40.474	35.675
Brazil, North-eastern grid	13.018	17.733	18.804	3.154	4.220	4.558	12.018	13.000	43.665	43.667	43.596
Brazil, Northern grid	10.918	10.630	12.694	1.817	3.311	3.497	8.638	9.620	40.992	40.994	36.975
Brazil, South-eastern grid	11.311	11.960	13.838	2.067	3.481	3.696	9.271	10.253	41.493	41.494	38.177
Brazil, Southern grid	10.428	8.974	11.269	1.505	3.099	3.249	7.850	8.832	40.369	40.370	35.436
Canada, Alberta	17.782	33.845	32.663	6.185	6.281	6.966	19.684	20.666	49.729	49.730	59.563
Canada, British Columbia	10.229	8.301	10.691	1.379	3.013	3.149	7.530	8.512	40.116	40.117	34.197
Canada, Manitoba	9.658	6.370	9.029	1.015	2.765	2.860	6.611	7.593	39.389	39.390	33.372
Canada, New Brunswick	12.369	15.537	16.915	2.740	3.938	4.230	10.973	11.955	42.839	42.841	44.683
Canada, Newfoundland and Labrador	9.920	7.254	9.790	1.182	2.879	2.992	7.032	8.014	39.721	39.723	33.991
Canada, Northwest Territories	12.361	15.509	16.891	2.735	3.935	4.226	10.960	11.942	42.828	42.830	45.136
Canada, Nova Scotia	18.943	37.769	36.039	6.924	6.783	7.553	21.551	22.533	51.206	51.207	64.470
Canada, Nunavut	21.021	44.796	42.084	8.246	7.682	8.603	24.895	25.877	53.850	53.852	70.087
Canada, Ontario	9.728	6.605	9.232	1.060	2.796	2.895	6.723	7.705	39.477	39.479	33.441
Canada, Prince Edward Island	11.306	11.944	13.824	2.064	3.479	3.693	9.264	10.246	41.487	41.488	40.518
Canada, Québec	9.208	4.848	7.721	0.729	2.571	2.633	5.887	6.870	38.816	38.818	31.795
Canada, Saskatchewan	17.133	31.648	30.774	5.772	6.000	6.638	18.639	19.621	48.902	48.904	57.560

	Silicon Metallurgic Grade	Silicon Solar Grade	Mono-Si Ingot	Multi-Si Ingot	Mono-Si Wafer	Multi-Si Wafer	Mono-Si PV Cell	Multi-Si PV Cell	Mono-Si PV Module	Multi-Si PV Module	CdTe PV Module
Canada, Yukon Territory	10.665	9.775	11.959	1.656	3.201	3.369	8.232	9.214	40.670	40.672	34.914
China, Southern Power Grid	16.464	37.416	28.828	5.347	5.711	6.300	17.563	18.545	48.031	48.053	51.191
China, State Grid Corporation	20.536	55.555	40.675	7.938	7.473	8.358	24.115	25.097	53.213	53.235	63.511
India, Eastern grid	26.478	82.024	57.961	11.719	10.052	11.362	33.676	34.659	60.796	60.798	81.074
India, North-eastern grid	18.776	47.713	35.553	6.818	6.719	7.469	21.282	22.265	50.993	50.995	57.989
India, Northern grid	22.834	65.790	47.358	9.400	8.475	9.520	27.812	28.794	56.158	56.159	70.203
India, Southern grid	23.280	67.777	48.656	9.684	8.668	9.745	28.530	29.512	56.725	56.727	71.660
India, Western grid	25.101	75.890	53.954	10.843	9.456	10.666	31.460	32.443	59.043	59.045	77.040
US, Alaska Systems Coordinating Council	15.029	24.534	24.655	4.434	5.090	5.575	15.254	16.236	46.225	46.227	49.456
US, HICC (Hawaii)	18.428	36.028	34.542	6.596	6.560	7.293	20.723	21.705	50.550	50.552	61.592
US, Midwest Reliability Organization, US part only	15.288	25.408	25.406	4.598	5.201	5.705	15.669	16.652	46.553	46.555	53.730
US, Northeast Power Coordinating Council, US part only	11.220	11.651	13.572	2.009	3.441	3.649	9.124	10.106	41.376	41.378	38.704
US, ReliabilityFirst Corporation	14.865	23.979	24.177	4.329	5.019	5.492	14.990	15.972	46.016	46.017	51.201
US, SERC Reliability Corporation	14.900	24.097	24.278	4.351	5.034	5.510	15.046	16.028	46.060	46.062	51.424
US, Texas Regional Entity	14.384	22.352	22.777	4.023	4.810	5.249	14.215	15.198	45.403	45.405	49.331
US, Western Electricity Coordinating Council, US part only	13.595	19.683	20.481	3.521	4.469	4.850	12.945	13.928	44.399	44.401	45.430

Annex D (Informative): Electricity CO2e Emission Factors used for Tables 3 and 4

Region	EF	Region	EF	Region	EF	Region	EF	Region	EF	Region	EF
Albania	0.141	Canada	0.197	Georgia	0.119	Korea, Dem. People's Rep.	0.188	Pakistan	0.511	Ukraine	0.533
Armenia	0.275	Canada - Alberta	0.804	Germany	0.558	Korea, Republic of	0.697	Philippines	0.741	United Arab Emirates	0.530
Australia	0.963	Canada - British Columbia	0.117	Gibraltar	0.937	Kosovo	1.318	Poland	0.996	United Kingdom	0.309
Austria	0.323	Canada - Manitoba	0.065	Greece	0.794	Kuwait	0.764	Portugal	0.394	USA	0.500
Azerbaijan	0.572	Canada - New Brunswick	0.312	Hong Kong	0.833	Kyrgyzstan	0.108	Qatar	0.520	USA - ASCC	0.554
Bahrain	0.526	Canada – Nfld. & Labr.	0.089	Hungary	0.440	Latvia	0.548	Romania	0.427	USA - HICC	0.863
Bangladesh	0.782	Canada - NW Territories	0.311	Iceland	0.050	Lebanon	0.955	Russia	0.714	USA - MRO, US part only	0.577
Belarus	0.634	Canada - Nova Scotia	0.909	India	1.384	Lithuania	0.473	Saudi Arabia	1.006	USA - NPCC, US part only	0.207
Belgium	0.259	Canada - Nunavut	1.098	India - Eastern grid	1.594	Luxembourg	0.489	Serbia	0.891	USA -Reliability First Corp	0.539
Bosnia and Herzegovina	0.855	Canada - Ontario	0.072	India - NE grid	0.894	Malaysia	0.832	Singapore	0.457	USA - SERC Reliability Corp	0.542
Brazil	0.221	Canada - P.E. Island	0.215	India - Northern grid	1.263	Malta	0.413	Slovakia	0.474	USA - Texas Regional Entity	0.495
Brazil - Midwest grid	0.143	Canada - Québec	0.024	India - Southern grid	1.304	Mexico	0.568	Slovenia	0.394	USA – WECC, US part only	0.423
Brazil - NE grid	0.371	Canada - Saskatchewan	0.745	India - Western grid	1.469	Moldova, Republic of	0.583	South Africa	1.081	Uzbekistan	0.632
Brazil - Northern grid	0.180	Canada - Yukon Territory	0.157	Indonesia	1.130	Mongolia	1.219	Spain	0.317	Viet Nam	0.562
Brazil - SE grid	0.216	China	1.023	Iran, Islamic Republic of	0.652	Montenegro	0.604	Sri Lanka	0.609	Yemen	1.031
Brazil – Southern grid	0.135	China - Southern Power Grid	0.684	Iraq	0.944	Myanmar	0.274	Sudan	0.434		
Brunei Darussalam	0.627	China - State Grid Corp	1.054	Ireland	0.396	Nepal	0.510	Sweden	0.044		
Bulgaria	0.544	Croatia	0.476	Israel	0.706	Netherlands	0.585	Switzerland	0.039		
Cambodia	0.550	Cyprus	1.008	Italy	0.397	New Zealand	0.109	Syrian Arab Republic	0.706		
		Czechia	0.865	Japan	0.668	North Macedonia	0.798	Taiwan, POC	0.758		
		Denmark	0.276	Jordan	0.538	Norway	0.022	Tajikistan	0.113		
		Estonia	0.870	Kazakhstan	1.002	Oman	0.611	Thailand	0.739		
		Finland	0.257					Turkey	0.626		
		France	0.079					Turkmenistan	0.711		

Annex E (Informative): Additional Reference Sources

While not explicitly cited elsewhere in this document, the following references are provided as informational guides for the application of this document.

Eco-labels and voluntary agreements recognized globally including:

- NSF 457 — Sustainability Leadership Standard for Photovoltaic Modules and Inverters
- EPEAT Ecolabel

Product Category Rulesets:

- EPD Italy — PCR for PV Panel: EPDItaly 014 – rel. 1
- European PCR — The International EPD System search database
- GHG Protocol Product Standard – Product Life Cycle Accounting and Reporting Standard to evaluate full lifecycle GHG emissions of a product
- IEC TR 62726:2014 Ed. 1.0 – Guidance on quantifying greenhouse gas emission reductions
- PEFCR — Products Environmental Footprint Category Rules
- PCR – Part B for a photovoltaic module used in the building and construction industry, – The Norwegian EPD Foundation NPCR 029 version 1.1
- UL PCR — Verify Environmental Product Declarations by using existing PCRs created by other program operators
- PEP Ecopassport PCR — PEP is an environmental identity card

IEA PVPS Task 12 LCA Guidelines – R. Frischknecht, G. Heath, M. Raugei, P. Sinha, M. de Wild-Scholten, V. Fthenakis, H. C. Kim, E. Alsema and M. Held, 2016, Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity, 3rd edition, IEA PVPS Task 12, International Energy Agency Photovoltaic Power Systems Programme. Report IEA-PVPS T12-06:2016, ISBN 978-3-906042-38-1.

RE100 Credibility Claims – J. Braslawsky, T. Jones and M. Sotos, 2016, Making credible renewable electricity usage claims, RE100 Technical Advisory Group.

RE100 Technical Guidance – A. Glumac, N. Fedson, J. Braslawsky, J. Critchfield, M. Ishida, T. Jones, D. Miller, and D. Riley, RE 100 Technical Criteria, RE100 Technical Advisory Group.

Document Change History

Issue	Revision	Owner	Description of Change	Approver	EPEAT Adoption Date	Publication Date
1	0	Vice President, Category and Criteria Development	Initial release	CEO	March 15, 2023	March 17, 2023