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2023-08-02

Quality assessment of life cycle inventory data for composites

Moutik, B

https://pearl.plymouth.ac.uk/handle/10026.1/21162

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ICCM 23
INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS
BELFAST 2021
1 - 6 AUGUST 2021

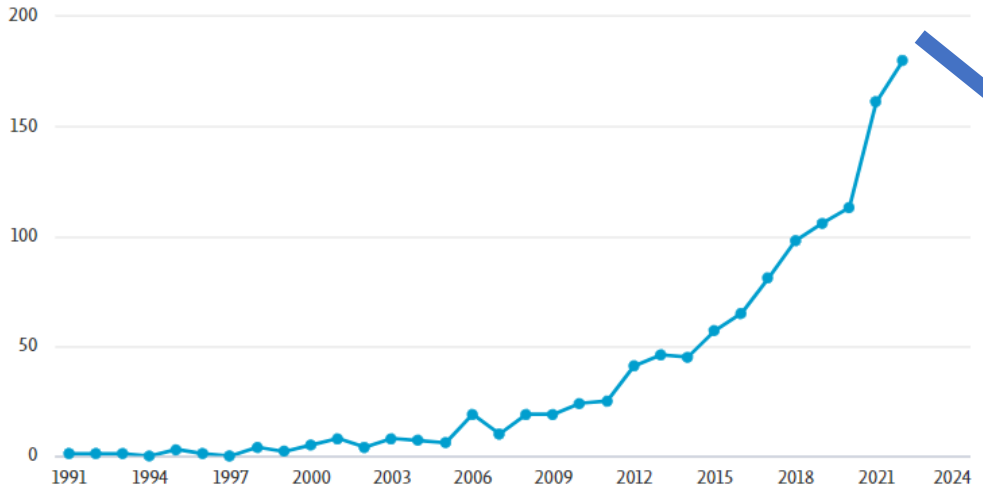
Quality assessment of life cycle inventory data for Composites

Badr Moutik

John Summerscales, Jasper Graham-Jones, and Richard Pemberton

UNIVERSITY OF PLYMOUTH

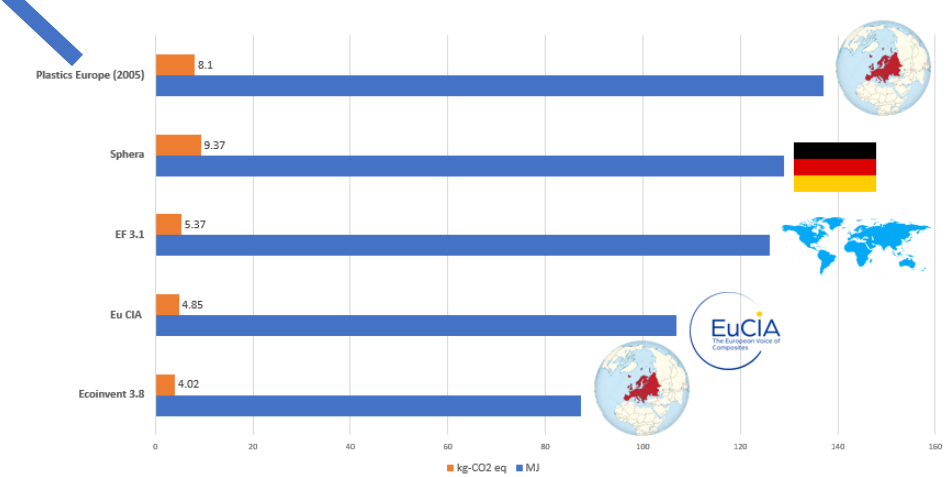
Background



Total: 1160 documents

Data quality assessment?

Potential for misleading composites LCA results and inaccurate conclusions/interpretations



MARINESHIFT360

Eco Impact Calculator By EuCIA

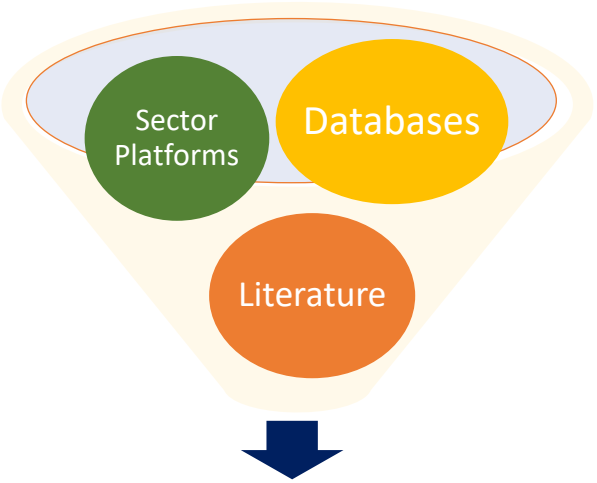
Aim

- To conduct a data quality assessment of key composite materials life cycle inventory “LCI” datasets

- To identify opportunities for enhancing the data quality of composites materials LCI datasets

Part of ongoing Ph.D. research: Life Cycle Assessment of Luxury Yacht Manufacture

Methodology



Composites Materials

LCA Data Collection

Data Selection → Data Preliminary Assessment → Data sources analysis → LCA data quality assessment; Case Study Scenario analysis; Uncertainty analysis → Acceptability & Interpretation

LCA is the “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” *(ISO,2006)*

Data Quality in LCA

ISO 14040/44:2006

"the characteristics of data
that relate to their ability
to satisfy **stated requirements**"

"**Data Quality requirements**
shall be specified to enable
the **goal** and **scope** of the LCA to be **met**"

LCA Data Quality Requirements

"where a study is intended to be used in comparative assertions intended to be disclosed to the public, the [following] data quality requirements" shall be addressed, *(ISO,2006)*

Time-related coverage	Geographical coverage	Technology coverage	Precision
Consistency	Uncertainty	Representativeness	Reproducibility
	Sources of the data	Completeness	

Data Quality in LCA:
open interpretation?

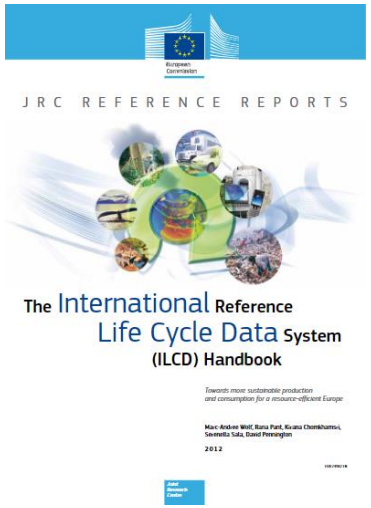
ISO 14040/44:2006

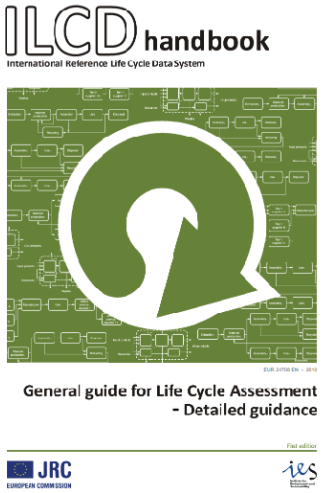
Flexibility in determining the approach for addressing DQA-specific areas

It does not specify to which component, or level, data quality analysis should be applied

↓

Main methodologies for LCI data quality assessment (DQA)





U.S Life Cycle Inventory Database

Pedigree matrix

Indicator score	1	2	3	4	5 (default)
Reliability	Verified[3] data based on measurements[4]	Verified data partly based on assumptions *or* non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered *or* >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered *or* some sites but from shorter periods	Representativeness unknown or data from a small number of sites *and* from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown *or* distinctly different area (North America instead of Middle East, OECD Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale or from different technology

Major LCI data sources

softwares

databases

sector platforms

literature

SimaPro

ecoinvent

Eco Impact Calculator By EuCIA

literature

openLCA

JRC EUROPEAN COMMISSION

MARINESHIFT360

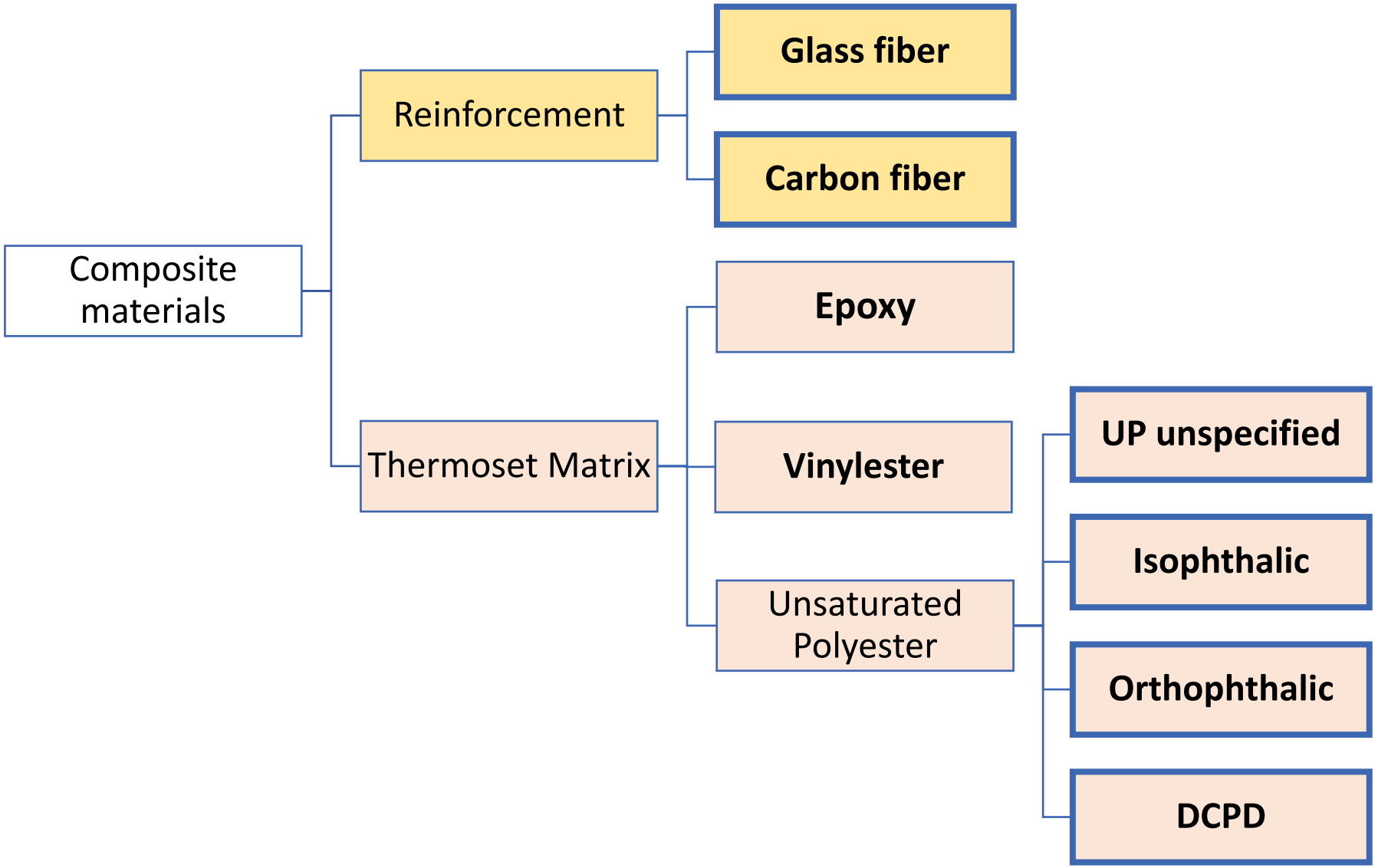
FEDERAL LCA COMMONS

thinkstep GaBi

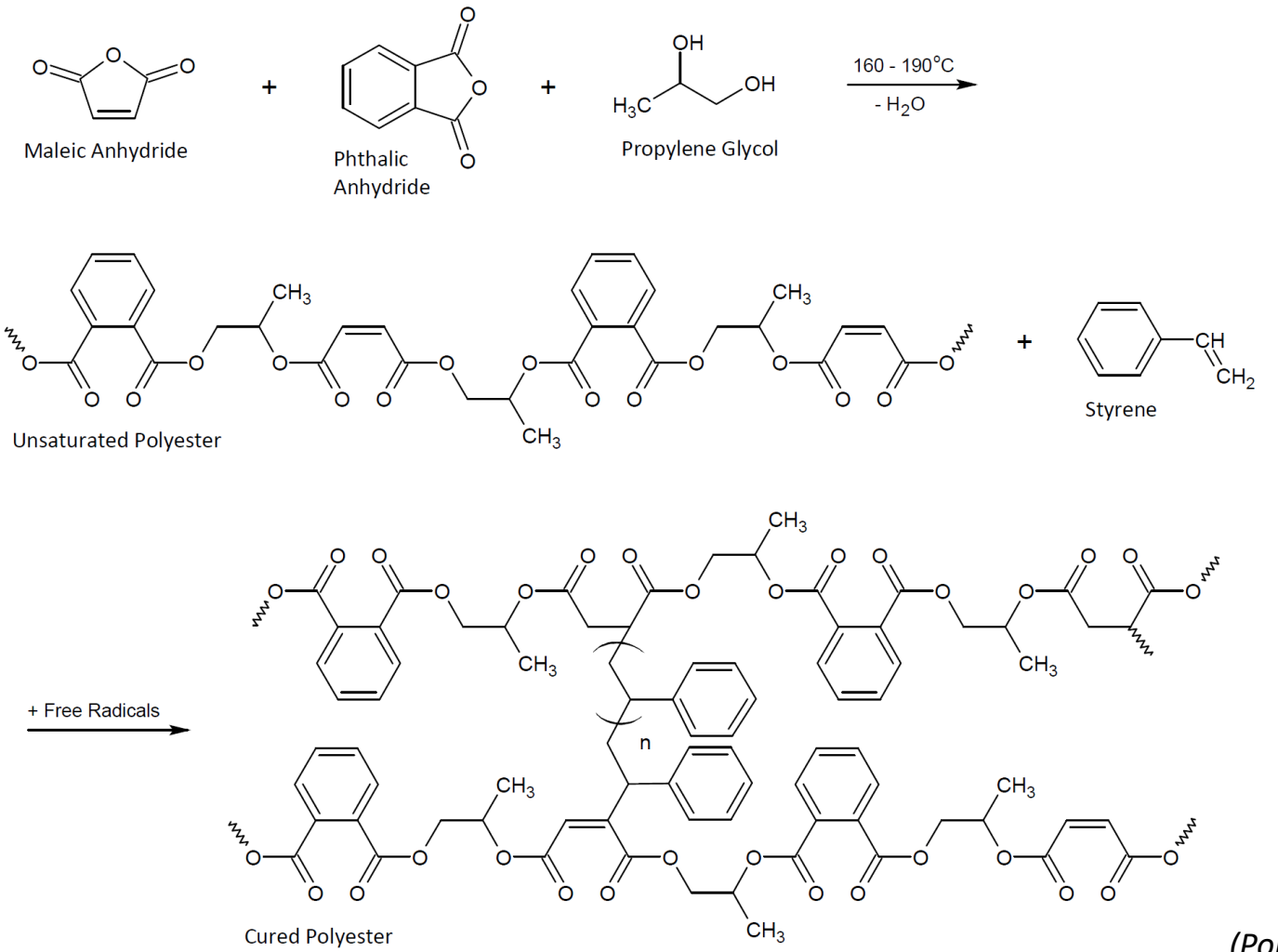
sphera®

Fiber Reinforced Composite Materials

Fiber Reinforced Composite Materials



Unsaturated polyester resin formulation



(Polymerdatabase, 2022)

Unsaturated polyester resin process data set

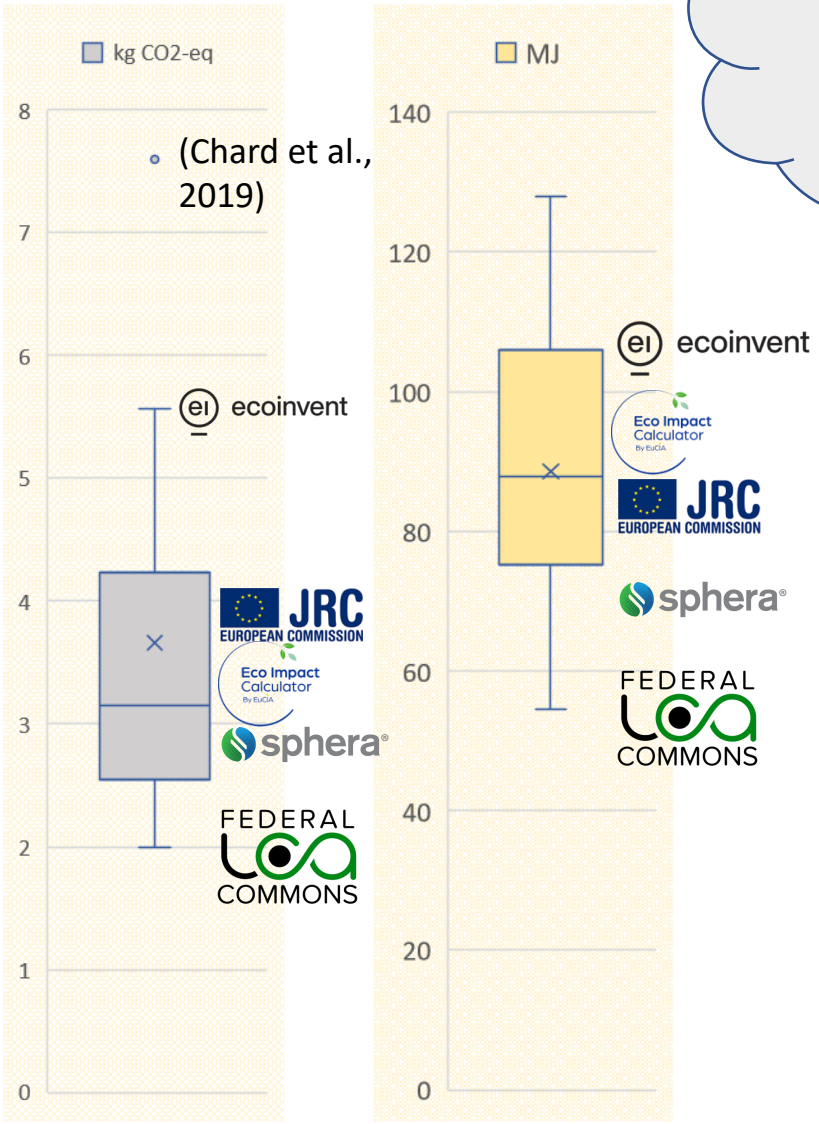
Ecoinvent/MS360
acetic anhydride
adipic acid
chemical factory, organics
electricity, medium voltage
ethylene glycol
heat, district or industrial, natural gas
heat, district or industrial, other than natural gas
phthalic anhydride
propylene glycol, liquid
Water, cooling, unspecified natural origin
Water, unspecified natural origin

Sphera
Electricity grid mix
Thermal energy from natural gas
Propylene glycol
Maleic anhydride (MA) (from n-butane)
Phthalic anhydride (by oxidation of xylene)
Styrene (ESBM dehydrogenation)
Nitrogen (gaseous)
Water (desalinated; deionised)
Catalyst

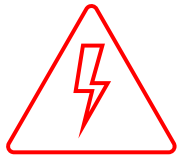
Eu Cia
Dicyclopentadiene based unsaturated polyester resin
Isophthalic acid based unsaturated polyester resin
Orthophthalic acid based unsaturated polyester resin
Maleic unsaturated polyester resin production

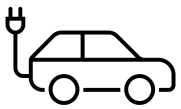
USLCI
Diesel, combusted in industrial equipment - RNA
Disposal, solid waste, unspecified, to municipal incineration
Disposal, solid waste, unspecified, to sanitary landfill
Disposal, solid waste, unspecified, to waste-to-energy
Electricity, at grid - RNA
Ethylene glycol, at plant, kg
Ethylene glycol, at plant, kg
Ethylene, at plant, kg
Maleic anhydride, at plant
Natural gas, combusted in industrial boiler - RNA
Neo pentyl glycol, at plant
Petroleum coke, at refinery - RNA
Phthalic anhydride, at plant
Polyethylene terephthalate, PET, virgin resin, at plant, kg
Propylene Glycol, liquid, at plant
Propylene Glycol, liquid, at plant
Purified terephthalic acid, PTA, at plant, kg
Purified terephthalic acid, PTA, at plant, kg
Styrene, at plant - RNA
Tetrabromophthalic acid, at plant
Transport, combination truck, diesel powered - RNA
Transport, train, diesel powered - RNA
Water

UP resin unspecified (per kg)



73 MJ is the average energy consumed by an electric car in about two and half days ~ 100 km



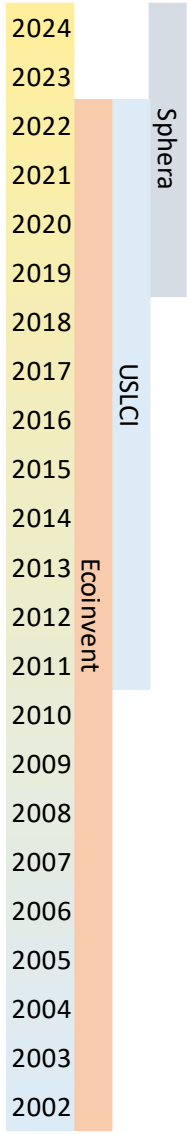


73 MJ is the energy consumed by an average household for a two and half days

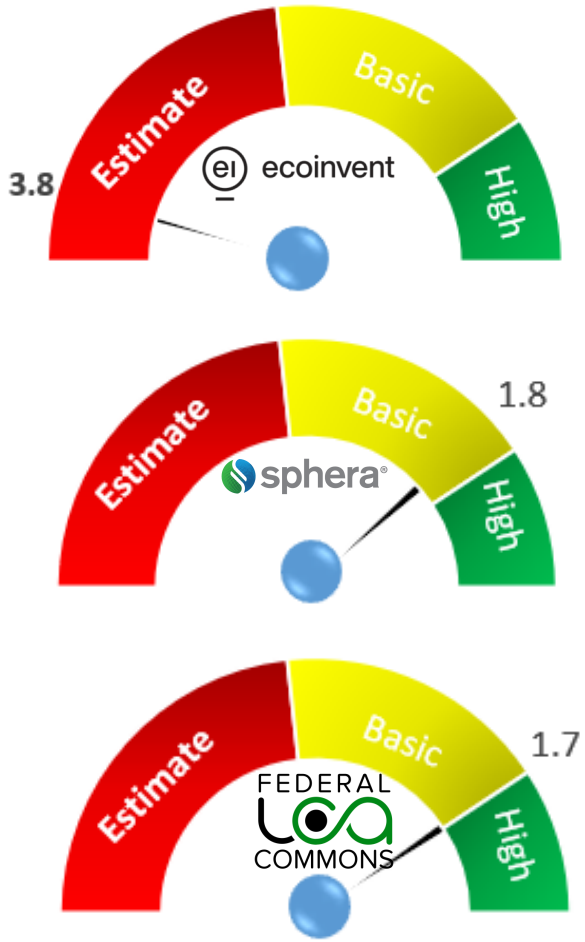
Data variation of 74 MJ for 1 kg of UP resin

DQA: Unsaturated Polyester Resin Unspecified

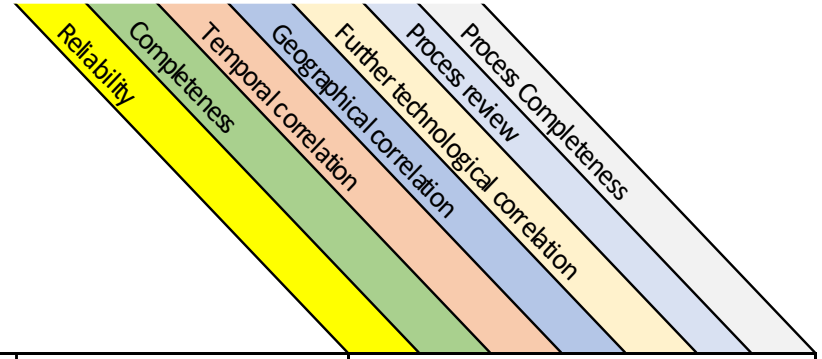
Data time reference



ILCD



Pedigree matrix/US EPA process

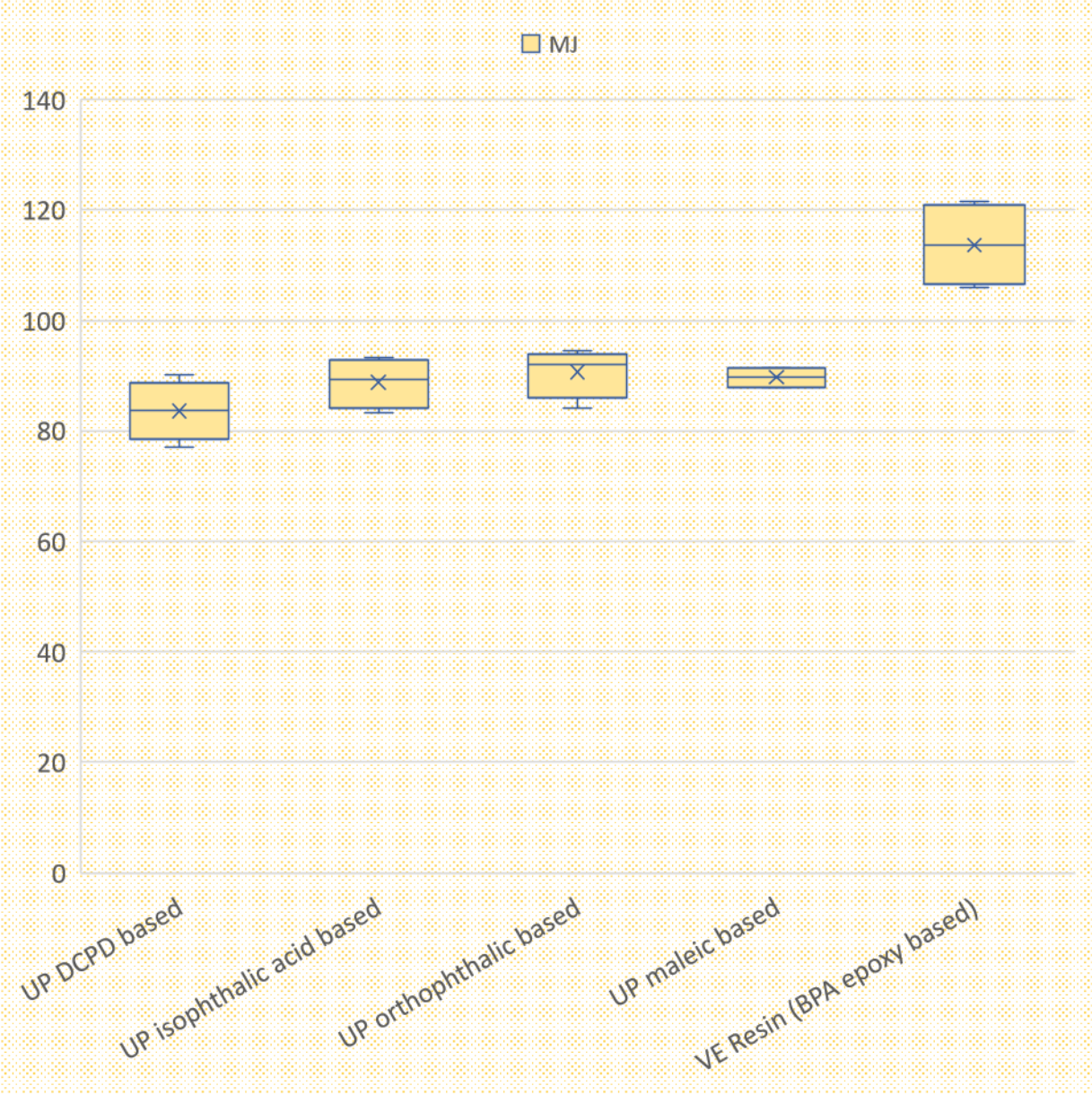


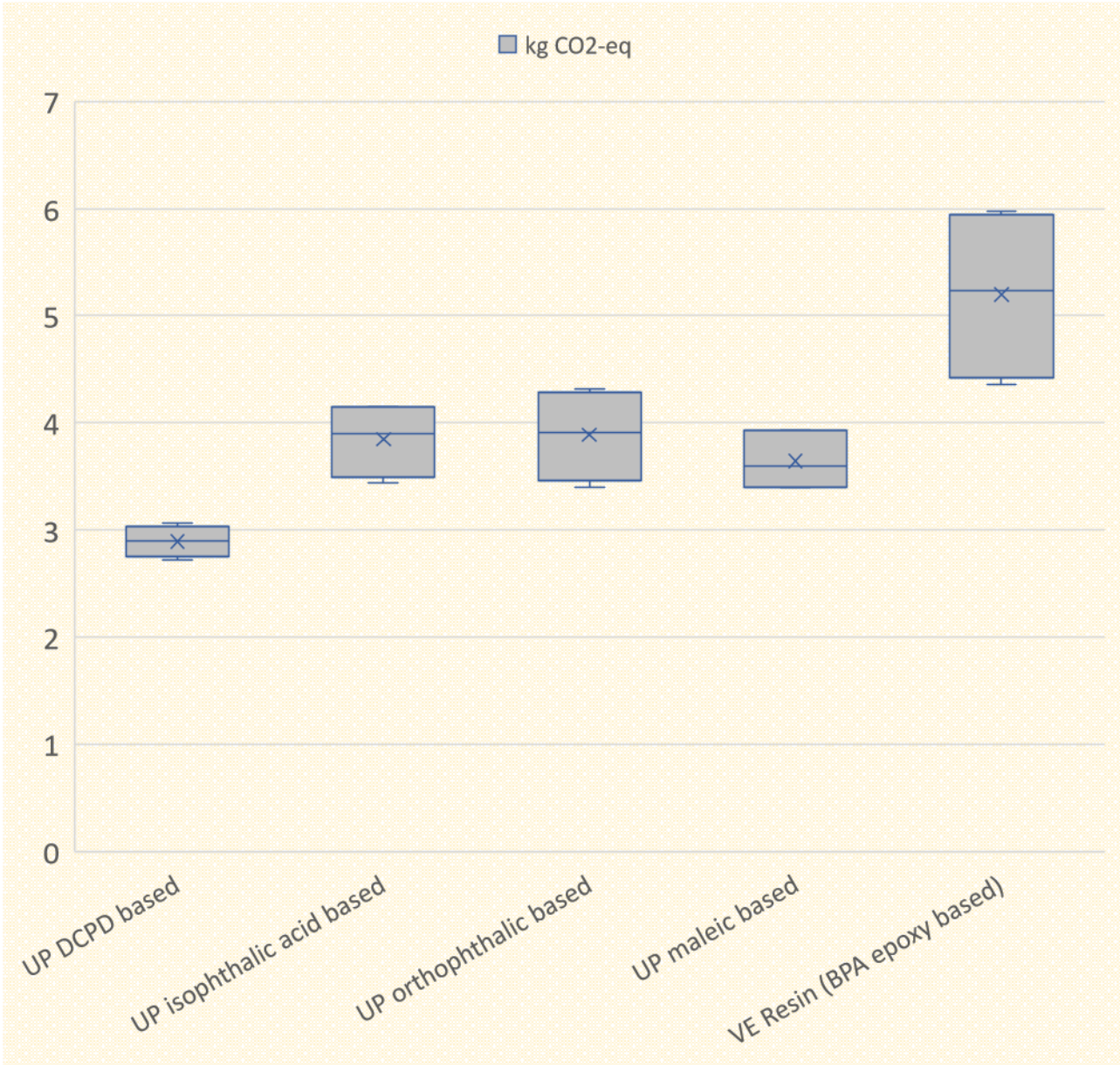
Original Document	Databases/Platforms	Data quality index						
		Pedigree					US EPA	
Life cycle inventories of chemicals	Ecoinvent/MS360	3.5	5	5	2	3.4	4	5
Life Cycle Inventory of Polymer Composites	USLCI	1	2	1	1	1	2	2
DE: Polyester Resin Unsaturated (UP)	Sphera	2	3	2	2	1	2	5
Background report V2.0	Eu Cia	4	5	5	5	5	4	5

Good ← → Poor

1	2	3	4	5

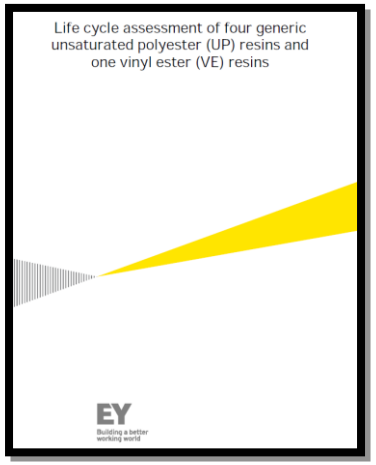
Orthophthalic acid/Isophthalic acid/DCPD/Maleic UP Resin - BPA epoxy-based vinyl ester resin (per kg)





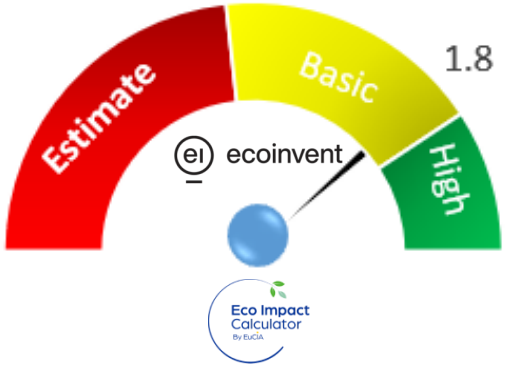
DQA: Orthophtalic acid based - Isophtalic acid based - DCPD based - Maleic - BPA epoxy based vinyl ester resin

Main common source:

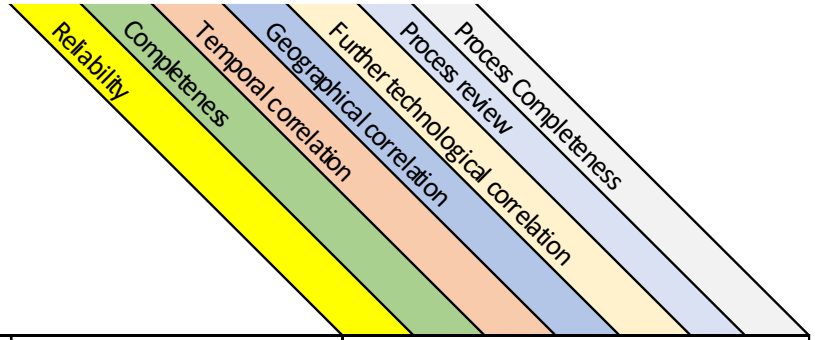


Data time reference

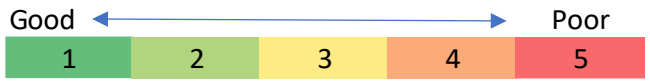
ILCD



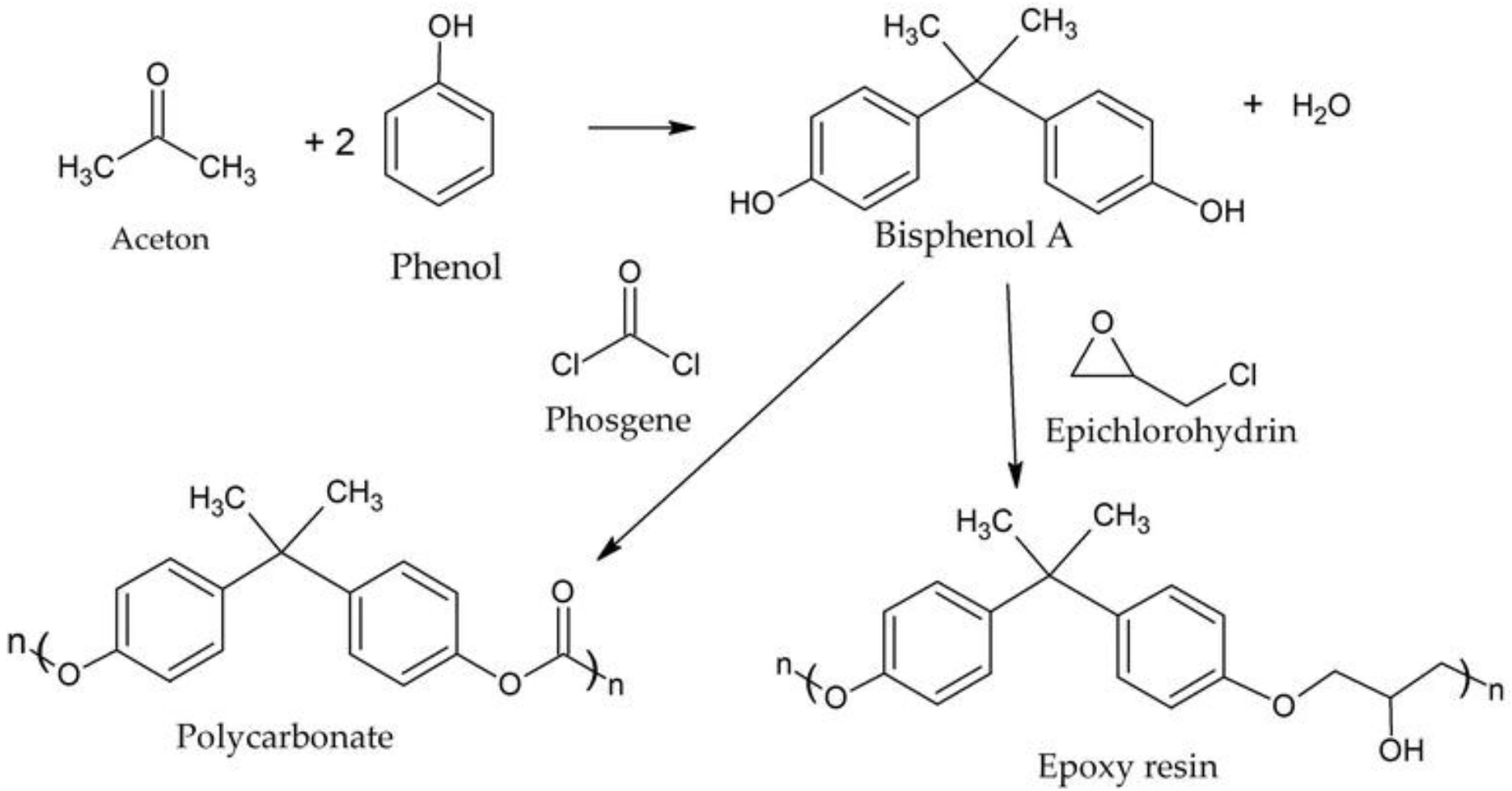
Pedigree matrix/US EPA process



Original Document	Databases/Platforms	Data quality index						
		Pedigree					US EPA	
Orthophtalic acid based UP resin (Rietveld and Hegger (2014))	Ecoinvent/MS360/ Eu Cia	1.3	3.2	2.3	1.1	1.4	4	5
Isophtalic acid based UP resin (Rietveld and Hegger (2014))		1.3	3.2	2.3	1.1	1.4	4	5
DCPD based UP resin (Rietveld and Hegger (2014))		1.3	3.2	2.3	1.1	1.4	4	5
Maleic UP resin (Rietveld and Hegger (2014))		1.3	3.2	2.3	1.1	1.4	4	5
BPA epoxy based vinyl ester resin (Rietveld and Hegger (2014))		1.3	3.2	2.3	1.1	1.4	4	5



Epoxy resin formulation



Epoxy resin process data set

Ecoinvent 3.9/Eu Cia
bisphenol A, powder
chemical factory, organics
electricity, medium voltage
epichlorohydrin
heat, district or industrial, natural gas
heat, from steam, in chemical industry
nitrogen, liquid
sodium hydroxide, without water, in 50% solution state
tap water
wastewater, average
wastewater, average

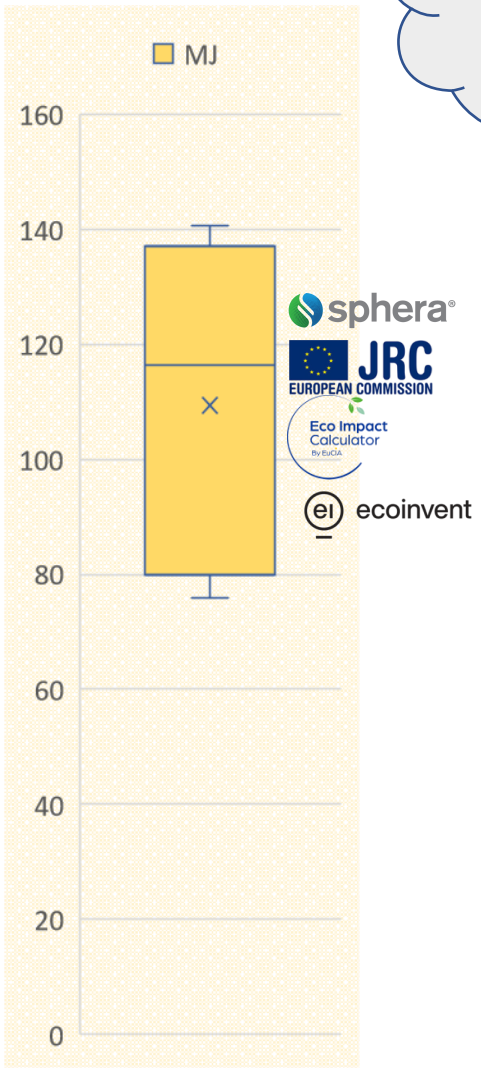
Sphera DE
Electricity grid mix
Water (desalinated; deionised)
Epichlorohydrin (by product calcium chloride, hydrochloric acid)
Bisphenol A
Isopropanol
Hydrochloric acid (100%) by-product epichlorohydrine, calcium chloride
Nitrogen (gaseous)
Sodium hydroxide (caustic soda) mix (100%)
Catalyst
Hazardous waste (non-specific) (C rich, worst case scenario incl. landfill)

Sphera RER/Plastics Europe
Diesel, combusted in industrial equipment - RNA
Bisphenol A by (phenol) (Acetone)
Epichlorohydrin by (allyl chloride) production
Natural Gas Production
Crude Oil production
Solvent
Sodium hydroxide

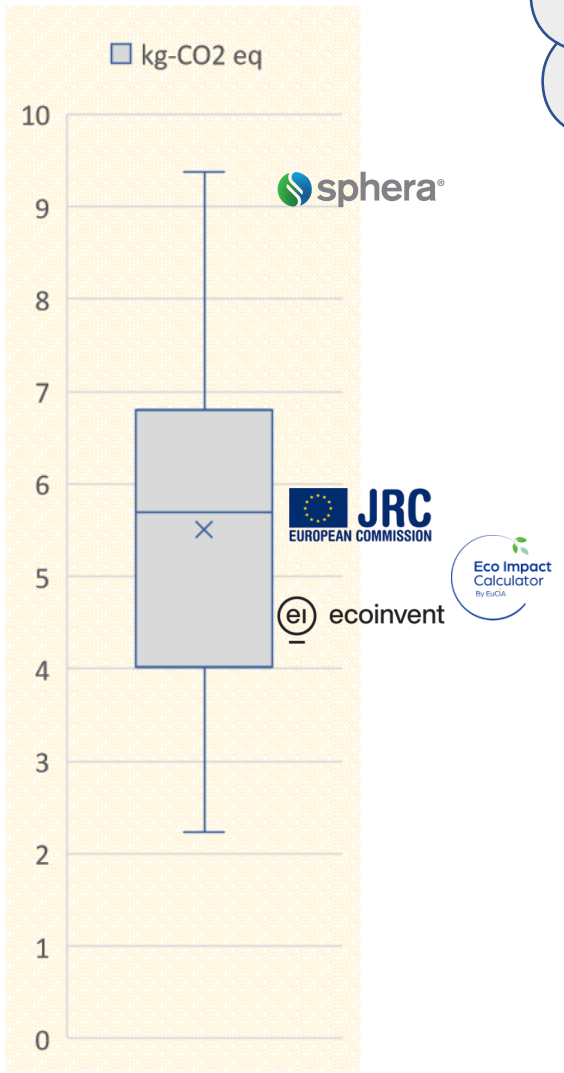
Ecoinvent 3.5
bisphenol A, powder
chemical factory, organics
electricity, medium voltage
epichlorohydrin
heat, district or industrial, natural gas
heat, from steam, in chemical industry
nitrogen, liquid
sodium hydroxide, without water, in 50% solution state
tap water
wastewater, average
wastewater, average

Epoxy resin (per kg)

A range of 64 MJ

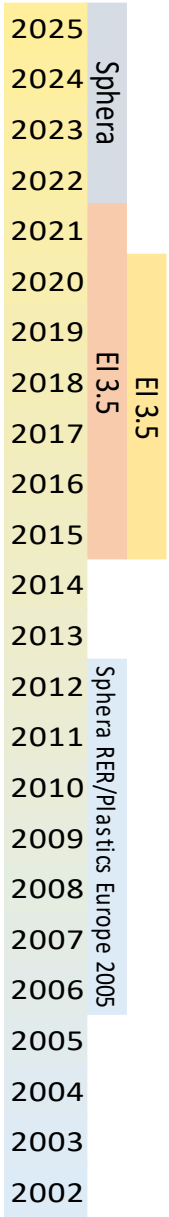


A range of 7.13 kg CO2 eq



DQA: Epoxy Resin

Data time reference



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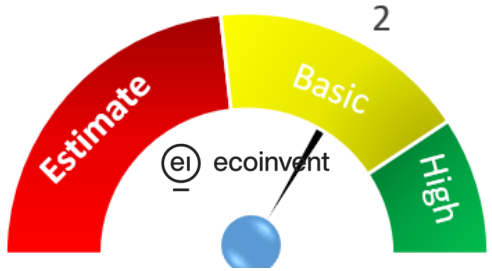
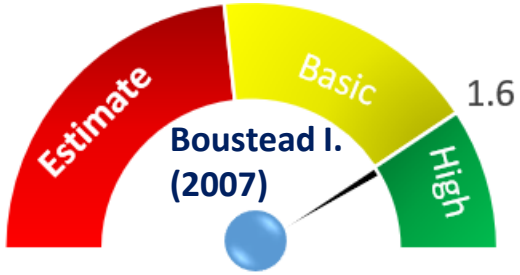
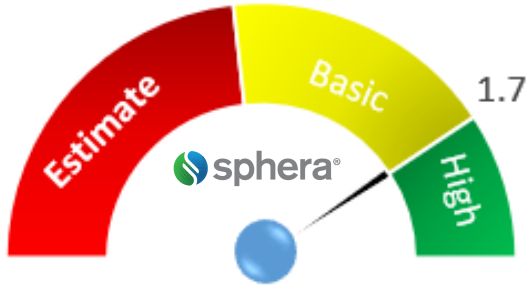


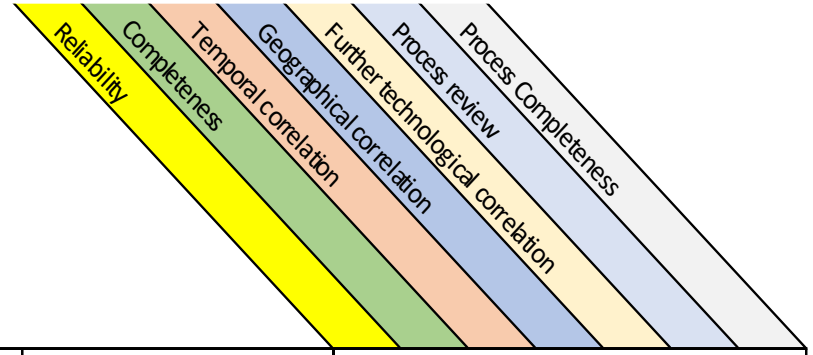




Main common source:

PLASTICS EUROPE

Pedigree matrix/US EPA process



Original Document	Databases/Platforms	Data quality index						
		Pedigree					US EPA	
Epoxy resin production - RER (obsolete)	Ecoinvent 3.5	2	3	2	2	3	4	5
Epoxy resin production, liquid - RER	Ecoinvent 3.9	2	3	2	2	3	4	5
LIQUID EPOXY RESINS by I Boustead. 2007/PlasticsEurope	Sphera/Ecoinvent	1	3	2	1	1	2	2
Epoxy resin production, liquid - DE/Sphera	Sphera	2	3	2	1	2	2	1

Good ← → Poor

1 2 3 4 5

Glass fiber input process data set

Ecoinvent 9.5
Aluminium oxide
Boric acid, anhydrous, power
Chemical, organic
Clay
Flat glass factory
Fluorspar
Lime
Lubricating oil
Nylon 6
Silica Sand
Silicone product
Tap water
Electricity
Heat, natural gas

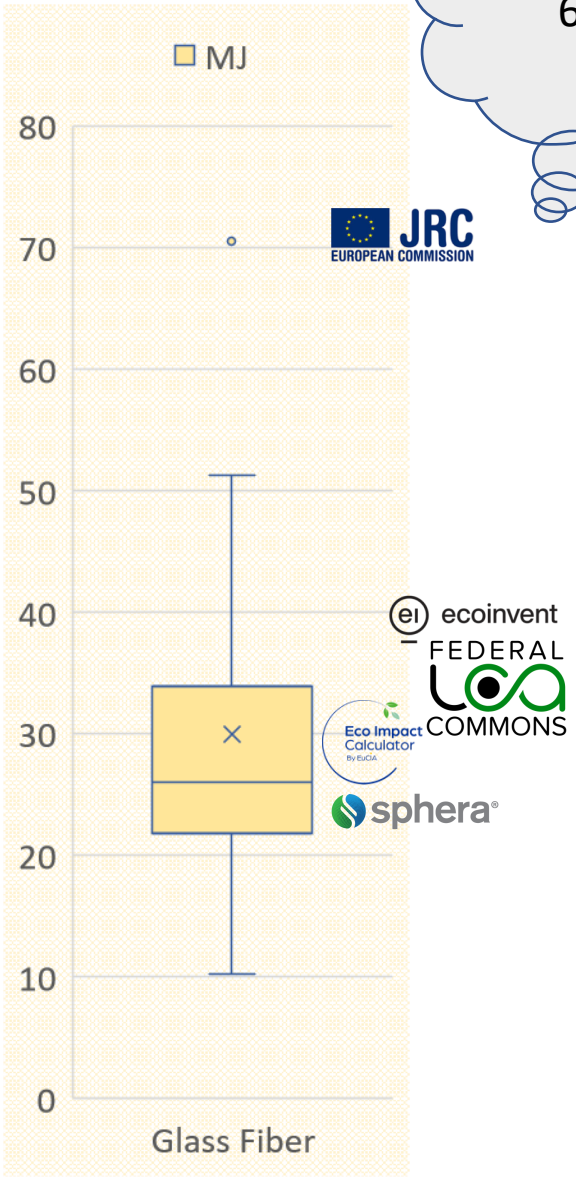
USLCI
Boric acid
Calcium borates
Clay
Electricity
Epoxy resin
Ethylene glycol
Limestone
Liquefied petroleum gas
Natural gas, in boiler
Quicklime
Residual fuel oil
Silicone dioxide
Soda power
Transport combination truck
Transport
Water

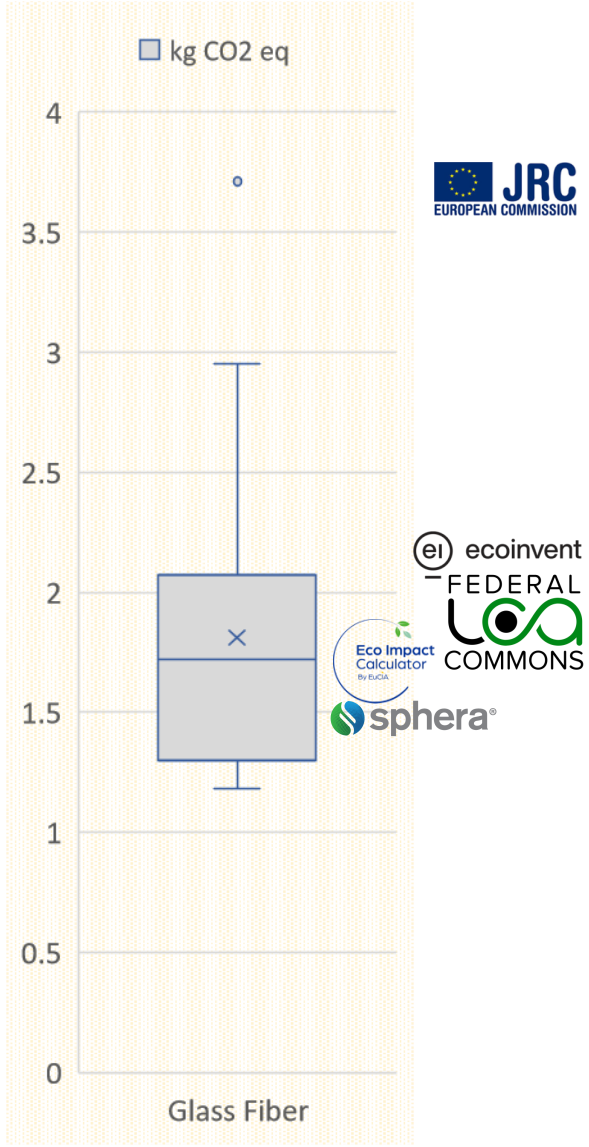
Sphera
Quartz sand
Colemanite
Clay
Fluorspar
Limestone flour
Phenolic resin
Dolomite
Electricity
Natural gas
Lubricants at refinery
Kaolin

GFE
Silica sand
Kaolin
Limestone
Dolomite
Electricity
Natural gas
Chemicals

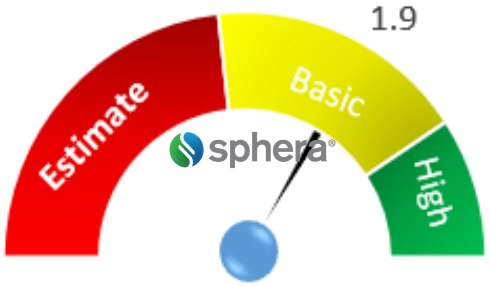
Glass fiber composites (per kg)

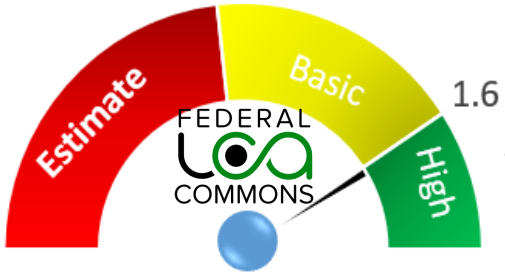
A range of 60.2 MJ

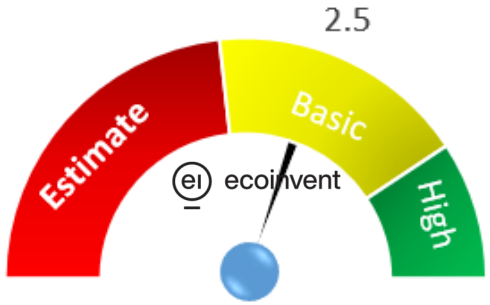


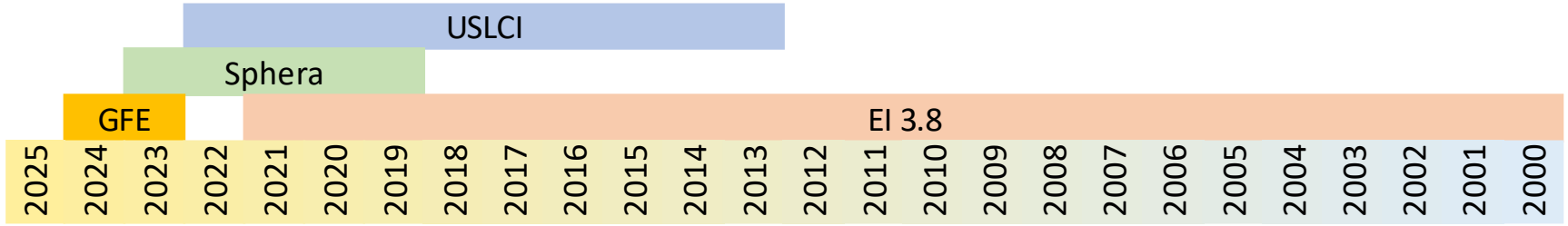


DQA: Glass fiber









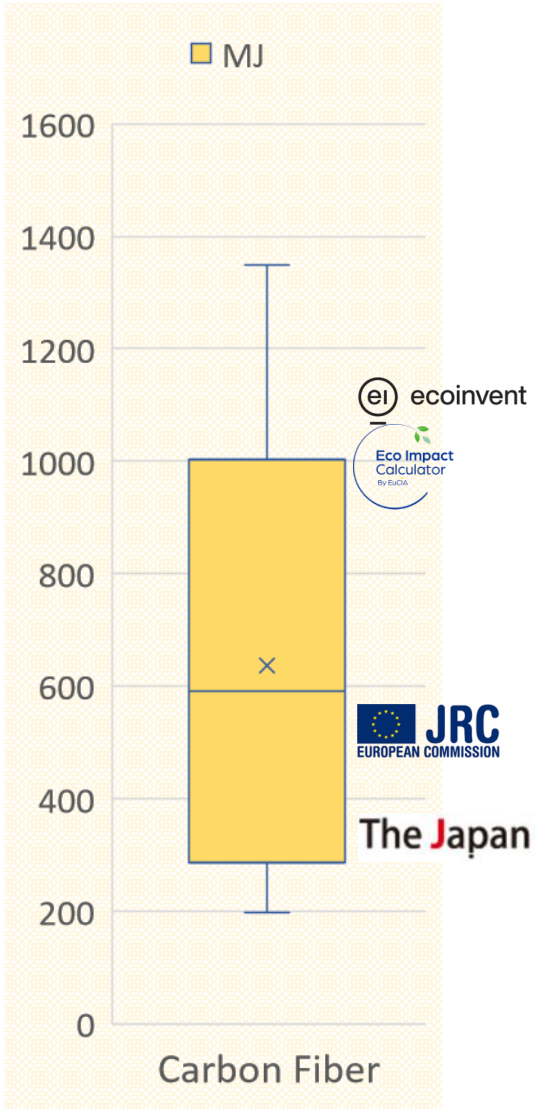
Original Document	Databases/Platforms	Data quality index						
		Pedigree					US EPA	
		Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Process review	Process Completeness
Life cycle assessment of CFGF – Continuous Filament Glass Fibre Products by pwc	EuCia	1	2	2	1	1	2	1
DE: Glass fibres	Sphera	2	2	2	1	2	2	1
E-glass, US	USLCI	1	2	2	1	1	2	1
Life cycle inventories of building prodcuts – Ecoinvent Data v2.0 by Hishier R. 2007, Glass fiber production	Ecoinvent/MS360	1.4	1.6	5	1.4	1.3	2	5
Life cycle inventories of building prodcuts – Ecoinvent Data v2.0 by Hishier R. 2007, GRP Polyester resin hand lay up	Ecoinvent	4	4	5	3	1	2	5
Life cycle inventories of building prodcuts – Ecoinvent Data v2.0 by Hishier R. 2007, GRP Polyester resin injection moulding	Ecoinvent	4	4	5	3	1	2	5

Good ← → Poor

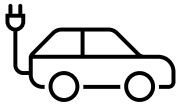
1 2 3 4 5

Carbon fiber (per kg)

A range of
1150 MJ



equivalent to the average energy consumed by an electric car in about one month and half ~ 1157 km



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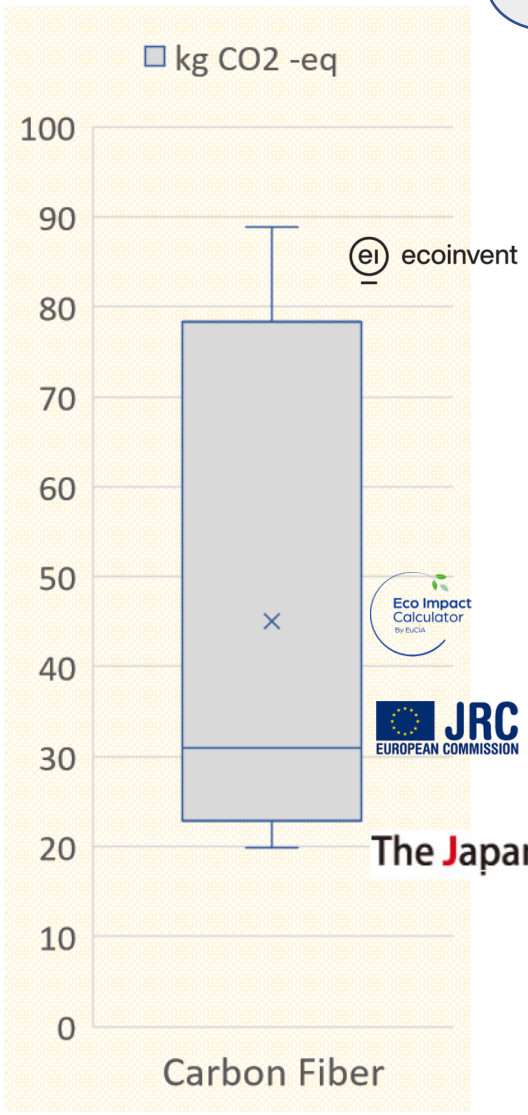
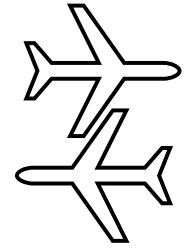
A range of
70 kg CO2 eq



equivalent to the carbon footprint of a short domestic flight of 367 km

~ Glasgow - Belfast



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Carbon fiber input process data set

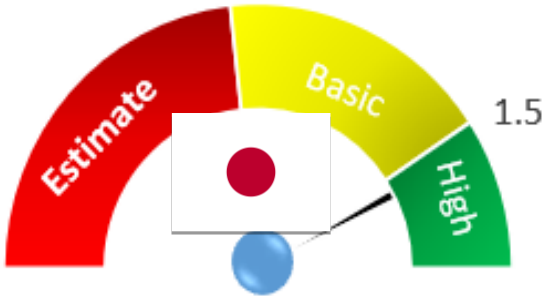
Ecoinvent 3.9 GLO
Acrylonitrile butadiene styrene co polymer GLO
chemical factory, organics
Injection moulding
Electricity, low voltage
heat, district or industrial, natural gas

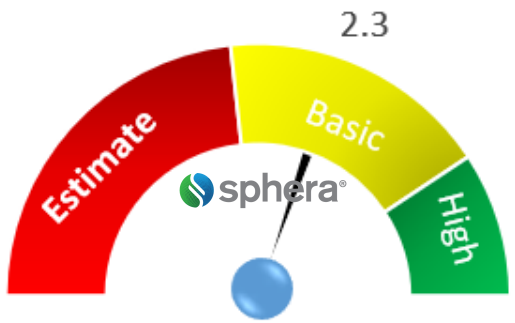
JCMA
Acrylonitrile (AN)
Comonomer
Polymerization catalyst
Solvent
PAN fiber oil (PG)
Carbon fiber sizing agent
Electrolyte (sulfuric acid)
Packaging film (PE)
tap water
Paper tube
Outer packaging material
Electricity Consumption
Steam Consumption
Fuel consumption
Utility gas (nitrogen)
Water consumption

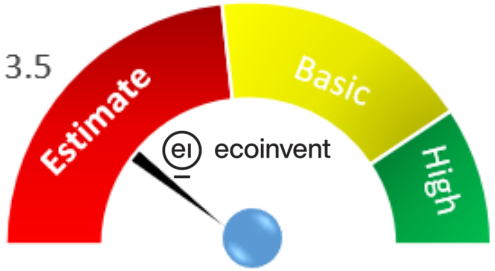
Eu Cia
Polyacrylonitrile fibres (PAN) from acrylonitrile and methacrylate, prod. mix
Water, decarbonised
Epoxy resin, liquid
Sulfuric acid
Ammonium bicarbonite
Polydimethylsiloxane
Unwinding primary electricity
Oxidation primary electricity
Carbonization LT primary electricity
Carbonization HT primary electricity
Exhaust gas treatment primary electricity
Elektrolysis primary electricity
Elektrolysis primary gas
Washing primary electricity
Washing primary gas
Drying-II primary electricity
Drying-II primary gas
Spooling primary electricity
Spooling primary gas

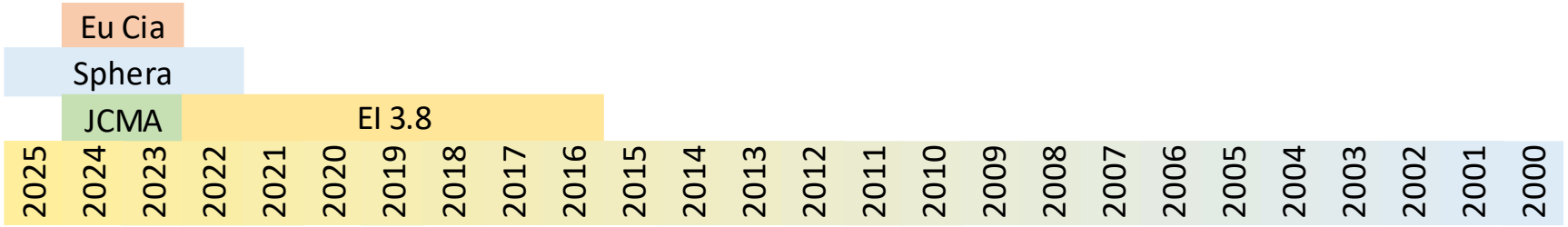
Sphera RER
Polyacrylonitrile Fibres (PAN)
Epoxy Resin (EP)
Hexamethylenediamine (HMDA; from acrylonitrile via adiponitrile)
Nitrogen (gaseous)
Ammonium hydrogen carbonate (Ammonium bicarbonate)
Deionised water- open input electricity
Deionised water- open input electricity
Electricity grid mix

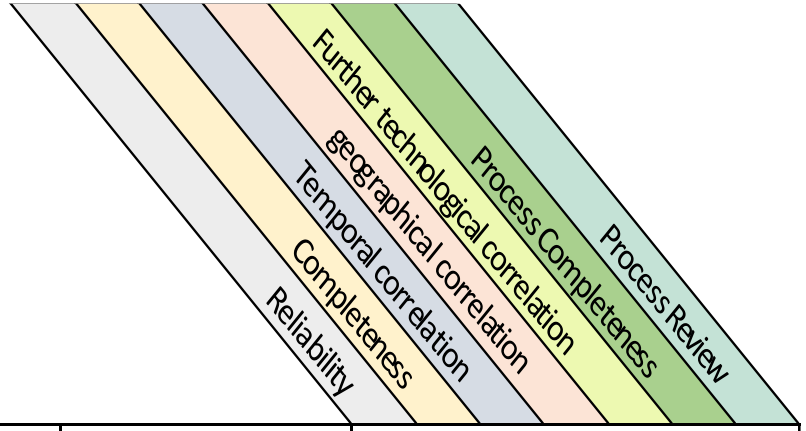
DQA: Carbon Fiber











Original document	Databases/Platforms	Data quality index						
		Pedigree					US EPA	
Carbon fibre reinforced plastic, injection moulded - GLO | Ecoinvent	Ecoinvent/MS360	4	5	4	5	4	5	2
Overview of LCI data for Carbon Fiber by JCMA	NA	1	2	1	1	1	2	1
Carbon fiber RER sphera	Sphera	3	3	2	1	3	1	2
Carbon Fiber by EuCia	EuCia	3	4	4	3	2	5	4

Good ← → Poor

1 2 3 4 5

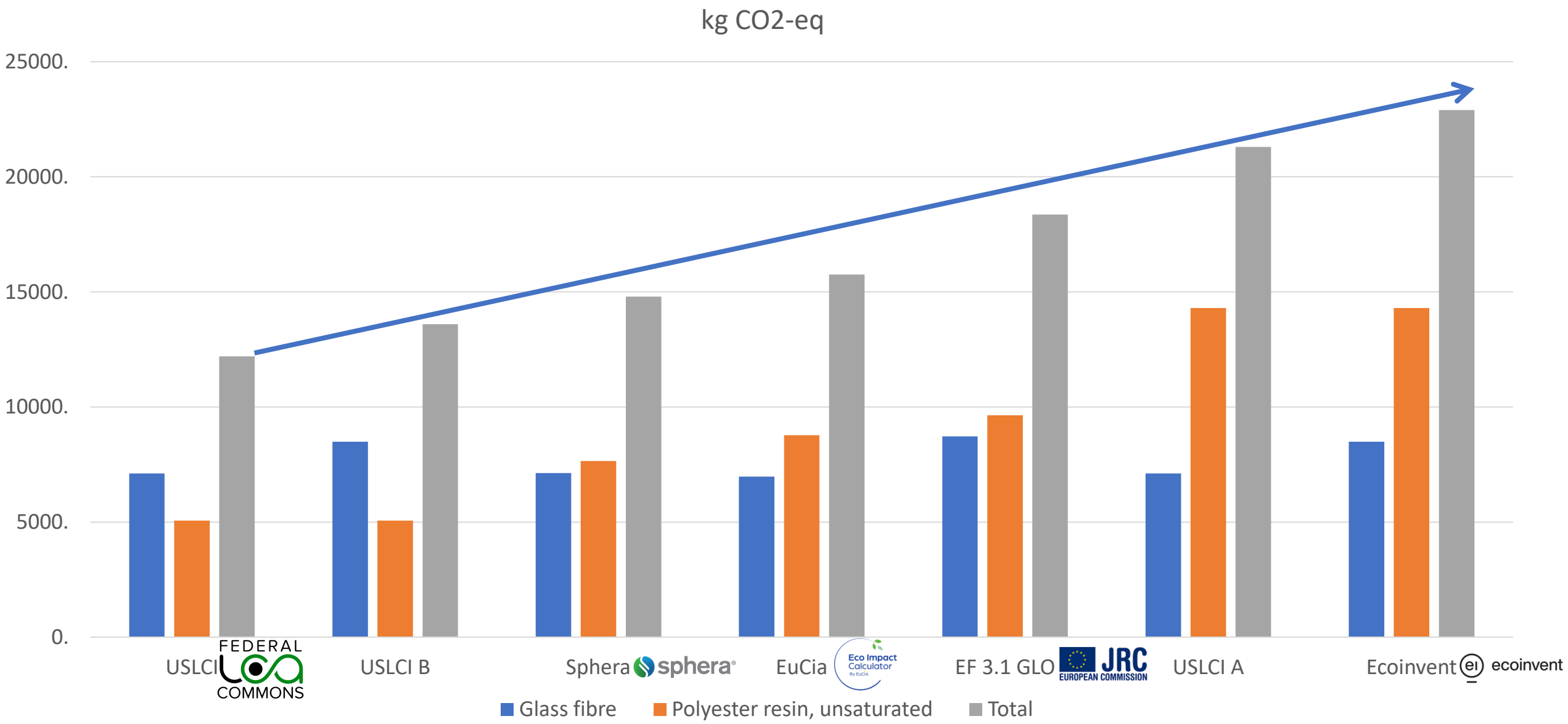
Case study / Scenario analysis

Fiberglass composite hull

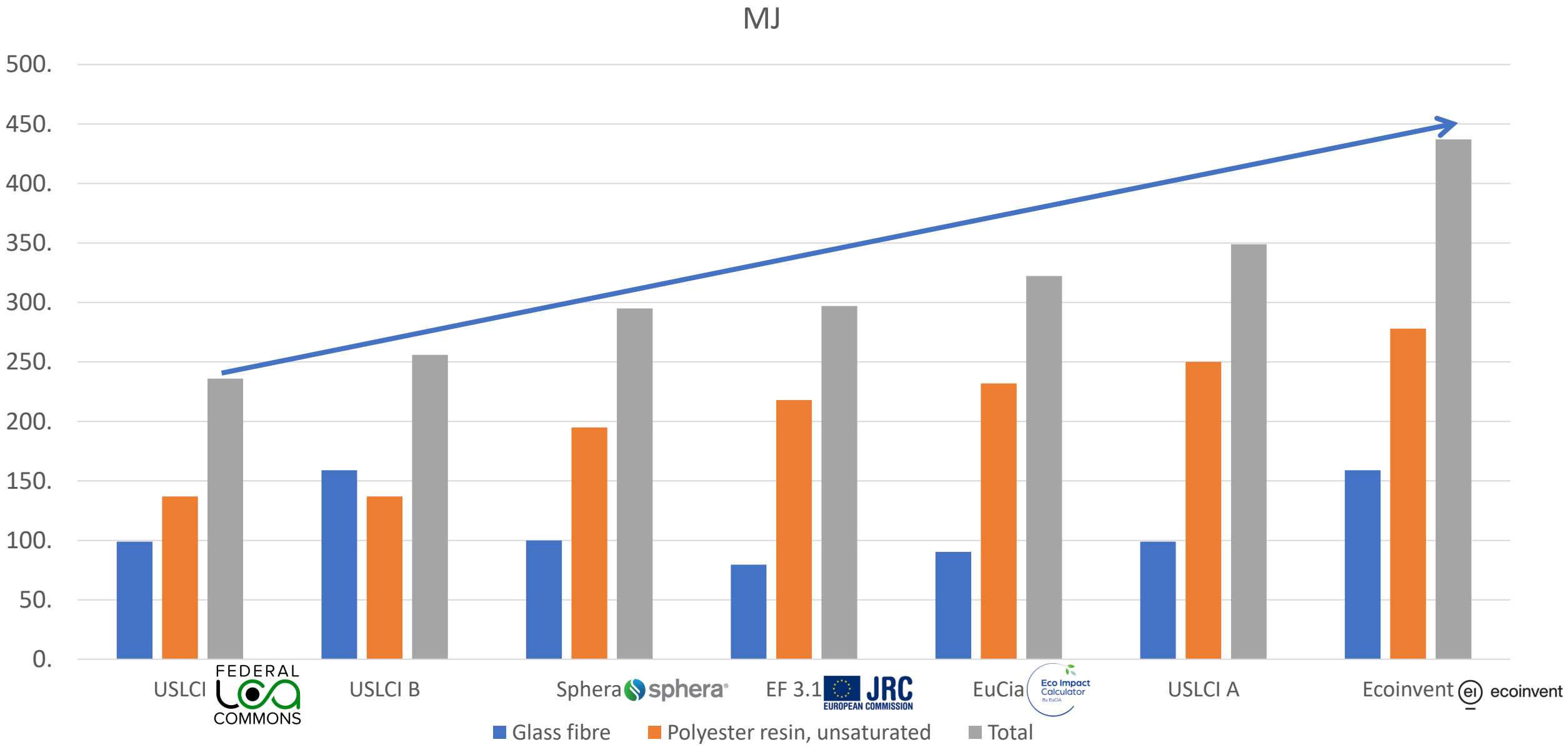
Materials	Total Weight (%)	MJ (%)	kg CO2-eq (%)
E-glass	**53**	29	31
UP Resin	29	**51**	**52**

Hull of outboard powerboats

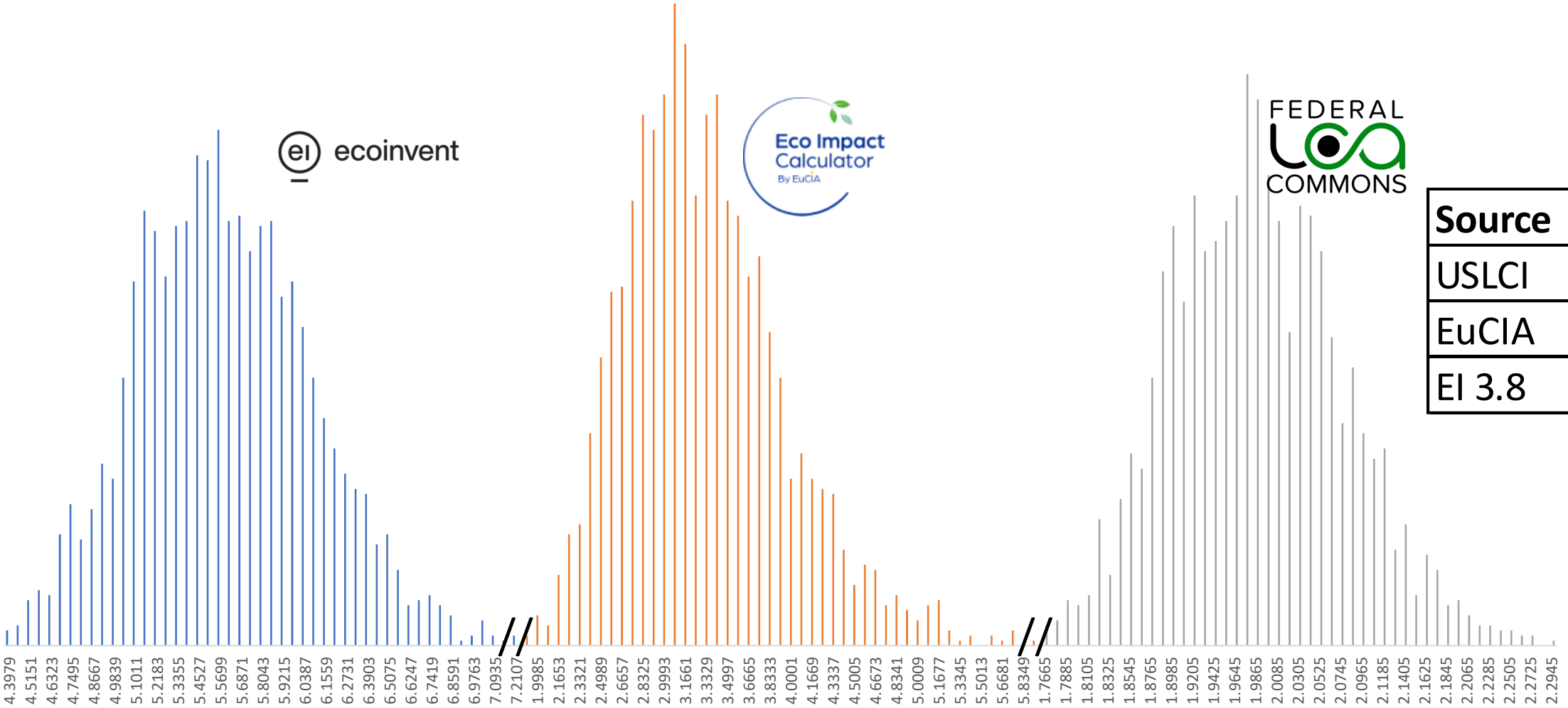
IPCC 2021 GWP (kg CO2-eq)



Cumulative energy demand (MJ)

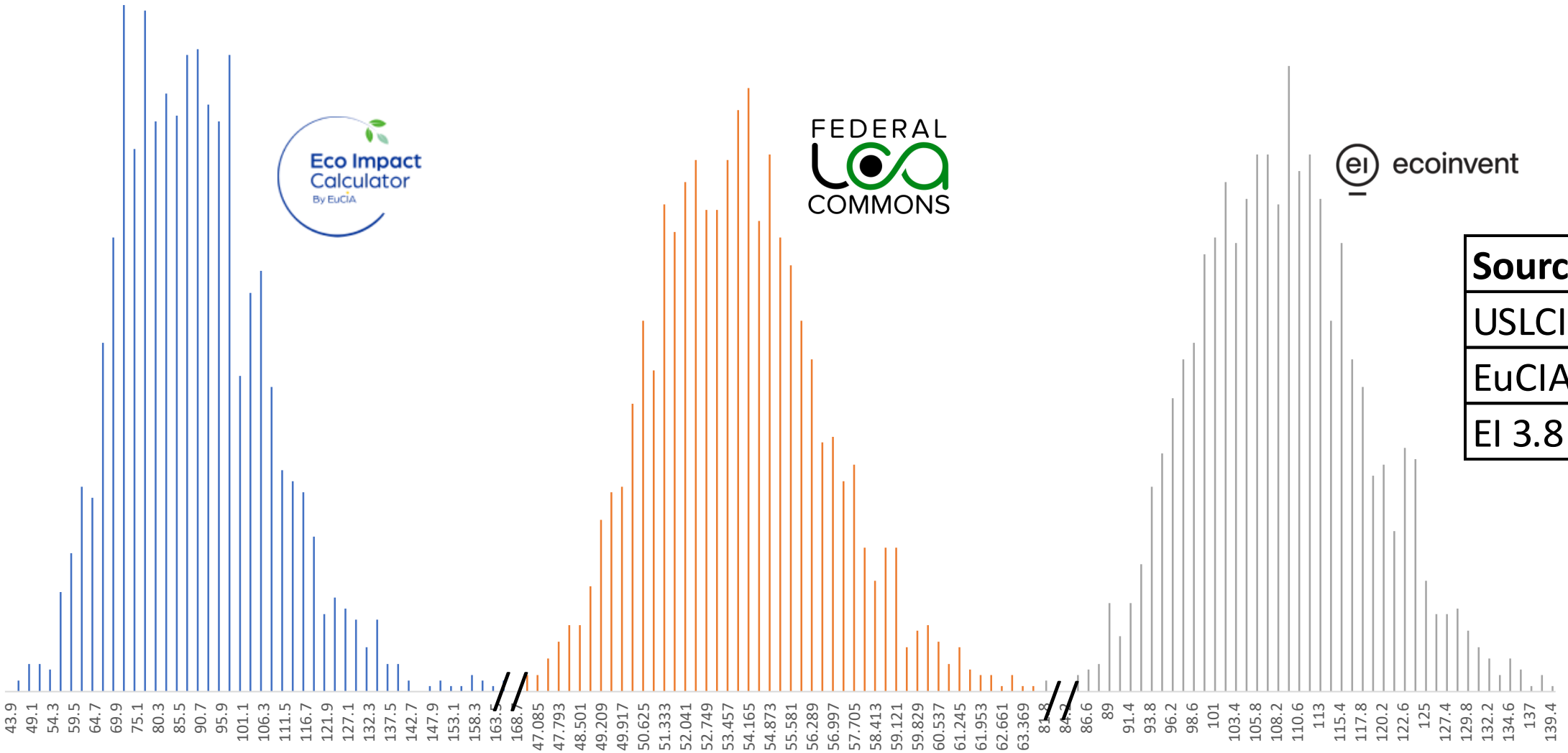


Uncertainty analysis /Monte Carlo simulation for UP resin
IPCC 2021 GWP



Source	CV
USLCI	4.31
EuCIA	15
EI 3.8	9.11

Uncertainty analysis /Monte Carlo simulation for UP resin
Cumulative energy demand (MJ)



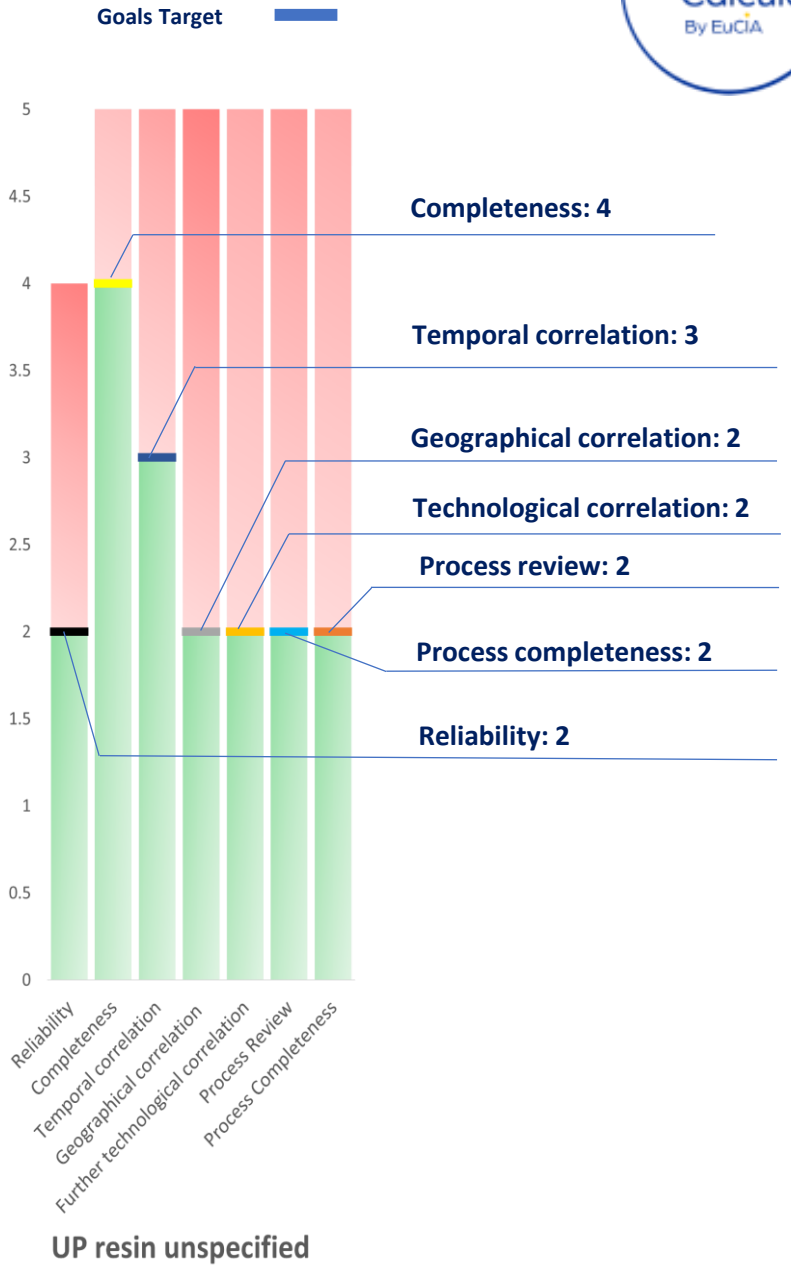
Source	CV
USLCI	5.33
EuCIA	20
EI 3.8	8.5

Common LCI data quality

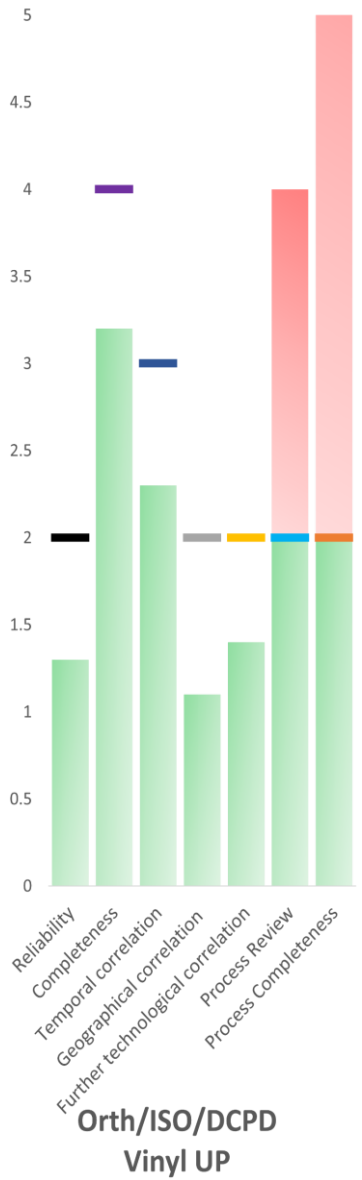
for Composites?

Time-related coverage	Geographical coverage	Technology coverage	Precision
Consistency	Uncertainty	Representativeness	Reproducibility
	Sources of the data	Completeness	Seen this before, Data quality requirements no change

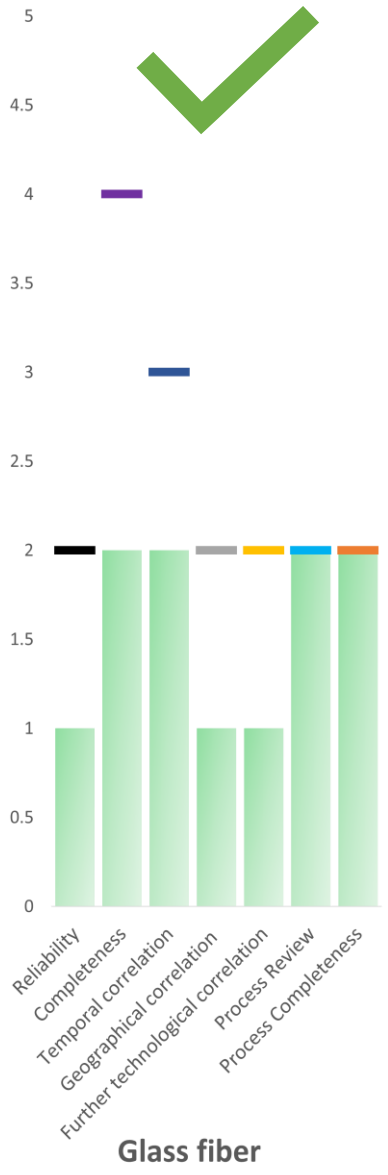
Acceptability



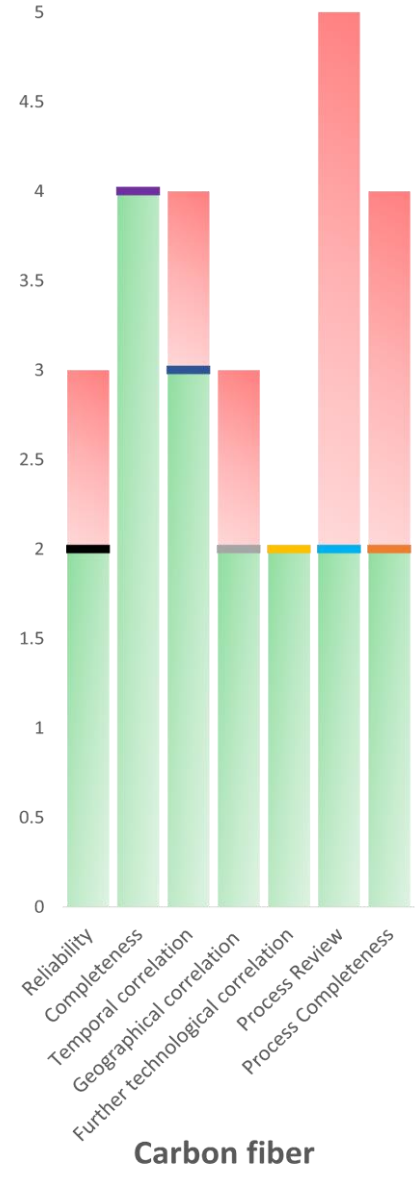
UP resin unspecified



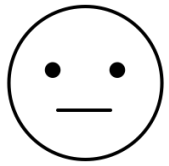
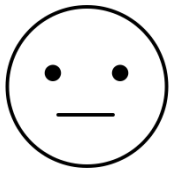
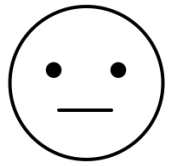
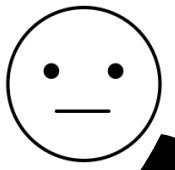
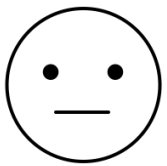
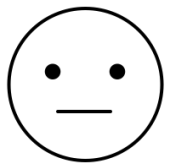
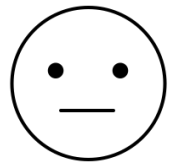
Orth/ISO/DCPD
Vinyl UP



Glass fiber



Carbon fiber

	UP resin unspecified	Ortho/ISO/DCPD/ Vinyl ester	Epoxy resin	Glass fiber	Carbon fiber
ecoinvent MARINESHIFT360					
FEDERAL LCA COMMONS					
sphera®					
EuCIA The European Voice of Composites					
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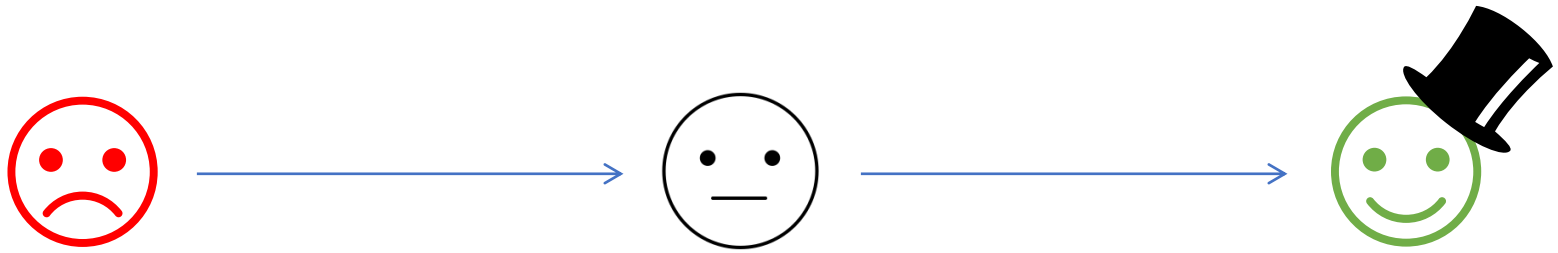
Conclusion and future work

- Defining a best-case LCI dataset or dataset range for composite materials (i.e., FU, SB…)
- Establishing acceptability criteria or "DQA goals" specific to composites LCI datasets in sector platforms would provide a standardized framework for evaluating data quality.
- The development of sector-specific guidelines for background data analysis would be valuable.
- Harmonizing the data quality assessment (DQA) methodology with the ILCD handbook, and to use in sector platforms datasets, would promote consistency and comparability in LCI data evaluations.



Southern Counties Materials, Minerals & Mining Society

Webinar

Southern Counties Materials Minerals

and Mining Society (SCMMMS) webinar

25 January 2024 (TBC)

Save the date, Join us

Thank you

UNIVERSITY OF PLYMOUTH