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Calculating the CO2- Footprint: Assessing the Environmental Impact of Mobility and CO2 Emissions

FH-Prof. DDI Dr. Hirut Grossberger

Wanna study in an awesome place?

Austria, Europe

- Climate: temperate
- Population: 9M
- Language: German
- Capital: Vienna

University of Applied Sciences St. Pölten - My Space to Grow

St. Pölten, Lower Austria

- Vienna 60km
  25 min. by train
- Salzburg 243km
- Munich 345km
- Budapest 280km
- Timisoara 560km
- Prague 310km

Facts & Figures

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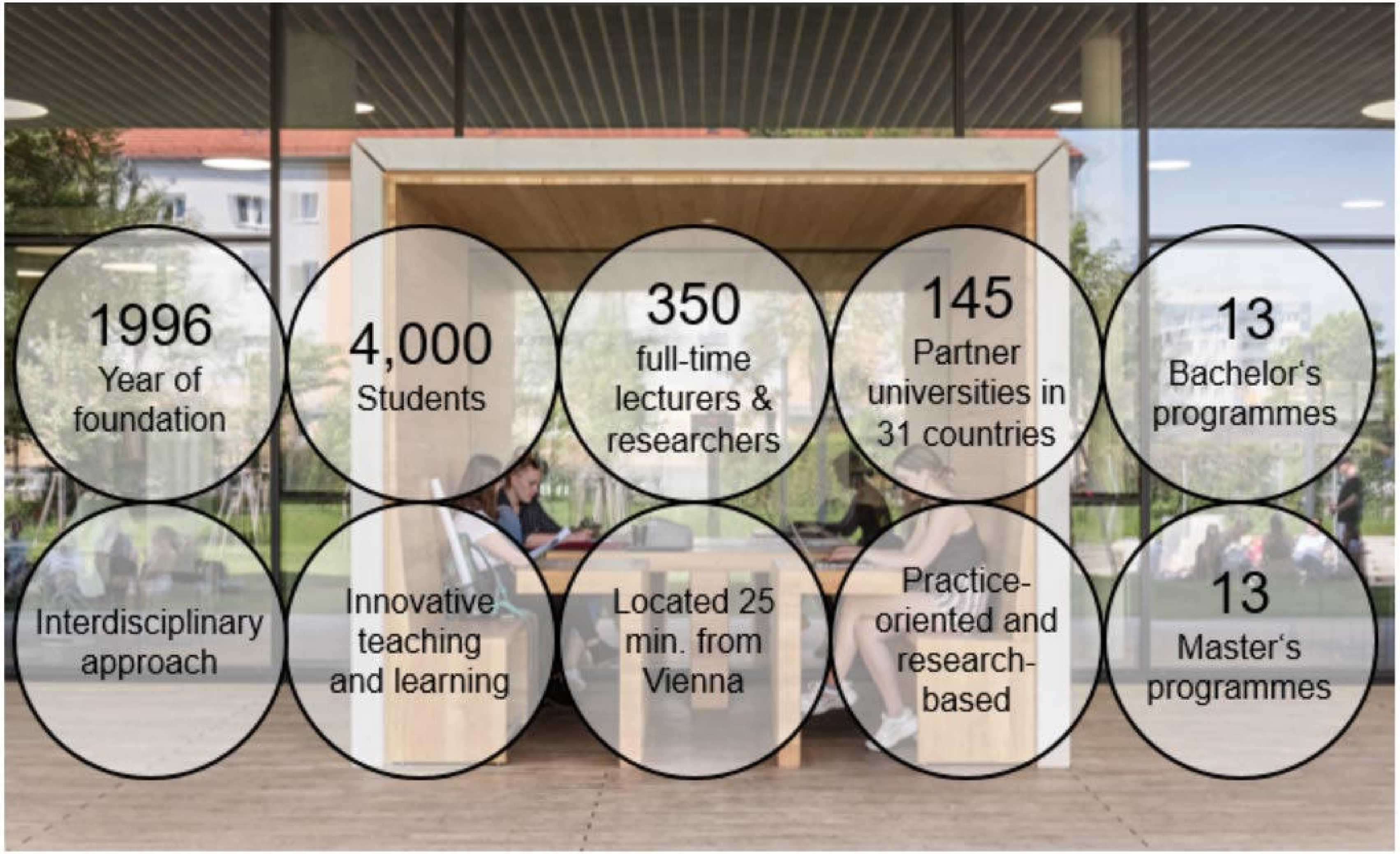

Department Rail Technology and Mobility

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Bachelor study programs

Rail Technology and Mobility – Full-time/Part-time

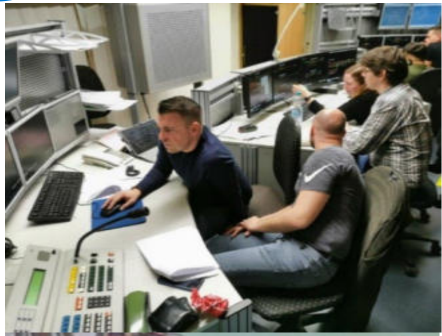
- 6 semesters
- 32 places/year financed by government grants (the Austrian Ministry of Science, Lower Austria, City of St. Pölten), tuition fee € 363/semester
- Degree: Bachelor of Science in Engineering (BSc)

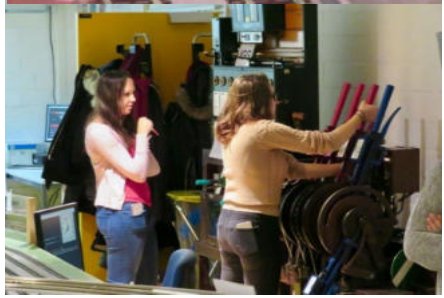
Rail Vehicle Technology – Full-time/Dual

- 6 semesters
- 20 places/year financed by government grants (the Austrian Ministry of Science, Lower Austria, City of St. Pölten), tuition fee € 363/semester
- Degree: Bachelor of Science in Engineering (BSc)

Master study program- Rail Technology and Management of Railway Systems – Part time

- 4 semesters
- 25 places/year financed by government grants (the Austrian Ministry of Science, Lower Austria, City of St. Pölten), tuition fee € 363/semester
- Degree: Diplom-Ingenieur (Master of Science in Engineering)
- Only vocational version





Continuing Education Courses: European Railway Systems

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- Master of Sciences
- Joint Degree
- 4 Semesters
- Vocational

Carl Ritter von Ghega Institute for Integrated Mobility Research

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- ➢ application-oriented research and development
- • on the topics of railway technology and mobility

Key Focuses

- **System Rail**
  - Alternative Drive Systems
  - Shunting Technologies
  - Control Center Technologies
  - Usability and Safety
- **Lifecycle of Technical Systems**
  - LCC, LCA, LCP
  - Sustainable Procurement
  - Optimization of Railway Infrastructure and vehicles
- **Mobility 4.0**
  - Digitization and automatization
  - Physical Internet and BigData
  - Sustainable Mobility and traffic turn

E³UDRES²

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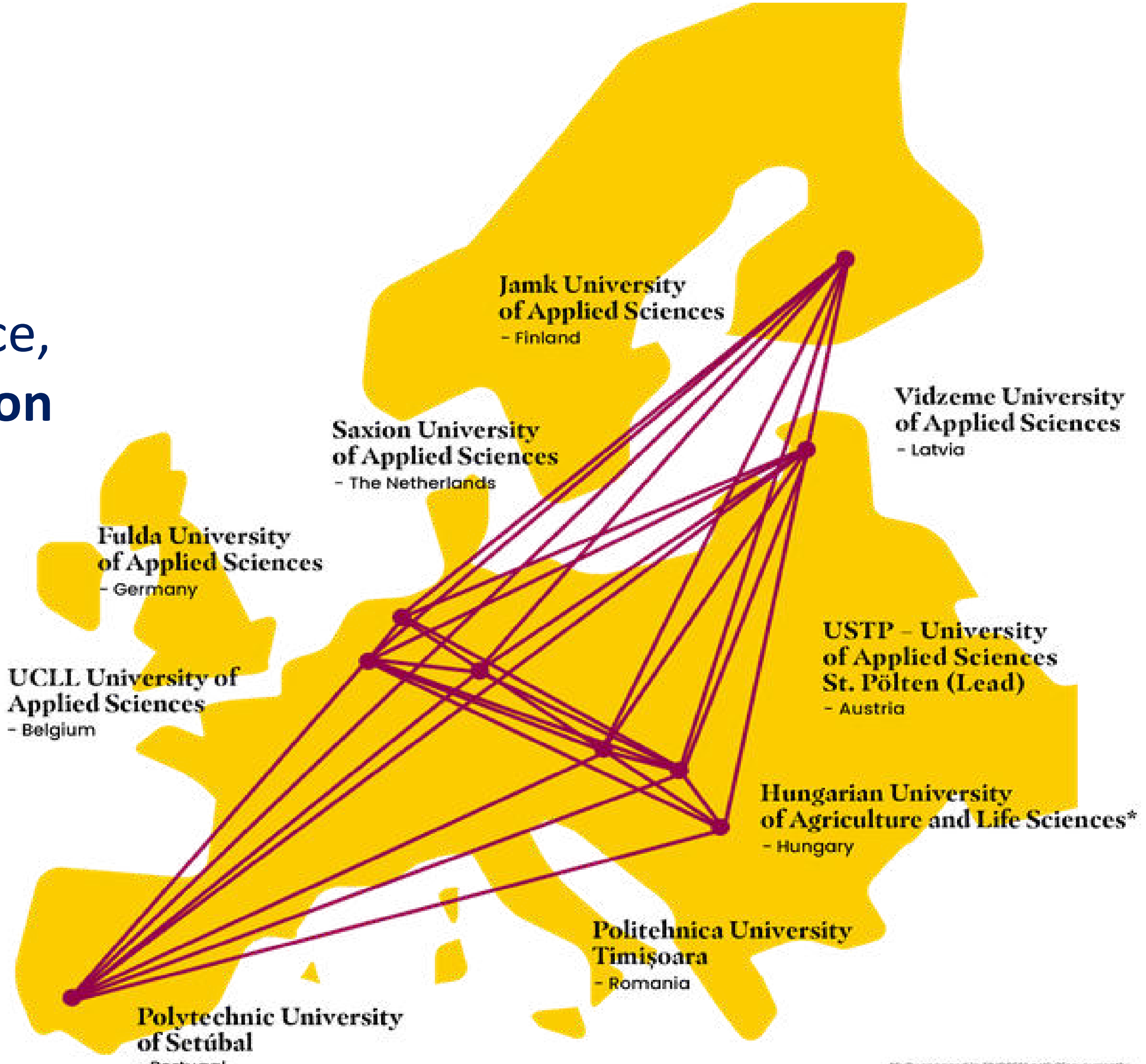
Studying at a European University

USTP – University of Applied Sciences St. Pölten is part of the European University **E³UDRES²**. Our university leads this alliance, which includes a total of **9 higher education institutions** from all over Europe.

https://youtu.be/DwYrlkTICdc



*fully engaged in E³UDRES² activities, currently holding the status of Associated Partner due to

Calculating the CO2- Footprint: Assessing the Environmental Impact of Mobility and CO2 Emissions

Environmental performance- Assessment methods

Why do we need to calculate the environmental performance?

To understand our **individual impact** on the planet and make choices
It is like holding a mirror

To measure, evaluate, and improve the environmental impact of organizations, industries, and products

Local decision makers- to optimize project investments

Help **businesses and governments** understand how their activities affec the environment and guide decision-making for sustainable practices.

Countries – to improve sustainability and well-being
Support broader climate and **sustainability goals.**

More?

Environmental performance- Assessment methods

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Why do we need to calculate the environmental performance?

Compliance with regulations:
National & international laws and standards to protect ecosystem and public health

Environmental impact reduction and contribution to climate goals
To quantify their environmental impact, carbon neutrality etc.
To identify operations or processes that contribute most to environmental degradation and make targeted efforts to reduce their ecological footprint.

Sustainability and resource efficiency
Guide toward more sustainable use of resources such as energy, water, and raw materials by providing insight into resource use across the entire lifecycle of a product. This leads to business efficiency and long-term sustainability

Stakeholder communication and reporting
Transparency regarding an organization's environmental performance
Allowing businesses to communicate their sustainability efforts credibly

Competitive advantage
A strong commitment to environmental responsibility
Attract eco-conscious customers

Environmental performance- Assessment methods

Why do we need to calculate the environmental performance?

Improvement of decision-making

Data-driven insights that are crucial for making informed decisions related to resource allocation, production processes, and product development

Better decision-making, enabling companies to adopt more sustainable strategies and optimize environmental and economic outcomes

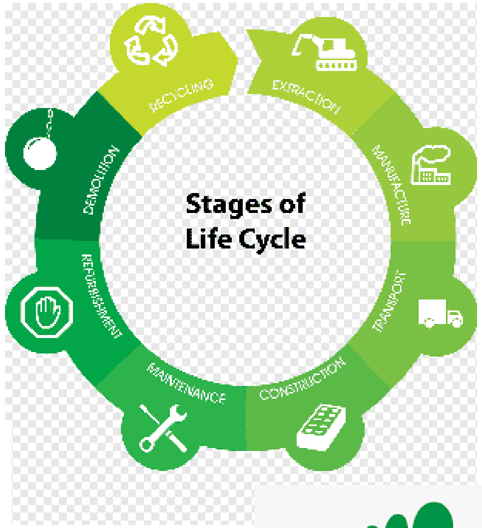
Corporate Social Responsibility (CSR)

To help businesses fulfill their environmental responsibilities, demonstrating their commitment to social and environmental welfare

More?

Assessment Methods

- Ecological footprint
- Ecological backpack
- Lifecycle Assessment
  - Carbon footprint (CO2- Foot print) – part of LCA



Ecological footprint

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Ecological footprint (gha- global hectare) – to quantify how much nature we have and how much nature we use.

It quantifies how much natural resources (such as water, land and energy) people consume and how much waste they produce compared to what the earth can generate.

global hectars (gha)

The world's annual amount of biological production for human use per hectare of biologically productive land.

- Global hectares of production/no. people on the globe
- A unit that represents the amount of biologically productive land and see area required to generate the resources humans consume and absorb the waste they generate

- The average biological productivity worldwide = 1.6 gha/person
- The average footprint currently is 2.7 gha/person

- Calculate your own ecological footprint: www.mein-fussabdruck.at

- *Who wants to help the nature, should live with ecological footprint **below 1.6 gha/person***

Ecological footprint

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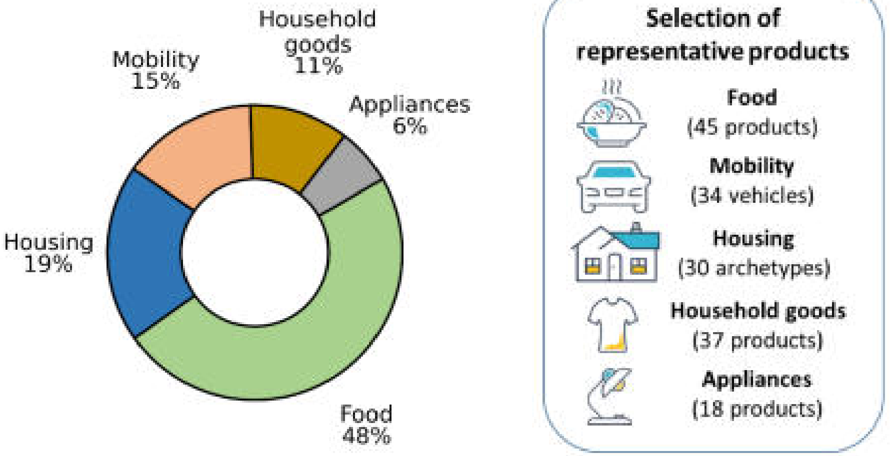
- Example: the average ecological footprint of the people in different countries
  - Qatar = 14.72 gha/person
  - USA = 7.5 gha/person
  - Latvia = 7 gha/person
  - Austria = 5.8 gha/person
  - Slovenia = 5.2 gha/person
  - Portugal = 3.9 gha/person
  - Romania = 2.8 gha/person
  - Nicaragua = 1.6 gha/person
  - Ethiopia = 0.9 gha/person
  - Eritrea = 0.7 gha/person

https://data.footprintnetwork.org/#/

However, compare BIOCAPACITY **RESERVE(+)/DEFICIT(-)**

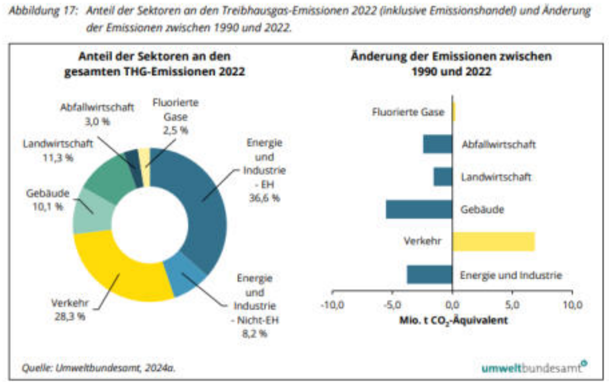


Consumption footprint of EU-27 by area of consumption (2021)

Sanye Mengual E & Sala S., 2023. Consumption Footprint and Domestic Footprint: Assessing the environmental impacts of EU consumption and production

Allocation of the ecological footprint in percent

- Food = 35% (animal products)
- Living = 25% (heating)
- Mobility = 22% (transport mode)
- Consumption = 18% (product purchase)



Klimaschutzbericht 2024 (umweltbundesamt.at)

Ecological backpack

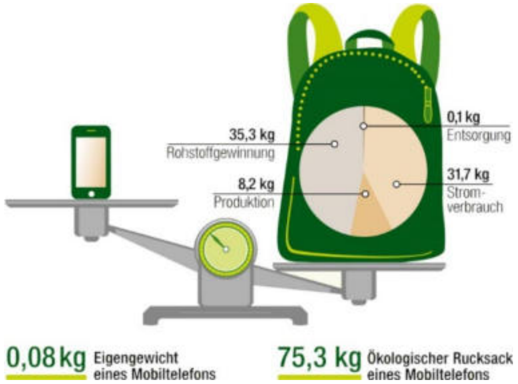
- Weight of all the natural resources extracted, and waste generated to produce, use and dispose a given product minus the weight of the product

Ecological Backpack=Total Resource Use−Product Weight

- The material input is calculated from five main categories: (i) abiotic materials, (ii) biotic materials, (iii) moved soil (agriculture and forestry), (iv) water and (v) air

A gold ring carries 2,000 kg of ecological backpack

A mobile phone 75,3 kg



Source - barthauer.de

Aluminum is 85:1 kg.
Recycled aluminum 3.5:1
Diamond the rucksack 53,000,000:1.

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Ecological backpack

- MIPS (Material Input Per Service unit)

MIPS approach provides relevant knowledge on **resource and energy input** at the micro level for fact-based decision-making in science, policy, business, and consumption.

Service unit can be defined in terms of:

Quantity: the number of uses or services the product offers (e.g. kilometers driven by a car)
Duration: the length of time a product is in service (e.g. the life span of washing machine)
Function: the specific function of the product (e.g the cooling capacity of a refrigerator)

MIPS= Material Input (MI)/Service Unit (S)

Measures to reduce MIPS: reduced material, energy and short transport routes, longer service life?

Circular Economy

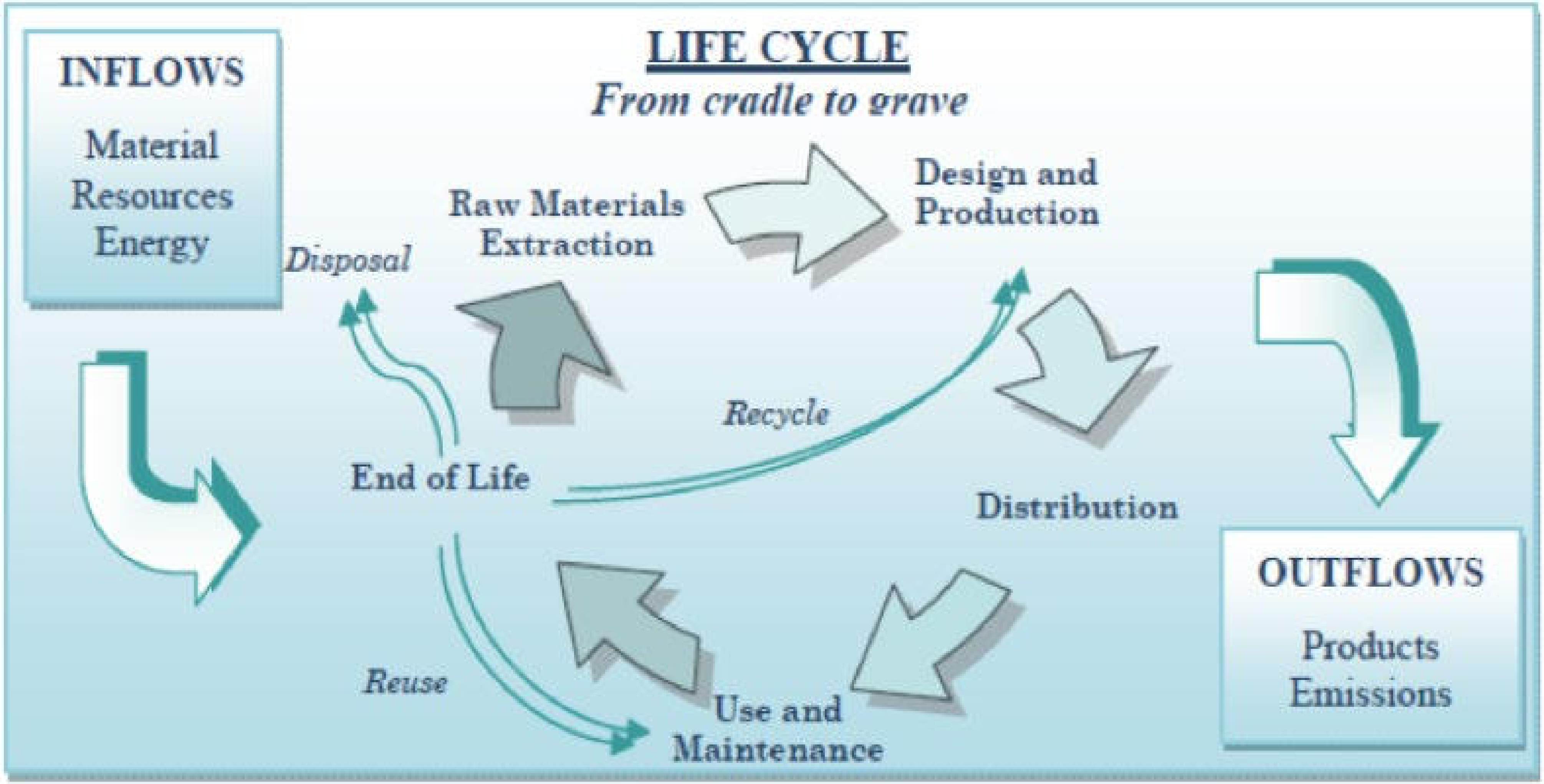
Lifecycle Assessment – LCA

- **All the ecological impacts** of a product during its **whole lifecycle**

- In all lifecycle phases - **production**, **operation** and **disposal/recycling phase** of a product

- It doesn’t only able to quantify the ecological impact of the **products** but also serves to assess the ecological impact of the **processes**, **services and facilities.**

Life cycle assessment



Source: San Martin, 2011

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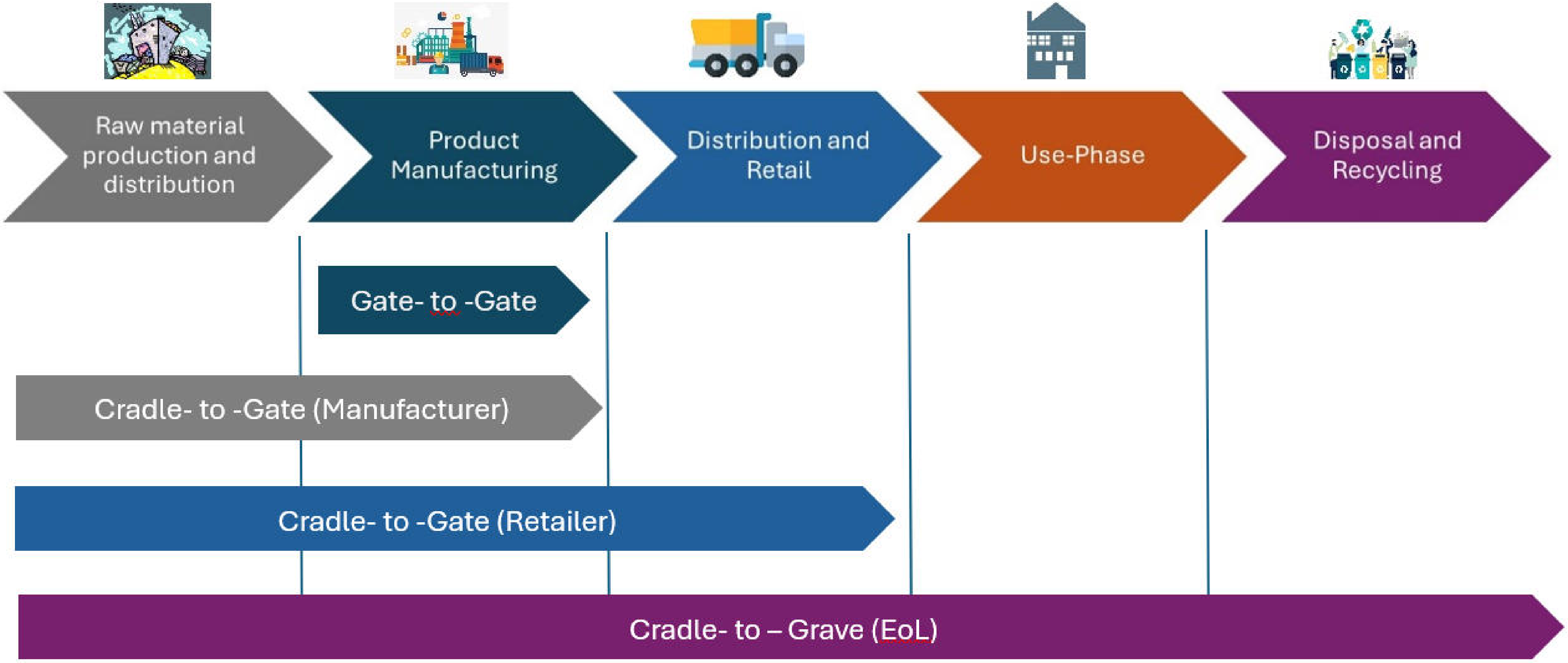
Life cycle assessment (LCA)



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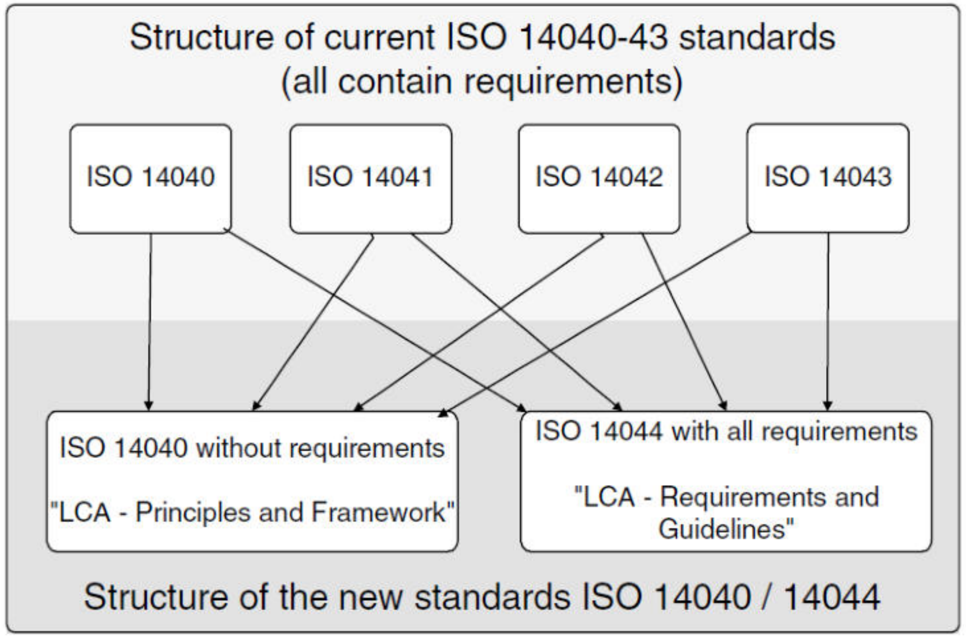
ISO (the International Organization for Standardization) – LCA

- ISO produced series of standards in 1997/98 that were recently revised in 2006
- Crucially contributed to the general acceptance of the LCA by all stakeholders and by the international community



ISO 14040: 1997
ISO 14041: 1999
ISO 14042: 2000
ISO 14043: 2000

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.482.5040&rep=rep1&type=pdf

ISO 14067:2018

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Greenhouse gases — **Carbon footprint of products** — Requirements and guidelines for quantification

- This document specifies principles, requirements and guidelines **for the quantification and reporting of the carbon footprint of a product (CFP)**, in a manner consistent with International Standards on life cycle assessment (LCA) (ISO 14040 and ISO 14044).

- Requirements and guidelines for the quantification of a partial CFP are also specified.

- This document is applicable to CFP studies, the results of which provide the basis for different applications.

- This document addresses **only a single impact category**: **climate change**. Carbon offsetting and communication of CFP or partial CFP information are outside the scope of this document.

- This document **does not** assess any **social or economic aspects** or impacts, or **any other environmental aspects** and related impacts potentially arising from the life cycle of a product.

LCA considers:

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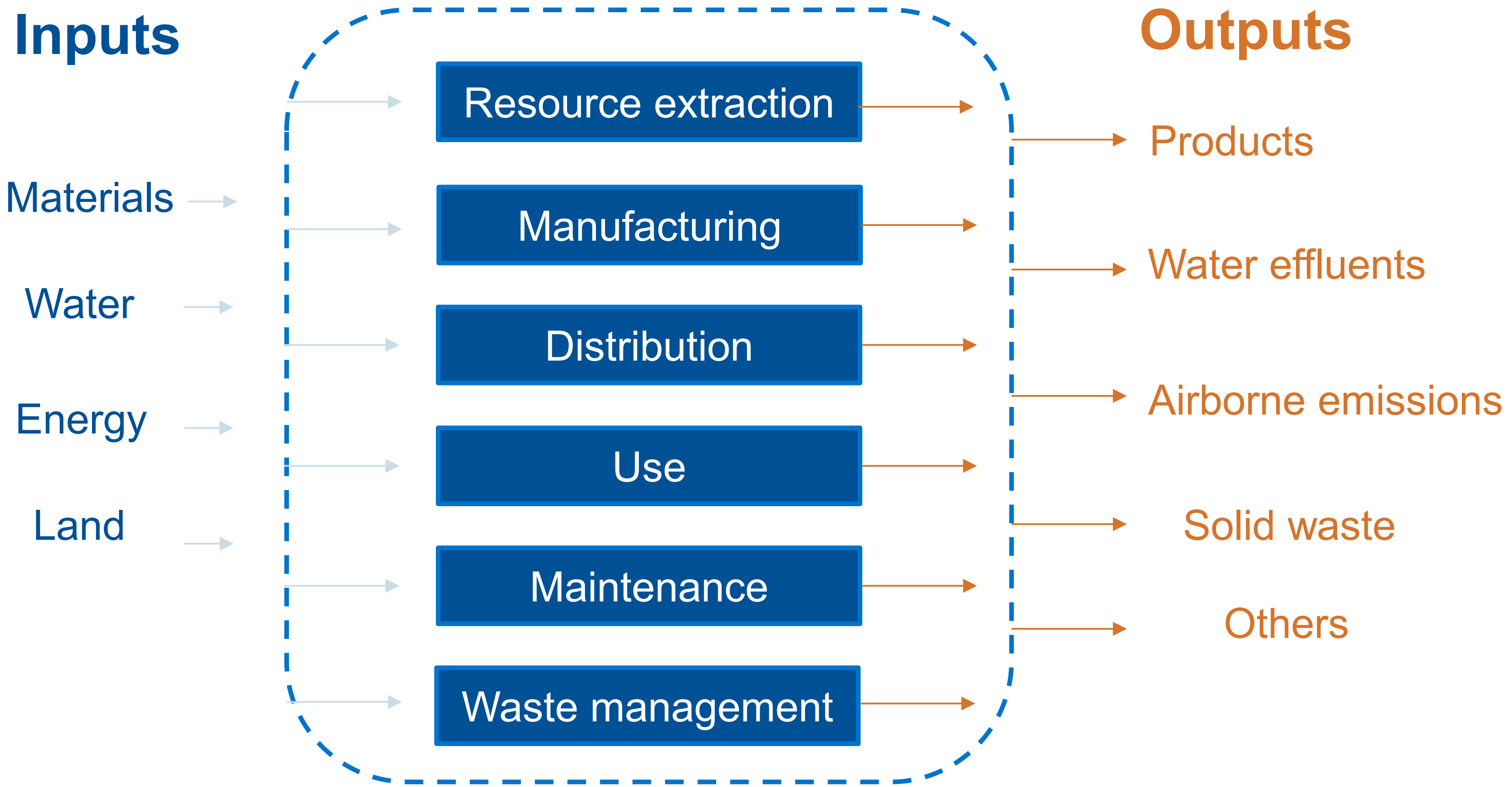

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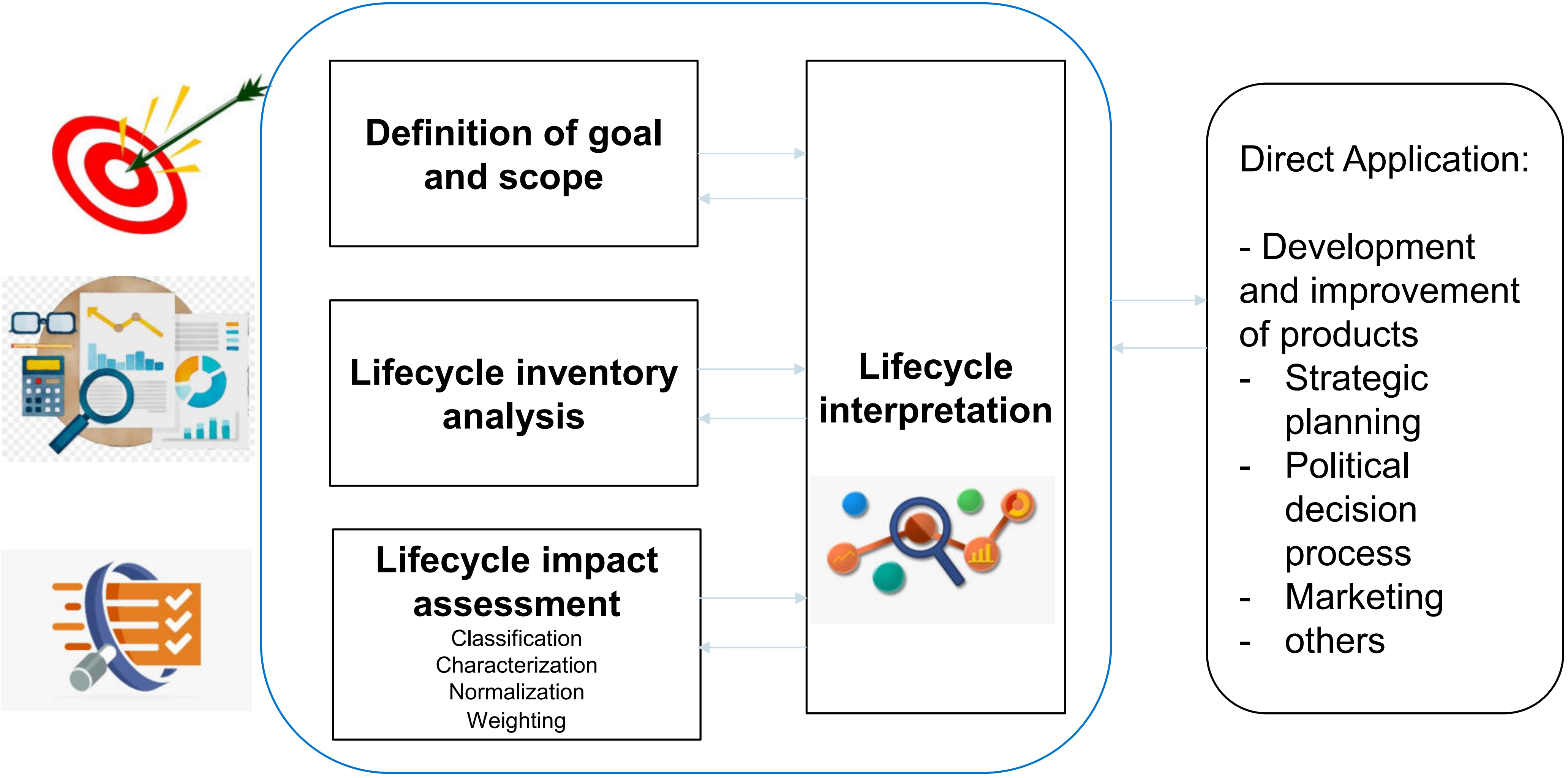
LCA framework according to ISO 14040



ISO 14067 – Carbon Footprint

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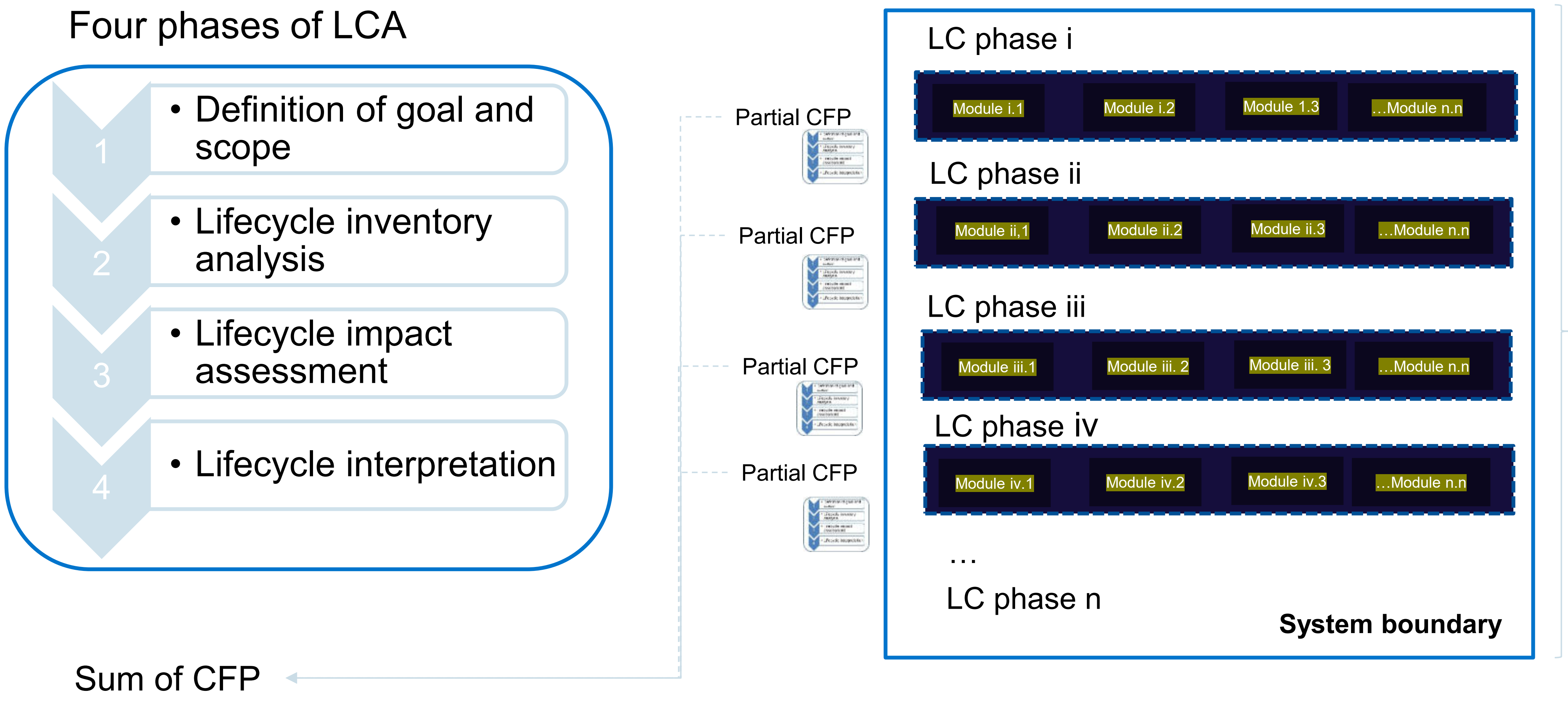
Method of quantifying the CFP and the partial CFP - Life Cycle Assessment



Breaking down LC into Lifecycle phases:
such as for example:
- raw material extraction,
Construction,
Production,
Transport,
Delivery,
Usage,
End of product life

ISO 14067 – Carbon Footprint of products
Methods of quantification of CFP and partial CFP – LCA

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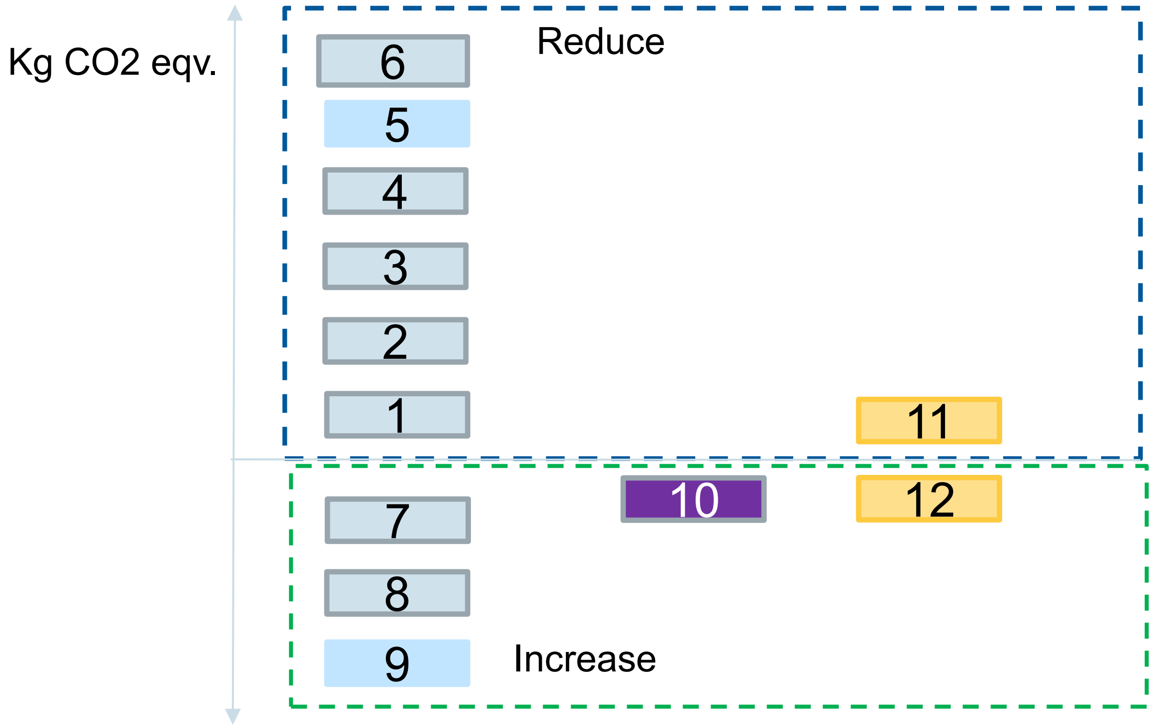
Legend

- Must be included in CFP or partial CFP
- Should be included in CFP or partial CFP
- Must be documented separately in the CFP – report but not be included in CFP
- Should be considered separately

1. GHG emissions other than those specified
2. GHG emissions from aviation
3. GHG quantities emitted from biogenic raw materials
4. GHG emissions from direct land use change and changed management practices
5. GHG emissions from land use excluded changed management practices
6. Net- quantities of GHG emissions & removals from fossile raw materials
7. GHG- quantities emitted and removed from biogenic raw materials
8. Withdrawal through direct land use change and altered management practices
9. Withdrawal through land use change and altered management practices
10. Biogenic carbon in the product
11. Emissions from indirect landuse change
12. Withdrawal through indirect landuse change



Iterative process

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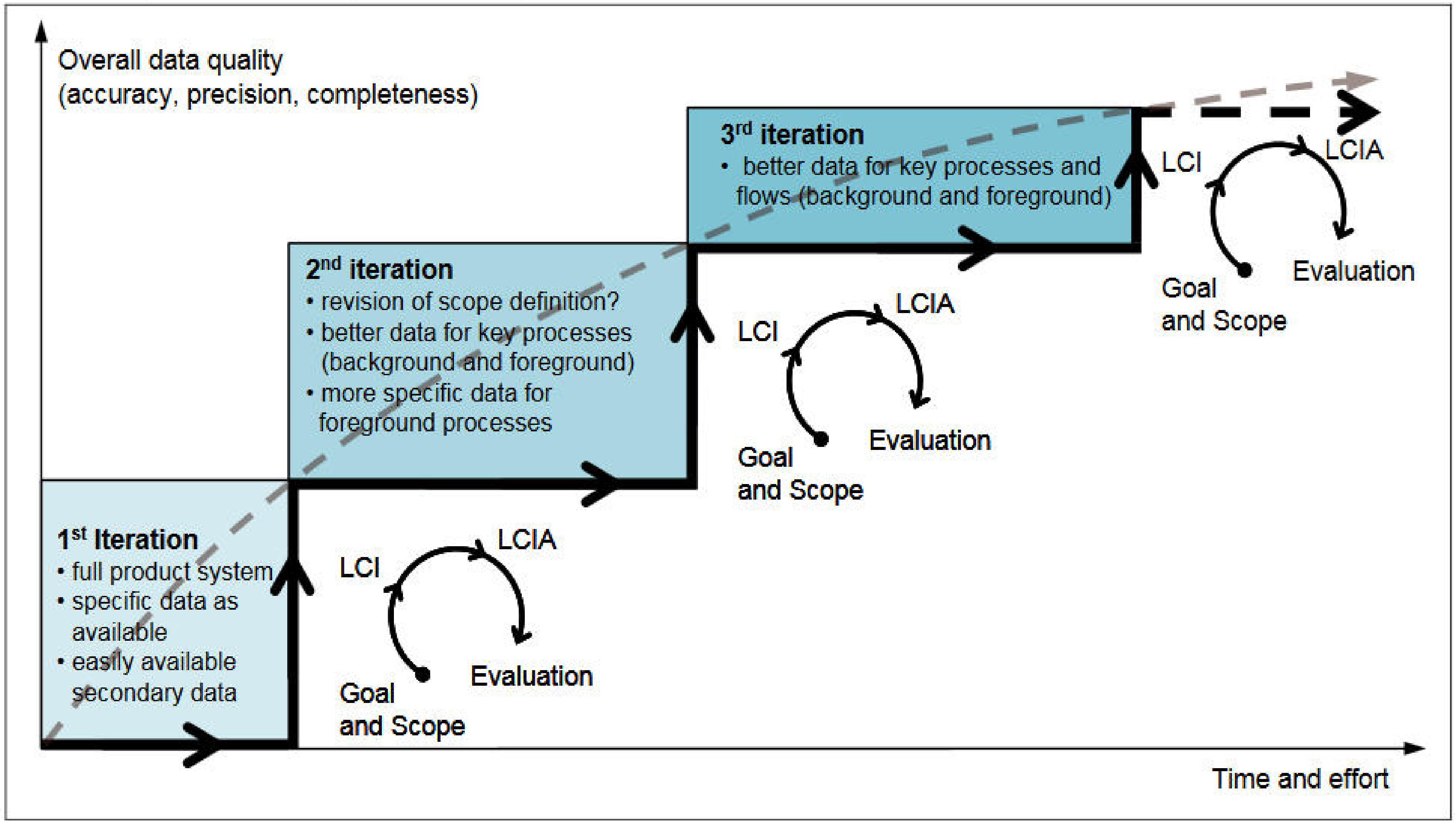

Source: ILCD Handbook

Throughout the process and at each stage, the analyst needs to check, interpret, and verify the work in progress: **redefine the goal and scope**

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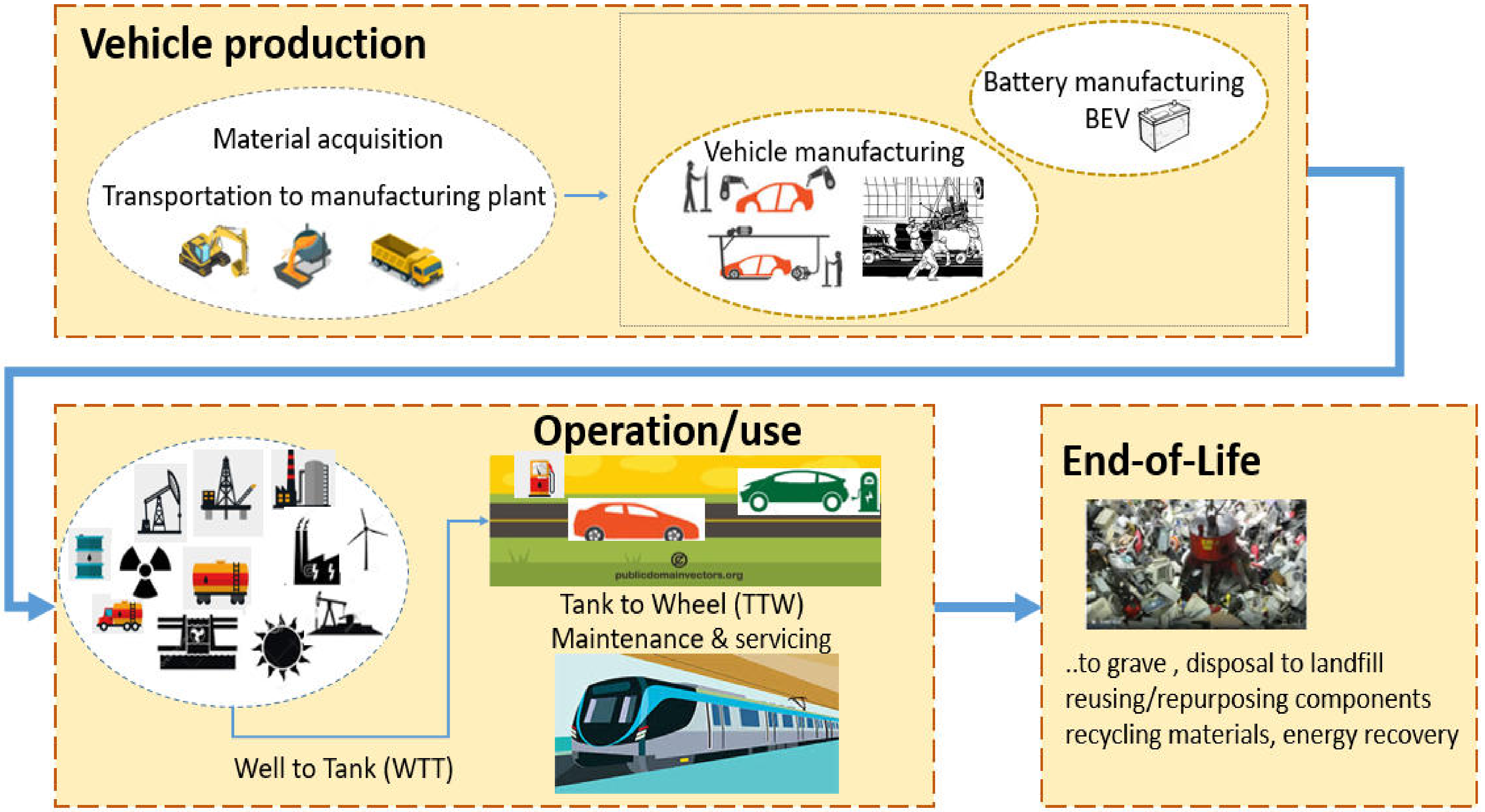
Goal & scope definition – Mobility

Schematic scope of Lifecycle Assessment (system boundaries)



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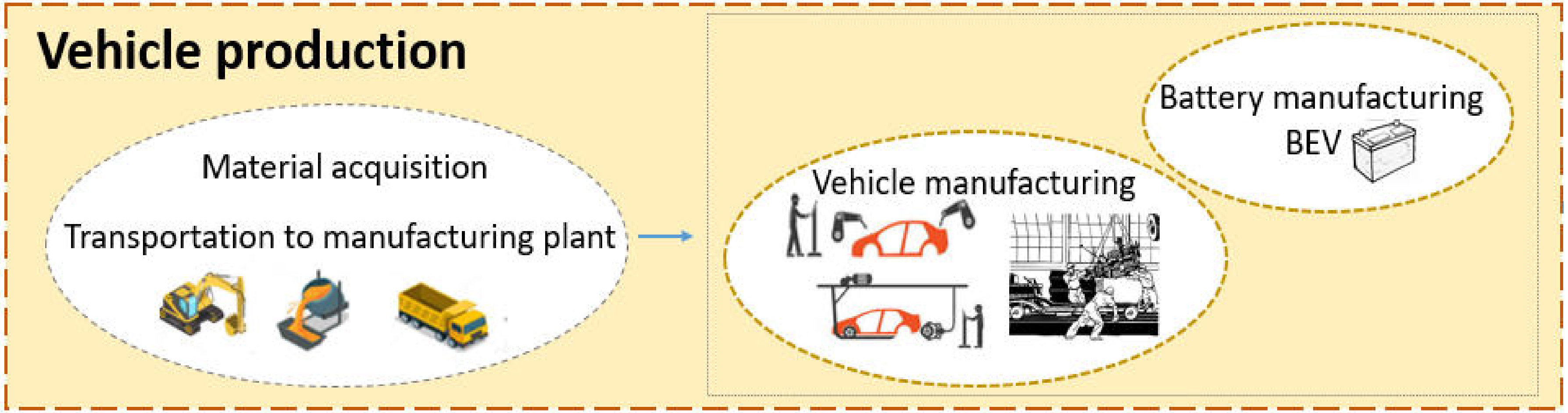
LC Phase - production



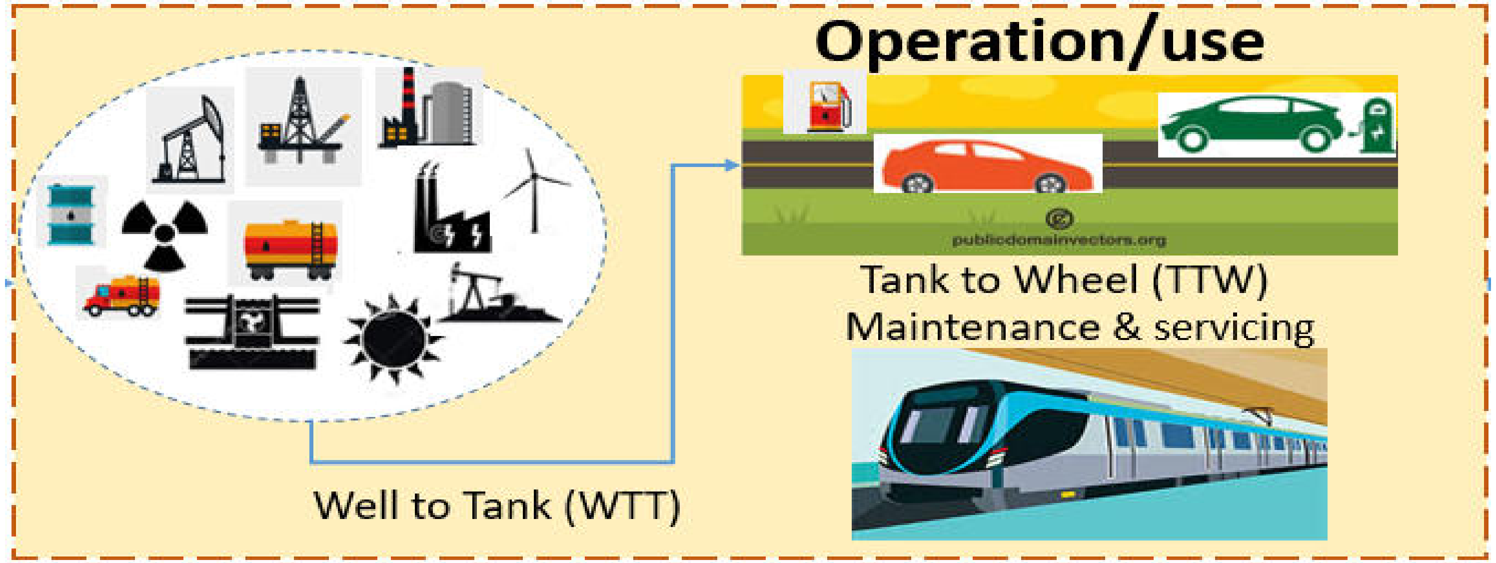
„Cradle –to- Gate“ assessment

Environmental impacts:

- raw material extraction
- processing, transport
- component manufacture
- Logistics
- vehicle assembly
- painting
- battery production in case of BEV

LC Phase - operation

Well-to-Wheel (WTW) = Well-to-Tank (WTT) + Tank-to-Wheel (TTW)



WTT: from production of the energy source (petrol, diesel, electricity, natural gas) to supply.

- Producing energy from primary energy to the charging point or fuel pump
- Emissions related to extraction, production, transport, distribution

TTW: from charging point or fuel pump to discharge (operation-being on the move)

- TTW thus describes the use of fuel or electric energy in the vehicle and emissions during driving

LC Phase – End- of - Life

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End-of-Life

..to grave , disposal to landfill
reusing/repurposing components
recycling materials, energy recovery

CFP- Train vs. Car drive phase

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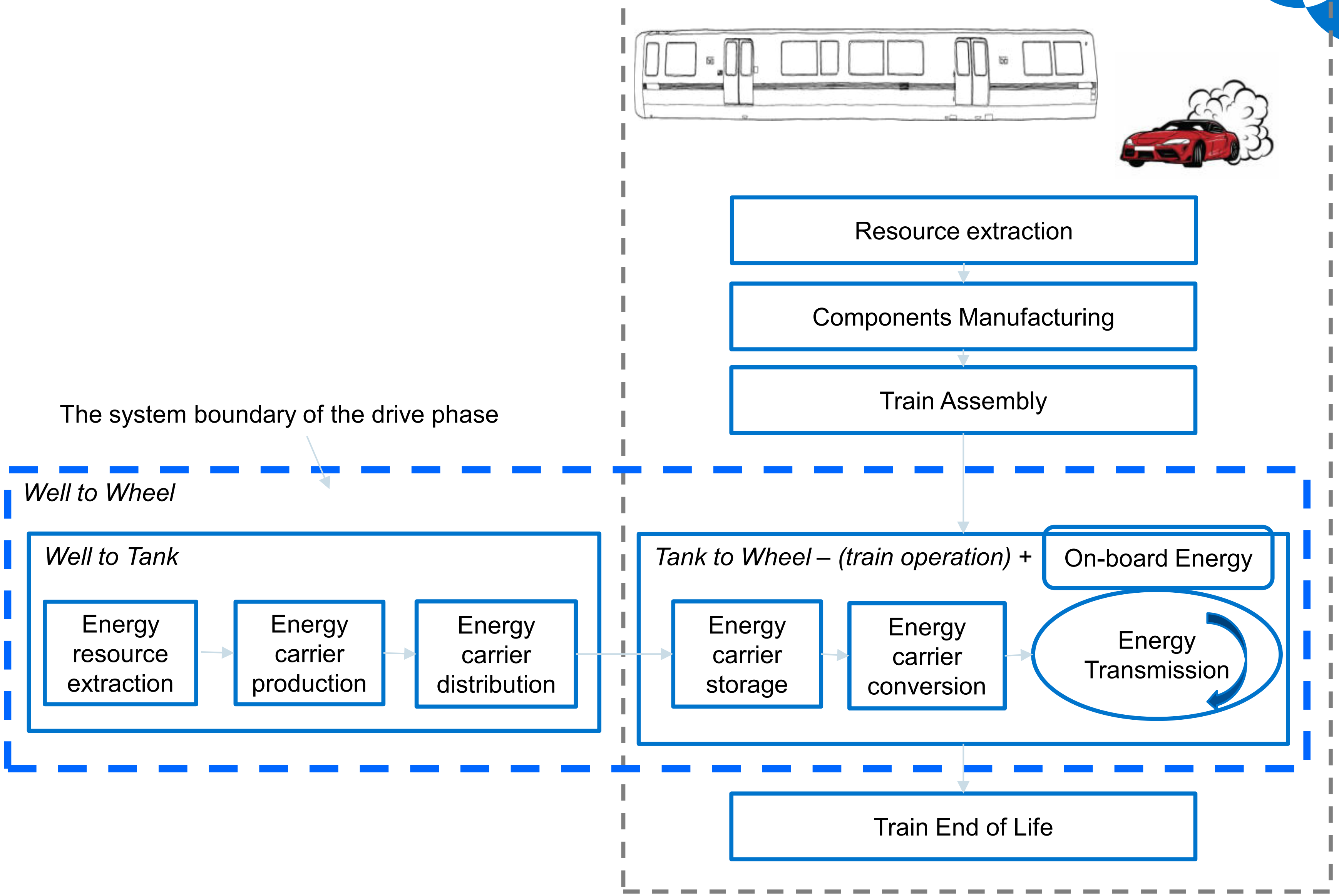


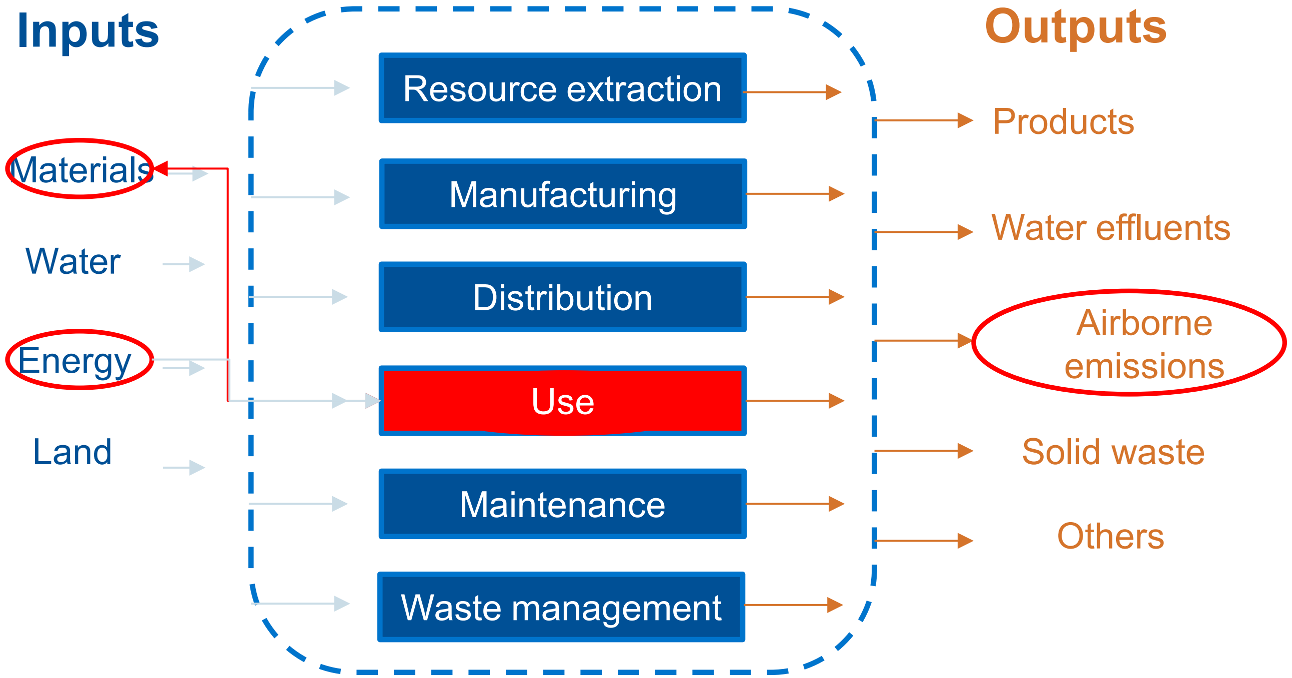
Example

Goal
Scope
Car and Train – the service phase only-
A to B 43 km (by Train), 38,5 km by car
Functional unit
Direct and indirect emissions

Inventory
Input -
Diesel
Electric energy

How many lit of diesel?

Amount of electric energy?



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How many liters of diesel?

Diesel 6,9 l/100km 38,5 km

-----? Liters of diesel

Amount of electric energy required for the train? (43 km)

A to B	Simulation	From Simulation = A to B = **288** kwh
B to A	Excel calculation	B to A = **87,3** kwh
	Database?	

https://secure.umweltbundesamt.at/co2mon/co2mon.html

Berechnung von Treibhausgas (THG)-Emissionen verschiedener Energieträger (https://secure.umweltbundesamt.at/co2mon/co2mon.html) Stand Nov. 2022						
			Gesamtmenge			
			CO_2-Äquivalent		CO_2-Äquivalent	
Energieträger	Menge	Einheit	inkl. Vorkette		ohne Vorkette	
Stromaufbringung Österreich		kWh	0,202	kg	0,16 1	kg
Umweltzeichen "Grüner Strom"		kWh	0,014	kg	0	kg
Diesel		l	3,134	kg	2,493	kg
Benzin	1,0	l	2,739	kg	2,137	kg

Impact analysis

Car

Calculation – CO2 eqv. (inc. pre-chain emission)

--- lit diesel * 3,134 = -----kg CO2 eqv.

Calculation – CO2 eqv. (without pre-chain emission)

--- lit diesel * 2,493 = -----kg CO2 eqv.

Train

A to B = **288** kwh
B to A = **87,3** kwh

288 *0,014 = ---- kg CO2 eqv.
87,3 * 0,014 = ----kg CO2 eqv.

Green or electricity mix?

Convert to the appropriate functional unit to compare

Average occupancy rate: Car = 1,14 Ö-
Umweltbundesamt
Train eg. 40 people

$(CO_2 \text{ eqv. } /(\text{Occupancy rate} * \text{distance}))*1000$ = g CO_2 eqv. /pkm

$(CO_2 \text{ eqv. } /(1{,}14 * 38{,}5*2))*1000$ =------ g CO_2 eqv. /pkm **Car**

$(CO_2 \text{ eqv. } /(40 * 43*2))*1000$ =------ g CO_2 eqv. /pkm **Train**

Emission factors

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Ziel der Publikation der Emissionsfaktoren der Verkehrsträger ist es, aus Sicht des Umweltbundeamtes möglichst realistische Angaben zu vor- und nachgelagerten THG-Emissionen von Verkehrsmitteln in Österreich zur Verfügung zu stellen. Die Österreichische Luftschadstoffinventur und das Computermodell GEMIS-Österreich bilden die Grundlage für die Erstellung dieser Emissionsfaktoren. Die Emissionsfaktoren berücksichtigen damit insbesondere auch spezifische nationale Bedingungen (z. B. österreichischer Strommix) und entsprechen daher nicht unbedingt den Vorgaben anderer Bewertungssysteme zu THG-Emissionen im Verkehr (z. B. EN ISO 14083:2023).

aktualisiert Mai 2025

bezogen auf Besetzungs-/Auslastungsgrad (g/Pkm bzw. g/Tkm)			**Emissionskennzahlen Datenbasis 2023**						**Verbrauch in kWh/Pkm oder Tkm**
			Direkte Emissionen in g/Pkm oder Tkm				**vorgelagerte THG Emissionen (g/Pkm bzw. g/Tkm)***		
			CO_2-Äquivalente*	**CO_2**	**NO_x**	**PM (10)*** Verbren-nung**	**Treibstoffherstellung bzw. Strombereitstel-lung**	**Fahrzeug-herstellung********	**spezf. Ver-brauch**
STRASSE	PKW Durchschnitt (inkl. BEV)*	g/Pkm	139,1	137,4	0,38	0,004	39,5	47,0	0,56
	PKW Benzin (B)*	g/Pkm	136,6	136,2	0,08	0,002	33,8	59,3	0,55
	PKW Diesel (D)*	g/Pkm	148,6	146,1	0,57	0,006	42,1	41,2	0,59
	BEV (Ö. Stromaufbringung inkl. Importen)	g/Pkm	-	-	-	-	28,1	77,5	0,18
	LKW LNF (< 3,5 t) (D)*	g/Tkm	633,5	623,7	2,23	0,049	179,9	154,1	2,52
	LKW SNF (< 18 t) (D)*	g/Tkm	283,1	277,2	0,82	0,008	72,2	24,6	1,17
	LKW SNF (> 18 t) (D)*	g/Tkm	108,3	106,8	0,25	0,002	27,8	6,7	0,45
	Sattelzüge (40 t) (D)*	g/Tkm	49,4	48,9	0,04	0,001	12,8	3,0	0,21
	Durchschnitt LKW SNF (> = 3,5t - 40t) D*	g/Tkm	66,9	65,9	0,10	0,001	17,3	4,4	0,28
	Reisebus (D)*	g/Pkm	35,2	34,7	0,07	0,001	8,7	4,7	0,14
	Linienbus (ÖV) (D inkl. E)*	g/Pkm	40,7	40,3	0,07	0,001	10,4	4,9	0,17
BAHN	Personenverkehr (PV) Schiene in Ö	g/Pkm	3,2	3,1	0,02	0,001	4,8	1,1	0,07
	Güterverkehr (GV) Schiene in Ö	g/Tkm	1,5	1,5	0,01	0,001	2,3	0,2	0,03
FLUG	Inlandsflug**	g/Pkm	439	217	0,83	0,007	51,0	0,8	0,86
	Kurz-/Mittelstrecke (bis 1.000 km)**	g/Pkm	253	125	0,66	0,004	29,4	0,5	0,50
	Kurze Langstrecke (bis 4.000 km)**	g/Pkm	231	114	0,78	0,003	26,8	0,4	0,45
	Langstrecke (>4.000 km)**	g/Pkm	193	96	0,44	0,003	22,4	0,3	0,38

BEV... *Battery Electric Vehicle*
SNF... *schwere Nutzfahrzeuge >= 3,5 t*
LNF... *leichte Nutzfahrzeuge < 3,5t hzG*
Pkm/Tkm... *Personenverkehr/Tonnenkilometer*
B... Benzin
D *Diesel*
kWh... *Kilowattstunde*

* *Emissionen bzw. Daten aus der Österreichischen Luftschadstoffinventur OLI2024 (1990-2023) sowie auf Basis von Harmonisierte Österreichische direkte und vorgelagerte Thg-Emissionsfaktoren für relevante Energieträger & Technologien*

** *Beim Flugverkehr werden Nicht- CO_2 Effekte durch den Faktor von 2 berücksichtigt*

*** *Feinstaub/particulate matter: Bei den Verbrennungsemissionen ist die Teilchengröße vorwiegend 1 µm*

**** *Die Lebensfahrleistung berechnet sich aus dem Durchschnitt der Jahresfahrleistungen der letzten 10 Jahre und einer Lebensdauer von 15 Jahren*

https://www.umweltbundesamt.at/fileadmin/site/themen/mobilitaet/daten/ekz_pkm_tkm_verkehrsmittel.pdf .

Global Warming Potential (GWP)

- CO_2 = GWP of 1 regardless of the time period used.
- CO_2 remains in the climate system for a very long time: will last thousands of years
- Methane (CH_4) is estimated to have a GWP of 25 times more global warming over 100 years compared to CO_2.
  - CH_4 also absorbs much more energy than CO_2. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP.
- Nitrous oxide (N_2O) has a GWP 265–298 times that of CO_2 for a 100-year timescale.
- Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) trap substantially more heat than CO2.

Global Warming Potential (GWP)

Kyoto Gases (IPCC* 2013-2020)

Greenhouse Gas	Global warming Potential (GWP) factor
Carbon dioxide (CO_2)	1
Methane (CH4)	25
Nitrous oxide (N_2O)	298
Hydroflourocarbons (HFCS)	124 - 14,800
Perflourocarbons (PFCs)	7,390 – 12,200
Sulfur hexafluoride (SF6)	22,800
Nitrogen trifluoride (NF3)	17,200

Kyoto 2nd commitment period (2013- 2020) added Nitrogen trifluoride. For the first commitment period (2008 to 2012) only the first six gases were included.

* IPCC: Intergovernmental Panel on Climate Change

Other impact categories: CFP (GWP) is only one of them

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- Global warming potential (GWP): contribution to the greenhouse effect in (kg CO2- equivalent)
- Ozone depletion potential (ODP): contribution to hole in the ozone layer in (kg R11- equivalent)
- Acidification potential (AP): contribution to acidic rain in (kg SO2 – equivalent)
- Eutrophication potential (EP): contribution to over fertilisation in (kg Phosphate – equivalent)
- Photochemical ozone creation potential (POCP): contribution to summer smog in (kg Ethen-equivalent)
- Non renewable primary energy demand in (MJ) – energetically used resources
- Solid waste
- Heavy metals
- Winter and summer smog
- Carcinogens

Inventory Data

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- Data sources and gathering
  - Reference sources (public)
    - ✓ https://www.umweltbundesamt.at/umweltthemen/mobilitaet/mobilitaetsdaten
    - ✓ Berechnung von Treibhausgas (THG)-Emissionen verschiedener Energieträger

      https://secure.umweltbundesamt.at/co2mon/co2mon.html
    - ✓ European commission, Joint Research Center (EC JRC): Life Cycle Data Network: http://eplca.jrc.ec.europa.eu/ELCD3/datasetDownload.xhtml **LCAI Methods**
    - ✓ EPD Bundesministerium Deutschland: http://www.oekobaudat.de/datenbank/browser-oekobaudat.html
    - ✓ Gemis: http://iinas.org/gemis-de.html
    - ✓ National Renewable Energy Laboratory (NREL), U.S. Life Cycle Inventory Database: https://www.nrel.gov/lci/
    - ✓ IDEMA- App
    - ✓ https://www.nrel.gov/lci/
  - Reference sources (commercial 6 partially free)
    - ✓ Ecoinvent (http://www.ecoinvent.org/)- can be also accessed as part of licensed user arrangements with LCA software e.g. SimaPro/GaBi
  - Reference sources (peer reviewed academic literature)
    - ✓ http://www.springer.com/environment/journal/11367
    - ✓ https://kmu-klima-deal.hszg.de/wissensdatenbank/datenbanken/auswahl-an-datenbanken-fuer-emissionsfaktoren#:~:text=Auswahl%20an%20Datenbanken%20f%C3%BCr%20Emissionsfaktoren.%20Quelle.%20Erl%C3%A4uterung.%20Link.

Group Exercise 1

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- Exercise 1: 4- 5 students in each group

- Passenger transport - modal split in Romania and Austria?

  - Emission factors in Austria and Romania
    - Train
    - Bus
    - Car

  - Calculate and compare emissions traveling 1000 km per person (using the average modal split of respective country)

Group Exercise 2

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How could we increase the environmental sustainability of freight transport in the EU?

Your task is to explore and propose innovative, practical, and sustainable solutions to improve the **environmental sustainability** of freight transport within the EU.

Key questions:

- What are the current emission challenges in EU freight transport?
- How can technology contribute to reduce emissions?
- What role do policy and regulation play?
- What are some best practices from EU member states or globally?
- What practices would you recommend?

You may use academic articles, EU transport policy documents, industry reports, and other credible sources. Remember to cite your sources appropriately.
Form groups of 4 persons and prepare a 10–15-minute visual presentation

Group Exercise 3

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CALCULATE YOUR MOBILITY EMISSIONS

KEY STEPS FOR CALCULATING MOBILITY EMISSIONS

Collecting Personal Mobility Data

Participants enter travel modes and distances into spreadsheets, establishing a baseline of individual mobility patterns.

Researching Emission Factors

Country-specific CO_2 emission factors are researched to understand regional differences in transport emissions.

- Romania – you need to search for data on the emission factors
- Austria – data on emission factors provided (see excel sheet)

Calculating and Comparing Emissions

Annual emissions are calculated using data from two countries to reveal the impact of local factors on emissions.

Group Discussion and Reflection

Discuss results, identify high-impact travel modes, and explore practical ways to reduce emissions.