GreenDelta

SH2E Criticality indicator method

Integration into ecoinvent v3.10 cut-off

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Introduction

The SH2E criticality indicator method was developed during the SH2E[1] EU Horizon project to address material criticality in the life-cycle profile of fuel cell and hydrogen (FCH) systems. Created by Bargiacchi et al. in 2022[2] and Zapp and Schreiber in 2021[3], it is based on the criticality assessment of the European Commission (EC)[4] and includes an indicator that considers Supply Risk (SR), material consumption (C) in the EU, import reliance (IR), and the recycling input rate (EoL_{RIR}). The SH2E criticality indicator characterization factor (CF) is derived by:

$$CF = \frac{SR}{C \times (1 - IR \times (1 - EoL_{RIR}))}$$

The final SH2E criticality indicator is calculated by multiplying the criticality factor (CF) of a material (m) by the mass (M) of that material in the foreground systems, according to the SH2E LCSA guidelines:

$$Criticality = M_m \times CF_m$$

However, to take the equation application a step further, the method was integrated into ecoinvent database. This integration allows the method to capture not only the mass of materials in the foreground data but also those in the background datasets based on the database.

[1] https://sh2e.eu/

[2] Bargiacchi E, Puig-Samper G, Campos-Carriedo F, Iribarren D, Dufour J, Ciroth A, et al. D2.2 Definition of FCH-LCA guidelines. 2022.

[3] Zapp P, Schreiber A. SH2E D3.1 Material criticality indicator. Brussels: Clean Hydrogen Partnership; 2021

[4] https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en

Implementation into ecoinvent

To integrate the SH2E criticality indicator as an LCIA method in the ecoinvent v3.10 cut-off system model, the criticality factors (CFs) were first calculated. The EU defines a material as critical when its SR > 1 and its EI > 2.8, also considering materials designated as strategic raw materials. This approach identified 30 critical raw materials (CRMs). However, this method includes not only these CRMs but also other non-critical materials, e.g. hydrogen.

As shown in Equation 1, the consumption (C) is sometimes defined as the level of extraction or production. Generally, materials are assessed at either the extraction or production stage to calculate the respective CFs. All values for EU consumption were obtained from the SCRREEN project website[5]. The Import Reliance (IR), SR, and Recycling Input Rate (EoL_{RIR}) are provided by the European Commission's critical raw material (CRM) list and associated factsheets (European Commission, 2023[6]; SCRREEN Project, 2023), which are updated and released every three years. The complete materials list can be found in the Annex.

Based on the derived parameters, the CFs for all 80 materials were calculated. In the ecoinvent database, these materials were then linked to the relevant elementary flows categorized as "resource -> in ground," typically based on their names. However, there were instances where materials from the list could not be found or existed only as product flows. The following materials were not found in the ecoinvent v3.10 Life Cycle Inventory (LCI):

1. Natural Cork
2. Natural Rubber
3. Natural Tak Wood
4. Sapele Wood

These materials are not present in the background database of ecoinvent v3.10, and users are advised to insert them manually if their product system contains any of these materials.

Additionally, the following materials were found in the database but existed only as product flows:

1. Barite
2. Helium

[5] https://scrreen.eu/crms-2023/

[6] Study on the critical raw materials for the EU 2023 - Publications Office of the EU (europa.eu)

3. Hydrogen
4. Titanium metal[7]

In these cases, a "shadow flow" was created for all four materials and inserted into the processes where the product flow was set as the quantitative reference, maintaining the mass ratios. For example, in the case of titanium metal, which is produced by the process of "titanium production," a "shadow" flow was inserted into the process (see Figure 1). This allows users to calculate the criticality score associated with titanium metal as well.

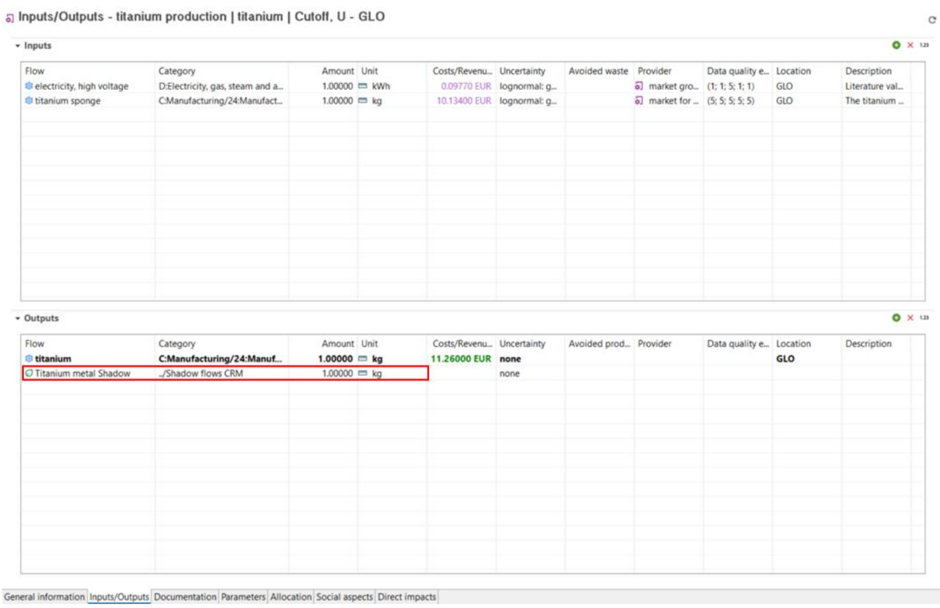


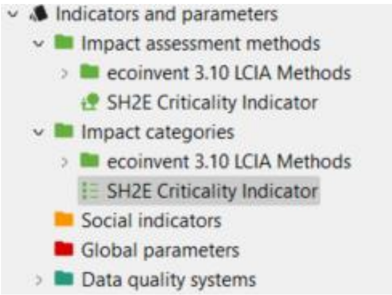
Figure 1 Titanium production process - ecoinvent v3.10 cut-off

However, it should be noted that the "titanium" elementary flow, classified as a resource in ground, already exists upstream of titanium production. This could potentially lead to double counting—once as titanium metal and once as titanium ore which requires further investigation. Despite this, the method developed remains consistent with the guidelines suggested by the European Commission's CRM framework.

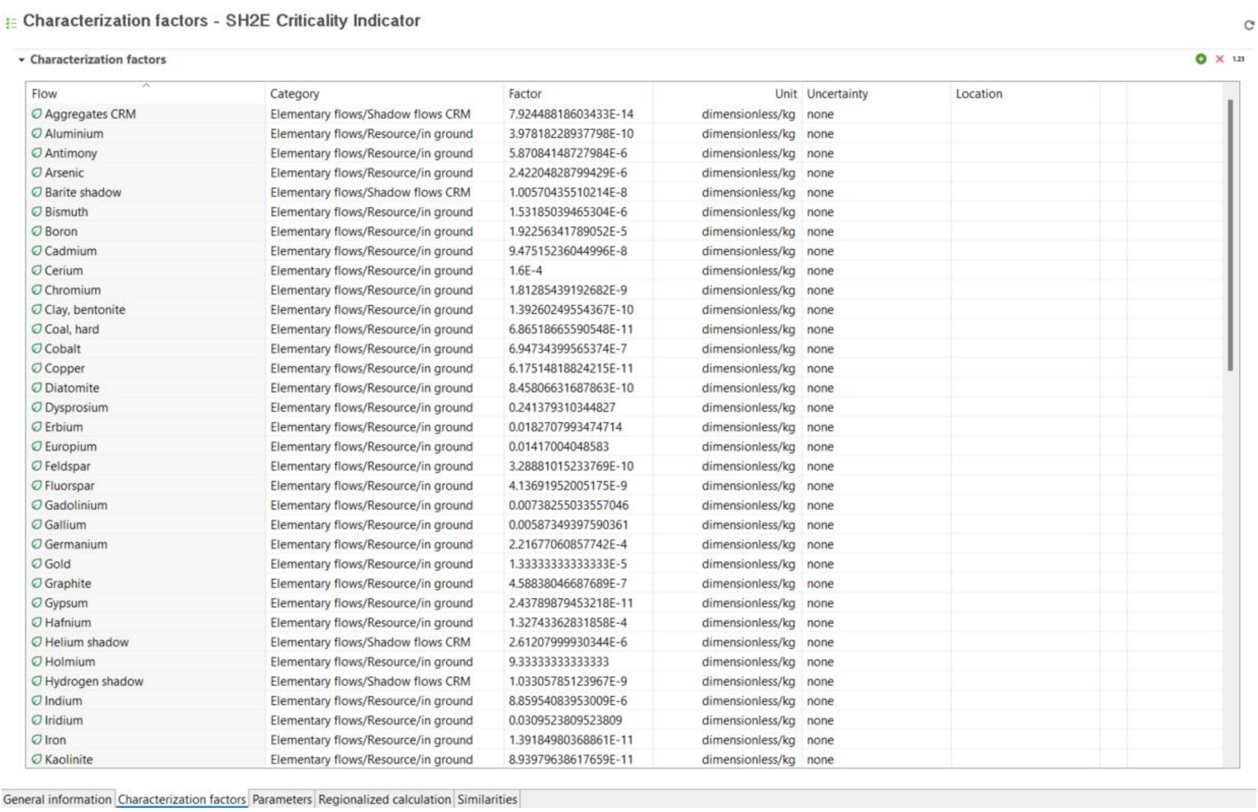
Results

The method – SH2E criticality indicator - exists as part of the circularity package and can be seen under 'Indicator and parameters'.

[7] Titanium metal has been assessed in addition to titanium according to EC. In the ecoinvent database, there exists only titanium flow as resource in ground which is allocated for the titanium ore.



Users can explore the characterization factor by double clicking on the 'SH2E criticality indicator' under impact categories and going to the characterization factors tab.



Characterization factors - SH2E Criticality Indicator

Characterization factors

Flow	Category	Factor	Unit	Uncertainty	Location
Aggregates CRM	Elementary flows/Shadow flows CRM	7.92448818603433E-14	dimensionless/kg	none	
Aluminium	Elementary flows/Resource/in ground	3.97818228937798E-10	dimensionless/kg	none	
Antimony	Elementary flows/Resource/in ground	5.87084148727984E-6	dimensionless/kg	none	
Arsenic	Elementary flows/Resource/in ground	2.42204828799429E-6	dimensionless/kg	none	
Barite shadow	Elementary flows/Shadow flows CRM	1.00570435510214E-8	dimensionless/kg	none	
Bismuth	Elementary flows/Resource/in ground	1.53185039465304E-6	dimensionless/kg	none	
Boron	Elementary flows/Resource/in ground	1.92256341789052E-5	dimensionless/kg	none	
Cadmium	Elementary flows/Resource/in ground	9.47515236044996E-8	dimensionless/kg	none	
Cerium	Elementary flows/Resource/in ground	1.6E-4	dimensionless/kg	none	
Chromium	Elementary flows/Resource/in ground	1.81285439192682E-9	dimensionless/kg	none	
Clay, bentonite	Elementary flows/Resource/in ground	1.39260249554367E-10	dimensionless/kg	none	
Coal, hard	Elementary flows/Resource/in ground	6.86518665590548E-11	dimensionless/kg	none	
Cobalt	Elementary flows/Resource/in ground	6.94734399565374E-7	dimensionless/kg	none	
Copper	Elementary flows/Resource/in ground	6.17514818824215E-11	dimensionless/kg	none	
Diatomite	Elementary flows/Resource/in ground	8.45806631687863E-10	dimensionless/kg	none	
Dysprosium	Elementary flows/Resource/in ground	0.241379310344827	dimensionless/kg	none	
Erbium	Elementary flows/Resource/in ground	0.0182707993474714	dimensionless/kg	none	
Europium	Elementary flows/Resource/in ground	0.01417004048583	dimensionless/kg	none	
Feldspar	Elementary flows/Resource/in ground	3.28881015233769E-10	dimensionless/kg	none	
Fluorspar	Elementary flows/Resource/in ground	4.13691952005175E-9	dimensionless/kg	none	
Gadolinium	Elementary flows/Resource/in ground	0.00738255033557046	dimensionless/kg	none	
Gallium	Elementary flows/Resource/in ground	0.00587349397590361	dimensionless/kg	none	
Germanium	Elementary flows/Resource/in ground	2.21677060857742E-4	dimensionless/kg	none	
Gold	Elementary flows/Resource/in ground	1.33333333333333E-5	dimensionless/kg	none	
Graphite	Elementary flows/Resource/in ground	4.58838046687689E-7	dimensionless/kg	none	
Gypsum	Elementary flows/Resource/in ground	2.43789879453218E-11	dimensionless/kg	none	
Hafnium	Elementary flows/Resource/in ground	1.32743362831858E-4	dimensionless/kg	none	
Helium shadow	Elementary flows/Shadow flows CRM	2.61207999930344E-6	dimensionless/kg	none	
Holmium	Elementary flows/Resource/in ground	9.33333333333333	dimensionless/kg	none	
Hydrogen shadow	Elementary flows/Shadow flows CRM	1.03305785123967E-9	dimensionless/kg	none	
Indium	Elementary flows/Resource/in ground	8.85954083953009E-6	dimensionless/kg	none	
Iridium	Elementary flows/Resource/in ground	0.0309523809523809	dimensionless/kg	none	
Iron	Elementary flows/Resource/in ground	1.39184980368861E-11	dimensionless/kg	none	
Kaolinite	Elementary flows/Resource/in ground	8.93979638617659E-11	dimensionless/kg	none	

General information | Characterization factors | Parameters | Regionalized calculation | Similarities

Figure 2 Characterization factors of the flows in SH2E criticality indicator list

As seen in Figure 2, the method is dimensionless based on equation 1. Users wishing to find out the criticality score of their product system can do so by running a normal calculation and interpreting the results the same way done in openLCA. In general, the higher the score of the criticality indicator means the higher usage of critical material.

Impact analysis - SH2E Criticality Indicator

Sub-group by (•) Flows ( ) Processes | Don't show < 1 %

Name	Category	Inventory result	Characterization factor	Impact assessment result
SH2E Criticality Indicator				0.00076 dimensionless
Samarium	Elementary flows/Resource/in ground	0.00272 kg	0.12545 dimensionless/kg	0.00034 dimensionless
Gallium	Elementary flows/Resource/in ground	0.04699 kg	0.00587 dimensionless/kg	0.00028 dimensionless
Tantalum	Elementary flows/Resource/in ground	0.16762 kg	0.00016 dimensionless/kg	2.71410E-5 dimensionless
Lithium	Elementary flows/Resource/in ground	0.18290 kg	0.00015 dimensionless/kg	2.70978E-5 dimensionless
Scandium	Elementary flows/Resource/in ground	0.00030 kg	0.06486 dimensionless/kg	1.95773E-5 dimensionless
Gadolinium	Elementary flows/Resource/in ground	0.00234 kg	0.00738 dimensionless/kg	1.72437E-5 dimensionless
Boron	Elementary flows/Resource/in ground	0.53682 kg	1.92256E-5 dimensionless/kg	1.03208E-5 dimensionless
Praseodymium	Elementary flows/Resource/in ground	0.02064 kg	0.00048 dimensionless/kg	9.85683E-6 dimensionless
Europium	Elementary flows/Resource/in ground	0.00067 kg	0.01417 dimensionless/kg	9.53013E-6 dimensionless

Figure 3 Impact analysis of the results for SH2E criticality indicator method

Commentary on using ecoinvent database

Applying this methodology to the ecoinvent database may lead to a significant underestimation of resource criticality, as the respective elementary flows used in ecoinvent do not adhere to mass-balance criteria due to economic allocation. This issue arises particularly when materials are sourced as by-products (e.g. indium, cadmium). **Therefore, we recommend cross-checking the life cycle inventory when working with critical raw materials.**

Annex

Table 1 List of materials included in the method. Materials are based on either E = extraction or P = production

Material	Stage	SR	EI	IR	EOL-RIR	EU consumption [t]
Aggregates	E	0.2	3.2	0.01	0.09	2547000000
Aluminium	P	1.2	5.8	0.58	0.32	4980933
Antimony	E	1.8	5.4	1	0.28	1095
Arsenic	P	1.9	2.9	0.39	0	1286
Baryte	E	1.3	3.5	0.74	0	497164
Bentonite	E	0.4	3.1	0.16	0.19	3300000
Bismuth	P	1.9	5.7	0.71	0	4277
Boron/borate (B2O3-eq.)	E	3.6	3.9	1	0.01	18725
Cadmium	P	0.2	4.1	0.08	0.3	2236
Cerium	P	4	4.9	1	0.01	2500
Chromium	P	0.7	7.2	0.42	0.21	577868
Cobalt	E	2.8	6.8	0.81	0.22	10946
Coking Coal	E	1	3.1	0.66	0	42841901
Copper	E	0.1	4	0.48	0.55	2065554
Diatomite	E	0.3	2.3	0	0.04	354691
Dysprosium	p	5.6	7.8	1	0.01	2.32
Erbium	P	5.6	3.5	1	0.01	30.65
Europium	P	5.6	3.3	1	0.38	1.04
Feldspar	E	1.5	3.2	0.54	0.01	9800000
Flourspar	E	1.1	3.8	0.6	0.01	654922
Gadolinium	P	3.3	3.3	1	0.01	44.7
Gallium	P	3.9	3.7	0.98	0	33.2
Germanium	P	1.8	3.6	0.42	0.02	13.8
Gold	E	0.4	2.4	0	0.05	30
Gypsum	E	0.6	2.7	0	0.01	24611358
Hafnium	P	1.5	4.3	0	0	11.3
Helium	P	1.2	2.9	0.94	0.02	5830
Holium	P	5.6	3.2	1	0.01	0.06
Lutetium	P	5.6	5	0	0.01	5.61
Thulium	P	5.6	3.2	0	0.01	0.2
Ytterbium	P	5.6	3.2	0	0.01	7.37
Hydrogen	P	0.5	2.9	0.56	0	1100000
Indium	P	0.6	2.6	0.11	0.01	76
Iridium	P	3.9	6.4	1	0.14	0.9
Iron Ore (60%, USGS)	E	0.5	7.2	0.77	0.31	76644797
Kaolin Clay	E	0.8	2.8	0.28	0.31	11091658

Material	Stage	SR	EI	IR	EOL-RIR	EU consumption [t]
Lanthanum	P	3.5	2.9	1	0.01	2242
Lead	E	0.1	4.2	0.21	0.83	270889
Limestone	E	0.3	3.6	0.05	0.01	22000000
Lithium	P	1.9	3.9	1	0.007	1832
Magnesite	E	0.6	3.6	0	0.02	2900000
Magnesium	P	4.1	7.4	1	0.13	120520
Manganese	E	1.2	6.9	0.96	0.09	270393
Molybdenum	E	0.8	6.7	1	0.3	9018
Natural Cork	E	0.9	1.7	0	0.08	160000
Natural Graphite	E	1.8	3.4	0.98	0.03	79412
Natural Rubber	E	0.9	6	1	0.02	1160141
Natural Tak Wood	E	1.7	2.4	1	0.05	34400
Neodymium	E	4.5	7.2	1	0.01	80.2
Nickel	P	0.5	5.7	0.75	0.16	257147
Niobium	P	4.4	6.5	1	0.6	2813
Palladium	P	1.5	8.1	0.93	0.28	20
Perlite	E	0.8	2.5	0	0.42	974249
Phosphate Rock	E	1	6.4	0.82	0.17	1961184
Platinum	P	2.13	6.9	0.98	0.25	72
Potash (USGS: K2O eq.)	E	0.7	6.2	0.33	0	5036000
Praseodymium	P	3.2	7	1	0.1	67
Rhodium	P	2.4	8.6	1	0.28	5
Ruthenium	P	3.8	5.5	1	0.11	2.5
Samarium	P	3.5	7.7	1	0.01	2.79
Sapele Wood	E	1.3	1.6	1	0.07	61043
Scandium	P	2.4	3.7	1	0.01	3.7
Selenium	P	0.3	4.8	0.02	0.01	835
Silica Sand	E	0.3	3.1	0	0.01	51100000
Silicon Metal	P	1.4	4.9	0.64	0	421141
Silver	E	0.8	4.6	0.05	0.04	3167
Strontium	E	2.6	6.5	0	0	53577
Sulphur	P	0.3	5	0	0	4866421
Talc	E	0.2	3.3	0.07	0.16	1116290
Tantalum	E	1.3	4.8	0.99	0.01	403.46
Tellurium	P	0.3	3.8	0	0.01	507
Terbium	P	4.9	6.4	1	0.06	1.56
Tin	P	0.9	4.5	0.73	0.31	48900
Titanium ore	E	0.5	5.4	1	0.01	456539
Titanium metal	P	1.6	6.3	1	0.01	9812
Tungsten	P	1.2	8.7	0.8	0.42	10481

Material	**Stage**	**SR**	**EI**	**IR**	**EOL-RIR**	**EU consumption [t]**
Vanadium	E	2.3	3.9	1	0.06	4351
Yttrium	P	3.5	2.9	1	0.31	56
Zinc	E	0.2	4.8	0.56	0.34	1720091
Zirconium	E	0.8	3.5	1	0.12	147666

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