ENV 501 / GR A3 30

Material Flow Analysis and resource management

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Fall 2025

Course room
GR A3 30

Computer lab
CM 1 111

- **Laboratory on Human-Environment Relations in Urban Systems**

Last session

- Different spatial approaches
- Temporal analysis
- Spatial stock analysis

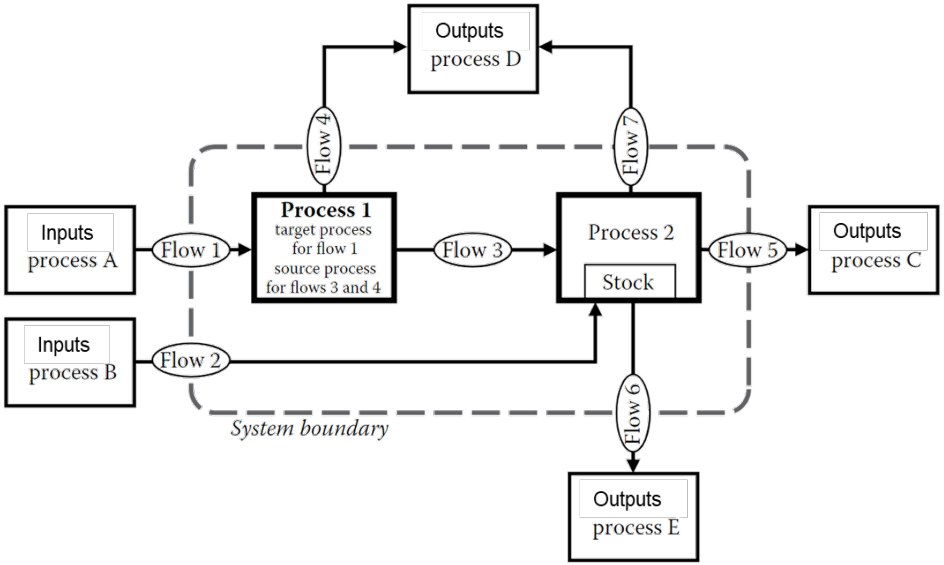
Course outline

		8:15 - 9:00 and 9:15 - 10:00		13:15 - 14:00	14:15 - 15:00
Block I: EW-MFA global / national	W1 - Sep 11	Introduction to the course and general concepts	All	Exercise	Project
	W2 - Sep 18	EW – MFA and EW – MFA in the Swiss context	External Guest – Florian Kohler	Exercise	Project
	W3 – Sep 25	Examples of EW – MFA. Scaling EW-MFA to Cantons	FMC	Exercise	Project
	W4 - Oct 02	Urban Metabolism and Circular Economy	FMC	Exercise	Project
Block II: MFA regional / urban	W5 - Oct 09	MFA method and the Stock-Flows-Service Nexus	CRB	Exercise	Project
	W6 - Oct 16	Dynamic MFA	CRB	Exercise	Project
	Oct 23	Autumn break			
	W7 - Oct 30	Applications of MFA – case study	External Guest – Guillaume Massard	Exercise	Project
	W8 - Nov 06	Input-Output Analysis and Material Flow Cost Accounting	External Guest – Vincent Moreau	Exercise	Project
	W9 - Nov 13	Spatial MFA	FMC	Exercise	Project
	W10 - Nov 20	Combined approaches: MFA + LCA; MFA + sociodemographics.	AS & FMC	Exercise	Project
Block III: Social sciences and public policy	W11 - Nov 27	Combined approaches: MFA + surveys; Quasi-dynamic MFA	GF & FMC	Exercise	Project
	W12 - Dec 04	Social metabolism	CRB	Past exam	Project
	W13 - Dec 11	Agent-based model	CRB, FMC, MAH, SLC	Project	Project
	W14 - Dec 18	Group Project Presentation	All	Project	Project

Content of lecture

- Recap of Material Flow Analysis & Life Cycle Analysis
- Linkages between MFA and LCA
- Example applications
- Key takeaways

Recap of Material Flow Analysis & Life Cycle Analysis



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Material Flow Analysis

MFA is…

- Material Flow Analysis (MFA) is the study of **physical flows of natural resources and materials** into, through and out of a given system (usually the economy).

Based on…

- It is based on accounts in **physical units,** and uses the principle of mass balancing to analyze the **relationships between material flows** (including energy), **human activities** (including economic and trade developments) and **environmental changes.**
- The system is defined in **space** and **time**.
- **Connects** the sources, pathways and sinks of a **material**.

Source: OECD, 2008

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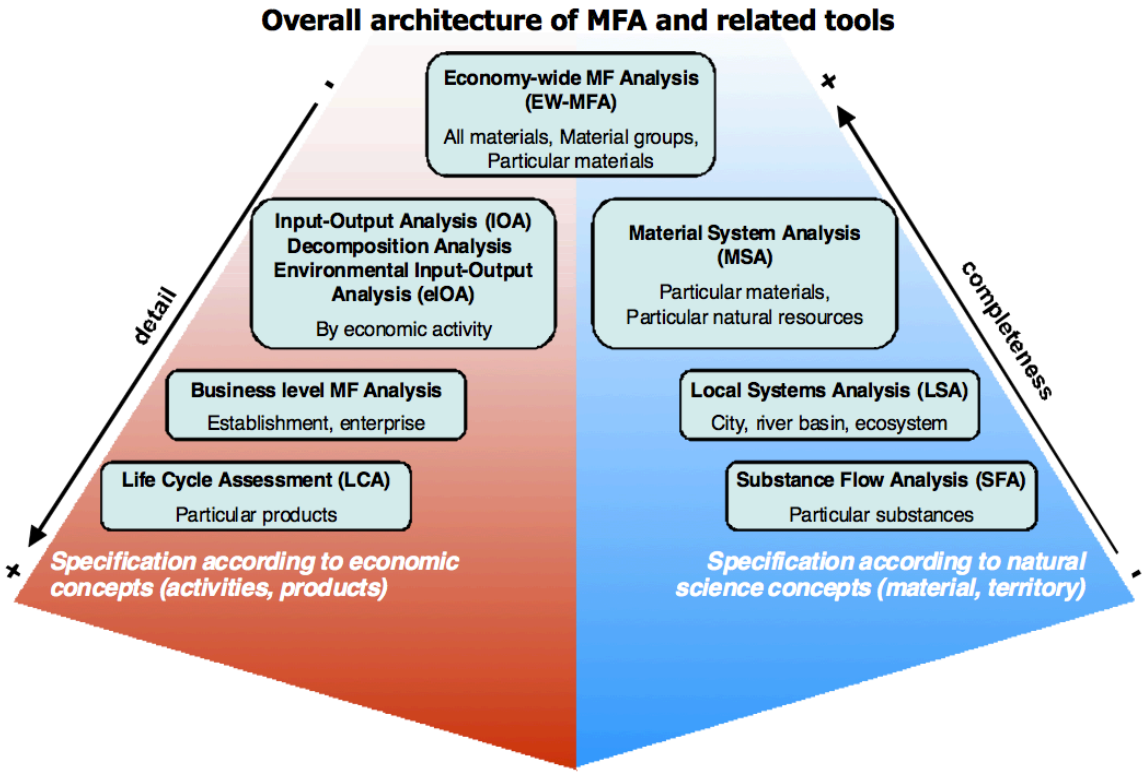
Material Flow Analysis



OECD, 2008

Material Flow Analysis

Main objective	Substances	Materials	Products, Goods and Services	Businesses	Economic activities	Countries, Regions
	e.g., chemical elements or compounds (Cd, Cl, Pb, Zn, Hg, N, P, C, CO_2, CFC)	e.g., raw materials and semi-finished goods, energy carriers, metals (ferrous and nonferrous), sand and gravel, timber, plastics	e.g., batteries, transportation, packaging	e.g., offices, plants, small and medium sized entreprises, multi-national entreprises	e.g., mining, construction, chemical industry, iron and steel industry	e.g., aggregated mass of materials and related mixed or selected materials
Type of analysis	**Substance Flow Analysis**	**Material Flow Analysis**	**Life Cycle Assessment**	**Business level Material Flow Analysis**	**Input–Output Analysis**	**Economy-wide Material Flow Analysis**
Type of analytical tools	Substance Flow Accounts	Material Flow Accounts, Industrial, Urban or Regional Metabolism	Life-Cycle Inventory, Impact Assessment (ISO 14040) / Lif-Cycle Costing	Material Flow Cost Accounting (ISO 14051) / Business Material Flow Accounting	Physical Input-Output Tables, NAMEA approaches	Economy-wide Material Flow Accounts

Source: Moreau and Massard, 2017

LCA as part of MFA

- Addresses **environmental impacts** throughout a **product's life cycle** starting from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)
- **Environmental impacts** e.g. climate change, human health, ecosystem quality, resource depletion
- Comprehensive approach which **identifies impact shifting** from **one phase** of the product life cycle **to another**

Source: https://www.nist.gov/systems-integration-division/lifecycle-graphic

Linkages between MFA and LCA

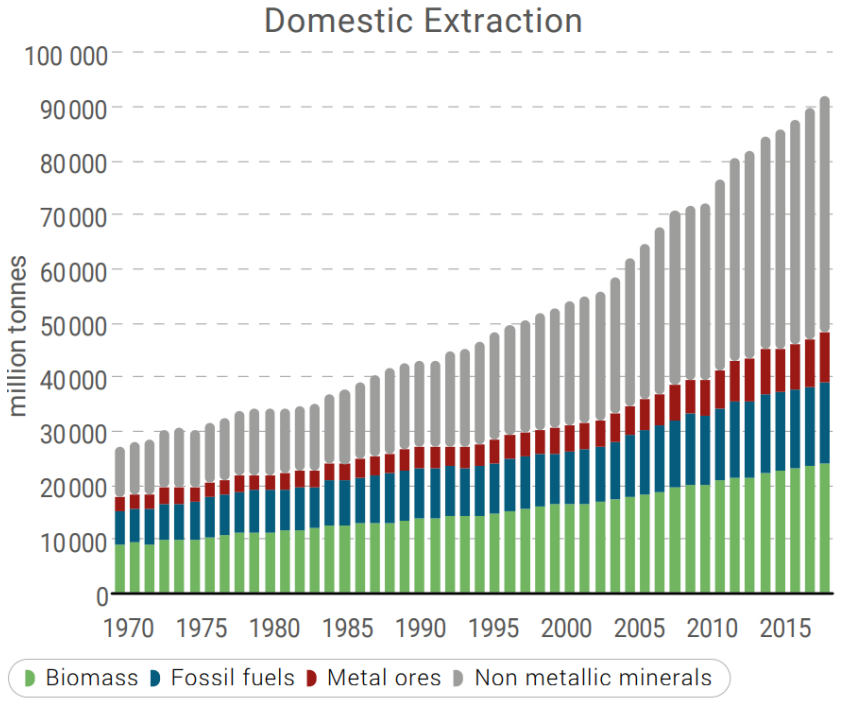
Where LCA fits relative to MFA

- **MFA**
  - Quantifies ***physical flows and stocks*** in a system (mass balance, process-based)
  - Provides the ***inventory baseline*** on which LCA can proceed.

- **LCA**
  - Quantifies ***environmental impacts*** linked to those flows (emissions, resource use, energy, etc.)
  - Adds: impact categories, supply chain processes, upstream and downstream insights

When MFA is the primary method

- **Use MFA when:**
  - The goal is to ***map material quantities***, physical **pathways**, **stocks**, or waste **streams**
  - You need material **balance**, flow **completeness**, or detection of **inconsistencies**
  - You need **scenario** analisis based on **physical** constraints (e.g., recycling potential, stock accumulation)
  - You are evaluating **circularity**, **substitution** options, or system **redesign** in terms of mass only
  - More **operational** (e.g., ID losses, optimization, waste generation)



Source: UNEP & IRP, 2018

When LCA is needed (when MFA is not enough)

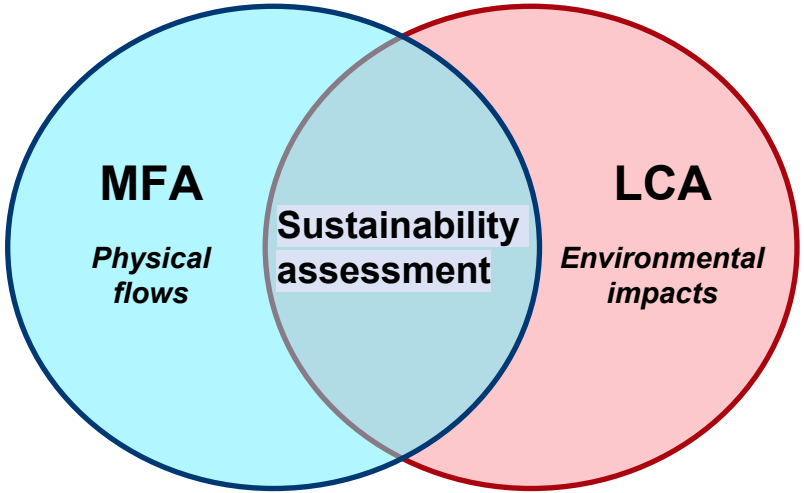
- **Use LCA to understand:**
  - Environmental ***impacts***, **not only mass** (e.g., emissions, resource depletion, land use)
  - **Comparison of design options** where impacts matter (e.g., emissions during use-phase)
  - **Tech substitution** with different profiles (e.g., diesel vs electric vs hydrogen)
  - **Trade-offs** across impact **categories** (e.g., climate change, human health, ecosystem quality)
  - **Burden shifting** across life-cycle **stages** (e.g., manufacturing vs use vs EoL)

Source: Grunver sostenibilidad, 2025

MFA + LCA: Combined power

- **MFA** ensures **complete and balanced inventories** and reduces LCA potential errors
- **LCA** transforms MFA outputs into **environmental meaning**

- Together they support sustainability assessments:
  - Technology design
  - Material substitution
  - Circularity strategies
  - Supply-chain interventions



Practical examples

The Swiss Solar Boat

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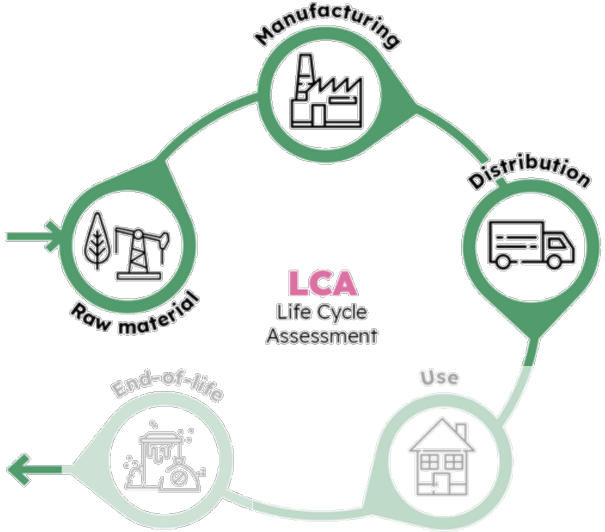
Solar boat

- Quantify the ***environmental impacts*** of producing a hydrogen and solar-powered **prototype boat**
  - **Scope**: Cradle to gate
  - **Primary indicator**: Global Warming Potential (GWP) [kg CO2eq]
  - **Data sources**: Ecoinvent, literature, direct experts consultation



- Evaluate 3 mitigation axes
  - A) **Design** choices (e.g., geometry, material use)
  - B) **Structural** production choices (e.g. composite materials, waste)
  - C) **Energy** systems (e.g., solar panels, electronics)

Source: Martin Cocoual, 2025

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Solar boat

- Where **MFA** is needed
  - **Bill of materials** → Quantify physical inputs
  - **Classify flows** (structural, functional, consumables, auxiliary, etc.)
  - **Identify waste** streams not ending in the final boat
  - **Ensure mass balance**, validate completeness of the inventory
  - **Visualize the material system**, showing which component dominate mass

- Where **LCA** is needed
  - Translate MFA flows into **environmental impacts**
  - **To assess trade-offs** between materials, manufacturing, and energy systems
  - **To compare design alternatives** within the 3 mitigation axes
  - To capture **upstream burdens**
  - To **avoid misleading interpretations** based only on mass

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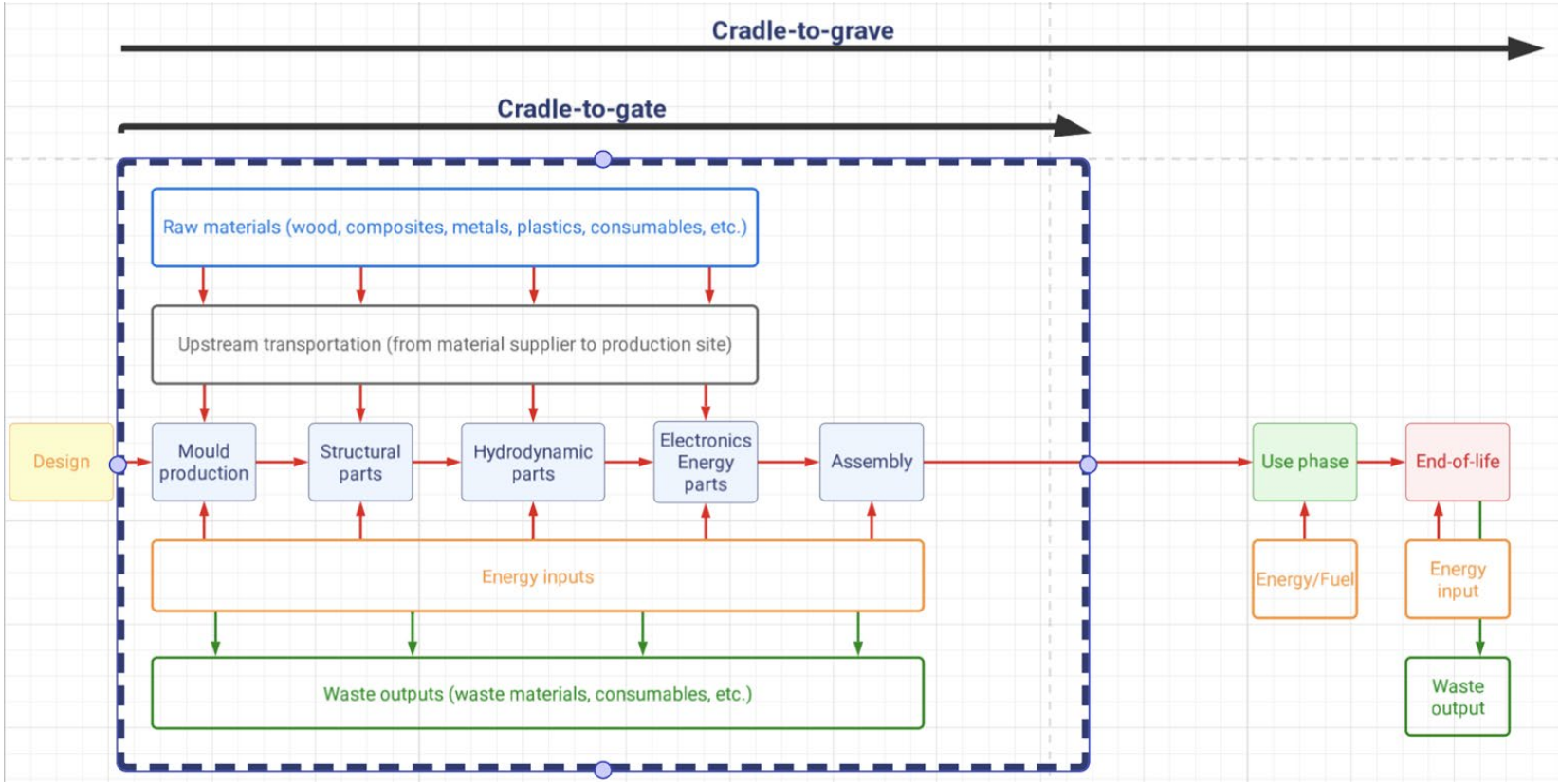
Solar boat - Scope



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Solar boat – Bill of materials

- Complete list of components for every part of the boat
- Associated materials, types and quantities

Classification			Part surface [m2]	Input	Amount estimated	Mass estimated
Main Hull + Omegas		Part	25,496	Okoumé 6mm	25,5 m2	79,55
				Carbon TWILL 200 gsm	51,0 m2	10,20
				Carbon Bibias 200 (220) gsm	51,0 m2	11,22
				Epoxy f. Okoumé (SR5550+SD5502)	8,3 kg	8,34
				Epoxy f. fibers (SR1710+SD8824+SD8822)	13,4 kg	13,39
		Cons.		Peelply	51,0 m2	4,23
				Flowgrid	51,0 m2	8,16
				Vacuum bag	153,0 m2	8,80
				Diadrain	35,6 m	0,89
				Vacuum tubes	72,0 m	#REF!
				Gumgum	306,0 m	#REF!
				Goretex	100,0 m	#REF!
	Omegas	Part	1,562	Rohacryl 20 mm	1,2 m2	1,42
				Carbon UD 100 (182) gsm	11,8 m2	2,15
				Carbon TWILL 200 gsm	5,9 m2	1,18
				Epoxy f. fibers (SR1710+SD8824+SD8822)	2,1 kg	2,05
Main Hull internal structure	All parts - omegas	Part	15,898	Rohacryl 10 mm	15,9 m2	9,54
				Carbon T800 30 gsm	45,4 m2	1,36
				Carbon T800 35 gsm	25,4 m2	0,89
				Carbon T800 40 gsm	76,1 m2	3,05
				Carbon T800 45 gsm	34,1 m2	1,53
				Carbon T800 50 gsm	15,5 m2	0,78
				Carbon T800 55 gsm	26,9 m2	1,48
				Carbon T800 60 gsm	45,4 m2	2,72
		Cons.		Silicon paper on both sides	537,5 m2	48,38
				Peel ply	15,9 m2	1,32
				Perforated plastic film	15,9 m2	0,55
				Bleeder	15,9 m2	2,38
				Vacuum bag	31,8 m2	1,83
				Gumgum	30,0 m	#REF!
		Capping	102 m	Carbon Bibias 200 (220) gsm	10,2 m2	2,25
				Epoxy for wet lay-up SR 8500	0,001 m3	1,24
				Epoxy hardener for wet lay-up SD 8701	0,000 m3	0,29
				ISOBOND SR7100	0,007 m3	8,00
				ISOBOND SD7105	0,003 m3	3,48
		Cons.	10,21	Masking tape	408,3 m	#REF!
				Peel ply	10,2 m2	0,85
				Perforated plastic film	10,2 m2	0,35
				Bleeder	10,2 m2	1,53
				Vacuum bag	20,4 m2	1,17
				Gumgum	204,2 m	#REF!
Floats (- superior wall and plancher)		Part	9,008	Rohacryl 10 mm	5,6 m2	3,39
				Carbon TWILL 200 gsm	63,0 m2	12,60
				Carbon Bibias 200 (220) gsm	47,1 m2	10,35
				Epoxy f. fibers (SR1710+SD8824+SD8822)	14,6 kg	14,61
		Cons.		Peel ply	9,0 m2	0,82
				Flow grid	9,0 m2	1,44
				Diadrain	15,3 m	0,38
				Goretex	10,0 m2	#REF!
				Vacuum bag	36,0 m2	2,07
				Bleeder	2,0 m2	0,30
				Gumgum	36,5 m	#REF!
Floats internal structure		Part	3,06	Rohacryl 10 mm	3,1 m2	1,84
				Carbon T800 35 gsm	24,5 m2	0,86
				Carbon T800 40 gsm	24,5 m2	0,98
		Cons.		Silicon paper on both sides	97,9 m2	8,81
				Peel ply	3,1 m2	0,25
				Perforated plastic film	3,1 m2	0,11
				Bleeder	3,1 m2	0,46
				Vacuum bag	6,1 m2	0,35
				Gumgum	10,0 m	#REF!
		Capping	30 m	Carbon Bibias 200 (220) gsm	3,0 m2	0,65
				Epoxy for wet lay-up SR 8500	0,0003 m3	0,36
				Epoxy hardener for wet lay-up SD 8701	0,0001 m3	0,09
				ISOBOND SR7100	0,002 m3	2,33

Solar boat - Systems

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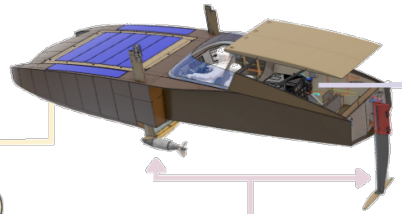

Renewable **E**nergy **F**oiler **(REF)**

- Structure
  - Main hull
  - Internal structure
  - Floats & Moulds
  - Scaffold
  - Deck
  - Headrest
  - Cockpit
  - Hydro. Structural parts
  - Elec/Energy Structural parts
- Hydrodynamic systems
  - Torpedoes & propellers
  - Main foil
  - Strut
  - Flap
  - Rudder blade
  - Stab
  - Fuselage
- Electronics & Energy systems
  - Batteries
  - Cables
  - Motors
  - Others
  - Fuel Cell
  - H2 tank
  - PV panels

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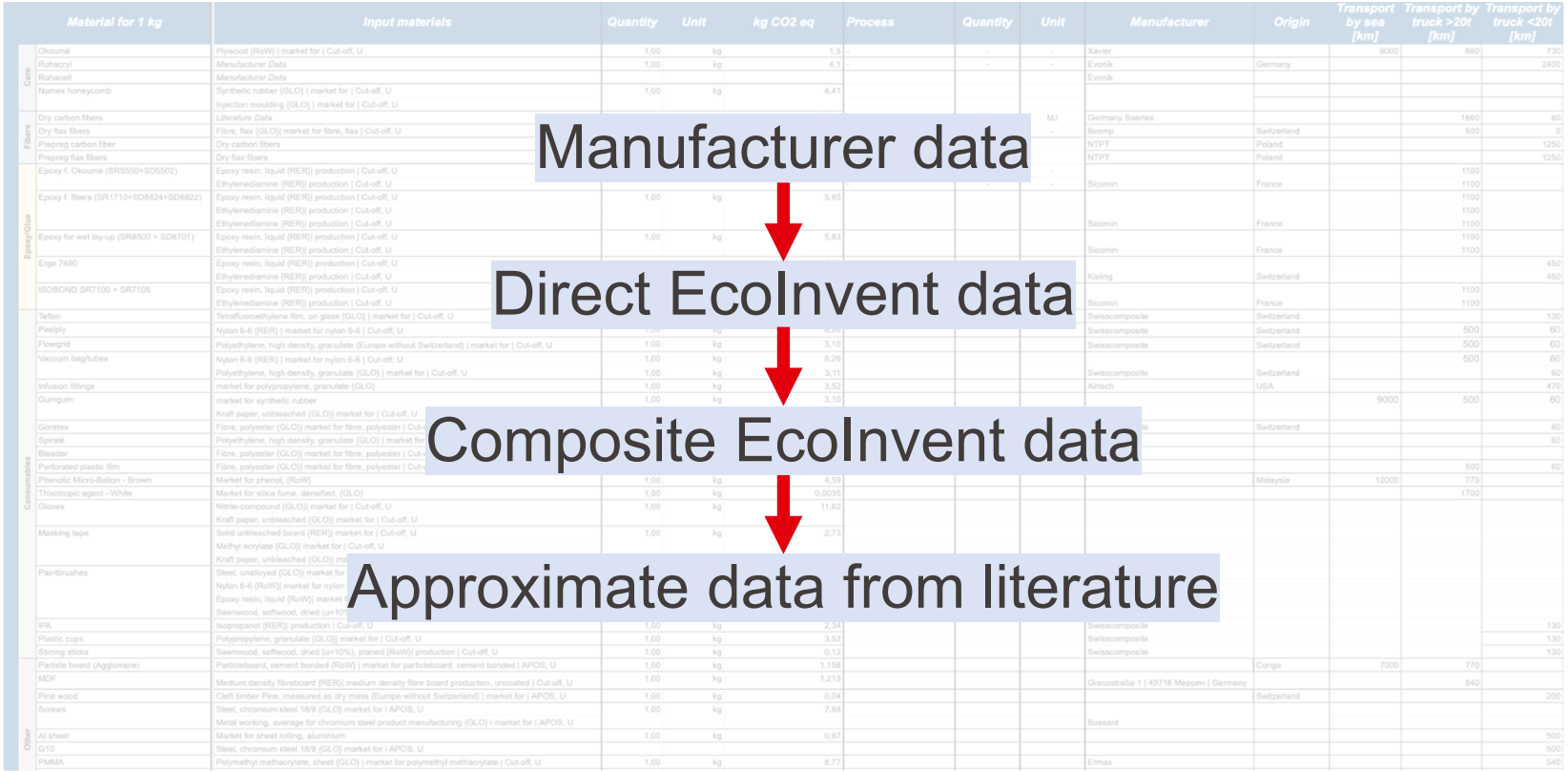
Solar boat – Environmental Impacts database



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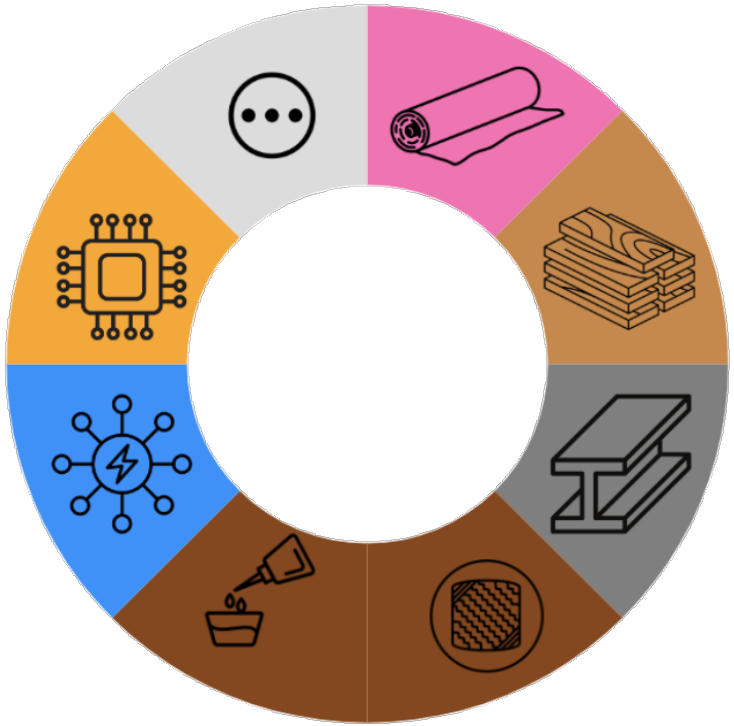
Solar boat: MFA categories



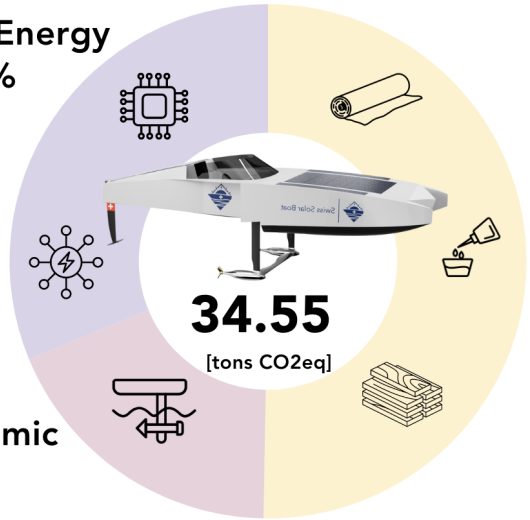
- Plastics
- Woods
- Metals
- Composite (Fibers&Resins)
- Energy systems
- Electronics
- Others

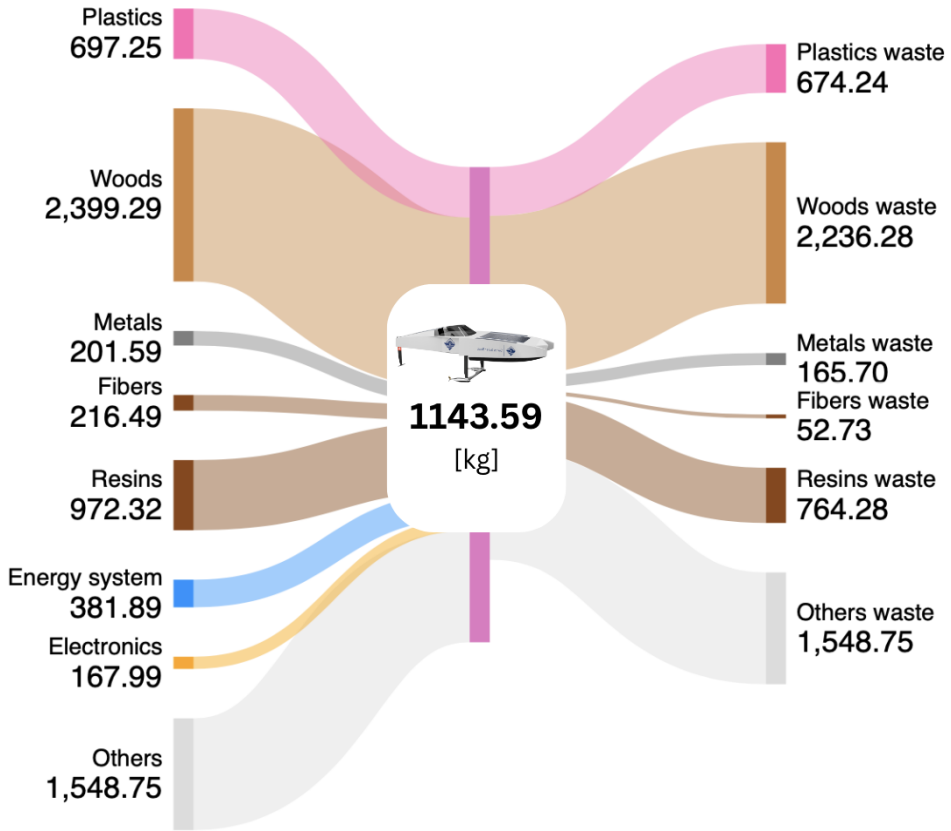
Solar boat: MFA + LCA

Mass by category | **Balance** | **Impacts**

Step	Part		Material	Amount [kg]	Amount + waste/consumables [kg]	Waste/Consumables [kg]	Woods [kg]	Wood Waste [kg]	Metals [kg]	Metal Waste [kg]	Fibers [kg]	Fibers waste [kg]	Resins [kg]	Resin Waste [kg]	Plastics [kg]	Plastics Waste [kg]	Other Waste [kg]	Mass Balance REF [kg]	Energy [kWh]	Cost [CHF]	Transport by sea [ton*km]	Transport by truck [ton*km]	Climate change kgCO2eq.	Transport kgCO2eq.	TOTAL kgCO2eq.
		Part	Okoumé	79,55	103,415	23,865	79,55	23,865	0	0	0	0	0	0	0	0	0	79,55			620,49	88,9369	144,3642203	23,34142582	167,7056461
			Dry carbon	24,75	32,175	7,425	0	0	0	0	24,75	7,425	0	0	0	0	0	24,75			0	61,776	638,641575	11,79088116	650,4324562
			Resin	23,83	30,979	7,149	0	0	0	0	0	0	23,83	7,149	0	0	0	23,83			0	34,0769	165,913656	6,504090232	172,4177462
			Rohacryl	1,42	1,846	0,426	0	0	0	0	0	0	0	0	1,42	0,426	0	1,42			0	0,23998	7,5686	0,045803801	7,614403802
			Peelply	4,23	5,499	5,499	0	0	0	0	0	0	0	0	4,23	5,499	0	0			0	3,40938	42,45397084	0,650731852	43,10470242
			Flowgrid	8,16	10,608	10,608	0	0	0	0	0	0	0	0	8,16	10,608	0	0			0	6,57696	34,30404282	1,255311994	35,55935481
			Vacuum bag	8,8	11,44	11,44	0	0	0	0	0	0	0	0	8,8	11,44	0	0			0	7,0928	88,32031758	1,353767837	89,67408542
		Infusion	Diadrain	0,89	1,157	1,157	0	0	0	0	0	0	0	0	0,89	1,157	0	0			0	0,15041	3,73711	0,02870801663	3,765818017
			Vacuum tubes	2,16	2,808	2,808	0	0	0	0	0	0	0	0	2,16	2,808	0	0			0	0,36504	9,080481923	0,069673888	9,150155311
			Gumgum	15,3	19,89	19,89	0	0	0	0	0	0	0	0	0	0	19,89	0			179,01	12,3318	64,34906608	4,190424691	68,53949077
			Goretex	4	5,2	5,2	0	0	0	0	0	0	0	0	4	5,2	0	0			0	0,676	26,32326936	0,1290247938	26,45229415
			Vacuum pump																158,4				4,779209966	0	4,779209966
			Heater																112				3,37923937	0	3,37923937
	Main hull + Omegas	Total		173,09	225,017	95,467	79,55	23,865	0	0	24,75	7,425	23,83	7,149	29,66	37,138	19,89	129,55	270,4	0	799,5	215,63217	1233,214759	49,35984332	1282,574603
		Part	Rohacryl	9,54	12,402	2,862	0	0	0	0	0	0	0	0	9,54	2,862	0	9,54			0	1,61226	50,8482	0,3077241333	51,15592413
			Dry carbon	7,7946	10,13298	2,33838	0	0	0	0	7,7946	2,33838	0	0	0	0	0	7,7946			0	19,4553216	201,12952	3,713341507	204,8428615
			Resin	4,0154	5,22002	1,20462	0	0	0	0	0	0	4,0154	1,20462	0	0	0	4,0154			0	5,742022	27,95676434	1,095951486	29,05271583
		Prepreg	Silicon paper	12,09384	15,721992	15,721992	0	0	0	0	0	0	0	0	0	0	15,721992	0			0	0	25,78406688	0	25,78406688
			Electricity				0	0	0	0	0	0	0	0	0	0	0	0	29,525				15,73024484	0	15,73024484
			Peelply	1,32	1,716	1,716	0	0	0	0	0	0	0	0	1,32	1,716	0	0			0	1,06392	13,24804764	0,2030651755	13,45111281
			Perforated plastic film	0,55	0,715	0,715	0	0	0	0	0	0	0	0	0	0	0,715	0			0	0,4433	3,619449537	0,0846104898	3,704060027
		Autoclave	Bleeder	2,38	3,094	3,094	0	0	0	0	0	0	0	0	0	0	3,094	0			0	0,40222	15,66234527	0,07676975233	15,73911502
			Vacuum bag	1,83	2,379	2,379	0	0	0	0	0	0	0	0	0	1,83	2,379	0			0	1,47498	18,3666115	0,2815221752	18,64813367
			Gumgum	1,5	1,95	1,95	0	0	0	0	0	0	0	0	0	0	1,95	0			17,55	1,209	6,308731968	0,4108259501	6,719557918
			Curing				0										0						398,5401677	0	398,5401677
		Capping	Dry carbon	2,25	2,925	0,675	0	0	0	0	2,25	0,675	0	0	0	0	0	2,25			0	5,616	58,058325	1,071898287	59,13022329
			Resin	13,01	16,913	3,903	0	0	0	0	0	0	13,01	3,903	0	0	0	13,01			0	18,6043	90,58064056	3,550911201	94,13155176
			Masking tape	1,37	1,781	1,781	0	0	0	0	0	0	0	0	0	0	1,781	0			0	0	4,272757419	0	4,272757419
			Peelply	0,85	1,105	1,105	0	0	0	0	0	0	0	0	0,85	1,105	0	0			0	0,6851	8,530939766	0,1307616661	8,661701432
		Wet lay-up	Perforated plastic film	0,35	0,455	0,455	0	0	0	0	0	0	0	0	0	0	0,455	0			0	0,2821	2,303286069	0,05384303897	2,357129108
			Bleeder	1,53	1,989	1,989	0	0	0	0	0	0	0	0	0	0	1,989	0			0	0,25857	10,06865053	0,04935198364	10,11800251
			Vacuum bag	1,17	1,521	1,521	0	0	0	0	0	0	0	0	0	1,17	1,521	0			0	0,94302	11,74258768	0,1799895874	11,92257727
			Gumgum	10,21	13,273	13,273	0	0	0	0	0	0	0	0	0	0	13,273	0			119,457	8,22926	42,9414356	2,7963553	45,7377909
			Vacuum pump																211,2				6,372279955	0	6,372279955
	Main hull internal structure	Total		71,76384	93,292992	56,682992	0	0	0	0	10,0446	3,01338	17,0254	5,10762	14,71	9,583	38,978992	36,61	240,725	0	137,007	66,0213736	1012,065052	14,00692173	1026,071974
		Part	Rohacryl	3,39	4,407	1,017	0										1,017	3,39			0	0,57291	18,0687	0,1093485128	18,17804851
			Dry carbon	22,95	29,835	6,885	0										6,885	22,95			0	57,2832	592,194915	10,93336253	603,1282775
			Resin	14,61	18,993	4,383	0										4,383	14,61			0	20,8923	101,720458	3,987610503	105,7080685
			Peelply	0,82	1,066	1,066	0										1,066	0			0	0,66092	8,229847775	0,1261465484	8,355994323
			Flowgrid	1,44	1,872	1,872	0										1,872	0			0	1,16064	6,053654615	0,221525646	6,275180261
			Diadrain	0,38	0,494	0,494	0										0,494	0			0	0,06422	1,59562	0,01225735541	1,607877355
			Goretex	0,4	0,52	0,52	0										0,52	0			0	0,0676	2,632326936	0,01290247938	2,645229415
		Infusion	Vacuum bag	2,07	2,691	2,691	0										2,691	0			0	1,66842	20,77534743	0,3184431162	21,09379055
			Bleeder	0,3	0,39	0,39	0										0,39	0			0	0,0507	1,974245202	0,009676859538	1,983922062
			Gumgum	1,83	2,379	2,379	0										2,379	0			21,411	1,47498	7,696653001	0,5012076591	8,19786066
			Vacuum pump															0	37,8				1,140493287	0	1,140493287
			Heater															0	112				3,37923937	0	3,37923937
	Floats	Total		48,19	62,647	21,697	0	0	0	0	0	0	0	0	0	0	21,697	40,95	149,8	0	21,411	83,89589	1777,526553	16,23248121	781,6939818

Solar boat – Results GWP & MFA





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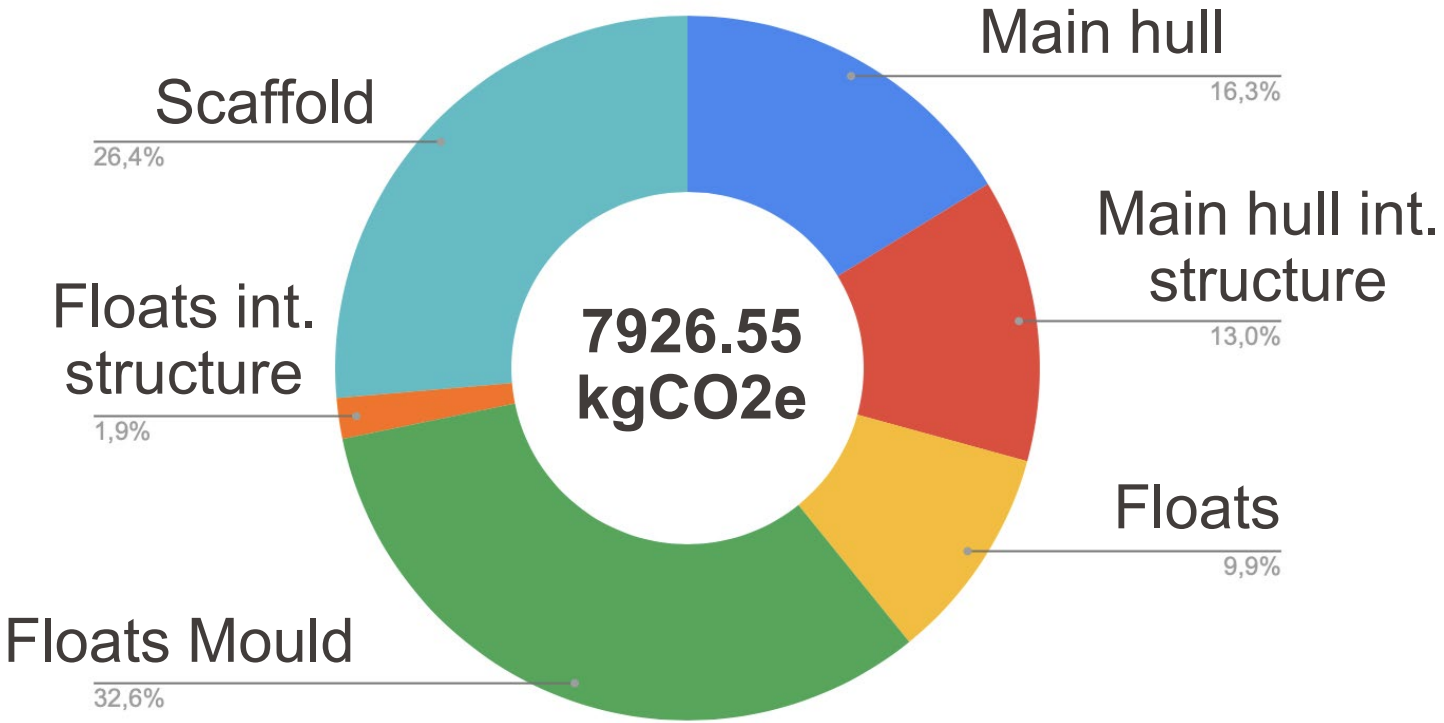
Solar boat – Results Global warming potential



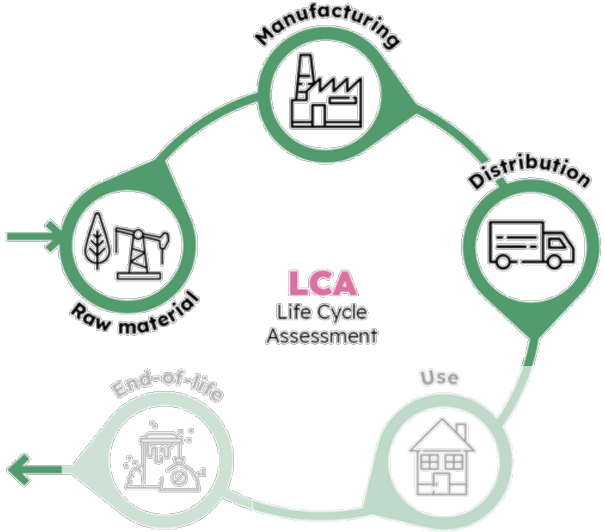
Practical examples

The Digital Displays

Digital displays

- Quantify and assess the ***environmental footprint*** of **digital displays (OLED + LCD)**
  - **Scope**: Manufacturing, transport & use
  - **Primary indicator**:
    - Resources depletion, minerals and metals
    - Acidification potential
    - GWP
    - Ionizing radiation
    - Particular matter
    - Total primary energy
  - **Data sources**: NegaOctet, Ecoinvent, literature, direct experts consultation

- Evaluate through multicriteria decision analysis



Source: Léa Bitard, 2025

Digital displays

- Where **MFA** is needed
  - **Classify material composition** of key components (display panel, electronics, backlight system)
  - **ID material** flows **not retained** in the final display (e.g., losses)
  - **Ensure mass balance**, validate completeness of the inventory
  - Quantify **physical inputs per** functional **unit**
  - Trace **critical material** flows (e.g., rare earths, etc.)

- Where **LCA** is needed
  - Translate MFA flows into multiple **environmental impacts**
  - **Compare tech alternatives** (OLED vs LCD) and design **configurations** (screen size, resolution)
  - Assess **trade-offs** across life-cycle **stages**
  - **ID impact drivers** not visible from mass quantities
  - **Impact** results as **evaluation metrics**

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Digital displays - Scope

Top-down

Input data

- **Source :** ESG* Report from AUO (LCD manufacturer), 2021
- Annual amount of material treated by the factory to manufacture the screen

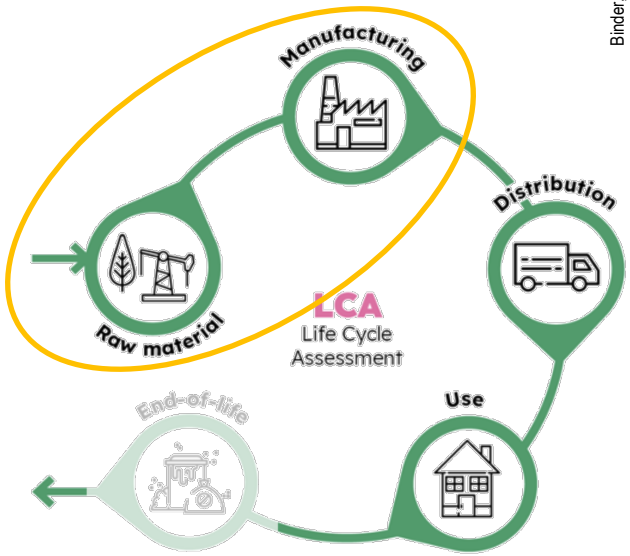
Estimation of the bill of materials for one display

Total quantities for each material

Total surface of screens produced by the factory in 2021

Adaptation to build a parametrized model

To adapt for OLED, use of existing literature on manufacturing processes for OLED to identify similarities and differences



Bottom-up

Input data

- Source : Socolof et al. 2001
- **LCA results** for 15" LCD
- Impacts decomposition **per LC steps → extraction of data for manufacturing**

Decomposition of the manufacturing impacts per manufacturing step/process

Identification of dimensioning parameters for each step

Screen technology, size, resolution, brightness, etc

Adaptation to build a parametrized model

To adapt for OLED, use of existing literature on manufacturing processes for OLED to identify similarities and differences

Digital displays - Scope

Input data

Impact factors in Ecoinvent, per transport mode per tons.km

➔ need to identify the transport mode, distance and mass per display

Mass

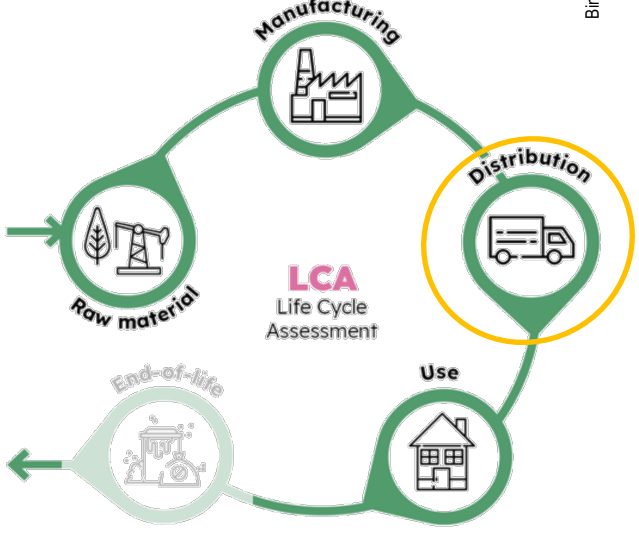
Obtained from manufacturing mass balance

Transport mode

Obtained from Lenovo datasheet :
100% by ship between exporting and importing countries
100% by truck inside countries

Distance

Identify **main exporters** from UN comtrade data
Identify **main importers in Europe** (largest harbor = Rotterdam)
Compute **distance** by ship (see next slide)
Distance by truck : hypothesis : 1'000 km (Source : *"Le numérique en Europe : une approche des impacts environnementaux par l'analyse du cycle de vie"*, NumEU, 2021)



UN comtrade request (input)

- **Year**: 2023
- **Exports**
- **HS code**: 8524 - Flat panel display modules, whether or not incorporating touch-sensitive screens

Laboratory on

reporterDesc	Trade value (USD)	Trade value cum	% cumulated	%
China	38760717077	38760717077	0,511197122	0,51119712
Rep. of Korea	17043201466	55803918543	0,735972003	0,22477488
China, Hong Kong SAR	10169510100	65973428643	0,870092955	0,13412095
Other Asia, nes	4367754564	70341183208	0,927697245	0,05760429
Japan	1798672745	72139855953	0,951419105	0,02372186
Germany	1605205741	73745061694	0,972589419	0,02117031

Identify countries representing **> 80%** of cumulated trade value

Identify each country's **largest port**
Source : various

Compute **sea distance** between this port and Rotterdam
Source : https://sea-distances.org

Compute **weighted average distance**

$$\text{avg distance by ship} = \sum \text{sea distance}_{\text{main port (export)}-\text{Rotterdam}} * \%\ \text{trade value}_{\text{export country}}$$

Digital displays - Scope

Input data

- Ecoinvent electricity mix for each country of use (impacts/kWh)
- Manufacturer's datasheets (technical specifications) :
  - Power
  - Screen size
  - Resolution
  - Technology (LCD/OLED)

Scrapping of **manufacturers data** to obtain a large sample

↓

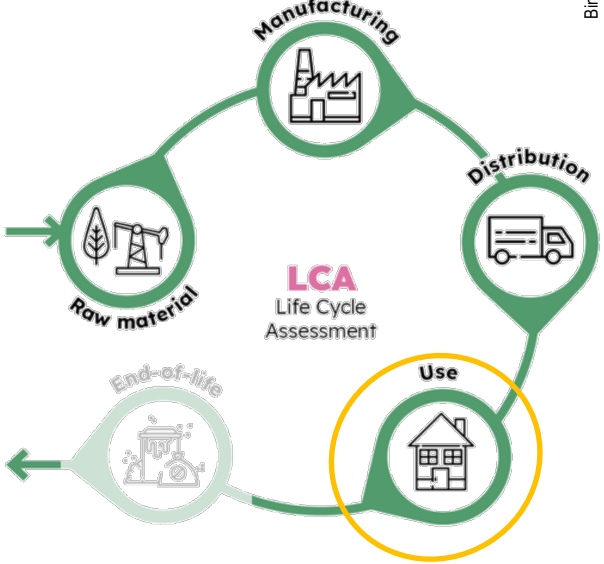
Plotting the **power as a function of the different parameters** (screen size, resolution), for each technology to obtain a **model**

↓

Determine which **parameter** is the **most relevant** based on the results

↓

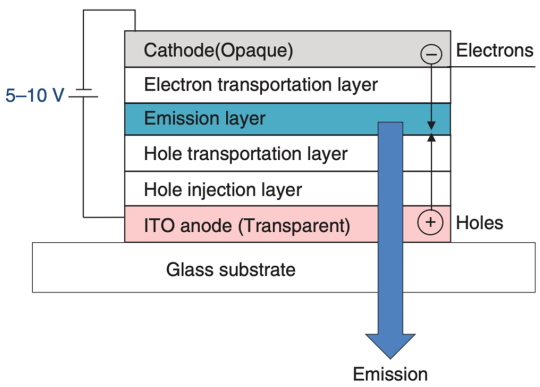
Use of this model for the **LCA parametrized model**



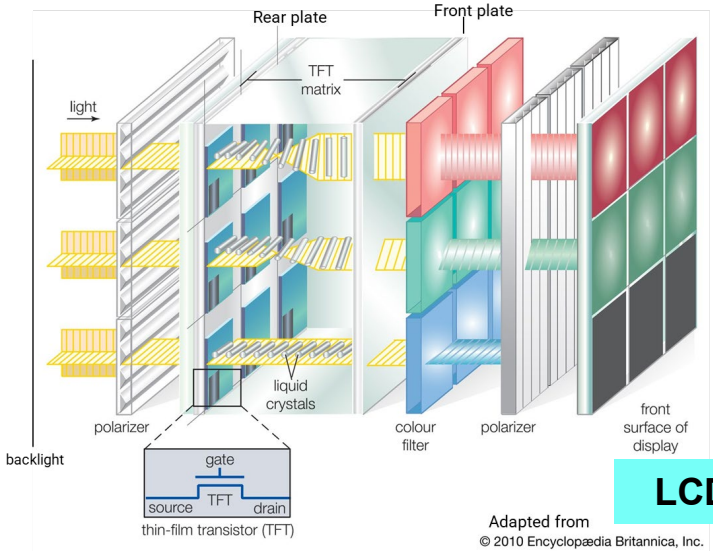
Digital display – Bill of materials

- Complete list of components for every part of the display
- Associated materials, types and quantities

Component	Sub component	Quantity per screen	Unit
PCB	-	22,8	cm^2
Cable	-	0,8	m
Holder	-	$6,62 \times 10^{-3}$	kg
Backlight	Connector	$2,27 \times 10^{-2}$	kg
	LED	$1,92 \times 10^{-3}$	kg
	Capacitor	$2,08 \times 10^{-6}$	kg
Panel	Glass substrate	$7,23 \times 10^{-2}$	kg
	Polarizing film	$2,72 \times 10^{-3}$	kg
	Liquid crystal	$7,97 \times 10^{-2}$	kg
	Backplate	$1,81 \times 10^{-2}$	kg
	Aluminum etchant	$5,18 \times 10^{-3}$	kg
	Electricity consumption	$1,04 \times 10^{1}$	kWh
	Natural gas	$3,67 \times 10^{-5}$	m^3
	Liquefied petroleum gas	$5,44 \times 10^{-4}$	kg
	Diesel	$1,44 \times 10^{-3}$	kg
	Gasoline	$1,44 \times 10^{-3}$	kg
	Water withdrawal	$2,68 \times 10^{-2}$	m^3
	Water discharge	$1,91 \times 10^{-2}$	m^3



OLED



LCD

Usually composed of indium tin-oxide (ITO) electrodes

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Digital display – Environmental impacts database

Manufacturing						
	Ref unit	material resources: metals/minerals	energy resources: non-renewable	acidification	ecotoxicity: freshwater	human toxicity: carcinogenic
PCB	per screen	0.0003876	27.36	0.014364	30.552	0.00000000110352
Cable	per screen	0.000135593926974708	6.10272843029201	0.0117673414645165	12.8925382883125	1.27230579437254E-09
Holder	per screen	1.49675546658742E-06	1.4046146659609	0.00101503354215246	0.476283540253324	9.86440686847104E-11
Backlight	mix	0.000154869973509165	103.706189201618	0.0492870641271547	27.7895309309511	1.61778344127952E-09
PCB	per screen	2.51987110633727E-05	1.77873254564984	0.000933834586466165	1.98625134264232	7.17422126745435E-11
LED	per m^2	0.000128525610305814	101.878567078927	0.0480106254049098	25.7263816456934	1.54462067454139E-09
Capacitor	per m^2	1.14565213997795E-06	0.0488895770405267	0.000342604135778785	0.0768979426154068	1.42055406358926E-12
Panel	per m^2	0.000398975806118608	2578.3856479266	1.03996445356634	1226.75259383571	4.23593534296758E-08
Glass substrate	per m^2	1.21643565443848E-05	12.8862194092882	0.012105276386622	9.56168812564362	1.63146032941384E-10
Polarizing film	per m^2	1.05355844858674E-05	82.5151409294738	0.032392712733116	39.4266358036728	1.24419986440593E-09
Liquid crystal	per m^2	0.000308997258326186	2420.07952684621	0.950043107499841	1156.34043699256	3.64910316486909E-08
Backplate	per m^2	6.60362763979275E-05	61.9710596584342	0.0447828900839576	21.0134468923383	4.35213842881876E-09
Aluminium etchant	per m^2	1.24233036424199E-06	0.933701083194434	0.000640466862804637	0.41038602149943	1.08837454818849E-10
Energy	per m^2	1.27257075066891E-06	19.5656917935766	0.0040302300956471	1.70654168669649	1.03992553102447E-10
Water	per m^2	3.83547717724314E-06	22.1548855631957	0.0148695128642124	5.14445477656751	2.71787653575477E-10
Transport						
market for transport - freight - sea - container ship - heavy fuel oi	tons.km	1.04E-08	0.12530687	0.00030062	0.00885077	2.16E-12
market for transport - freight - lorry - unspecified	tons.km	5.04E-07	2.17161325	0.00069196	0.28517567	3.86E-11
Usage						
market group for electricity - low voltage - RER - kWh	kWh	4.46E-06	7.58483663331967	0.00189342771074605	1.08182074417033	9.81E-11

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Digital display: MFA + LCA

Impacts

	ADPe	ADPf	AP	CTUe	CTUh-c	CTUh-nc	Epf	Epm	Ept	GWP	GWPb	GWPf	GWPlu	IR	LU	ODP	PM	POCP	WU	TPE
	material reso	energy reso	acidification	ecotoxicity	human toxi	human toxi	eutrophica	eutrophica	eutrophica	climate cha	climate cha	climate cha	climate cha	ionising rad	land use	ozone deple	particulate	photochem	water use	Cumulative E
Manufacturin	0.00058299676	205.4863454	0.096757864	124.0246207	5.292852E-09	2.438504E-07	0.00642137	0.027534811	0.160065203	15.80454545	0.031903651	15.74854197	0.02367489	4.281397895	38.27826408	1.419094E-06	9.119519E-07	0.049955239	4.518085145	239.1983823
PCB	0.0003876	27.36	0.014364	30.552	1.10352E-09	4.56E-08	3.8304E-06	0.00145464	0.0154812	2.09304	0.001881	2.09076	1.71E-09	2.6676	0.00151848	2.8272E-07	7.866E-08	0.0053124	0.5358	28.272
Cable	0.00013559393	6.10272843	0.011767341	12.89253829	1.272306E-09	1.085294E-07	0.000915982	0.000803188	0.01048662	0.422253391	0.001687697	0.419870902	0.000694792	0.034335274	6.539164859	2.655629E-08	4.676614E-08	0.003154902	0.227262039	7.591916475
Holder	1.4967555E-06	1.404614666	0.001015034	0.476283543	9.864407E-11	2.088867E-09	3.126422E-05	0.00015704	0.001641649	0.13808133	0.000695825	0.136994258	0.000391247	0.003450238	0.300892683	1.371316E-10	1.211551E-08	0.00051054	0.037540469	1.652675189
Backlight	3.3241863E-05	8.101012608	0.003933053	3.586757874	1.676389E-10	3.874732E-09	0.000260346	0.000686983	0.006833433	0.615981161	0.00084155	0.6142544	0.000859271	0.230026455	1.238856554	2.333362E-08	3.391385E-08	0.00201594	0.22864726	9.369654809
PCB	2.5198711E-05	1.778732546	0.000933835	1.986251343	7.174221E-11	2.964554E-09	2.490226E-07	9.456928E-05	0.001006466	0.13607304	0.000122288	0.135924812	1.111708E-10	0.173426423	9.871966E-05	1.838024E-08	5.113856E-09	0.000345371	0.034833512	1.838023631
LED	7.9720904E-06	6.319247577	0.002977967	1.595736763	3.580858E-11	5.90691E-09	0.00025985	0.00059179	0.005818652	0.479689062	0.000718961	0.478111215	0.000858886	0.056579464	1.237440149	4.951498E-09	2.876798E-08	0.001667116	0.193717394	7.528084209
Capacitor	7.1061654E-08	0.003032486	2.125079E-05	0.004769768	3.811307E-14	3.267229E-12	2.461519E-07	5.235826E-07	3.314486E-06	0.000219059	3.012486E-07	0.000218373	3.852293E-07	2.056729E-05	0.001317686	1.885231E-12	3.202292E-11	3.453851E-06	9.635462E-05	0.003546969
Panel	2.5064211E-05	162.5179897	0.065678437	76.51704104	2.650743E-09	7.875733E-08	0.005189948	0.02443296	0.1256223	12.53518957	0.026797579	12.48666241	0.021729578	1.345985929	30.19783151	1.085647E-06	7.404963E-07	0.038961456	3.488835376	192.3121358
Glass substrate	7.5452161E-07	0.799296782	0.000750857	0.593085241	1.01195E-11	3.632616E-10	3.613063E-06	0.000122194	0.001479389	0.076707485	0.000529904	0.076150933	2.664752E-05	0.001110296	0.237523681	7.553159E-10	3.243523E-09	0.000411561	0.018903926	0.902871993
Polarizing film	6.5349336E-07	5.118187459	0.002009231	2.445525883	7.71743E-11	2.35434E-09	0.000164777	0.000375602	0.003800563	0.386229699	0.00078545	0.384771368	0.00067288	0.043657578	0.945605522	3.561978E-08	2.272125E-08	0.001195956	0.109342348	6.062497801
Liquid crystal	1.9166251E-05	150.1108832	0.058928563	71.72461994	2.263438E-09	5.905025E-08	0.004832744	0.011015987	0.111466379	11.32769787	0.023036406	11.28492662	0.019734845	1.28042938	27.73358367	1.044689E-06	5.663897E-07	0.035076098	3.206892404	177.8064807
Backplate	4.0960488E-06	3.843894548	0.00277776	1.303406371	2.699512E-10	5.716431E-09	0.000140291	0.000429759	0.004492568	0.377875928	0.001904207	0.374901028	0.001070693	0.009441985	0.823428489	2.29091E-09	3.315554E-08	0.001397153	0.102733944	4.522741576
Aluminium etchant	7.7058339E-08	0.057914913	3.97264E-05	0.025455117	5.750888E-12	5.490682E-11	1.597474E-06	1.686922E-06	0.000122981	0.007442881	1.190774E-06	0.007434954	3.736899E-06	0.000195366	0.013763505	2.424392E-10	2.945963E-10	1.403305E-05	0.002886523	0.066556763
Energy	7.8934067E-08	1.2136061	0.000249984	0.105852092	5.450372E-12	1.8049E-10	2.997332E-06	9.752906E-05	0.001057426	0.076467286	3.819143E-06	0.076448658	3.808185E-06	0.000610151	0.049080285	1.156464E-09	1.324453E-09	0.000377155	0.00255205	1.348185548
Water	2.3790411E-07	1.374206675	0.000922315	0.319096394	1.685824E-11	1.037651E-09	3.892819E-05	0.012387203	0.003202995	0.282768422	0.000527602	0.282028853	0.000211968	0.010541173	0.394846359	3.925859E-10	3.367301E-09	0.000489501	0.04552418	1.602801469
Transport	1.07E-07	4.77E-01	2.06E-04	6.10E-02	8.46E-12	3.22E-10	2.28E-06	7.18E-05	7.87E-04	3.34E-02	6.57E-06	3.33E-02	1.20E-05	5.68E-04	3.38E-01	7.15E-10	3.13E-09	2.63E-04	2.57E-03	5.15E-01
Ship	2.16E-09	2.60E-02	6.24E-05	1.84E-03	4.48E-13	6.29E-12	7.51E-08	1.55E-05	1.73E-04	2.13E-03	3.26E-07	2.12E-03	1.14E-06	1.12E-05	1.89E-03	2.99E-11	6.27E-11	4.68E-05	7.49E-05	2.78E-02
Truck	1.05E-07	4.51E-01	1.44E-04	5.92E-02	8.01E-12	3.15E-10	2.20E-06	5.63E-05	6.14E-04	3.12E-02	6.25E-06	3.12E-02	1.08E-05	5.57E-04	3.36E-01	6.85E-10	3.07E-09	2.16E-04	2.49E-03	4.87E-01
Usage	2.26E-04	3.84E+02	9.60E-02	5.48E+01	4.97E-09	2.71E-07	1.60E-02	1.53E-02	1.35E-01	1.68E+01	3.49E-02	1.67E+01	4.92E-02	1.08E+01	7.52E+01	3.10E-07	3.41E-07	4.33E-02	1.08E+01	5.04E+02

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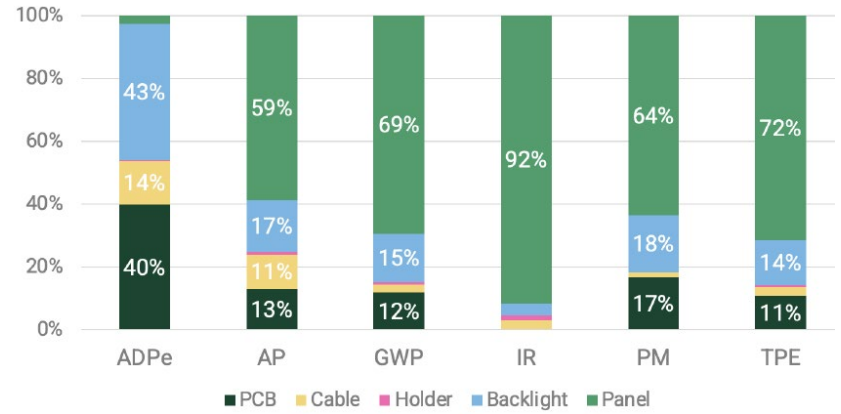
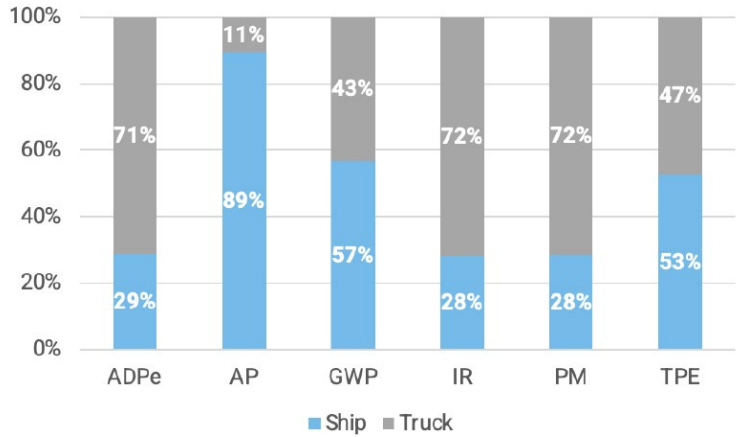
Digital display - Results Environmental impacts

Manufacturing



Distribution



Use

Indicator	ADPe	AP	GWP	IR	PM	TPE
Unit	kg Sb eq.	mol H^+eq.	kg CO_2 eq.	kBq U_{235} eq.	diseases occurrence	MJ
LCD	$2,26 \times 10^{-4}$	$9,60 \times 10^{-2}$	$1,68 \times 10^{1}$	$1,08 \times 10^{1}$	$3,41 \times 10^{-7}$	$5,04 \times 10^{2}$
OLED	$6,49 \times 10^{-4}$	$2,75 \times 10^{-1}$	$4,81 \times 10^{1}$	$3,09 \times 10^{1}$	$9,79 \times 10^{-7}$	$1,45 \times 10^{3}$

Key takeaways

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	Advantages	Limitations
MFA	• Physically consistent (**mass balance**) • Simple data requirements (**mass-based**) • Good **for mapping flows, stocks, waste** streams • Useful **for circularity and system redesign**	• No **environmental impact** results • Does not capture **emissions or energy use** • Material **categorization may hide** detailed **impacts** •
LCA	• Captures **multiple environmental impact** categories • **Allows comparison** of alternatives and trade-offs • Addresses **full life cycle** • Enables **decision support**	• **Results** depend strongly on **data quality** and assumptions • Can be **complex and time intensive** • May **miss material completeness without MFA** •
Combined MFA + LCA	• MFA **improves inventory quality** for LCA • **Enables** robust **evaluation** of design/technology **options** • **Supports data validation** and system boundary alignment	• Requires **alignment of system definition** • Additional **effort to compile and synchronize both methods** • **Uncertainty** across both analyses

Key takeaways

- **Align** system **boundary** and **functional unit** before combining methods
- Ensure **data completeness** and document key **assumptions**
- Perform **sensitivity analisis** on critical parameters
- **Expand scope** where relevant (e.g., in use-phase)
- Consider **dynamic or temporal elements** if system evolves over time

Thank you for your attention!