GLOBAL ELECTRONICS COUNCIL

Sustainability for a Connected Future

GEC – ULCS – 2021

Criterion for the Sustainability Assessment of Ultra-Low Carbon Solar Modules

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Draft for Technical Committee and public consultation

Prepared by Anthesis

GLOBAL ELECTRONICS COUNCIL
Sustainability for a Connected Future

Contents

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 criterion address priority impacts throughout the life cycle of the product, based on an evaluation of scientific evidence and international best practices, as presented in State of Sustainability Research for each criterion development process.

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 criterion development process and procedures governing the process are publicly available.[3]

GEC Criteria are owned by GEC and, unless noted otherwise, their use is limited to the tools and resources developed by GEC as part of its mission activities. All GEC Criteria are publicly available.

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[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
[3] Available at: https://globalelectronicscouncil.org/ecolabels/

Participants

The following stakeholders were members of the Technical Committee:

[once participation is finalized, insert alphabetical list by name and organization]

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

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

1.0 Purpose

The purpose of this ULCS Criterion (herein referred to as "Criterion") is to establish a framework and standardized methodology and performance objectives for manufacturers and the supply chain in the design and manufacture of photovoltaic (PV) modules. For purchasers, this Criterion provides a consensus-based definition of low-embodied carbon for procuring PV modules. This Criterion is used within EPEAT, an established system for the identification of sustainability / environmentally preferable products by purchasers, and to provide market recognition for conforming products and brand manufacturers.

The ULCS Criterion is developed based on the principle that low-embodied carbon in solar PV modules is critical for achieving net-zero emissions with renewable energy. This Criterion will be continually maintained and periodically reviewed to ensure that the definition of low embodied carbon solar, as reflected in the performance criterion, progresses with the evolution of technology and services and sustainability/environmental improvements in the product sector.

1.1 Scope

The scope of this criterion includes:

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

Embodied carbon calculations for crystalline silicon-based PV modules must include the following production unit processes based on IEA PVPS (2020) Task 12 LCI:

- Basic Silicon Products (3.2.4 from Task 12 LCI)
- Single and Multi-crystalline silicon (3.2.5 from Task 12 LCI)
- Silicon wafer production (3.2.6 from Task 12 LCI)
- Photovoltaic cell, laminate and panel production (3.2.7 from Task 12 LCI)

Embodied carbon calculations for thin-film-based PV modules must include the following production unit processes:

- Integrated CdTe photovoltaic cell, laminate, and panel production (3.3 from Task 12 LCI)

Other PV technologies, including copper indium gallium disselenide (CIGS) solar cells4 and tandem solar cells5, may be considered in future efforts. However, they are not the focus of the current ULCS criterion development.

Other module technologies can be considered in future versions the ULCS designation and/or via Path B specific LCAs.

[4] Mansfield, Lorelle (2021). "*Copper Indium Gallium Diselenide Solar Cells*." National Renewable Energy Laboratory. Photovoltaic Research: Materials Science. Retrieved February 28, 2021 from https://www.nrel.gov/pv/copper-indium-gallium-diselenide-solar-cells.html.

[5] Helmholtz-Zentrum Berlin für Materialien und Energie. (2020, April 14). Tandem solar cell world record. ScienceDaily. Retrieved February 28, 2021 from www.sciencedaily.com/releases/2020/04/200414122758.htm.

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 criterion.

Life Cycle Assessments (LCA) guidance focused on PV systems:

- IEA PVPS Task 12 – Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems
- IEA PVPS Methodology — Guidelines on Life Cycle Assessment of Photovoltaic Electricity
- ISO 14067 Greenhouse gases — Carbon footprint of products
- ISO 14040/44 Environmental management — Life cycle assessment

3.0 Definitions and Acronyms

3.1 Definitions

Declaration / declare: Information made publicly available on the EPEAT Registry.

Disclosure / disclose: Information made available to the audience specified in criterion (e.g., purchasers, public, etc.).

Category level: means that evidence provided to support conformance with the criterion shall be at the individual product category level. Manufacturers may indicate if the submitted evidence addresses multiple product categories.

Corporation level: means that evidence provided to support conformance with the criterion shall be at the organizational level and must address all product categories in which the manufacturer has EPEAT-registered products.

Manufacturer: refers to any natural, legal person or entity who:
- manufactures a product;
- 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.

Product level: means that evidence provided to support conformance with the criterion shall be for individual EPEAT-registered products.

Publicly available: Obtainable by the public without restriction of access; for example, cannot require member only access. A requirement to provide a name and, or organization to obtain access is not considered a "restriction of access".

Supplier: Entity that provides goods or services to the manufacturer.

3.2 Acronyms

CdTe	Cadmium-telluride
CIS / CIGS	Copper-indium-selenide / Copper-indium-gallium-selenide
c-Si	Crystalline silicon
DU	Declared unit
EAC	Energy Attribute Certificate
EPD	Environmental product declaration
ESL	Estimated service life
FU	Functional unit
HJT	Heterojunction technology
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
RSL	Reference service life
Si	Silicon
SoG-Si	Solar grade silicon
SOSR	State of Sustainability Research
VCP	Voluntary Consensus Process
Wp	Watt-peak

4.0 Ultra-Low Carbon Solar

4.1 Lifecycle GHG Emissions and Assessment

To conform with this criterion, the PVmodule shall have a Simplified Carbon Footprint that is less than 550 kgCO2e / kWp[6].

DISCUSSION POINT FOR TECHNICAL COMMITTEE & PUBLIC COMMENT	
DP1	Threshold for ULCS

The threshold of what defines ULCS is to be determined. The 550 kgCO2e/kWp listed above is referenced from the French Tender.

Options:

1. Align with French Tender (frameless)
2. Align with Korean threshold (with frame)
3. Calculate yearly (?) vintaged 'average' from market data e.g. IHS Markit data referenced in IEA LCI (section 3.2.2, page 23)
4. Reference product approach analogous to EU PEF

Additional discussion:

- A pilot / example of the complete (Path A & B) simplified GHG emission approach will help to develop consensus on approach and resulting threshold
- Pilot can likely be done in parallel with Technical Committee process and iterative based on options that the Technical Committee is considering
- An additional/alternative idea is to include an exact replication of the French Tender example calculation which would also illustrate alignment/differences between ULCS and French methods
- Note, a complete pilot is challenging due to likely confidentiality concerns
- Additional 'pilot' approach is to have additional consultants experienced with other methods (e.g., French) to review and comment

4.2 Simplified Carbon Footprint Process

Manufacturer shall calculate the Simplified Carbon Footprint via the method described in Annex A. The method is based on the IEA PVPS Task 12 from 2020 LCI.[7], with variations due to unit supplier-specific material and energy flows conforming with specific rules as per the Annex.

This method allows the Simplified Carbon Footprint to be calculated in one of two ways:

[6] Kilowatt Peak

[7] 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

Path A: Simplified Carbon Footprint Method via Standard Value Tables

This methodology is:

- Intended to be simpler to calculate but likely to be more conservative and/or less accurate for a specific module producer
- Based on the IEA PVPS Task 12 Life Cycle Inventory with standardized more specific location-based electricity carbon intensities

Path B: Simplified Carbon Footprint Method via Standard Values + Additional LCA Data

This methodology is:

- Based on Path A method with ability to substitute coefficients derived from supplier-specific Life Cycle Assessment data
- Based on existing relevant Product Category Rulesets as described in the Annex

4.3 Verification requirements

The Simplified Carbon Footprint assessment must be carried out according to Annex A by a certification body with an accreditation according to EN ISO 17025 and / or EN ISO 17065 and / or EN ISO 17021 for certification of photovoltaic modules, issued by the national accreditation authority. The certification body is subject to audit within twelve (12) months of assessment completion.

DISCUSSION POINT FOR TECHNICAL COMMITTEE & PUBLIC COMMENT	
DP2	Verification Requirements
The verification requirements listed in section 4.3 above are adapted from the French Tender process documentation and have not been discussed in detail by the Expert Ad Hoc Group to date. (Note: The requirements for assurance of Life Cycle Assessment results for Path B are not included here but rather are included in Annex A.)	

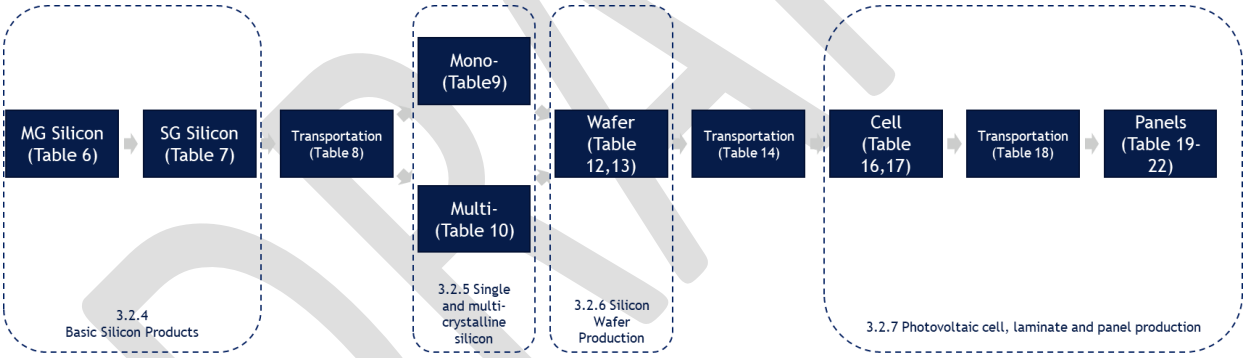
Annex A: Simplified Carbon Footprint Method

This 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*," or in this document "French Tender"). This method was developed with the intent to maintain as much similarity to the French Tender process as possible, to build on the strengths of the process, and minimize burdens on PV manufacturers. Changes to the process are largely to enable a global application of the logic inherent in the French Tender process.

A. Method Overview

The Simplified Carbon Footprint method evaluates embodied carbon based solely on the greenhouse gas (GHG) emissions assessment of the unframed[8] photovoltaic module. Any GHG emissions related to other components of the module are not considered. The embodied carbon footprint calculation is based on the IEA PVPS Task 12 LCI from 2020.[9]

For crystalline silicon products, the following production steps including upstream transportation are included:



- Production of basic silicon
  - Metallurgical-grade silicon (Task 12 LCI Table 6)
  - Solar-grade silicon (Task 12 LCI Table 7)
- Production of crystalline silicon
  - Mono-crystalline silicon (Task 12 LCI Table 9)
  - Multi-crystalline silicon (Task 12 LCI Table 10)
- Production of the silicon wafer (Task 12 LCI Table 12-13)
- Production of the photovoltaic cell, laminate and panel

[9]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

- Cell (Task 12 LCI Table 16-17)
- Transportation (Task 12 LCI Table 18)
- Panels (Task 12 LCI Table 19-22)
- Transportation (Task 12 LCI Table 23-25)

For thin film products, the Simplified Carbon Footprint is based on a single integrated unit process including CdTe photovoltaic cell, laminate, and panel 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 that is used for manufacturing and operating buildings and utilities equipment is considered in the calculation of emissions.

The Simplified Carbon Footprint method is a summary of individual PV module components that are calculated via standard tables, a combination of standard tables and LCA calculated values. Mathematically, the method is calculated using the following Formula 1:

$$G = \sum_{module\ components} G_i \qquad \text{(Formula 1)}$$

Wherein:

- G is obtained by the addition of Gi, representing the values of GHG emissions of each component i of a photovoltaic module on a kilowatt-peak (kWp).
- Gi is expressed in the same unit as G (kWp). Each Gi is obtained by Formula 2.

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

Wherein:

- G [kg CO2e / kWp] represents the amount of GHG emissions generated during the manufacture of one kWp.
- Qi represents the amount of component i required for the manufacture of a photovoltaic module kWp, including losses and breakages.
- Xij, is used only when the module components are manufactured in multiple locations. It is unitless and represents the distribution fraction of manufacturing sites j of the i component (as determined in step 2 below). This coefficient is averaged over a year of supply.
- GWPij expressed in kg CO2e, represents the specific emission associated with the manufacture of component i per component of the quantization unit (e.g., m² for the module) in the j manufacturing site (GWP = Global Warming Potential). This value is either determined by geographic location of manufacture (Path A) or via LCA derived values (Path B)

B. Calculating Carbon Footprint

Step 1: Inventory the amount of material required for the manufacture of the module or film

The first step of calculating the Simplified Carbon Footprint of the photovoltaic module is to identify and quantify the components necessary to manufacture one kilowatt peak photovoltaic module. We apply the coefficients in Table 2, relative to the amount of materials and components needed to manufacture the intermediate product, to account for losses and breakage during module manufacturing crystalline silicon technologies. The amount of each component required to manufacture in one kilowatt peak module, denoted Qi, is indicated in an own unit to the component:

- Metallurgical-grade Silicon (in kg). This value is adjusted to the weight of silicon required for the production of one module kWp. Losses and breakages will be considered.
- Solar-grade Silicon (in kg). This value is adjusted to the weight of silicon required to produce one module kWp. Losses and breakages will be considered.
- Ingots of Silicon (in kg). This value is adjusted to the weight of silicon required for the manufacture of one module kWp. Losses and breakages will be considered.
- Wafers (in number of wafers). This amount is reduced to the number of wafers required for 1 kWp. Losses and breakages will be considered. If appropriate, the contribution will be reduced to the actual surface of wafers (wafer reference 156 x 156 mm).
- Cells (in number cell). This value is the number of cells needed to 1kWp. Losses and breakages will be considered. If appropriate, the contribution will be reduced to the actual cell surface in m2 (reference wafer 156 x 156 mm but different wafer sizes can be adjusted to a per m2 basis).
- Modules (in m^2 of modules). This value is the unit area required to produce 1 kWp electricity.

Step 2: Identification of each component manufacturing sites

The calculation of the Simplified Carbon Assessment requires knowledge of the manufacturing site location for each photovoltaic module component, allowing the calculation of GHG emissions that vary by geographic electricity grid emissions.

The site and each component manufacturing countries are required to be reported in columns 4 and 5 of Table 1.

If one component i come from different manufacturing sites j, the distribution coefficients xij sources of supply on the various production sites (averaged over a year's supply) must be indicated in column 6 of Table 1 (for each component i, the sum over j of xij equals 1). [10]

[10] Final calculation guidance (i.e., which data goes in which column) TBD

Step 3: Determination of the GWP contribution (in kg CO2e) from the manufacture of module components.

Module component GWP contribution (GWPij units from Formula 2 above) may be determined in two unique ways.

Path A: Calculation Method via Standard Value Tables

GWPij units are determined using the values provided in Table 3 according to the methodology described in the paragraph below. Table 3 shows the GWP emission values for the manufacturing steps for each type of photovoltaic module component depending on the country or geographical area in the country of manufacture.

- If manufacturing country is known and shown in the table, the value of specific emission of CO2e of the corresponding column should be used;
- If manufacturing country is known and is not listed in Table 3: a conservative specific emission value in the world will be used (i.e., column "others[11]").

DISCUSSION POINT FOR TECHNICAL COMMITTEE & PUBLIC COMMENT	
DP3	Geographic level and source of electricity related emission factors

Emission factors must be from a single discrete third-party referenceable source that is as up to date as possible. Emission factors should be full cradle to gate (i.e., including Scope 3: Category 3 Fuel and Energy Related Activities related emissions). GWP calculated via IPCC2013 GWP100a v1.03 method

Expert Ad Hoc committee (EAH) has discussed two options for geographic level and source of electricity-related emission factors. EAH is not aligned on best choice for ULCS criterion method. Options and pros/cons listed below:

Options:

1. Use only full country level emission factors (EFs)
    a. Pros
        i. Simplifies selection of the correct EFs
        ii. National grids are products of national policies that drive change (or lack thereof)
        iii. Countries are reporting EFs internationally
        iv. In line with Norwegian PCR
        v. National grids are products of national policies that drive change (or lack thereof), thus alignment helps drive national policies
    b. Cons
        i. Less accurate when more geographically specific EFs are available and have confidence
        ii. Creates a potential disadvantage for larger countries that have physically distinct grids
2. Use commonly available sub-country level emission factors from specific third-party sources (e.g., Ecoinvent 3.7) **(NOTE: Review Ecoinvent 3.8, major updates on grid-level EFs)**
    a. Pros
        i. Likely more accurate when geographically specific EFs are available and have confidence
        ii. Many large geographic countries have grids that are driven by regional policy

[11] TBD

iii. Aligned with already acceptable methods for accounting, e.g., WRI GHG reporting protocol

b. Cons

i. May increase verification complexity to ensure appropriate EF selection

ii. Possibly opens the door to greenwashing by "cherry-picking" inappropriate but lower geographies?

iii. May be more or less 'implementable' in varying countries (i.e., US zipcode look-up quite simple; Canada based on provincial boundaries)

Path B: Calculation Method via Additional LCA Data

Path B should be applied in the case where the component manufacturer would like the value of GWPij unit associated with this manufacturing step to be different from those shown in Table 3. The new value used for this process step must be from a recent full life-cycle assessment, conducted within the previous twelve (12) months, and performed on the component's manufacturing process according to ISO 14040: 2006. The LCA must also have been the subject of an independent critical review according to the requirements of ISO 14044:2006[12].

This life-cycle assessment report must detail

- origin of data,
- time periods of inventories,
- detailed description of the flow of materials and energy,
- assumptions concerning the distribution and flow of material, energy and environmental flows, and
- the impact factors and methods applied.

For consistency, the life-cycle assessment must take into account the same assumptions that were applicable to Table 3, namely:

- The GWPij are obtained using the values of the GHG emissions for the manufacture of components corresponding to values CO2e calculated as IPCC2013-GWP100a method[13]. These calculations should be based on the electricity mix of the country or subregion of manufacture of component i j (based on emission factors as decided via DP3, e.g. Ecoinvent 3.8)[14].
- No components can include a recycled silicon content greater than 35%[15].
- Unless otherwise specified elsewhere in the Annex, the LCA must conform with the Norwegian Photovoltaic Module Product Category Ruleset, as adapted to produce results for the specific GWPij component gate-to-gate results.

DISCUSSION POINT FOR TECHNICAL COMMITTEE & PUBLIC COMMENT	
DP4	Application of PCR
EAH recommends alignment with the Norwegian PCRfor Path B. There is a mismatch in scope between Path A and Path B. Since the two Paths are inter-related and Path B only provides an alternative GWPij coefficient for a specific process in Path A, the PCR does not provide sufficient guidance to create a scope appropriate coefficient for the method.	

[12] TBD
[13] TBD
[14] TBD
[15] TBD

For example, if you calculate the carbon footprint of a thin film module using the Norwegian PCR, it includes the whole module (including the glass and EVA). But the alternative GWPij that is needed is for "module processing" (excluding the glass and EVA).

Similarly, if you calculate the carbon footprint of a mono-crystalline silicon wafer using the Norwegian PCR, it includes the whole wafer (including the polysilicon and ingot supply chain). But the GWPij that is needed is for "wafer processing" (excluding the polysilicon and ingot supply chain).
In other words, you cannot take the result of a EPD and use it directly with Path A. The general principles of a PCR can still be used but the system boundary of any Path B LCA is unique to this program.

Options:

1. Reference specific sections of the Norwegian PCR that are requirements for ULCS and include guidance for how those requirements need to be integrated into Path B
2. Find a separate PCR that is better aligned with ULCS needs
3. Proceed without a specific reference to a PCR

Additional Discussion

1. LCA under PCR produces two results based on cradle-to-gate and ULCS-specific process steps (coefficients) as gate-to-gate
    a. I.e., these additional requirements from Norwegian PCR (section 7.2.4.2) could be noted here for consistency with Path A: "Electricity shall be the physical national grid mix. Electricity based on guarantees of origin shall not be used to model electricity for the PV value chain, but LCIA results using these may be reported as additional environmental information."
2. Should consider "LCA expiration" period (i.e., 12 months? Longer?) in a manner that tries to ensure up-to-date information but does not place undue burden on manufacturers, e.g., when processes are not updated frequently.

DISCUSSION POINT FOR TECHNICAL COMMITTEE & PUBLIC COMMENT	
DP5	Acceptable sources of electricity-related emission factors (Usage of Energy Attribute Certificates, RECs, Guarantees of Origin)

The EAH has discussed this topic at length. There are very important concerns about potential for any market-based methods for electricity-related emission factors that could be subject the criterion to substantial risk related to green-washing and/or misrepresentation of carbon footprint.

Current EAH position: Electricity related CO2e Emission Factors should be applied in the same manner in Path A and Path B, unless misuse of non-location-based emission factors is prevented in a very highly confident manner.

Also, ULCS should be as simple as possible, so complicated methods cause complexity. Also, ULCS should not disadvantage small companies, since complex methods may not be as available to a smaller company, creating an inherent advantage to companies able to commit more resources.

Option to allow creation of two values.

Options:

1. Use only full country level emission factors (EFs) (or EFs as per DP3)

a. (French Tender approach)
b. Pros
    i. Substantially prevents inappropriate selection of EFs (i.e. “misrepresentation”)
    ii. In line with Norwegian PCR
c. Cons
    i. Does not provide an incentive to use market mechanisms to add renewable power

2. Allow electricity-related EFs as per ISO 14067 and EU PEF CR requirements.
    a. Pros
        i. Enables use of market mechanisms to add renewable power
    b. Cons
        i. Opens up complexity that can lead to inappropriate selection of EFs (i.e., “cheating”)
        ii. Not directly in line with Norwegian PCR

Additional discussion points

- Developing international power trading mechanisms (for residual power)

Step 4: Final calculation of G

The final calculation of G from formula 1 is done through the addition of Gi for all i components of the module.

Table 1:

- Inventory of the composition of one kilowatt peak module or photovoltaic film (Qi)
- Identification of manufacturing sites and distribution of sources of supply for a component that can come from several manufacturing sites
- GWPij values (Global Warming Potential) for each module of the component or the film photovoltaic, presented in Table 3

	Quantizing each component for the manufacture of 1 kWc power. Qi (unit corresponding to the relevant component)	**component type Reference**	**Site (s) of manufacture**	**Manufacturing country j**	**distribution coefficients of supply sources the different manufacturing sites** (Xij value coefficients between 0 and 1 for each component i of the sum over j = 1 xij)	**Values GWPij unit** (Kg eq CO_2 / quantization unit component)
polysilicon	Unit: kg		Site 1 Site 2 ...	country 1 Country 2 ...	X_{11}: X_{12}:	**kg eqCO_2 / kg** **kg eqCO_2 / kg**
ingots	Unit: kg		Site 1 Site 2 ...	country 1 Country 2 ...	X_{21}: X_{22}:	**kg eqCO_2 / kg** **kg eqCO_2 / kg**

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

Table 3: Values in GHG emissions in CO 2 eq for the manufacture of components:

GWP = Global Warming Potential IPCC2013 GWP100a v1.02; Ecoinvent 3.8; Source: Ultra Low Carbon Solar Alliance

	Silicon - Metallurgical Grade	Silicon - Solar Grade	Single-Si Ingot	Multi-Si Ingot	Single-Si Wafer	Multi-Si Wafer	Single-Si PV Cell	Multi-Si PV Cell	Single-Si PV Laminate	Multi-Si PV Laminate	Single-Si PV Module	Multi-Si PV Module
Reference Flow	kg	kg	kg	kg	m2	m2	m2	m2	m2	m2	m2	m2
Albania	13.328	23.556	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Armenia	11.472	13.583	14.361	2.202	3.553	3.771	9.559	10.549	26.566	26.567	41.930	41.932
Australia	19.693	50.200	38.275	7.433	7.110	7.926	22.786	23.776	37.028	37.029	52.392	52.394
Austria	12.688	21.945	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Azerbaijan	15.436	31.239	25.892	4.724	5.268	5.775	15.937	16.926	31.610	31.611	46.975	46.976
Bahrain	14.720	28.048	23.808	4.269	4.958	5.413	14.784	15.774	30.699	30.700	46.063	46.065
Bangladesh	16.462	35.809	28.876	5.377	5.712	6.293	17.588	18.577	32.916	32.917	48.280	48.282
Belarus	15.793	29.756	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Belgium	11.561	19.109	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Bosnia and Herzegovina	19.565	39.244	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Brunei Darussalam	15.728	32.537	26.740	4.910	5.394	5.922	16.406	17.395	31.981	31.982	47.346	47.348
Bulgaria	15.776	29.713	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Cambodia	17.171	38.966	30.938	5.828	6.018	6.652	18.728	19.718	33.818	33.819	49.182	49.184
Canada, Alberta	17.990	32.941	33.322	6.350	6.365	7.066	20.047	21.036	34.861	34.862	50.225	50.227
Canada, British Columbia	9.972	5.825	9.997	1.247	2.895	3.013	7.145	8.134	24.656	24.657	40.020	40.022
Canada, Manitoba	9.711	4.944	9.238	1.081	2.782	2.881	6.725	7.715	24.324	24.325	39.689	39.690
Canada, New Brunswick	13.287	17.035	19.639	3.357	4.329	4.689	12.479	13.468	28.875	28.876	44.239	44.241
Canada, Newfoundland and Labrador	9.907	5.606	9.808	1.206	2.867	2.980	7.040	8.030	24.573	24.574	39.938	39.940
Canada, Northwest Territories	13.430	17.519	20.056	3.448	4.391	4.761	12.709	13.698	29.057	29.058	44.421	44.423
Canada, Nova Scotia	19.541	38.186	37.834	7.337	7.036	7.850	22.542	23.532	36.835	36.836	52.199	52.201
Canada, Nunavut	21.317	44.191	42.999	8.467	7.804	8.747	25.399	26.389	39.095	39.096	54.459	54.461
Canada, Ontario	9.733	5.018	9.302	1.095	2.792	2.892	6.761	7.750	24.352	24.353	39.716	39.718
Canada, Prince Edward Island	11.970	12.583	15.809	2.519	3.760	4.023	10.360	11.349	27.199	27.200	42.563	42.565
Canada, Québec	9.213	3.257	7.788	0.764	2.566	2.629	5.923	6.912	23.690	23.691	39.054	39.056

	Silicon - Metallurgical Grade	Silicon - Solar Grade	Single-Si Ingot	Multi-Si Ingot	Single-Si Wafer	Multi-Si Wafer	Single-Si PV Cell	Multi-Si PV Cell	Single-Si PV Laminate	Multi-Si PV Laminate	Single-Si PV Module	Multi-Si PV Module
Canada, Saskatchewan	17.357	30.800	31.480	5.947	6.091	6.746	19.028	20.017	34.055	34.056	49.419	49.421
Canada, Yukon Territory	10.199	6.592	10.656	1.391	2.993	3.128	7.510	8.499	24.944	24.945	40.309	40.311
China Southern Power Grid	16.382	35.451	28.643	5.326	5.669	6.253	17.459	18.448	32.793	32.815	48.158	48.180
State Grid Corporation of China	20.439	53.525	40.446	7.908	7.424	8.304	23.988	24.977	37.958	37.979	53.322	53.344
Croatia	14.106	25.513	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Cyprus	20.014	40.375	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Czechia	18.574	36.752	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Denmark	11.540	19.059	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Estonia	19.056	37.964	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Finland	11.399	18.703	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
France	10.082	15.389	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Georgia	10.281	8.274	10.895	1.444	3.037	3.169	7.642	8.631	25.049	25.050	40.413	40.415
Germany	15.408	28.786	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Gibraltar	19.182	38.282	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Greece	17.836	34.895	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
HICC	18.631	35.110	35.187	6.758	6.642	7.390	21.079	22.068	35.677	35.678	51.041	51.043
Hong Kong	18.077	43.002	33.574	6.405	6.410	7.110	20.186	21.175	34.971	34.972	50.335	50.337
Hungary	13.818	24.788	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Iceland	9.445	13.788	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
India, Eastern grid	26.223	79.291	57.273	11.589	9.936	11.227	33.295	34.284	45.340	45.341	60.704	60.706
India, North-eastern grid	18.621	45.424	35.156	6.751	6.646	7.385	21.061	22.051	35.663	35.664	51.028	51.029
India, Northern grid	22.643	63.343	46.858	9.311	8.386	9.418	27.534	28.523	40.783	40.784	56.147	56.149
India, Southern grid	23.123	65.480	48.254	9.616	8.594	9.660	28.306	29.295	41.394	41.394	56.758	56.760
India, Western grid	24.895	73.372	53.408	10.744	9.361	10.556	31.157	32.146	43.649	43.649	59.013	59.015
Indonesia	21.218	56.994	42.711	8.404	7.770	8.697	25.240	26.230	38.969	38.970	54.333	54.335
Iran (Islamic Republic of)	15.956	33.554	27.404	5.055	5.493	6.038	16.773	17.763	32.272	32.273	47.636	47.638
Iraq	19.719	50.319	38.352	7.450	7.121	7.940	22.829	23.818	37.062	37.063	52.426	52.428
Ireland	13.897	24.987	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Israel	16.781	37.229	29.804	5.580	5.850	6.455	18.101	19.090	33.322	33.323	48.686	48.688

	Silicon - Metallurgical Grade	Silicon - Solar Grade	Single-Si Ingot	Multi-Si Ingot	Single-Si Wafer	Multi-Si Wafer	Single-Si PV Cell	Multi-Si PV Cell	Single-Si PV Laminate	Multi-Si PV Laminate	Single-Si PV Module	Multi-Si PV Module
Italy	13.839	24.841	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Japan	16.804	37.333	29.872	5.595	5.860	6.466	18.139	19.128	33.352	33.353	48.716	48.718
Jordan	15.142	29.928	25.036	4.537	5.140	5.626	15.464	16.453	31.236	31.237	46.600	46.602
Kazakhstan	19.718	50.311	38.347	7.449	7.120	7.939	22.826	23.816	37.059	37.060	52.424	52.426
Korea, Democratic People's Republic of	11.466	13.552	14.341	2.198	3.550	3.768	9.548	10.537	26.557	26.558	41.921	41.923
Korea, Republic of	16.450	35.756	28.842	5.370	5.707	6.287	17.569	18.558	32.901	32.902	48.265	48.267
Kosovo	23.558	49.289	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Kuwait	18.132	43.247	33.734	6.440	6.434	7.137	20.275	21.264	35.041	35.042	50.406	50.407
Kyrgyzstan	10.152	7.699	10.519	1.362	2.981	3.104	7.434	8.423	24.885	24.886	40.249	40.251
Latvia	13.469	23.910	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Lebanon	19.267	48.302	37.035	7.162	6.925	7.711	22.101	23.090	36.486	36.486	51.850	51.852
Lithuania	13.315	23.523	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Luxembourg	14.783	27.216	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Malaysia	17.781	41.684	32.714	6.217	6.282	6.960	19.710	20.700	34.595	34.596	49.959	49.961
Malta	14.305	26.013	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Mexico	15.296	23.829	25.483	4.635	5.199	5.704	15.711	16.700	31.432	31.432	46.796	46.798
Moldova, Republic of	15.328	28.586	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Mongolia	22.278	61.717	45.796	9.078	8.228	9.233	26.947	27.936	40.318	40.319	55.683	55.685
Montenegro	18.562	36.721	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Myanmar	11.939	15.660	15.718	2.499	3.754	4.007	10.310	11.299	27.159	27.160	42.524	42.525
Nepal	14.530	27.204	23.257	4.148	4.876	5.317	14.480	15.469	30.458	30.458	45.822	45.824
Netherlands	15.385	28.731	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
New Zealand	10.111	7.520	10.402	1.336	2.964	3.084	7.369	8.359	24.834	24.834	40.198	40.200
North Macedonia	18.997	37.815	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Norway	9.117	12.962	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Oman	15.560	31.789	26.251	4.803	5.321	5.837	16.136	17.125	31.768	31.768	47.132	47.134
Pakistan	14.807	28.437	24.062	4.324	4.995	5.457	14.925	15.914	30.810	30.811	46.174	46.176
Philippines	16.816	37.386	29.906	5.603	5.865	6.472	18.158	19.147	33.367	33.368	48.731	48.733
Poland	19.699	39.581	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385

	Silicon - Metallurgical Grade	Silicon - Solar Grade	Single-Si Ingot	Multi-Si Ingot	Single-Si Wafer	Multi-Si Wafer	Single-Si PV Cell	Multi-Si PV Cell	Single-Si PV Laminate	Multi-Si PV Laminate	Single-Si PV Module	Multi-Si PV Module
Portugal	14.271	25.927	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Qatar	14.656	27.766	23.624	4.228	4.930	5.381	14.683	15.672	30.618	30.619	45.982	45.984
Romania	13.941	25.097	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Russia	16.720	32.088	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Saudi Arabia	19.988	51.515	39.134	7.621	7.237	8.076	23.262	24.251	37.404	37.405	52.768	52.770
Serbia	19.430	38.904	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Singapore	14.055	25.088	21.875	3.846	4.670	5.077	13.715	14.704	29.853	29.854	45.217	45.219
Slovakia	14.551	26.631	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Slovenia	13.390	23.710	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Spain	12.996	22.719	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Sri Lanka	17.068	38.506	30.638	5.763	5.974	6.600	18.562	19.552	33.687	33.688	49.051	49.053
Sweden	9.321	13.477	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Switzerland	9.979	15.131	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
Syrian Arab Republic	16.633	36.571	29.374	5.486	5.786	6.380	17.863	18.852	33.134	33.135	48.498	48.500
Taiwan, Province of China	17.479	40.337	31.834	6.024	6.152	6.807	19.224	20.213	34.210	34.211	49.574	49.576
Tajikistan	9.786	6.069	9.454	1.129	2.823	2.919	6.845	7.834	24.419	24.420	39.783	39.785
Texas Regional Entity	14.756	22.003	23.913	4.292	4.965	5.431	14.843	15.832	30.745	30.746	46.109	46.111
Thailand	16.630	36.556	29.365	5.484	5.784	6.378	17.858	18.847	33.130	33.131	48.494	48.496
Turkey	15.484	31.450	26.030	4.755	5.288	5.799	16.013	17.003	31.671	31.672	47.035	47.037
Turkmenistan	16.781	37.230	29.804	5.580	5.850	6.455	18.101	19.090	33.322	33.323	48.686	48.688
Ukraine	14.629	26.828	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
United Arab Emirates	14.784	28.333	23.994	4.309	4.985	5.445	14.888	15.877	30.780	30.781	46.144	46.146
United Kingdom	12.620	21.775	19.784	3.388	4.351	4.714	12.558	13.548	28.087	28.087	43.385	43.385
United States of America												
Alaska Systems Coordinating Council	14.795	22.137	24.028	4.317	4.982	5.451	14.906	15.895	30.795	30.796	46.159	46.161
Florida Reliability Coordinating Council	14.434	20.914	22.976	4.087	4.826	5.268	14.324	15.313	30.335	30.336	45.699	45.701
Midwest Reliability Organization, US part only	16.146	26.706	27.958	5.176	5.567	6.134	17.080	18.069	32.514	32.515	47.879	47.881
Northeast Power Coordinating Council, US part only	11.397	10.643	14.141	2.154	3.511	3.733	9.437	10.426	26.469	26.470	41.833	41.835

	Silicon - Metallurgical Grade	Silicon - Solar Grade	Single-Si Ingot	Multi-Si Ingot	Single-Si Wafer	Multi-Si Wafer	Single-Si PV Cell	Multi-Si PV Cell	Single-Si PV Laminate	Multi-Si PV Laminate	Single-Si PV Module	Multi-Si PV Module
ReliabilityFirst Corporation	15.347	24.002	25.633	4.668	5.221	5.730	15.794	16.783	31.497	31.498	46.861	46.863
SERC Reliability Corporation	15.418	24.241	25.838	4.713	5.251	5.766	15.907	16.896	31.587	31.588	46.951	46.953
Western Electricity Coordinating Council, US part only	13.523	17.834	20.326	3.507	4.432	4.808	12.859	13.848	29.175	29.176	44.540	44.542
Uzbekistan	16.182	34.561	28.061	5.199	5.590	6.152	17.137	18.126	32.560	32.560	47.924	47.926
Viet Nam	13.763	23.785	21.024	3.660	4.544	4.929	13.245	14.234	29.481	29.482	44.845	44.847
Yemen	18.896	46.650	35.957	6.926	6.765	7.524	21.504	22.493	36.014	36.015	51.378	51.380

Annex B: Bibliography

While not explicitly cited in the criterion section of this document, the following references are provided as non-normative useful 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 — Based on NSF 457

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
- PCR for PV Module — PCR for PV produced energy: EPDItaly 014 – rel. 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

Document Change History

Issue	Revision	Author	Description of Change	Approver	Approval Date	Effective Date
1	0	Anthesis	Initial release		XX	XX