Introduction

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The labs

« Normal » time :

3 hours lab

Questions time at the end

1 part « hand calculations »

1 part « Application in OpenLCA » (screen projected on the board)

Distance learning :

Shorters labs

Questions time at the end

1 synchronous part « hand calculations »

1 asynchronous part « Application in OpenLCA » : video capsules

DDI8003 – Lab1 – Define the scope and model the carbon footprint of Aluminum cans of carbonated water

Created by Laure Patouillard, Ivan Viveros Santos, Anne-France Bolay, Julien Pedneault and Laura Debarre

Info on projects

- Detailed guidelines will be posted on moodle by the end of the week
- Additional requirement this year about time needed to collect data and the uncertainty associated with it

Documentation for Lab 1

Before Lab

DDI8003_A2021_Lab1_ENG.pdf

During Lab

DDI8003_A2021_Lab1_presentation_ENG

After Lab

DDI8003_A2021_Lab1_solution_ENG.pdf

DDI8003_A2021_Lab1_solution.ENG

ddi8003_ecoinvent_3_6_Lab1

Context

- You want to **calculate the cradle-to-grave carbon footprint of cans of carbonated water** produced in the United States (Portland, Maine).
- You have access to information (primary data) on the production processes of aluminium cans and on the filling process
- You also have access to aggregated data for a series of products (electricity, aluminium, water, etc.)

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Goal and scope

Your objectives are to:

- **Calculate the cradle-to-grave carbon footprint of cans of carbonated water produced in the United States**
- **Identify areas of improvement**

The scope of the study is as follows:

- **Function: to drink a can of carbonated water**
- **Functional unit: Drinking 1 can of carbonated water refrigerated of 355ml in 2021 in the United States**

Data

- The emission factor related to the combustion of natural gas is 1.9 kg CO_2/Nm^3 natural gas.
- We assume that the cans are 100% virgin aluminium.
- We assume that there are no aluminium losses during the production of the empty cans.
- We assume that all of the filled cans will be consumed.
- We assume that all of the cans at the end-of-life are disposed into a landfill.
- The cans are refrigerated for one week during the use phase.
- The volume of the refrigerator is 290 litres and the lifespan of the fridge is 15 years. A refrigerator consumes 288 kWh/year.
- The transport between the production of the can and the use of the can is assumed to be 30 km.
- Other inputs (lubricants, solvents, etc.) are assumed to be environmentally negligible.
- Here only CO2 and CH4 emissions will be considered in the calculation of the carbon footprint: GWP CO_2: 1 kg CO_2e/kg CO_2, GWP CH_4: 29,7 kg CO_2e/kg CH_4

Data

Unit processes	Flow type	Flow	Quantity	Unit
Filling of cans of carbonated water	Intermediary flows - Outputs	Can of carbonated water	1	Can
	Intermediary flows– Inputs	Electricity	9	Wh
		Tap water	0.355	L
		Pressurized CO_2	20	g
		Empty aluminium can	1	Can
Production of an aluminium can (including rolling)	Intermediary flows - Outputs	Empty aluminium can	1	Can
	Intermediary flows – Inputs	Electricity	30	Wh
		Natural gas	0.003	Nm3
		Aluminium	13	g
	Elementary flows	CO_2	**Tbd**	gCO2
Use of a can of carbonated water	Intermediary flows - Outputs	Can of carbonated water used	1	Can
	Intermediary flows – Inputs	Can of carbonated water	**Tbd**	Can
		Can at end-of-life	**Tbd**	Can
		Refrigerated can	**Tbd**	Can
		Transport	**Tbd**	tkm
Refrigeration	Intermediary flows - Outputs	Refrigerated can	**Tbd**	Can
	Intermediary flows – Inputs	Electricity	**Tbd**	Kwh
		Fridge	**Tbd**	fridge
End-of-life of can	Intermediary flows - Outputs	Can at end-of-life	1	Can
	Intermediary flows – Inputs	Transport	3.9 E-03	tkm
		Aluminium landfilled	13	g

TBD: to be determined

Data

Aggregated processes	Elementary flows		Unit	Ecoinvent 3.6 process
	CO2	CH4		
Tap water (RoW)	9.80E-04	2.30E-06	kg/m³ potable water	market for tap water | tap water | Cutoff, S - RoW
Pressurized CO_2 (RoW)	5.18E-01	1.15E-02	kg/kg CO_2 (pressurized)	market for carbon dioxide, liquid | carbon dioxide, liquid | cut-off, S
Primary (virgin) Aluminum (US)	1.06E+01	1.72E-02	kg/kg primary aluminium	aluminium production, primary, ingot | aluminium, primary, ingot | Cutoff, S - RNA
Natural gas (US)	1.57E-01	9.79E-03	kg/Nm³ natural gas	market for natural gas, high pressure | natural gas, high pressure | Cutoff, S - US
Electricity, medium voltage (NPCC, US)	2.22E-01	7.10E-04	kg/kWh electricity	electricity, high voltage, production mix | electricity, high voltage | Cutoff, S – NPCC, US only
Transport (RoW)	1.32E-01	1.83E-02	Kg/tkm	market for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, S - RoW
Refrigerator (GLO)	1.92E+02	9.43E-01	kg/unit	market for refrigerator | refrigerator | Cutoff, S - GLO
Landfiling (RoW)	9.37E-02	2.91E-02	Kg/kg waste	market for municipal solid waste | municipal solid waste | Cutoff, S - RoW

Goal and scope

Question 1

1.1 Draw a process tree or flow diagram that represents the "cradle-to-grave" product system of the can of carbonated water.

1.2 Identify the aggregated unit processes (cradle-to-gate) and disaggregated (gate-to-gate) processes of the process tree.

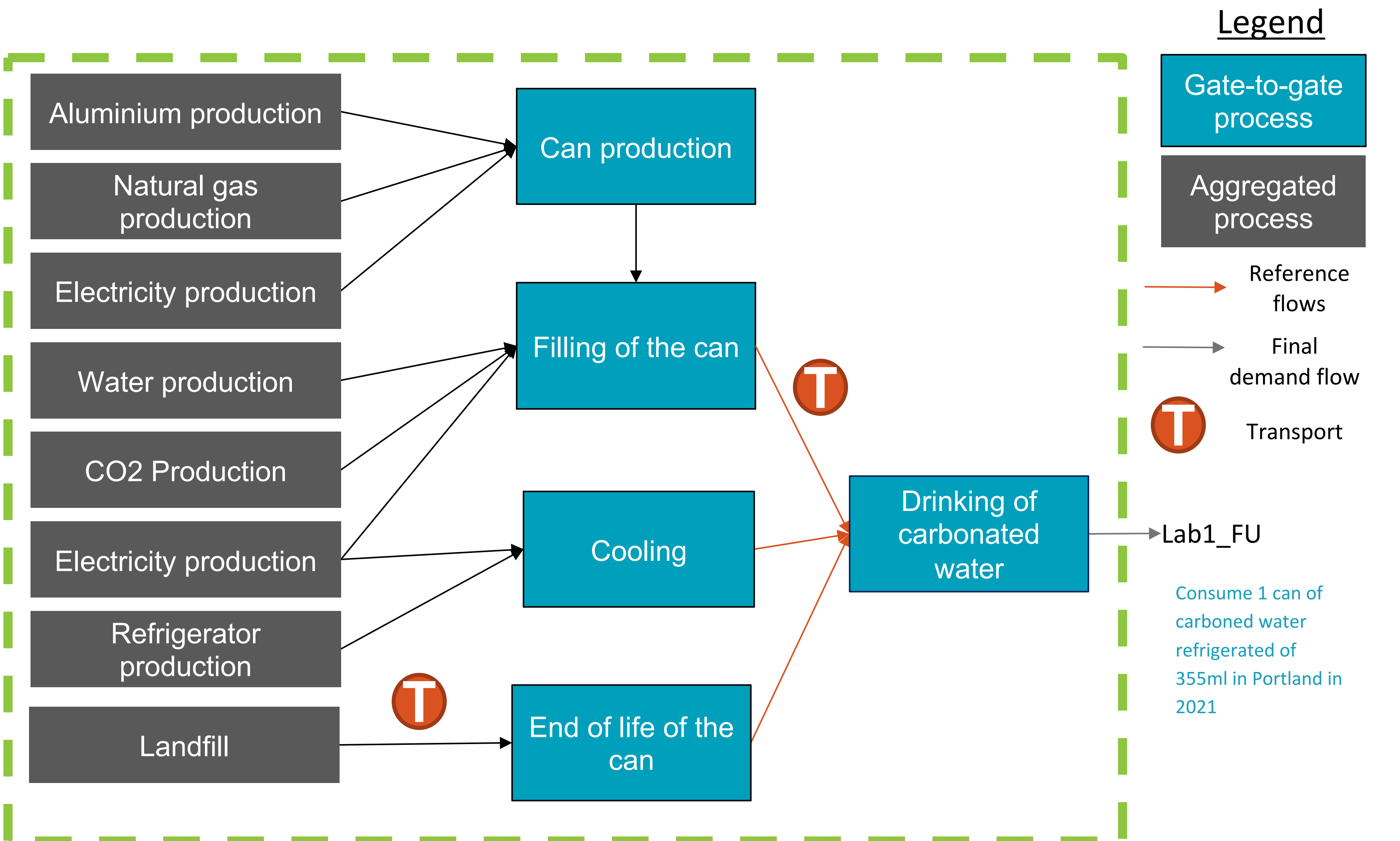
1.3 Recall the definition of a reference flows then identify which of the intermediate flows in the products system are reference flows.

1.4 Certain flows in table 1 are Tbd (to be determined). For each of them, identify the information you need to put their value at the scale of the output intermediary flow. What is the name of this type of information when it allows to quantify the reference flows allowing to achieve the functional unit?

Data

Unit processes	Flow type	Flow
Filling of cans of carbonated water	Intermediary flows - Outputs	Can of carbonated water
	Intermediary flows– Inputs	Electricity
		Tap water
		Pressurized CO_2
		Empty aluminium can
Production of an aluminium can (including rolling)	Intermediary flows - Outputs	Empty aluminium can
	Intermediary flows – Inputs	Electricity
		Natural gas
		Aluminium
	Elementary flows	CO_2
Use of a can of carbonated water	Intermediary flows - Outputs	Can of carbonated water used
	Intermediary flows – Inputs	Can of carbonated water
		Can at end-of-life
		Refrigerated can
		Transport
Refrigeration	Intermediary flows - Outputs	Refrigerated can
	Intermediary flows – Inputs	Electricity
		Fridge
End-of-life of can	Intermediary flows - Outputs	Can at end-of-life
	Intermediary flows – Inputs	Transport
		Aluminium landfilled

Process tree of the system



Goal and scope

Question 1

1.1 Draw a process tree or flow diagram that represents the “cradle-to-grave” of the can of carbonated water product system.

1.2 Identify the aggregated unit processes (cradle-to-gate) and disaggregated (gate-to-gate) processes of the process tree.

1.3 Recall the definition of a reference flow then identify which of the intermediate flows in the products system are reference flows.

1.4 **Certain flows in table 1 are Tbd (to be determined). For each of them, identify the information you need to put their value at the scale of the output intermediary flow. What is the name of this type of information when it allows to quantify the reference flows allowing to achieve the functional unit?**

Data

Unit processes	Flow type	Flow	Quantity	Unit
Filling of cans of carbonated water	Intermediary flows - Outputs	Can of carbonated water	1	Can
	Intermediary flows– Inputs	Electricity	9	Wh
		Tap water	0.355	L
		Pressurized CO_2	20	g
		Empty aluminium can	1	Can
Production of an aluminium can (including rolling)	Intermediary flows - Outputs	Empty aluminium can	1	Can
	Intermediary flows – Inputs	Electricity	30	Wh
		Natural gas	0.003	Nm3
		Aluminium	13	g
	Elementary flows	CO_2	**Tbd**	gCO2
Use of a can of carbonated water	Intermediary flows - Outputs	Can of carbonated water used	1	Can
	Intermediary flows – Inputs	Can of carbonated water	**Tbd**	Can
		Can at end-of-life	**Tbd**	Can
		Refrigerated can	**Tbd**	Can
		Transport	**Tbd**	tkm
Refrigeration	Intermediary flows - Outputs	Refrigerated can	**Tbd**	Can
	Intermediary flows – Inputs	Electricity	**Tbd**	Kwh
		Fridge	**Tbd**	fridge
End-of-life of can	Intermediary flows - Outputs	Can at end-of-life	1	Can
	Intermediary flows – Inputs	Transport	3.9 E-03	tkm
		Aluminium landfilled	13	g

Key parameters: “Data needed to calculate the reference flows”

e.g. Lifespan, Number of re-uses possible, Quantity of material / energy used by a service rendered Efficiency

Not a figure but a **word**

Goal and scope

What are the information you need to calculate the amount of electricity used for your FU?

Reference flow	Unit	Key parameters [Unit]
Electricity - refrigerator	kWh/FU	•Refrigeration time of 1 can = 1 week/can •Electricity consumed by 1 refrigerator = 277 Kwh/yr/fridge •Volume of 1 can = 0.355 L/can •Volume of 1 fridge = 290 L/fridge
Refrigerator	unit/FU	•Fridge life = 15 years/fridge •Refrigeration time of 1 can = 1 week/can •Volume of 1 can = 0.355 L/can •Volume of 1 fridge = 290 L/fridge
Transport	t.km/FU	•Transport between production plant and use = 30 km •Weight of 1 empty can = 13 g/can
Carbonated water can	unit/FU	•Waste rate of a can = 0%
End of life of the can	unit/FU	•End of life can rate = 100% of used cans have an end of life

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Inventory calculation by hand

Question 2

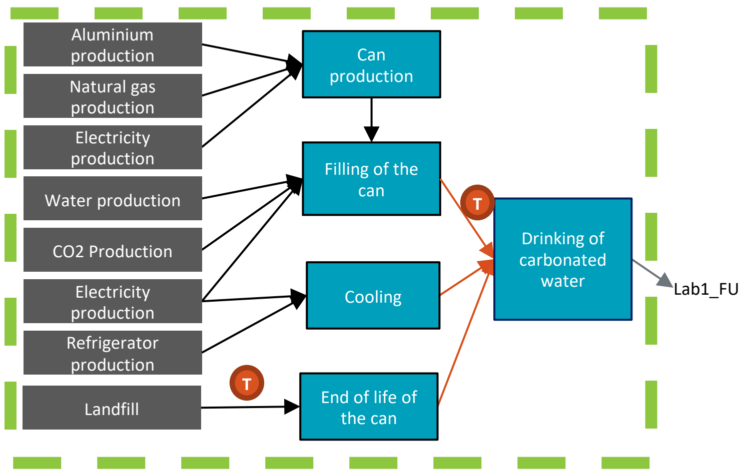
2.1 Quantify the reference flows (scaled to the functional unit) from question 1.3.

2.2 Calculate the value of the flows associated with each unit process (scaled to the output intermediary flow first and to the functional unit of the product system afterwards).

2.3 Carry out the life cycle inventory, i.e., calculate all the quantities of elementary flows involved in the system and scaled to the functional unit. (Note: for simplification, only CO_2 and CH_4 flows are considered here. In a "classic" LCA, an inventory can be made up of several hundred different elementary flows).

Inventory calculation by hand

Question 2

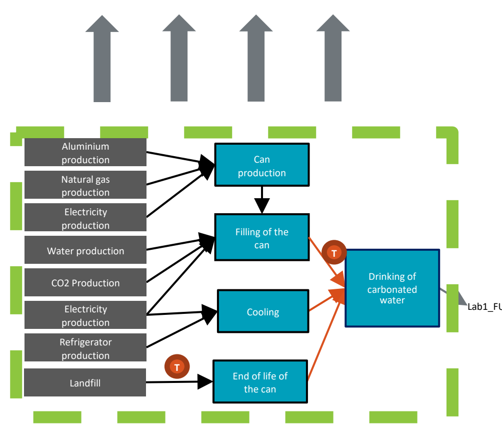


1) A product system

Aggregated processes	Elementary flows		Unit	Ecoinvent 3.6 process
	CO2	CH4		
Tap water (RoW)	9.80E-04	2.30E-06	kg/m³ potable water	market for tap water | tap water | Cutoff, S - RoW
Pressurized CO_2 (RoW)	5.18E-01	1.15E-02	kg/kg CO_2 (pressurized)	market for carbon dioxide, liquid | carbon dioxide, liquid | cut-off, S
Primary (aluminium) (US)	1.06E+01	1.72E-02	kg/kg primary aluminium	aluminium production, primary, ingot | aluminium, primary, ingot | Cutoff, S - RNA
Natural gas (US)	1.57E-01	9.79E-03	kg/Nm³ natural gas	market for natural gas, high pressure | natural gas, high pressure | Cutoff, S - US
Electricity, medium voltage (NPCC, US)	2.22E-01	7.10E-04	kg/kWh electricity	electricity, high voltage, production mix | electricity, high voltage | Cutoff, S – NPCC, US only
Transport (RoW)	1.32E-01	1.83E-02	Kg/tkm	market for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, S - RoW
Refrigerator (GLO)	1.92E+02	9.43E-01	kg/unit	market for refrigerator | refrigerator | Cutoff, S - GLO
Landfiling (RoW)	9.37E-02	2.91E-02	Kg/kg waste	treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, S - RoW

2) Information about elementary flows for each processes in stardard quantities (1m3, 1kg etc.)

3) Quantification of each intermediary flows to scale the system elementary flows

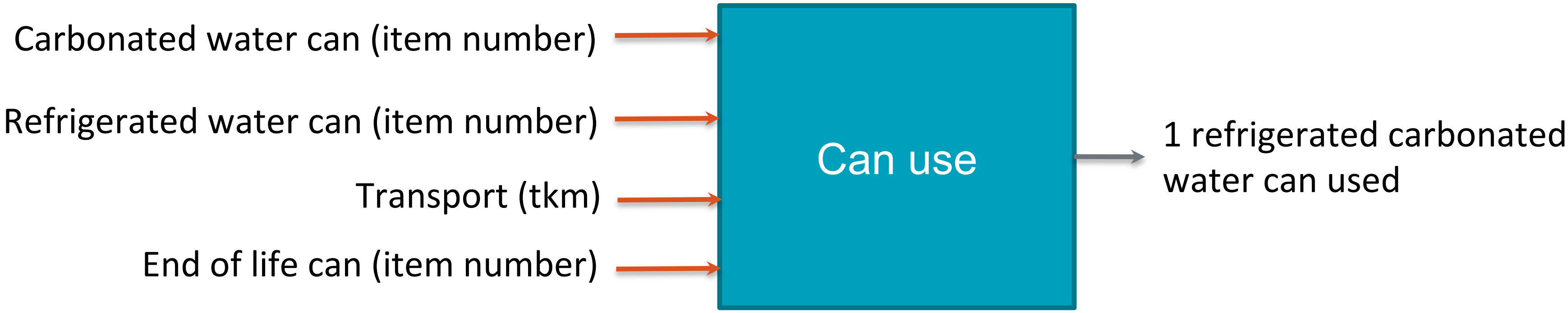


Question 2

2.1 Quantify the reference flows (scaled to the functional unit).

Unit processes	Flow type	Flow	Quantity	Unit
Filling of cans of carbonated water	Intermediary flows - Outputs	Can of carbonated water	1	Can
	Intermediary flows– Inputs	Electricity	9	Wh
		Tap water	0.355	L
		Pressurized CO_2	20	g
		Empty aluminium can	1	Can
Production of an aluminium can (including rolling)	Intermediary flows - Outputs	Empty aluminium can	1	Can
	Intermediary flows – Inputs	Electricity	30	Wh
		Natural gas	0.003	Nm3
		Aluminium	13	g
	Elementary flows	CO_2	**Tbd**	gCO2
Use of a can of carbonated water	Intermediary flows - Outputs	Can of carbonated water used	1	Can
	Intermediary flows – Inputs (reference flows)	Can of carbonated water	**Tbd**	Can
		Can at end-of-life	**Tbd**	Can
		Refrigerated can	**Tbd**	Can
		Transport	**Tbd**	tkm
Refrigeration	Intermediary flows - Outputs	Refrigerated can	**Tbd**	Can
	Intermediary flows – Inputs	Electricity	**Tbd**	Kwh
		Fridge	**Tbd**	fridge
End-of-life of can	Intermediary flows - Outputs	Can at end-of-life	1	Can
	Intermediary flows – Inputs	Transport	3.9 E-04	tkm
		Aluminium landfilled	13	g

2.1 Quantify the reference flows



- Waste rate of a can between plant and consumer = 0%
- Consumer can waste rate = 0%
- End of life can rate = 100% of used cans have an end of life
- Transport between production plant and use = 30 km
- Weight of 1 empty can = 13 g/can
- Volume of 1 can = 0.355 L/can
- Density of carbonated water = 1kg/L

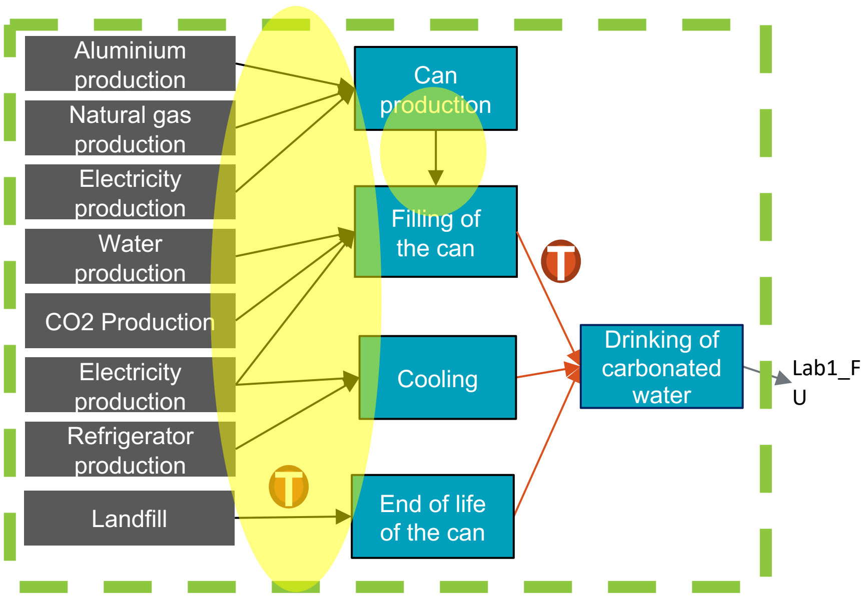
2.1 Quantify reference flows

Unit processes	Flow type	Flow	Quantity	Unit
Filling of cans of carbonated water	Intermediary flows - Outputs	Can of carbonated water	1	Can
	Intermediary flows– Inputs	Electricity	9	Wh
		Tap water	0.355	L
		Pressurized CO_2	20	g
		Empty aluminium can	1	Can
Production of an aluminium can (including rolling)	Intermediary flows - Outputs	Empty aluminium can	1	Can
	Intermediary flows – Inputs	Electricity	30	Wh
		Natural gas	0.003	Nm3
		Aluminium	13	g
	Elementary flows	CO_2	**Tbd**	gCO2
Use of a can of carbonated water	Intermediary flows - Outputs	Can of carbonated water used	1	Can
	Intermediary flows – Inputs (reference flows)	Can of carbonated water	**1**	Can
		Can at end-of-life	**1**	Can
		Refrigerated can	**1**	Can
		Transport	**1.1 E-02**	tkm
Refrigeration	Intermediary flows - Outputs	Refrigerated can	**Tbd**	Can
	Intermediary flows – Inputs	Electricity	**Tbd**	Kwh
		Fridge	**Tbd**	fridge
End-of-life of can	Intermediary flows - Outputs	Can at end-of-life	1	Can
	Intermediary flows – Inputs	Transport	3.9 E-04	tkm
		Aluminium landfilled	13	g

Inventory calculation by hand

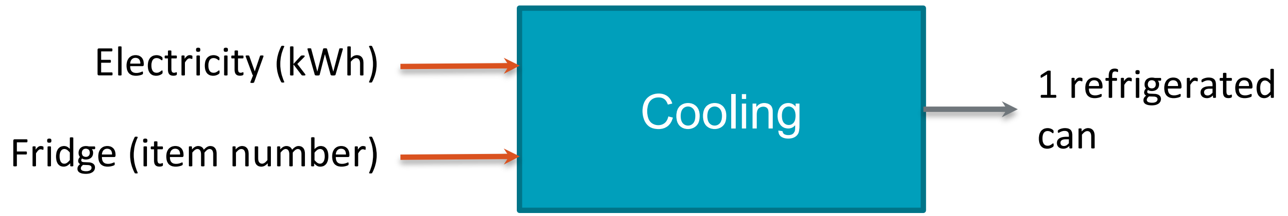
Question 2

2.2 Calculate the intermediary flows (scaled to the functional unit) corresponding to all the remaining processes of the system.



Unit processes	Flow type	Flow	Quantity	Unit
Filling of cans of carbonated water	Intermediary flows - Outputs	Can of carbonated water	1	Can
	Intermediary flows– Inputs	Electricity	9	Wh
		Tap water	0.355	L
		Pressurized CO_2	20	g
		Empty aluminium can	1	Can
Production of an aluminium can (including rolling)	Intermediary flows - Outputs	Empty aluminium can	1	Can
	Intermediary flows – Inputs	Electricity	30	Wh
		Natural gas	0.003	Nm3
		Aluminium	13	g
	Elementary flows	CO_2	**Tbd**	gCO2
Use of a can of carbonated water	Intermediary flows - Outputs	Can of carbonated water used	1	Can
	Intermediary flows – Inputs (reference flows)	Can of carbonated water	**Tbd**	Can
		Can at end-of-life	**Tbd**	Can
		Refrigerated can	**Tbd**	Can
		Transport	**Tbd**	tkm
Refrigeration	Intermediary flows - Outputs	Refrigerated can	**Tbd**	Can
	Intermediary flows – Inputs	Electricity	**Tbd**	Kwh
		Fridge	**Tbd**	fridge
End-of-life of can	Intermediary flows - Outputs	Can at end-of-life	1	Can
	Intermediary flows – Inputs	Transport	3.9 E-04	tkm
		Aluminium landfilled	13	g

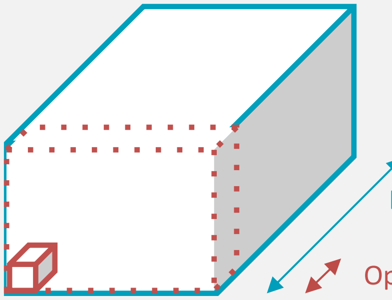
2.2 Calculation of intermediary flow



- Volume of 1 can = 0.355 L/can
- Volume of 1 fridge = 290 L/fridge
- Fridge life = 15 years/fridge
- Refrigeration time of 1 can = 1 week/can
- Electricity consumed by 1 refrigerator = 277 Kwh/yr/fridge

Calculation of intermediary flow

FU here = 1 can



only a part of the refrigerator volume is used for can cooling

Inventory calculation by hand

Question 2

2.3 Calculate the life cycle inventory, i.e. the overall quantities of elementary flows scaled to the functional unit of the studied product system.

Several steps:

1) Collect the data for all processes emissions
2) Scale the emissions
3) Calculate the total emissions for the system

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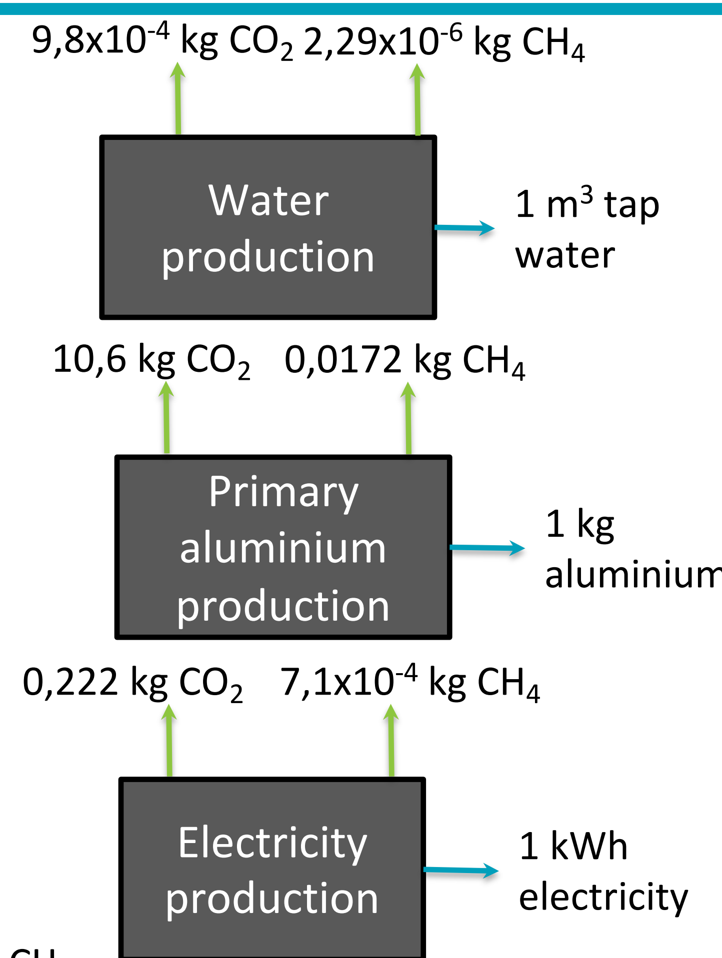
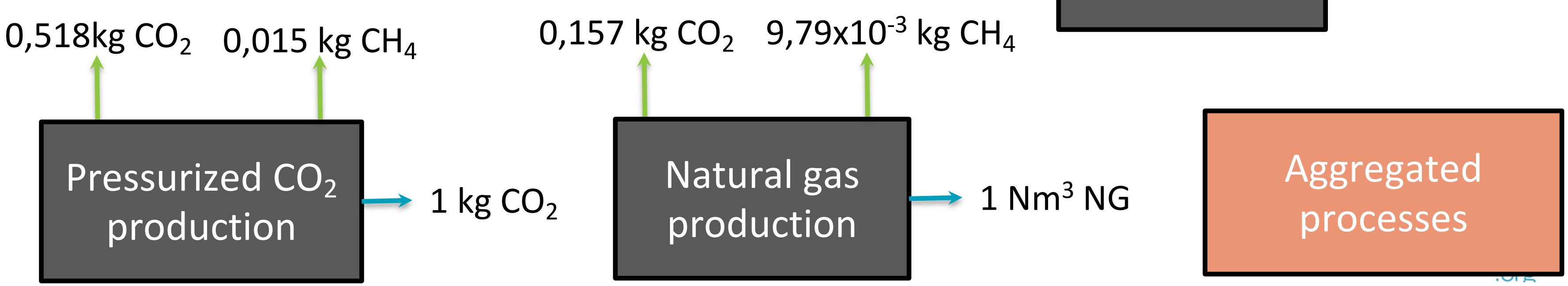
2.3 Calculate the life cycle inventory

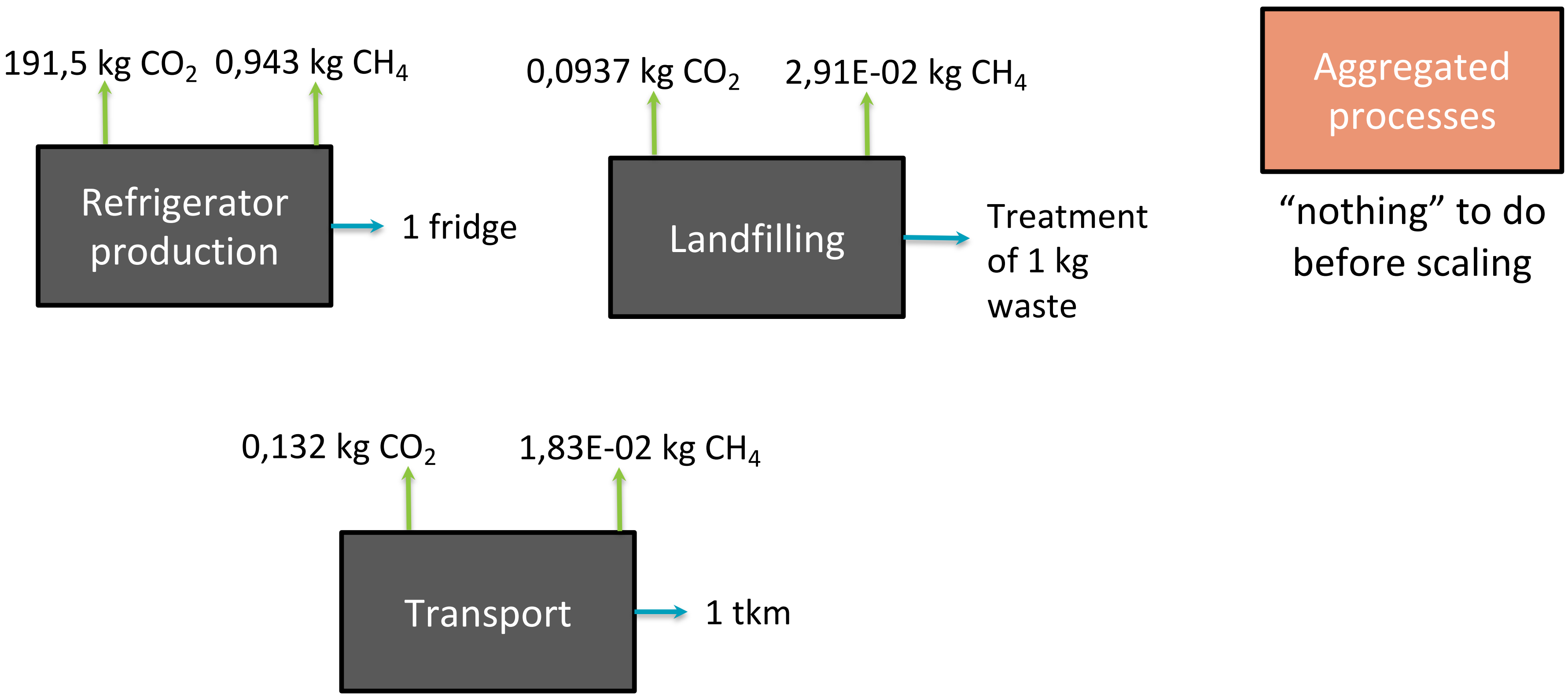
Aggregated processes	Elementary flows		Unit	Ecoinvent 3.6 process
	CO2	CH4		
Tap water (RoW)	9.80E-04	2.30E-06	kg/m³ potable water	market for tap water | tap water | Cutoff, S - RoW
Pressurized CO_2 (RoW)	5.18E-01	1.15E-02	kg/kg CO_2 (pressurized)	market for carbon dioxide, liquid | carbon dioxide, liquid | cut-off, S
Primary aluminium (US)	1.06E+01	1.72E-02	kg/kg primary aluminium	aluminium production, primary, ingot | aluminium, primary, ingot | Cutoff, S - RNA
Natural gas (US)	1.57E-01	9.79E-03	kg/Nm³ natural gas	market for natural gas, high pressure | natural gas, high pressure | Cutoff, S - US
Electricity, medium voltage (NPCC, US)	2.22E-01	7.10E-04	kg/kWh electricity	electricity, high voltage, production mix | electricity, high voltage | Cutoff, S – NPCC, US only
Transport (RoW)	1.32E-01	1.83E-02	Kg/tkm	market for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, S - RoW
Refrigerator (GLO)	1.92E+02	9.43E-01	kg/unit	market for refrigerator | refrigerator | Cutoff, S - GLO
Landfiling (RoW)	9.37E-02	2.91E-02	Kg/kg waste	treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, S - RoW





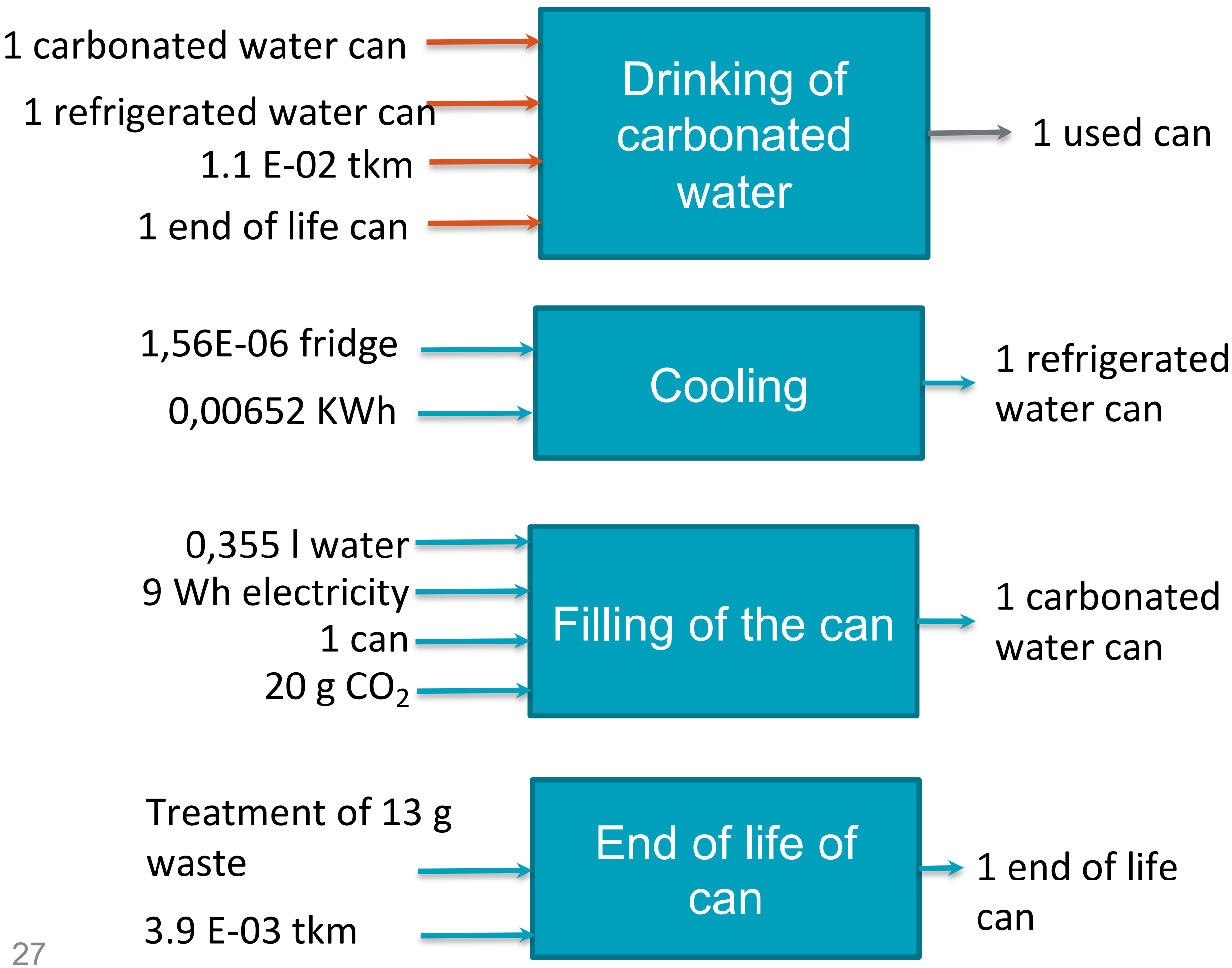
2.3 Calculate the life cycle inventory

In the case of aggregated processes, we just transcribe the table!



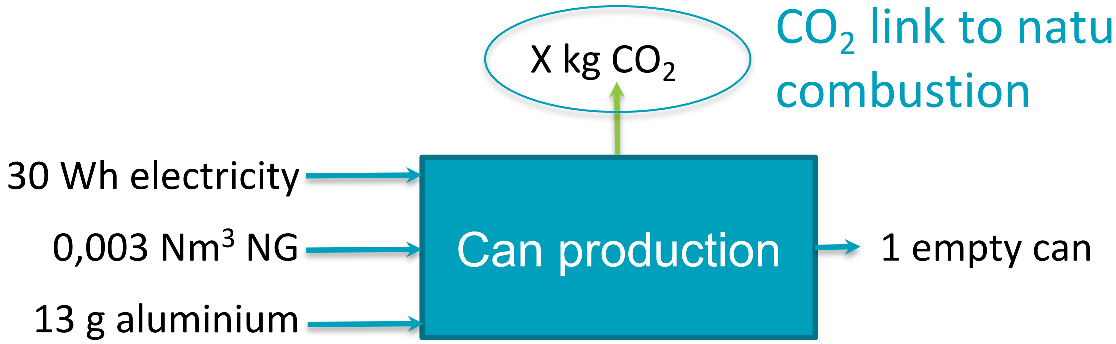
2.3 Calculate the life cycle inventory

Second, we calculate the quantity of intermediate flows for each of the disaggregated processes as well as their direct emissions



No direct CO_2 and CH_4 emissions for these processes

Second, we calculate the quantity of intermediate flows for each of the disaggregated processes as well as their direct emissions



CO_2 link to natural gas combustion

Disaggregated processes : Calculation must be done because of direct emissions

2.3 Calculate the life cycle inventory

Calculation of the quantity of the elementary flows (CO_2 and CH_4) for each of the unit processes of the product system (related to a product unit)

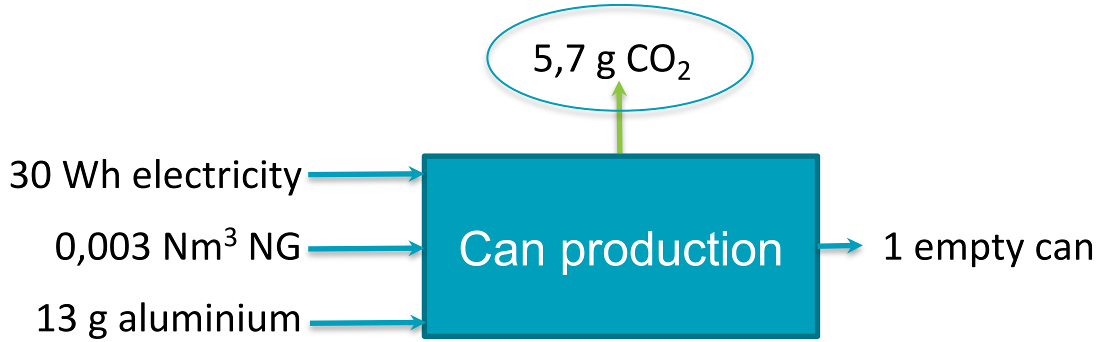
Combustion emission factor: 1,9 kg CO_2/Nm^3 natural gas

x

Natural gas combustion : 0,003 Nm^3 natural gas/empty can

= 5,7 g CO_2/empty can

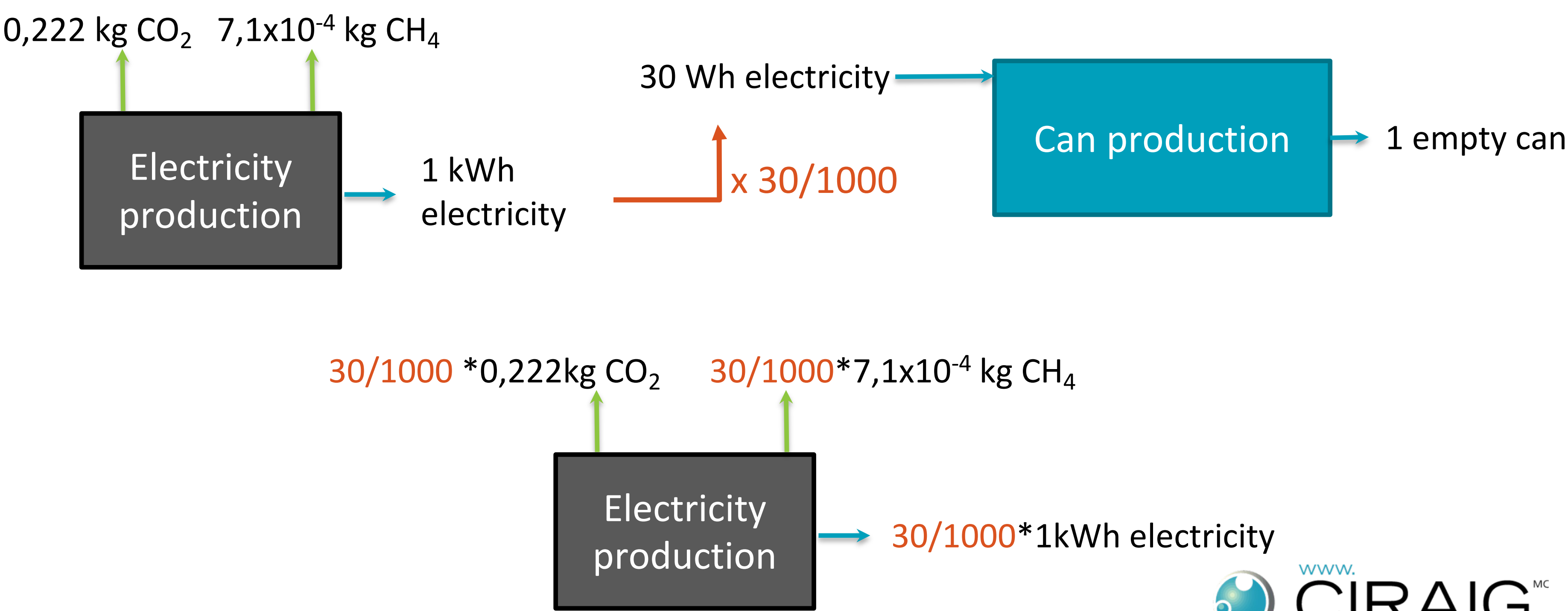
Disaggregated processes : A calculation to do



2.3 Calculate the life cycle inventory

Thirdly, we calculate the quantity of elementary flows (CO_2 and CH_4) for each of the unit processes of the product system (**related to the functional unit**)

Example: Calculation for electricity



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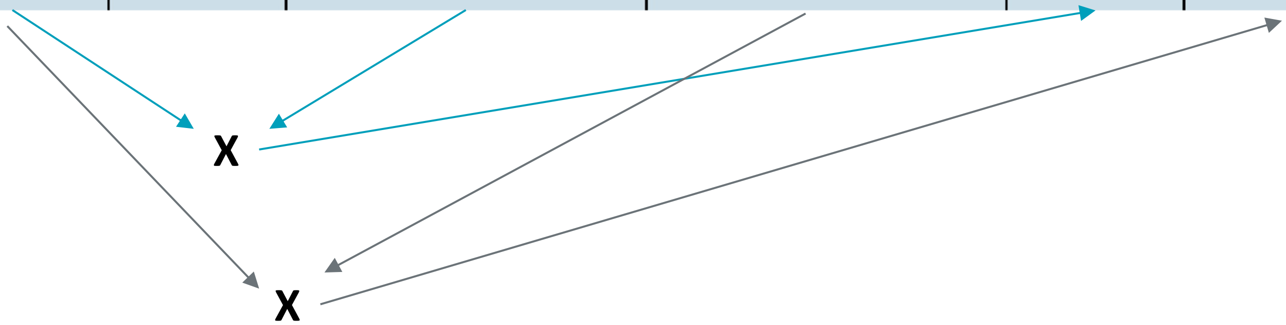
2.3 Calculate the life cycle inventory

Thirdly, we calculate the quantity of elementary flows (CO_2 and CH_4) for each of the unit processes of the product system (**related to the functional unit**)

Example: calculation for electricity

Intermediary flow	Quantity	Unit	Elementary flow CO2 production elec. (kg/kWh electricity)	Elementary flow CH4 production elec. (kg/kWh electricity)	Elementary flow CO2	Elementary flow CH4
Electricity production	3,00E-02	kWh	2,22E-01	7,10E-04	6,66E-03	2,13E-05



We do this calculation for each processes

It can be useful to make small diagrams to make sure you don't forget anything!

2.3 Calculate the life cycle inventory

PROCESSES	Intermediary flows			Elementary flows CO2 (kg)	CH4 (kg)
Drinkink of carbonated water	Carbonated water can	1	item		
	Refrigerated water can	1	item		
	End of life can	1	item		
	Transport	1.10E-02	tkm	1.45E-03	2.01E-04
Can production	Electricity production	3.00E-02	kWh	6.66E-03	2.13E-05
	Natural gas production	0.003	Nm3	4.71E-04	2.94E-05
	Aluminium production	1.30E-02	kg	1.38E-01	2.24E-04
	Elementary flow link to NG combustion			5.70E-03	
Filling	Electricity production	9.00E-03	kWh	2.00E-03	6.39E-06
	Tap water production	3.55E-04	m3	3.48E-07	8.13E-10
	Pressurized CO2 production	2.00E-02	kg	1.04E-02	2.30E-04
	Can production	1	item		
Cooling	Electricity production	0.00652	kWh	1.45E-03	4.63E-06
	Fridge production	1.57E-06	frigo	3.01E-04	1.48E-06
End of life can	Transport	3.90E-03	tkm	5.15E-04	7.14E-05
	Landfill Aluminium	1.30E-02	kg	1.21E-03	3.78E-04
				1.68E-01	1.17E-03

Impact assessment

Question 3

3.1 Calculate the carbon footprint for the entire product system (scaled to the functional unit)

3.2 How would the results evolve if the functional unit was changed for "Consuming 1000 cans of carbonated water"?

Impact assessment

3.1 Calculate the carbon footprint for the entire product system (scaled to the functional unit)

Gas	GWP
CO_2	1 CO_2e/kg
CH_4	29,7 CO_2e/kg

PROCESSES	Intermediary flows			Elementary flows CO2 (kg)	CH4 (kg)
Drinkink of carbonated water	Carbonated water can	1	item		
	Refrigerated water can	1	item		
	End of life can	1	item		
	Transport	1.10E-02	tkm	1.45E-03	2.01E-04
Can production	Electricity production	3.00E-02	kWh	6.66E-03	2.13E-05
	Natural gas production	0.003	Nm3	4.71E-04	2.94E-05
	Aluminium production	1.30E-02	kg	1.38E-01	2.24E-04
	Elementary flow link to NG combustion			5.70E-03	
Filling	Electricity production	9.00E-03	kWh	2.00E-03	6.39E-06
	Tap water production	3.55E-04	m3	3.48E-07	8.13E-10
	Pressurized CO2 production	2.00E-02	kg	1.04E-02	2.30E-04
	Can production	1	item		
Cooling	Electricity production	0.00652	kWh	1.45E-03	4.63E-06
	Fridge production	1.57E-06	frigo	3.01E-04	1.48E-06
End of life can	Transport	3.90E-03	tkm	5.15E-04	7.14E-05
	Landfill Aluminium	1.30E-02	kg	1.21E-03	3.78E-04
				1.68E-01	1.17E-03

Impact assessment

3.1 Calculate the carbon footprint for the entire product system (scaled to the functional unit)

PROCESSES	Intermediary flows			Elementary flows CO2 (kg)	CH4 (kg)	Total CO2 CO2e (kg)
Drinkink of carbonated water	Carbonated water can	1	item			
	Refrigerated water can	1	item			
	End of life can	1	item			
	Transport	1.10E-02	tkm	1.45E-03	2.01E-04	7.43E-03
Can production	Electricity production	3.00E-02	kWh	6.66E-03	2.13E-05	7.29E-03
	Natural gas production	0.003	Nm3	4.71E-04	2.94E-05	1.34E-03
	Aluminium production	1.30E-02	kg	1.38E-01	2.24E-04	1.45E-01
	Elementary flow link to NG combustion			5.70E-03		5.70E-03
Filling	Electricity production	9.00E-03	kWh	2.00E-03	6.39E-06	2.19E-03
	Tap water production	3.55E-04	m3	3.48E-07	8.13E-10	3.72E-07
	Pressurized CO2 production	2.00E-02	kg	1.04E-02	2.30E-04	1.72E-02
	Can production	1	item			0.00E+00
Cooling	Electricity production	0.00652	kWh	1.45E-03	4.63E-06	1.58E-03
	Fridge production	1.57E-06	frigo	3.01E-04	1.48E-06	3.45E-04
End of life can	Transport	3.90E-03	tkm	5.15E-04	7.14E-05	2.63E-03
	Landfill Aluminium	1.30E-02	kg	1.21E-03	3.78E-04	1.24E-02
				1.68E-01	**1.17E-03**	**2.03E-01**

Impact assessment

3.2 How would the results evolve if the functional unit was changed for “Consuming 1000 cans of carbonated water”?

We just multiply the result by 1000 because LCA is linear!

So 201 kg CO_2 eq.

Interpretaion

Question 4

4.1 Calculate the contribution of each unit process to the carbon footprint.

4.2 Identify areas for improvement in the carbon footprint of cans of carbonated water.

Interpretation

4.1 Calculate the contribution of each unit process to the carbon footprint.

PROCESSES	Intermediary flows			Elementary flows CO2 (kg)	CH4 (kg)	Total CO2 CO2e (kg)
Drinkink of carbonated water	Carbonated water can	1	item			
	Refrigerated water can	1	item			
	End of life can	1	item			
	Transport	1.10E-02	tkm	1.45E-03	2.01E-04	7.43E-03
Can production	Electricity production	3.00E-02	kWh	6.66E-03	2.13E-05	7.29E-03
	Natural gas production	0.003	Nm3	4.71E-04	2.94E-05	1.34E-03
	Aluminium production	1.30E-02	kg	1.38E-01	2.24E-04	1.45E-01
	Elementary flow link to NG combustion			5.70E-03		5.70E-03
Filling	Electricity production	9.00E-03	kWh	2.00E-03	6.39E-06	2.19E-03
	Tap water production	3.55E-04	m3	3.48E-07	8.13E-10	3.72E-07
	Pressurized CO2 production	2.00E-02	kg	1.04E-02	2.30E-04	1.72E-02
	Can production	1	item			0.00E+00
Cooling	Electricity production	0.00652	kWh	1.45E-03	4.63E-06	1.58E-03
	Fridge production	1.57E-06	frigo	3.01E-04	1.48E-06	3.45E-04
End of life can	Transport	3.90E-03	tkm	5.15E-04	7.14E-05	2.63E-03
	Landfill Aluminium	1.30E-02	kg	1.21E-03	3.78E-04	1.24E-02
				1.68E-01	**1.17E-03**	**2.03E-01**

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Interpretation

4.1 Calculate the contribution of each unit process to the carbon footprint.

PROCESSES	Intermediary flows			Elementary flows CO2 (kg)	CH4 (kg)	Total CO2 CO2e (kg)	Contribution
Drinking of carbonated water	Carbonated water can	1	item				
	Refrigerated water can	1	item				
	End of life can	1	item				
Can production	Transport	1.10E-02	tkm	1.45E-03	2.01E-04	7.43E-03	3.66%
	Electricity production	3.00E-02	kWh	6.66E-03	2.13E-05	7.29E-03	3.59%
	Natural gas production	0.003	Nm3	4.71E-04	2.94E-05	1.34E-03	0.66%
	Aluminium production	1.30E-02	kg	1.38E-01	2.24E-04	1.45E-01	71.37%
	Elementary flow link to NG combustion			5.70E-03		5.70E-03	2.81%
Filling	Electricity production	9.00E-03	kWh	2.00E-03	6.39E-06	2.19E-03	1.08%
	Tap water production	3.55E-04	m3	3.48E-07	8.13E-10	3.72E-07	0.00%
	Pressurized CO2 production	2.00E-02	kg	1.04E-02	2.30E-04	1.72E-02	8.46%
	Can production	1	item			0.00E+00	0.00%
Cooling	Electricity production	0.00652	kWh	1.45E-03	4.63E-06	1.58E-03	0.78%
	Fridge production	1.57E-06	frigo	3.01E-04	1.48E-06	3.45E-04	0.17%
End of life can	Transport	3.90E-03	tkm	5.15E-04	7.14E-05	2.63E-03	1.30%
	Landfill Aluminium	1.30E-02	kg	1.21E-03	3.78E-04	1.24E-02	6.13%
				1.68E-01	**1.17E-03**	**2.03E-01**	100.00%

Interpretation

4.1 Calculate the contribution of each unit process to the carbon footprint.

PROCESSES	Intermediary flows			Elementary flows CO2 (kg)	CH4 (kg)	Total CO2 CO2e (kg)	Contribution	Total per process CO2e (kg)	Contrib per process
Drinking of carbonated water	Carbonated water can	1	item					7.43E-03	3.66%
	Refrigerated water can	1	item						
	End of life can	1	item						
	Transport	1.10E-02	tkm	1.45E-03	2.01E-04	7.43E-03	3.66%		
Can production	Electricity production	3.00E-02	kWh	6.66E-03	2.13E-05	7.29E-03	3.59%	1.59E-01	78.43%
	Natural gas production	0.003	Nm3	4.71E-04	2.94E-05	1.34E-03	0.66%		
	Aluminium production	1.30E-02	kg	1.38E-01	2.24E-04	1.45E-01	71.37%		
	Elementary flow link to NG combustion			5.70E-03		5.70E-03	2.81%		
Filling	Electricity production	9.00E-03	kWh	2.00E-03	6.39E-06	2.19E-03	1.08%	1.94E-02	9.54%
	Tap water production	3.55E-04	m3	3.48E-07	8.13E-10	3.72E-07	0.00%		
	Pressurized CO2 production	2.00E-02	kg	1.04E-02	2.30E-04	1.72E-02	8.46%		
	Can production	1	item			0.00E+00	0.00%		
Cooling	Electricity production	0.00652	kWh	1.45E-03	4.63E-06	1.58E-03	0.78%	1.93E-03	0.95%
	Fridge production	1.57E-06	frigo	3.01E-04	1.48E-06	3.45E-04	0.17%		
End of life can	Transport	3.90E-03	tkm	5.15E-04	7.14E-05	2.63E-03	1.30%	1.51E-02	7.42%
	Landfill Aluminium	1.30E-02	kg	1.21E-03	3.78E-04	1.24E-02	6.13%		
				1.68E-01	**1.17E-03**	**2.03E-01**	100.00%	**2.031E-01**	**100.00%**

4.2 Identify areas for improvement in the carbon footprint of cans of carbonated water.

Ways to reduce the carbon footprint :

- Find aluminium with a smaller footprint
- Minimize the amount of aluminium used
- Change the type of material to deliver carbonated water
- Change your location to have access to electricity with a lower carbon footprint

Contribution analysis is the basis for answering the question

4.2 Identify areas for improvement in the carbon footprint of cans of carbonated water.

Ways to improve the quality of carbon footprint (analysis):

- Improve the aluminum production modelling process
- Assure that the quantity of primary aluminum per can is correct
- Assure that the assumption of 100% primary aluminum is correct

Inventory modelling in OpenLCA

QUESTION 5

Bonus

Build a technology matrix, an environmental matrix and a final demand vector for this product system.

Bonus – Technology matrix

Processes

Economic flow

	Drinking 1 carbonated water can	Filling	Cooling	End of life can	Can production	Electricity production	NG production	Aluminium production	Water production	Pressurized CO2 prod	Fridge production	Landfilling	Transport
Used can [Unit]	1												
Carbonated can [unit]	-1	1											
Refrigerated can [unit]	-1		1										
End of life can [unit]	-1			1									
Empty aluminium can [unit]		-1			1								
Electricity [kWh]		-9	-0.00652		-3.00E-02	1							
Natural gas [Nm3]					-0.003		1						
Aluminium [kg]					-1.30E-02			1					
Tap water [m3]		-0.355							1				
Pressurized CO2 [kg]		-0.02								1			
Fridge [unit]			-1.57E-06								1		
Landfilling [kg]				-1.30E-02								1	
Transport [tkm]	-1.10E-02			-3.90E-03									1

Bonus

Environmental matrix

Elementary flow

Processes

	Drinking 1 carbonated water can	Filling	Cooling	End of life can	Can production	Electricity production	NG production	Aluminium production	Water production	Pressurized CO2 prod	Fridge production	Landfilling	Transport
CO2 [kg]	0	0	0	0	5,70E-03	2,22E-01	1,57E-01	1,06E+01	9,80E-01	5,18E-01	1,92E+02	9,30E-02	1,32E-01
CH4 [kg]	0	0	0	0	0,00E+00	7,10E-04	9,80E-03	1,72E-02	2,29E-03	1,15E-02	9,43E-01	2,91E-02	1,83E-02

Final demand vector

Economic flow

	Drinking 1 carbonated water can
Used can [Unit]	1
Carbonated can [unit]	0
Refrigerated can [unit]	0
End of life can [unit]	0
Empty aluminium can [unit]	0
Electricity [kWh]	0
Natural gas [Nm3]	0
Aluminium [kg]	0
Tap water [m3]	0
Pressurized CO2 [kg]	0
Fridge [unit]	0
Landfilling [kg]	0
Transport [tkm]	0

Inventory modelling in OpenLCA

QUESTION 5

Context

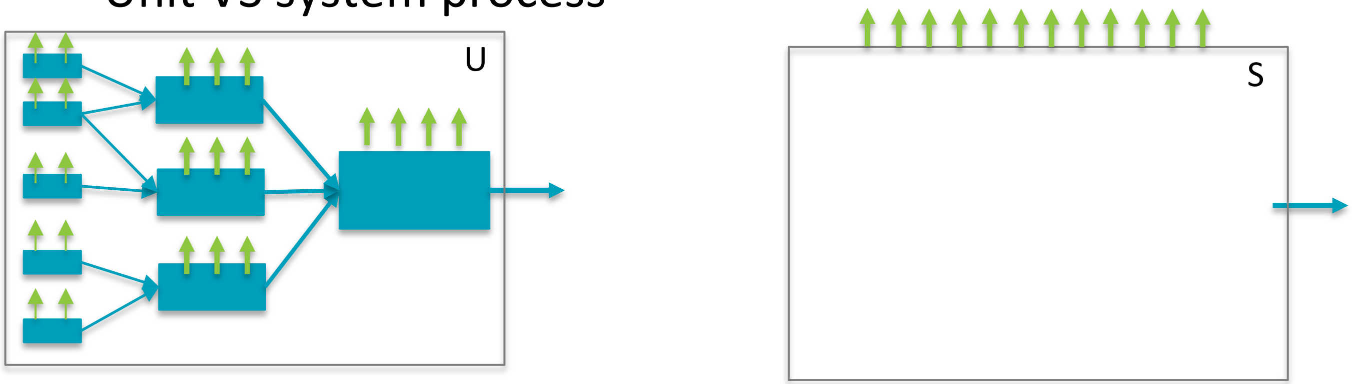
After the calculation by hand of the carbon footprint of the can of carbonated water you want to:

- Reproduce the calculation with openLCA
- Compare the results

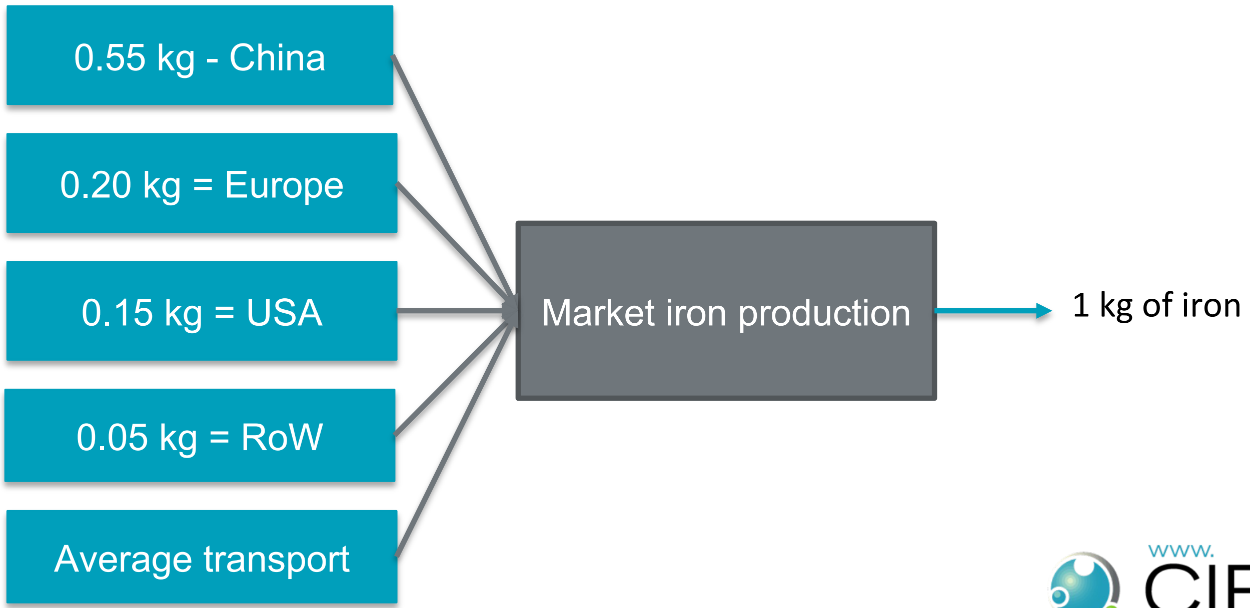
Openlca overview

Introduction to openLCA – key concepts

- Unit VS system process



- Market



Introduction to openLCA – key concepts

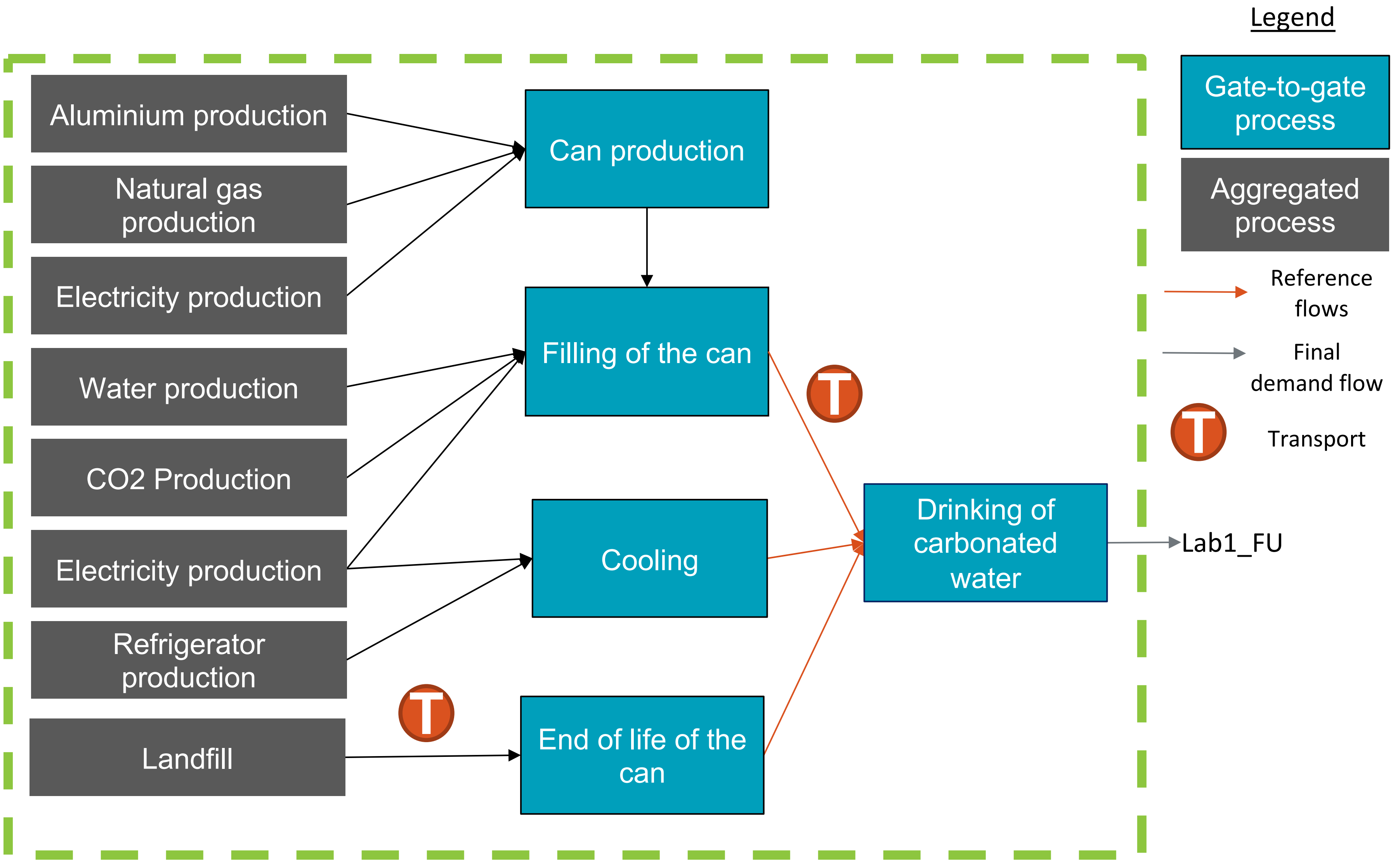
- Regions

Code	Region
RoW	Rest of the world
GLO	Global
ReR	Europe
CH	Switzerland
Qc	Québec
And many more…!	

- Parameters
  - **Global VS local**

Openlca modeling

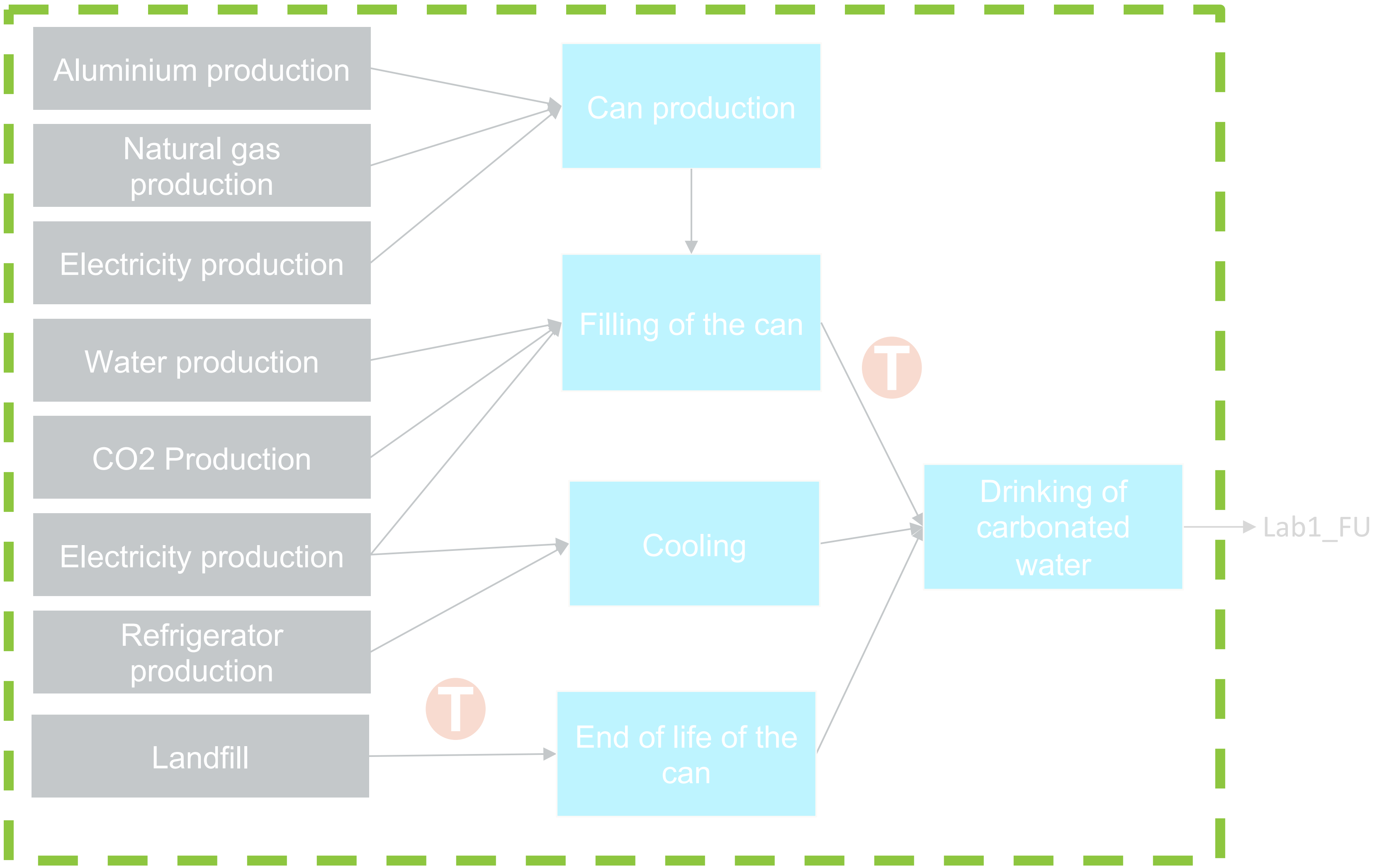
Process tree of the system



List of processes, flows and quantities

Process	Flow	Quantity	unit
Drinking of carbonated water	Filled can	1	Item
	End of life of a can	1	Item
	Cooling of a can	1	item
Can production	Aluminium production	13*	g
	Natural gas production	0.003	Nm^3
	Electricity production	0.03	kWh
Filling of the can	Water production	355	mL
	Electricity production	0.009	kWh
	CO2 Production	20	g
	Transport	0.011	tkm
Cooling	Refrigerator production	1.57E-6	frigo
	Electricity production	0.00652	kWh
End of life	Transport	0.00039*	tkm
	Landfilling	13	g

Process tree of the system



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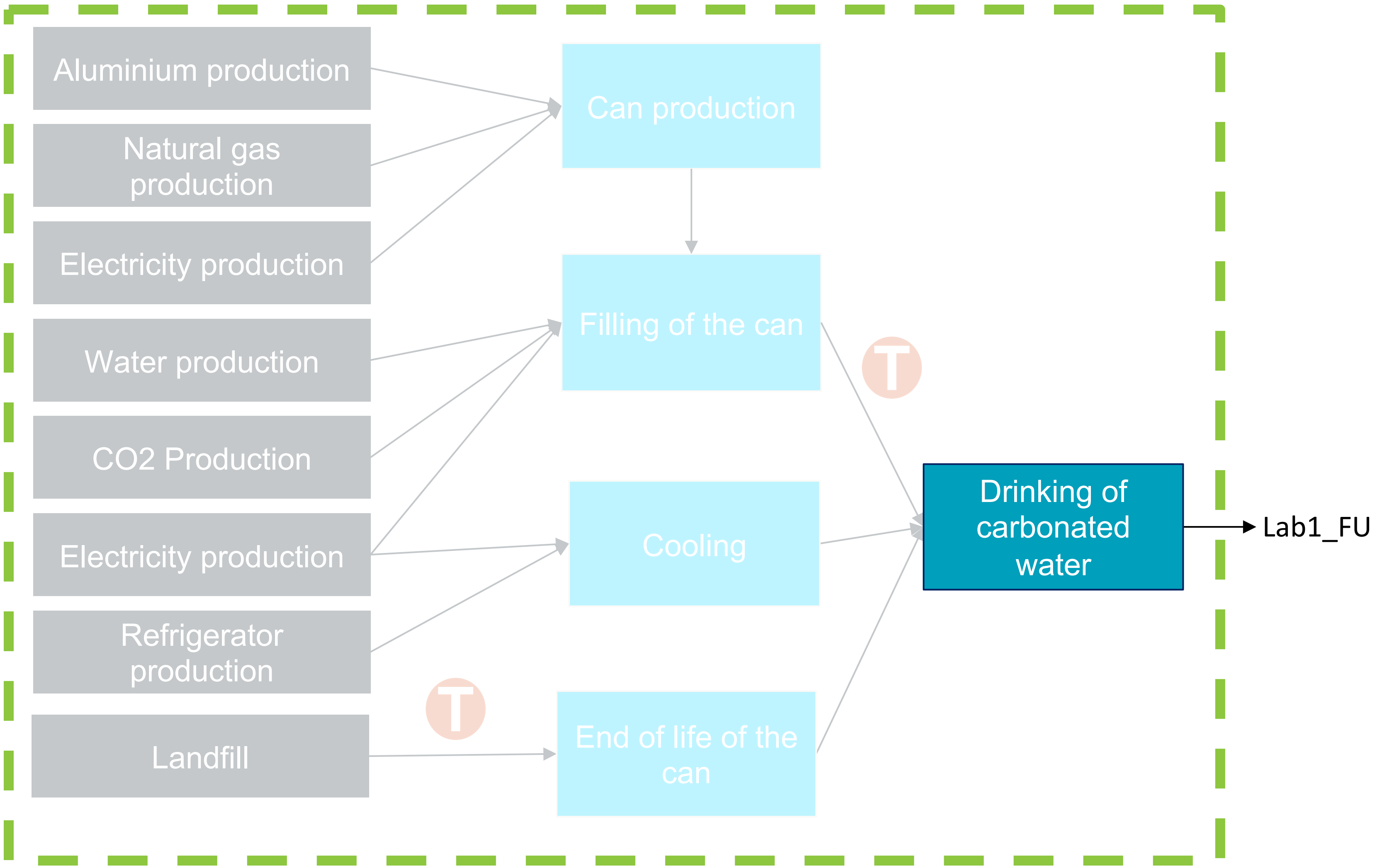
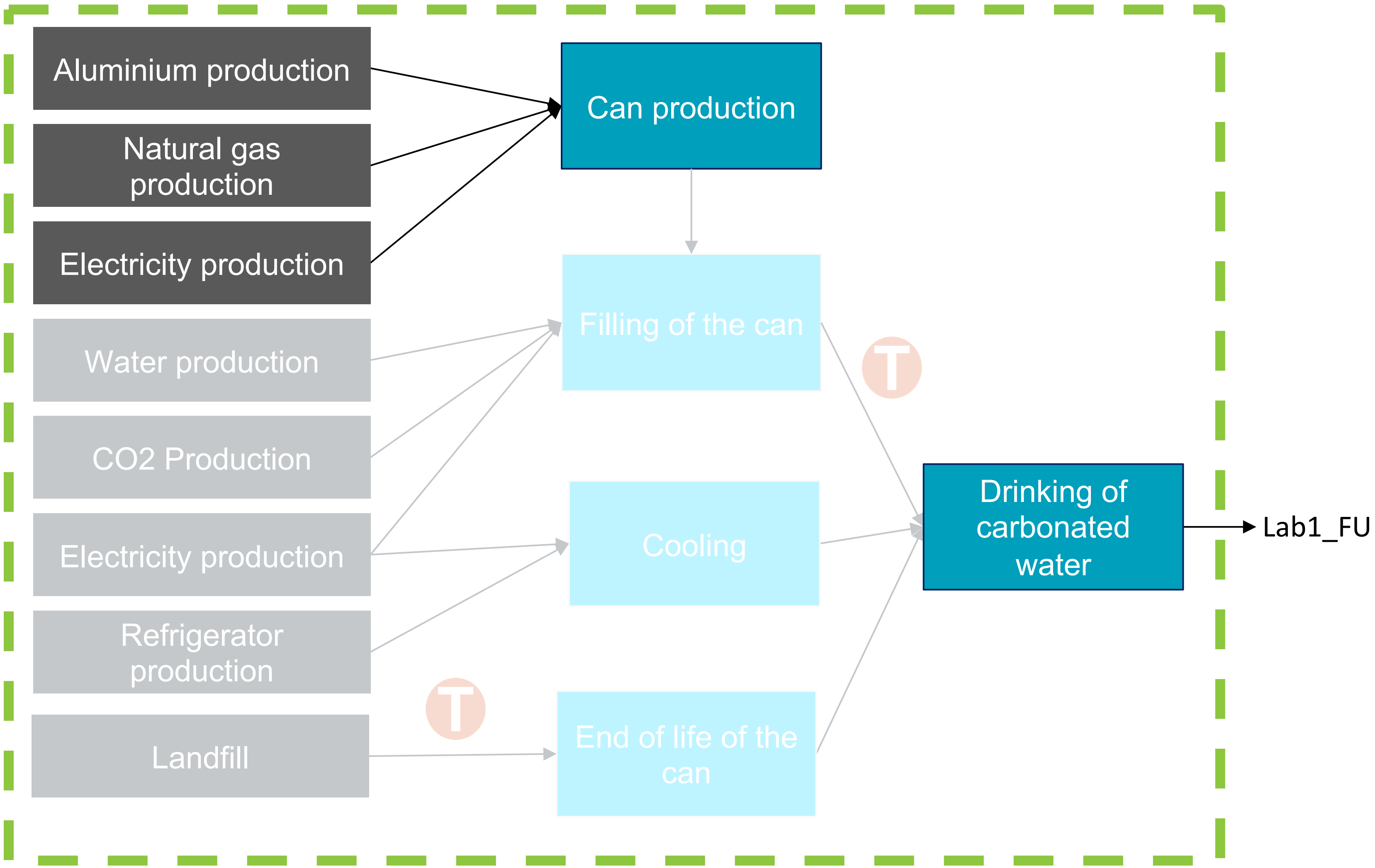
Main steps

1) Create a flow
2) Create a process
    1) **Add inputs / outputs**
    2) **Set quantities**
    3) **Select providers**
3) Repeat 1) and 2) untill the system is complete
4) Create the product system
5) Calculate impacts

Process tree of the system



Process tree of the system



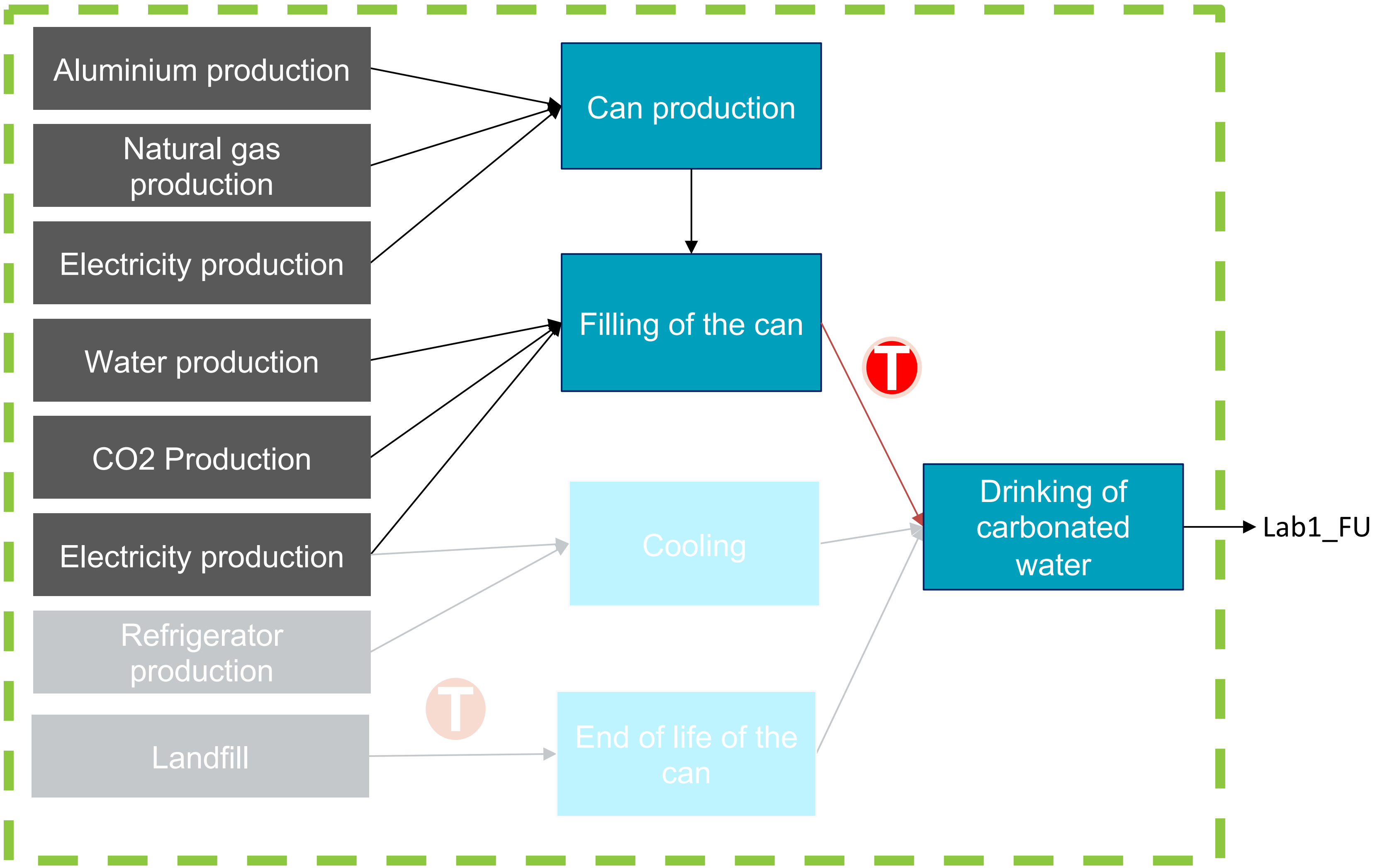
Input flows and provider – Can production

Flow	Provider	Quantity	unit
aluminium, primary, ingot	aluminium production, primary, ingot | aluminium, primary, ingot | Cutoff, S - RNA	13*	g
natural gas, high pressure	market for natural gas, high pressure | natural gas, high pressure | Cutoff, S - US	0.003	Nm^3
electricity, high voltage	electricity, high voltage, production mix | electricity, high voltage | Cutoff, S – NPCC, US only	0.03	kWh
Carbon dioxide, fossil	***elementary flow***	5,7	g

*Parameter:

- mass_can = 13 g

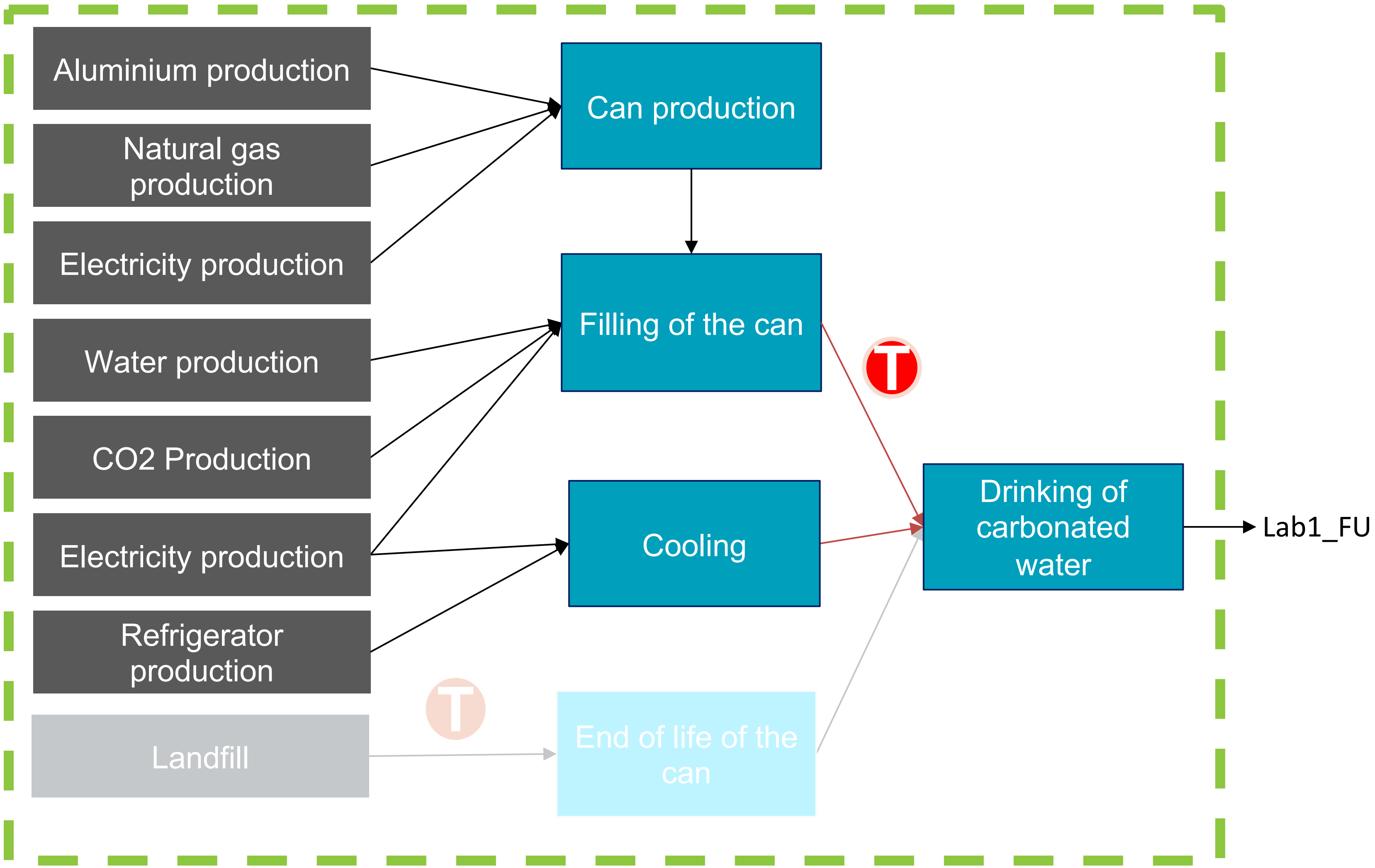
Process tree of the system



Input flows and provider - Filling the can

Flow	Provider	Quantity	unit
Tap water	market for tap water | tap water | Cutoff, S - RoW	355	ml
electricity, high voltage	electricity, high voltage, production mix | electricity, high voltage | Cutoff, S – NPCC, US only	0.009	kWh
carbon dioxide, liquid	carbon dioxide production, liquid | carbon dioxide, liquid | Cutoff, S - RoW	20	g
transport, freight, lorry, unspecified	market for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, S - RoW	0.011	tkm

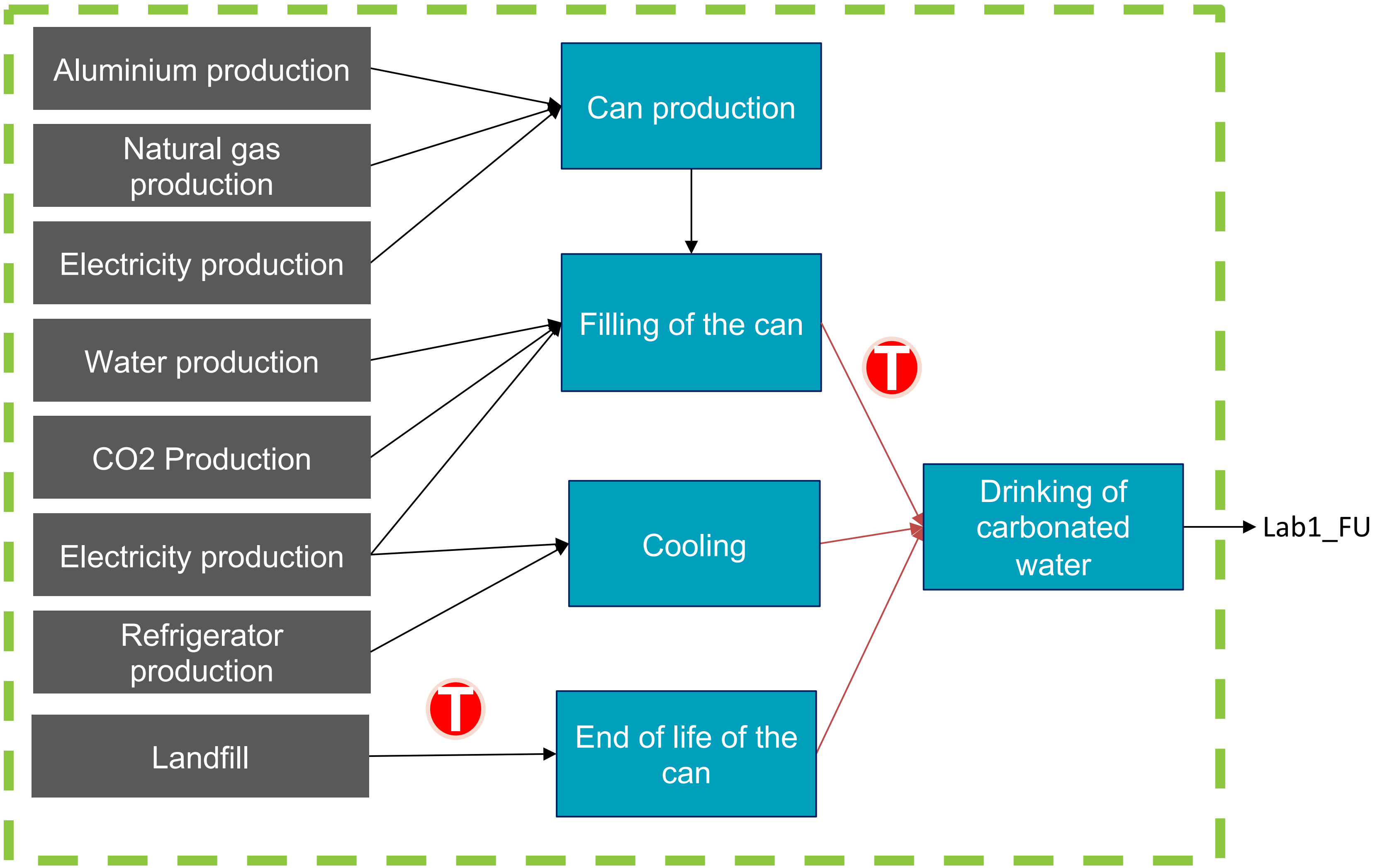
Process tree of the system



Input flows and provider – Cooling

Flow	Provider	Quantity	unit
Refrigerator	market for refrigerator | refrigerator | Cutoff, S - GLO	1.57E-6	frigo
electricity, low voltage	market for electricity, low voltage | electricity, low voltage | Cutoff, S - NPCC, US only	0.00652	kWh

Process tree of the system



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Input flows and provider – End of life

Flow	Provider	Quantity	unit
transport, freight, lorry, unspecified	market for transport, freight, lorry, unspecified | transport, freight, lorry, unspecified | Cutoff, S - RoW	0.0039*	tkm
municipal solid waste	market for municipal solid waste | municipal solid waste | Cutoff, S - RoW	mass_can	g

*Parameters:
- dist_eol = 300 km
- transp_eol = (mass_can * dist_eol) /1 000 000

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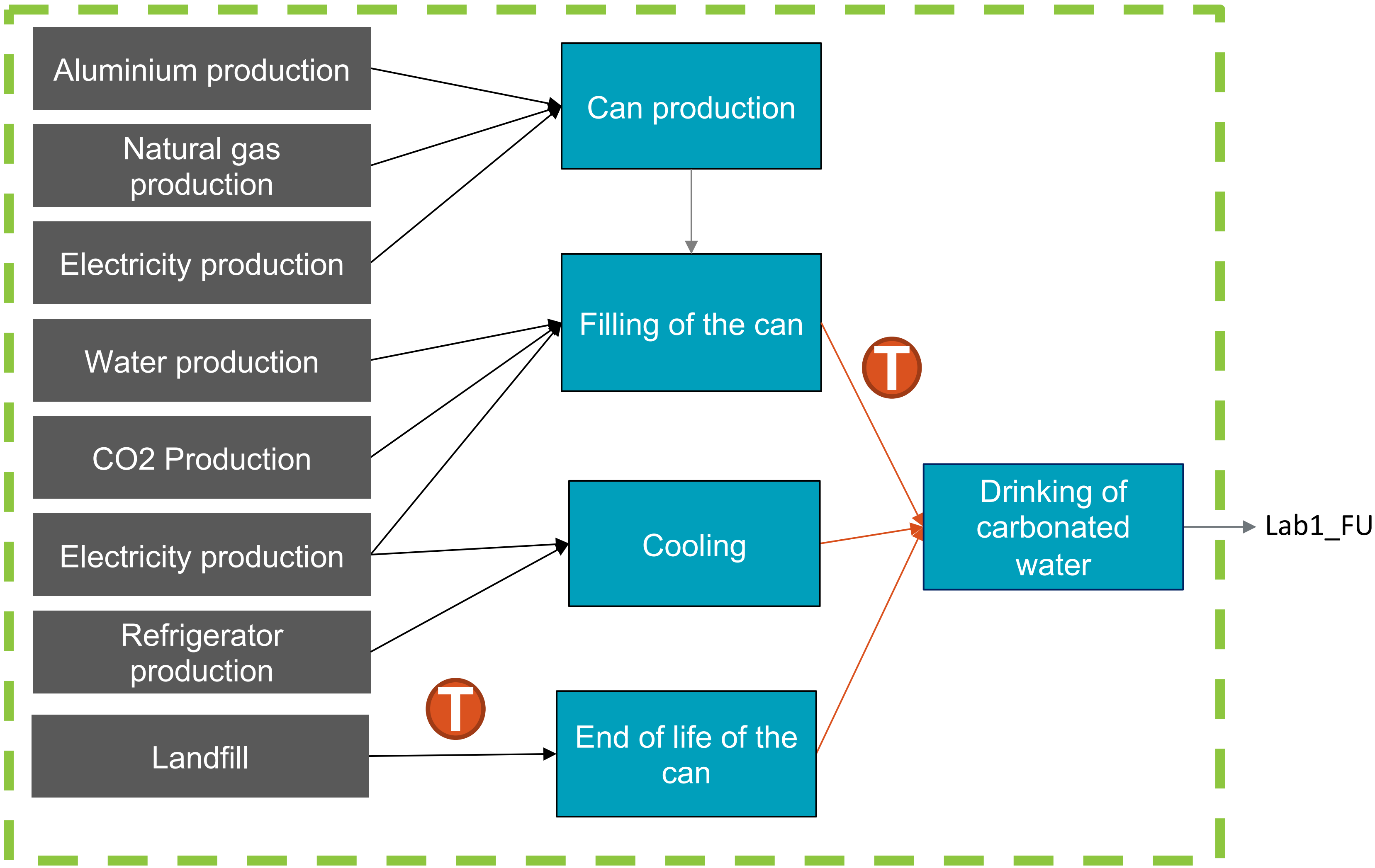
Process tree of the system



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Results

- Create a product system with the *Drinking of carbonated water* process.
- Validate the process tree
- Calculate results

Result comparison

Results comparison

	By hand	openLCA
Can production	1.59E-01	1.72E-01
Filling of the can	2.72E-02	2.17E-02
Cooling of the can	1.94E-03	2.10E-03
End of life	1.51E-02	1.30E-02
Total	**2.03E-01**	**2.08E-01**

Difference of 2.3%

Can you explain this difference?

CFC

N2O

Other GHG