AquaSPICE

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Design and Assessment of Water Reuse Systems

Dr Athanasios Angelis-Dimakis, University of Huddersfield

AquaSPICE Summer School 2024

The AquaSPICE project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958396.

Learning Objectives

- Understand the different options for water reuse and regeneration in an industrial plant with multiple processes
- Size and design a maximum water reuse system using Water Integration
- Introduce the main concepts of Life Cycle Assessment
- Compare a static/conventional and a dynamic Life Cycle Assessment
- Assess a water reuse system using Life Cycle Assessment

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Design and Assessment of Water Reuse Systems

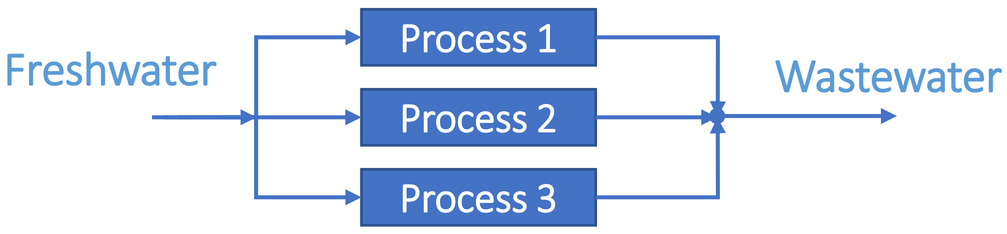
Part 1. Water Integration

The AquaSPICE project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958396.

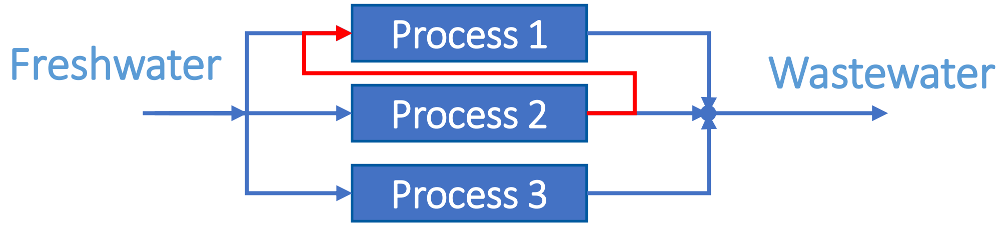
Motivation for Water Integration

- Water was assumed to be an infinite low-cost resource
- Nowadays, there is an increasing pressure on water resources
- Water scarcity is increasing as demand for water intensifies with population and economic growth
  - Restrictions in water use
  - Stricter discharge regulations
  - Recycle, Reuse & Regenerate

Alternative Water Reuse Schemes

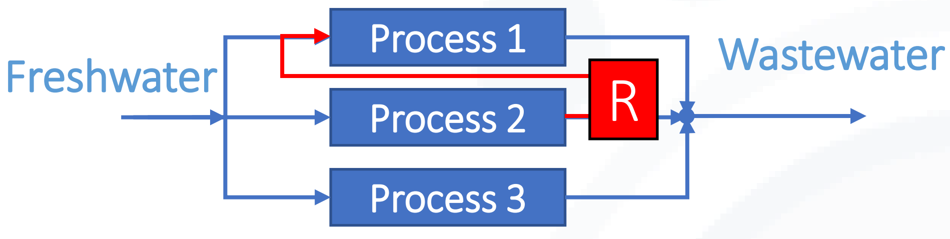


(a) Freshwater Use

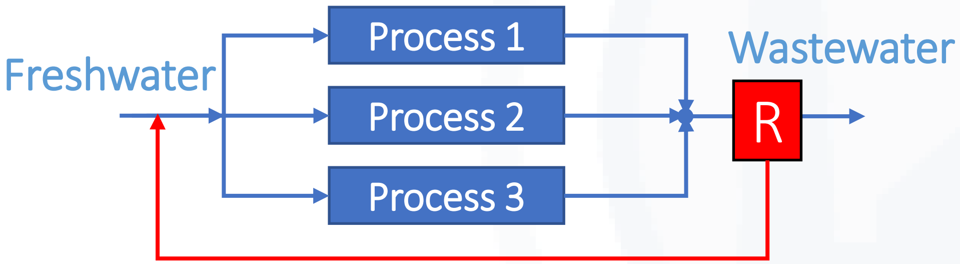


(b) Water Reuse

Contamination level at the outlet of (2) should be acceptable at the inlet of (1)



(c) Regeneration Reuse



(d) Regeneration Recycle

Contrary to regeneration reuse, water can go through any given process more than once

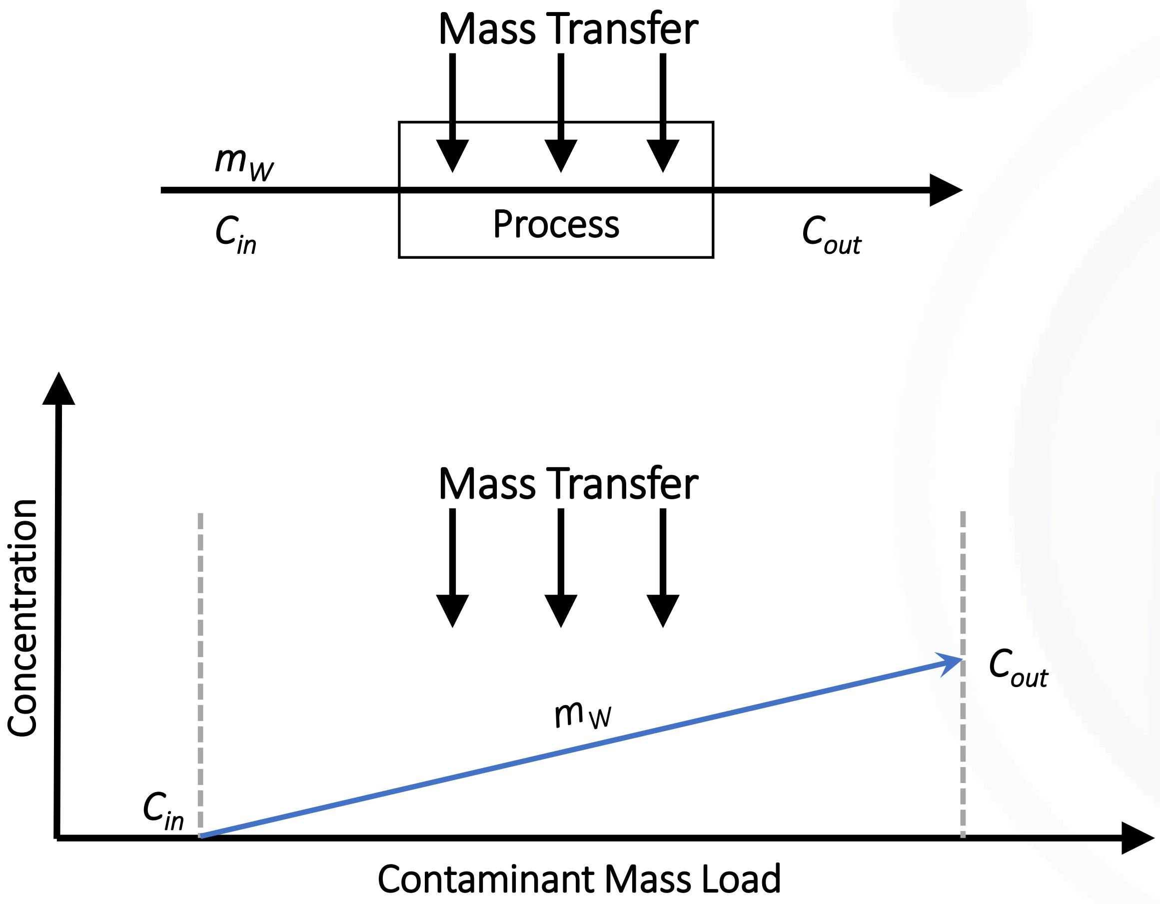
Analysis for a Single Contaminant

- All water use processes have one thing in common.
- Water comes into contact with process materials and becomes contaminated
- For a given process, with a specific contaminant load (Δm_C), then:

$$\Delta m_C = m_W \times \Delta C$$

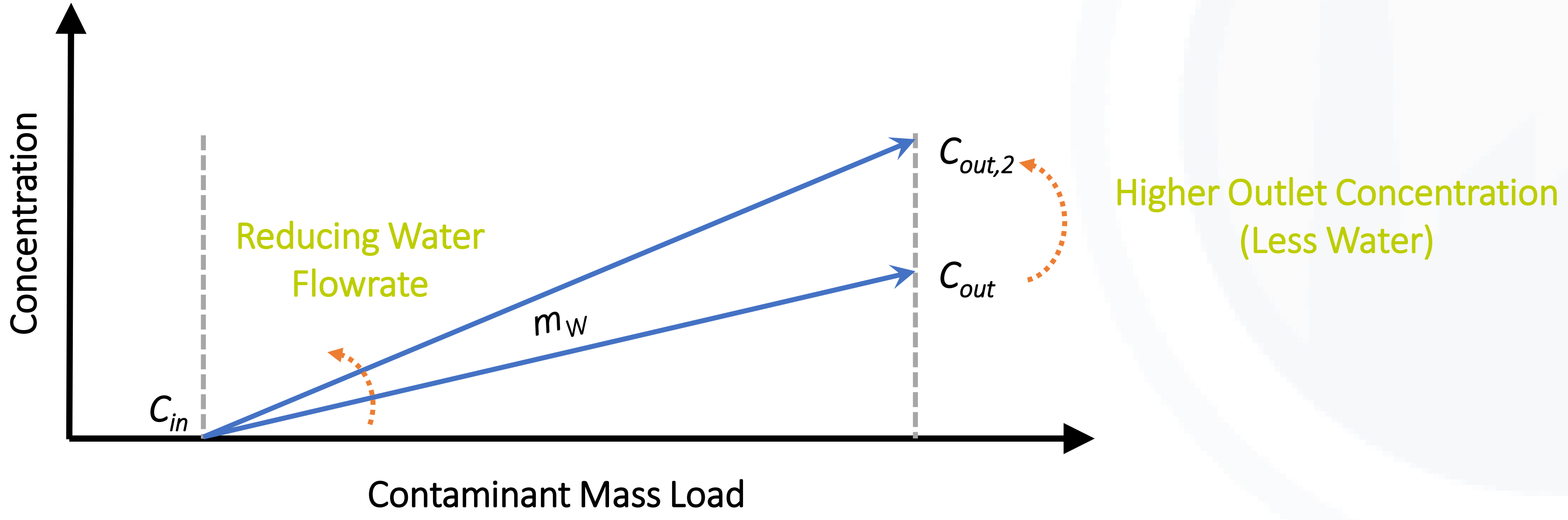
  - where m_W is the water flowrate and $\Delta C = C_{out} - C_{in}$ the concentration change of the water
- **Note**: Concentration is defined on the basis of the mass flowrate of the water and not of the mixture, since the difference between the two quantities is very small

Representing Water Use



Representing Changes in Flowrate

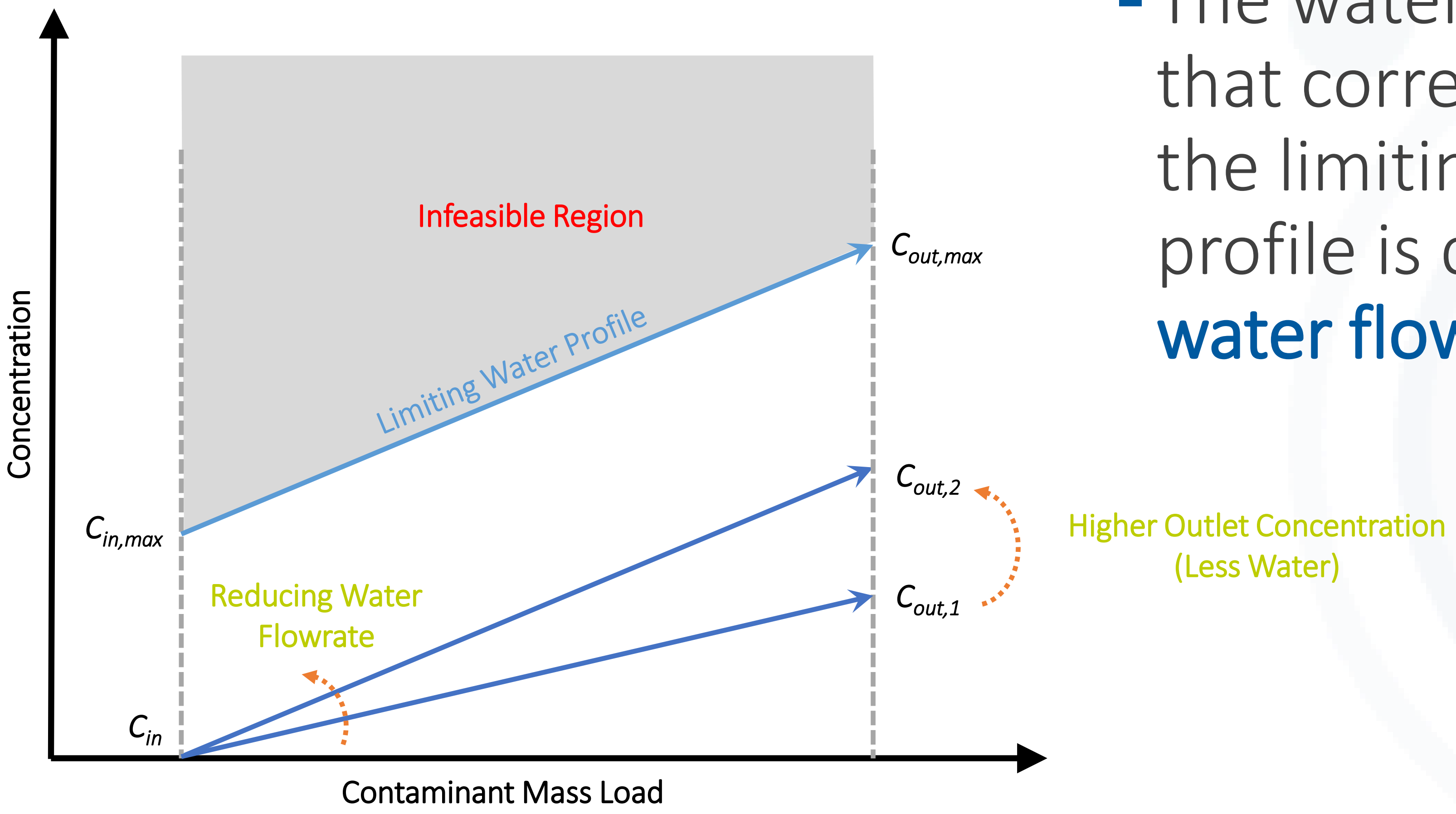
- If **water flowrate is reduced** for the same mass load of contaminant the result will be:
  - Higher outlet concentration
  - Steeper line



Achieving minimum water use

- The objective is to reduce water use as much as possible
- Limitations:
  - Minimum flowrate required by the operation
  - Maximum value for outlet concentration (discharge limitations)
- Moreover, in order to allow for reuse, some level of inlet contamination should be allowed

Limiting Water Profile



- The water flowrate that corresponds to the limiting water profile is called **limiting water flowrate**

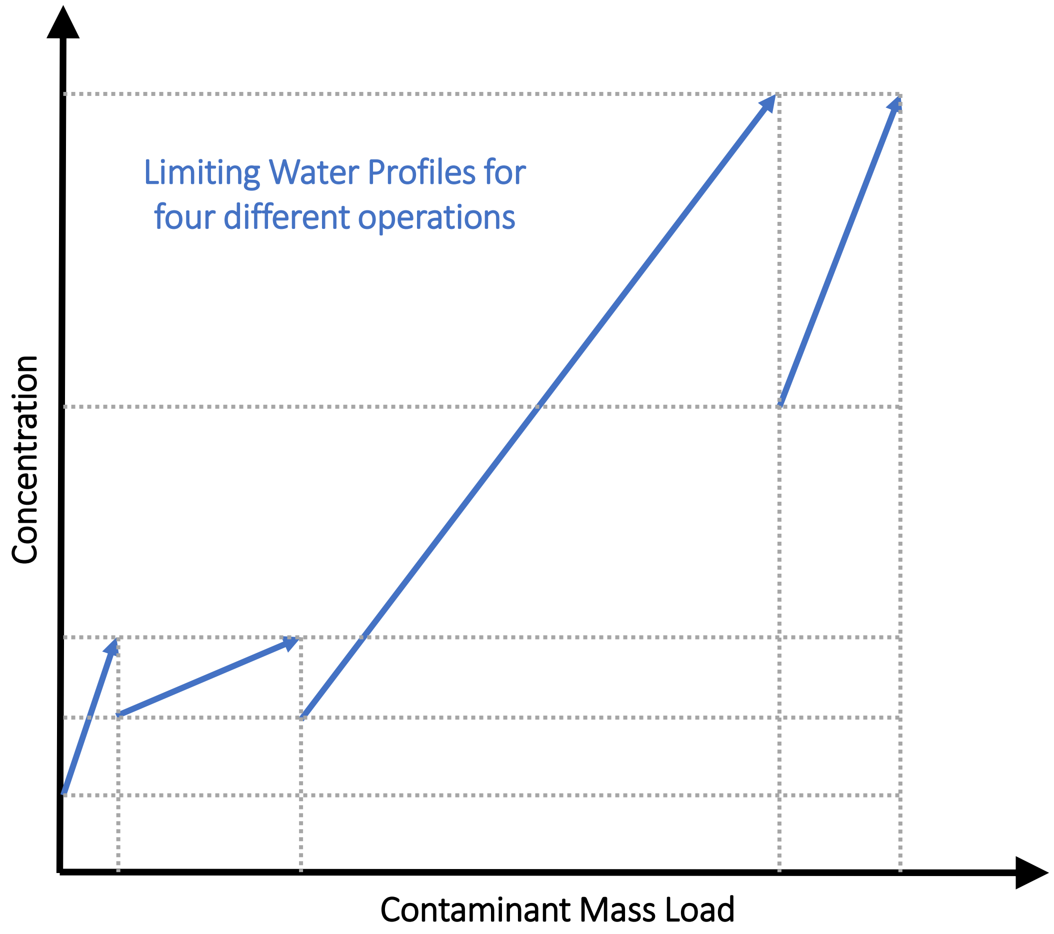
Limiting Water Profile

Advantages of its usage

- Operations with different characteristics can be compared
- Mass transfer does not need to be modeled in detail
- The flow pattern does not affect the results
- Can be applied in all different types of water use operations (co-current, countercurrent)

Limiting Composite Curve

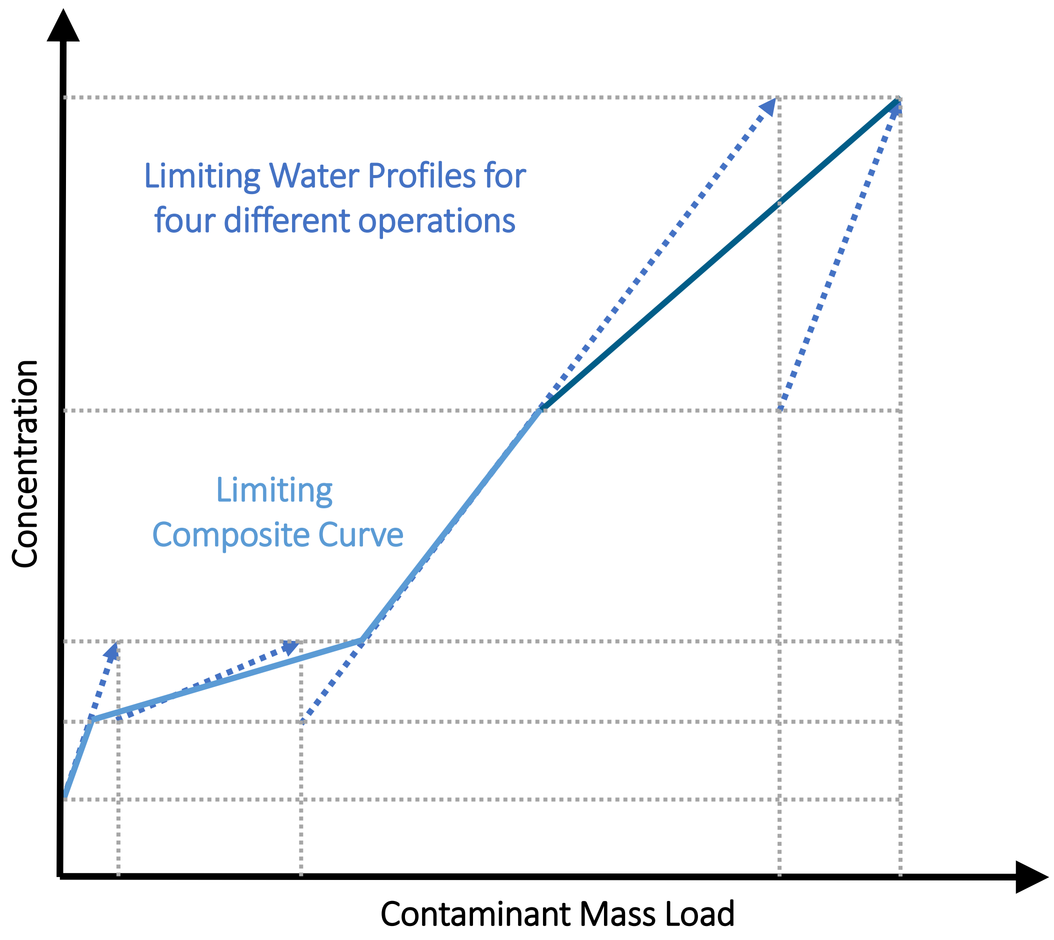
The case of one contaminant



- When combining limiting water profiles for various operations in the same chart, the output will be the limiting composite curve of the water streams

Limiting Composite Curve

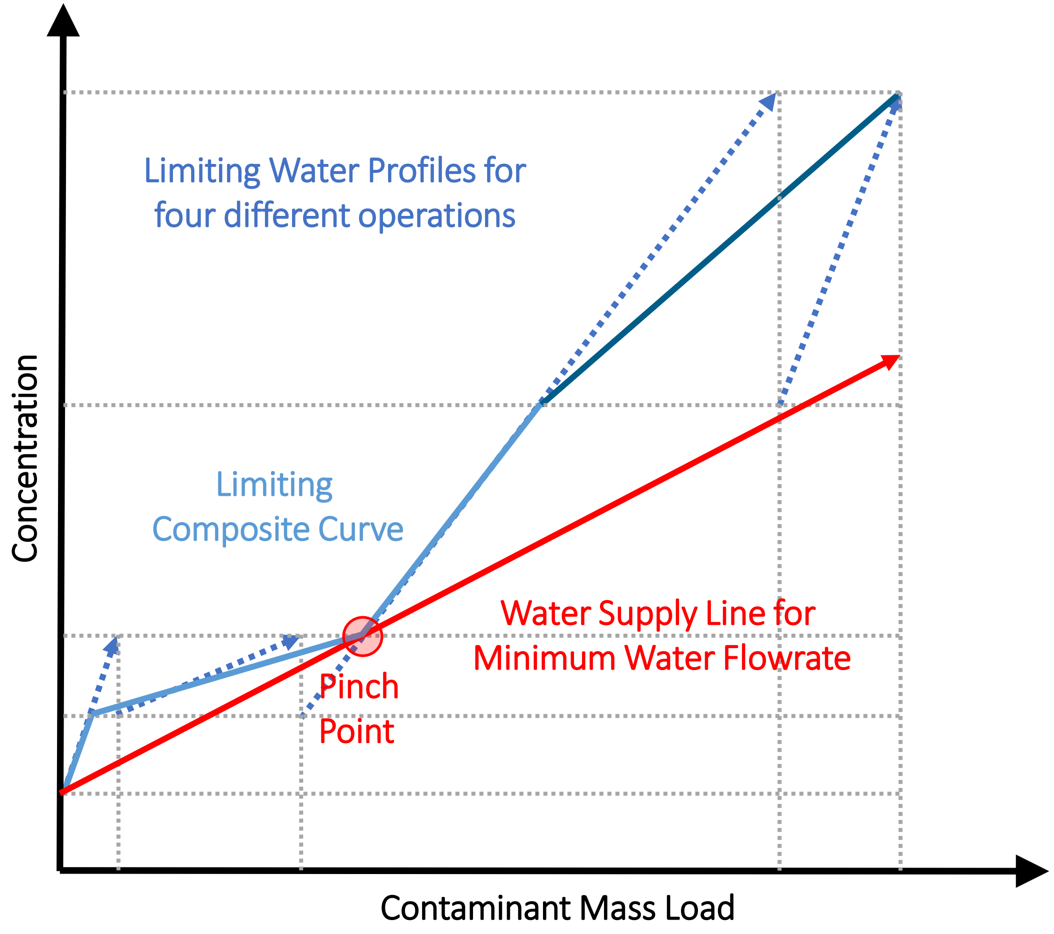
The case of one contaminant



- For the drawing of the limiting composite curve, the y-axis is divided into the corresponding concentration intervals and the contaminant loads in each interval are combined to create the composite curve.

Limiting Composite Curve

The case of one contaminant



- The minimum water flowrate for a given process can be specified by drawing the water profile curve which **begins from the minimum acceptable inlet concentration and passes from the pinch point**

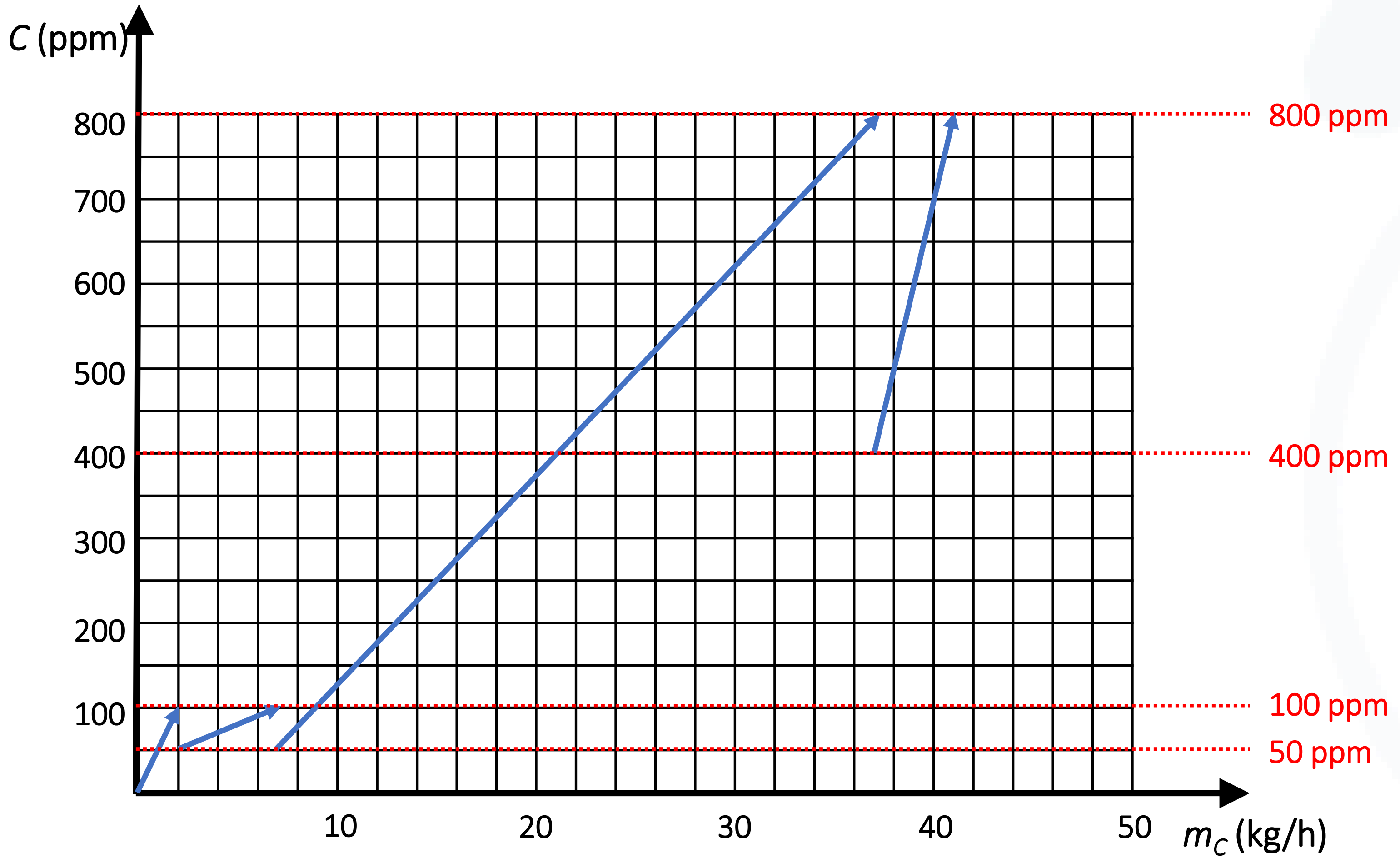
Let’s try an example

- An industrial unit has 4 operations which use water, and their specifications are presented in the following table. If the maximum inlet and outlet concentrations refer to a single contaminant:
  - Calculate the limiting water flowrate, which would maximize the water reuse in the system and draw the corresponding water supply line
  - Estimate the water savings compared to the case where all processes use freshwater

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	2000	0	100	20
2	5000	50	100	100
3	30000	50	800	40
4	4000	400	800	10

Step 1. Limiting Water Profiles

Draw the Limiting Water Profiles for the four different operations



Step 2. Concentration Intervals

Calculate the concentration intervals and the corresponding contaminant loads in each interval

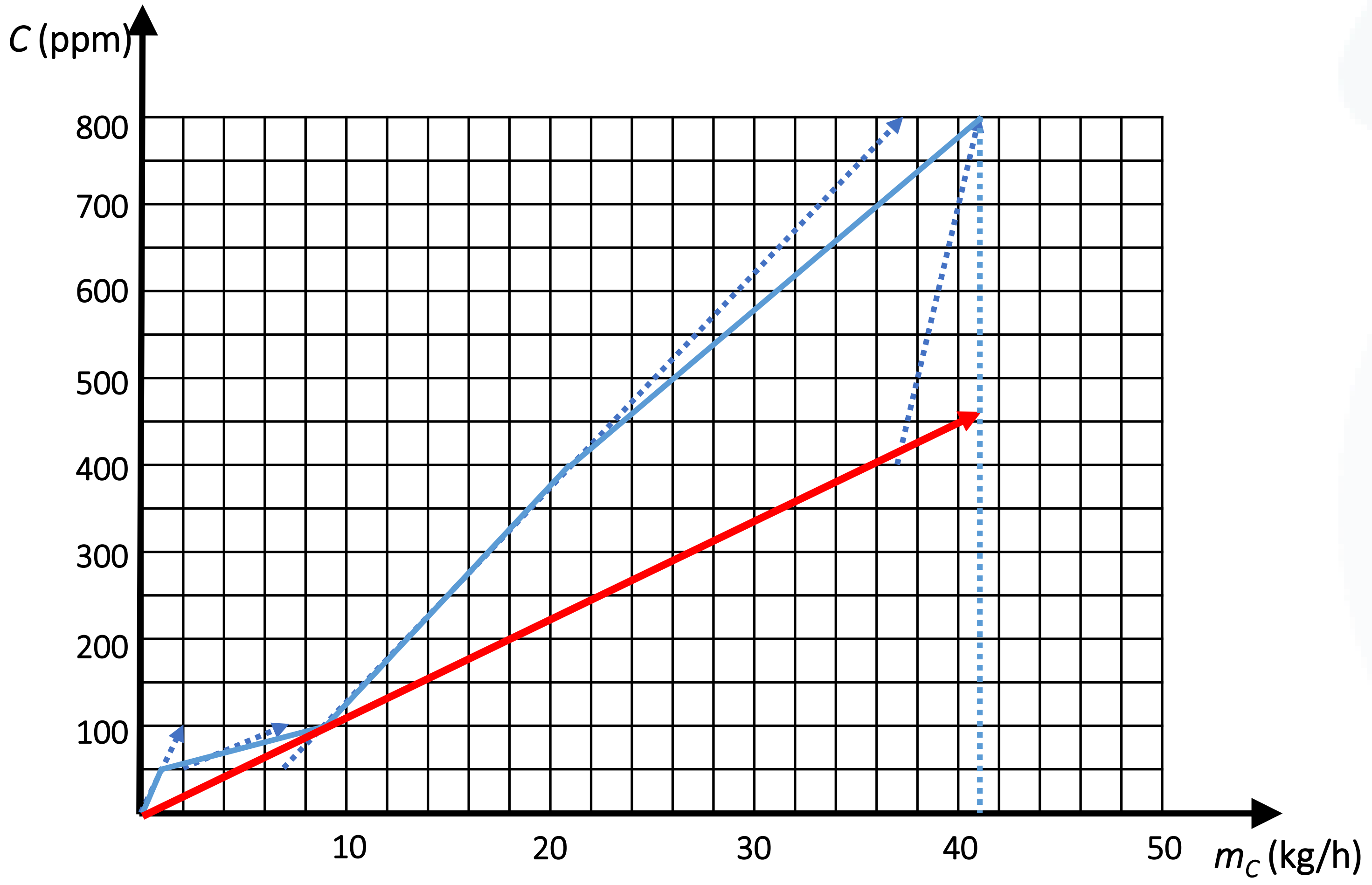
No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load
C1	0	50	20	1000
C2	50	100	100 + 40 + 20	8000
C3	100	400	40	12000
C4	400	800	40 + 10	20000

$$\Delta m_{C1} = m_{W1} \times \Delta C_1 = 20 \times (50 - 0) = 1000$$

$$\Delta m_{C2} = m_{W2} \times \Delta C_2 = 160 \times (100 - 50) = 8000$$

Step 3. Composite Curve

Draw the composite curve and the minimum flowrate water supply line



Step 4. Minimum Flowrate

Calculate the minimum flowrate and water savings

- From the pinch point

$$m_{w,min} = \frac{\Delta m_{C,pinch}}{\Delta C_{pinch}} = \frac{9000}{100} = 90\ \text{t/h}$$

- If all processes used freshwater:

No	Contaminant Mass (g/h)	Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	2000	0	100	2000/100 = 20
2	5000	0	100	5000/100 = 50
3	30000	0	800	30000/800 = 37.5
4	4000	0	800	4000/800 = 5

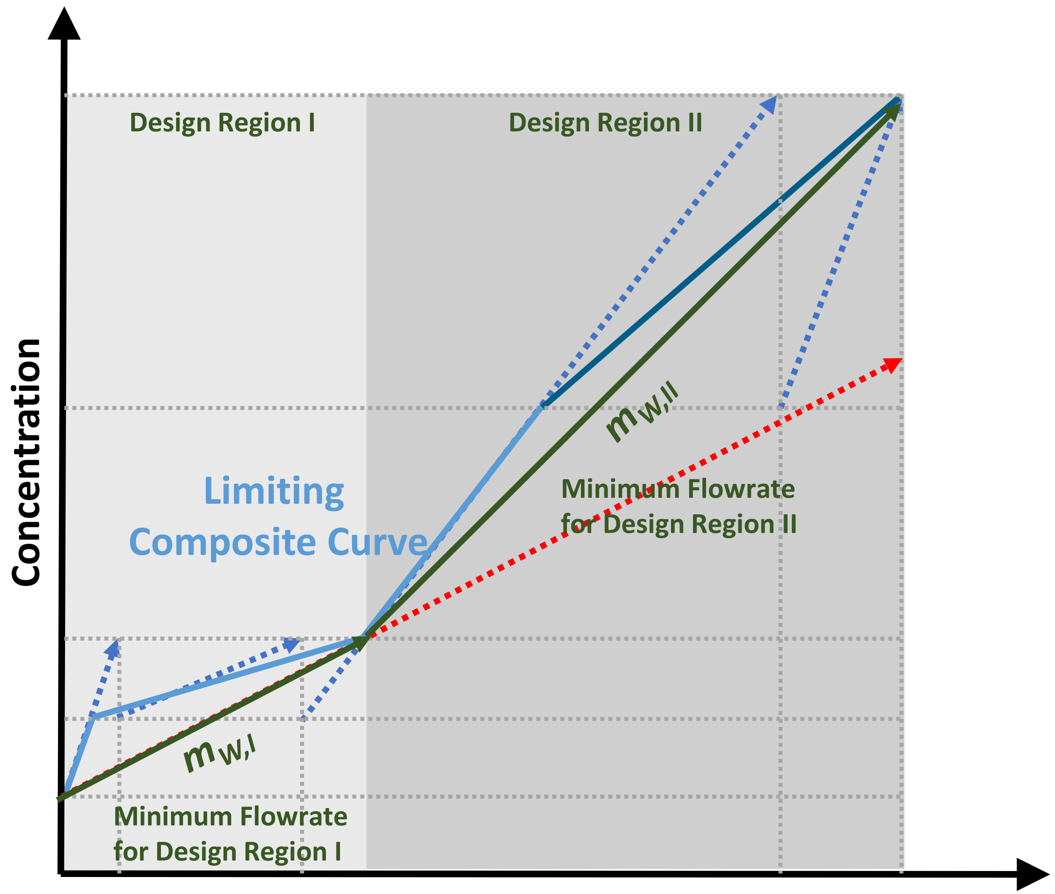
Savings = 112.5 – 90 = 22.5 t/h

Designing a maximum reuse system

In the case of a single contaminant

- After having calculated the minimum water flowrate required for the system, the next step is to actually design the system
  - Specify how exactly the water will flow among the different processes.
- Two (or more) different design regions can be identified in any scheme
  - **Below the pinch**, with limiting flowrate equal to the target minimum water flowrate of the system
  - **Above the pinch**, where the flowrate can be lower than the target minimum water flowrate

Separate Design Regions

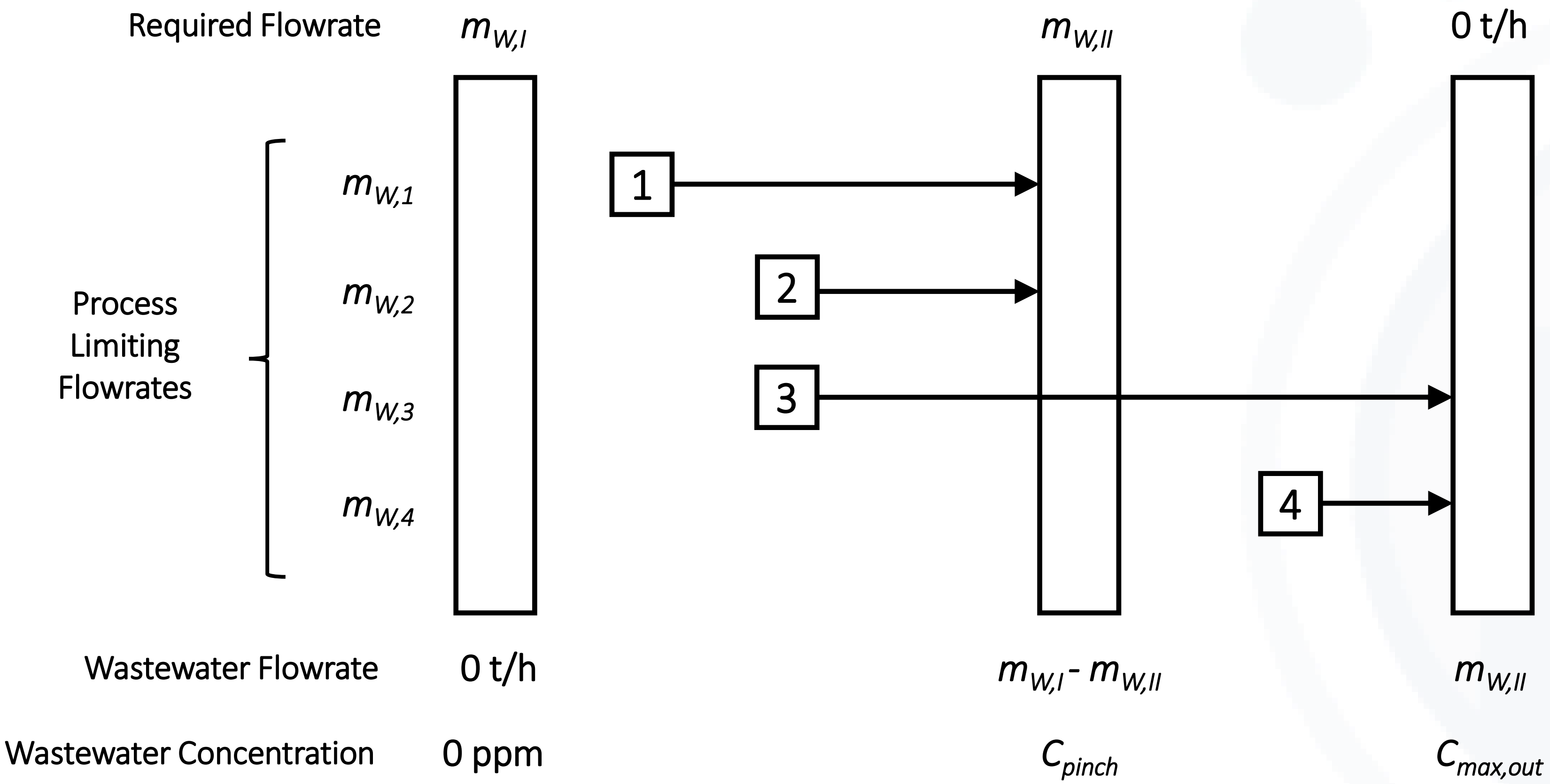


Designing a maximum water reuse system

In the case of a single contaminant

- Objective of the design
  - Use the target flowrate below the pinch and only the required flowrate in the other regions
- Four step procedure
  - Set up the design grid and include all the necessary water mains
    - Freshwater stream
    - Stream(s) with pinch concentration
    - Stream with maximum acceptable concentration;
  - Connect all the processes with water mains;
  - Amend the individual processes where the flowrate changes among water mains; and
  - Remove all the unnecessary water mains and connect all the processes directly, where possible.

A typical design grid



Let's carry on with that example

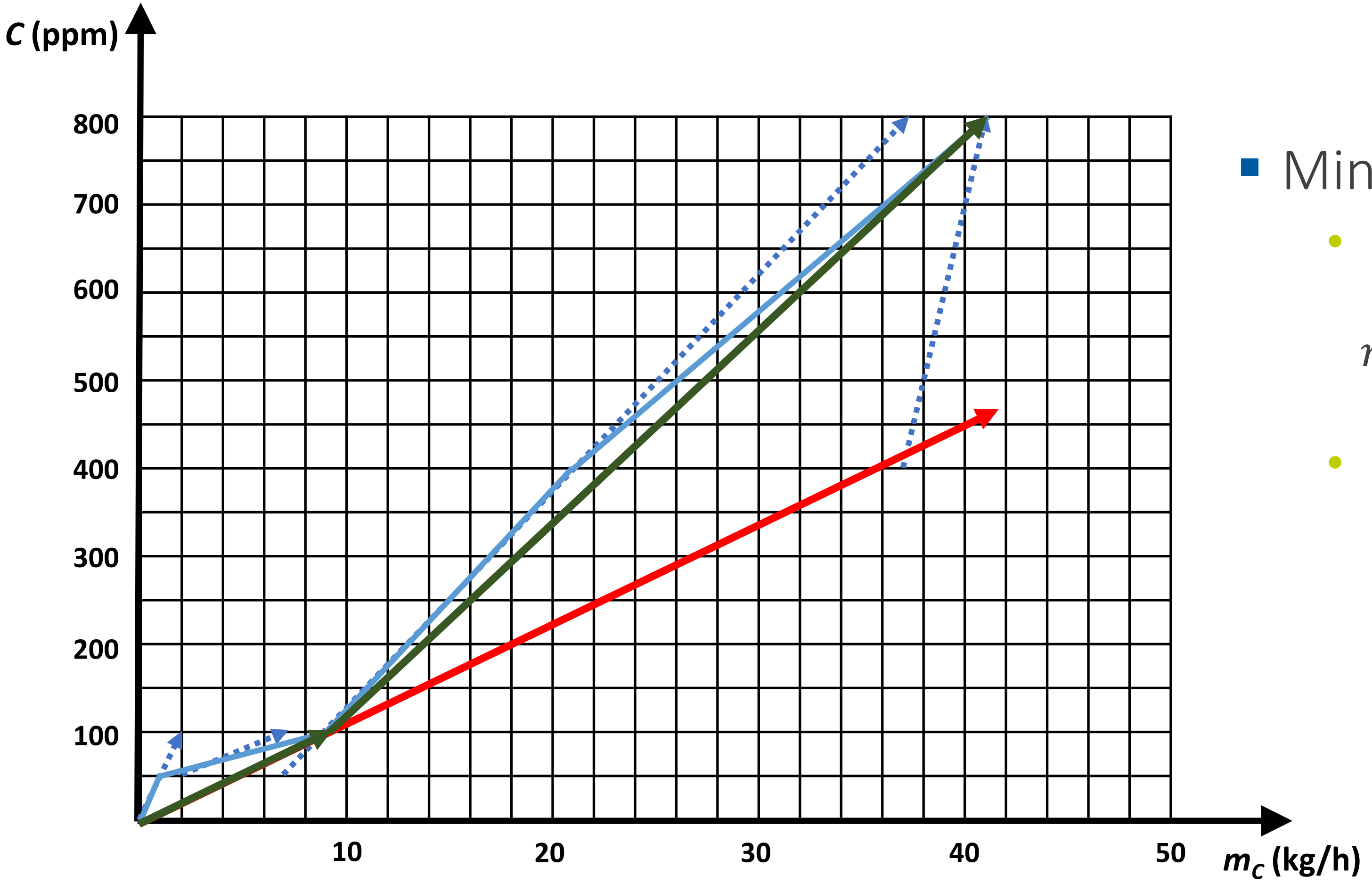
- Designing a network for the target water consumption, as calculated earlier.

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	2000	0	100	20
2	5000	50	100	100
3	30000	50	800	40
4	4000	400	800	10

- Two processes operating below pinch (1 & 2), one process operating above pinch (4) and one process operating in both regions.

Step 5. Minimum water use per region

Calculate minimum flow rate for each design region



- Minimum flow rate
  - Flow Rate in Design Region I

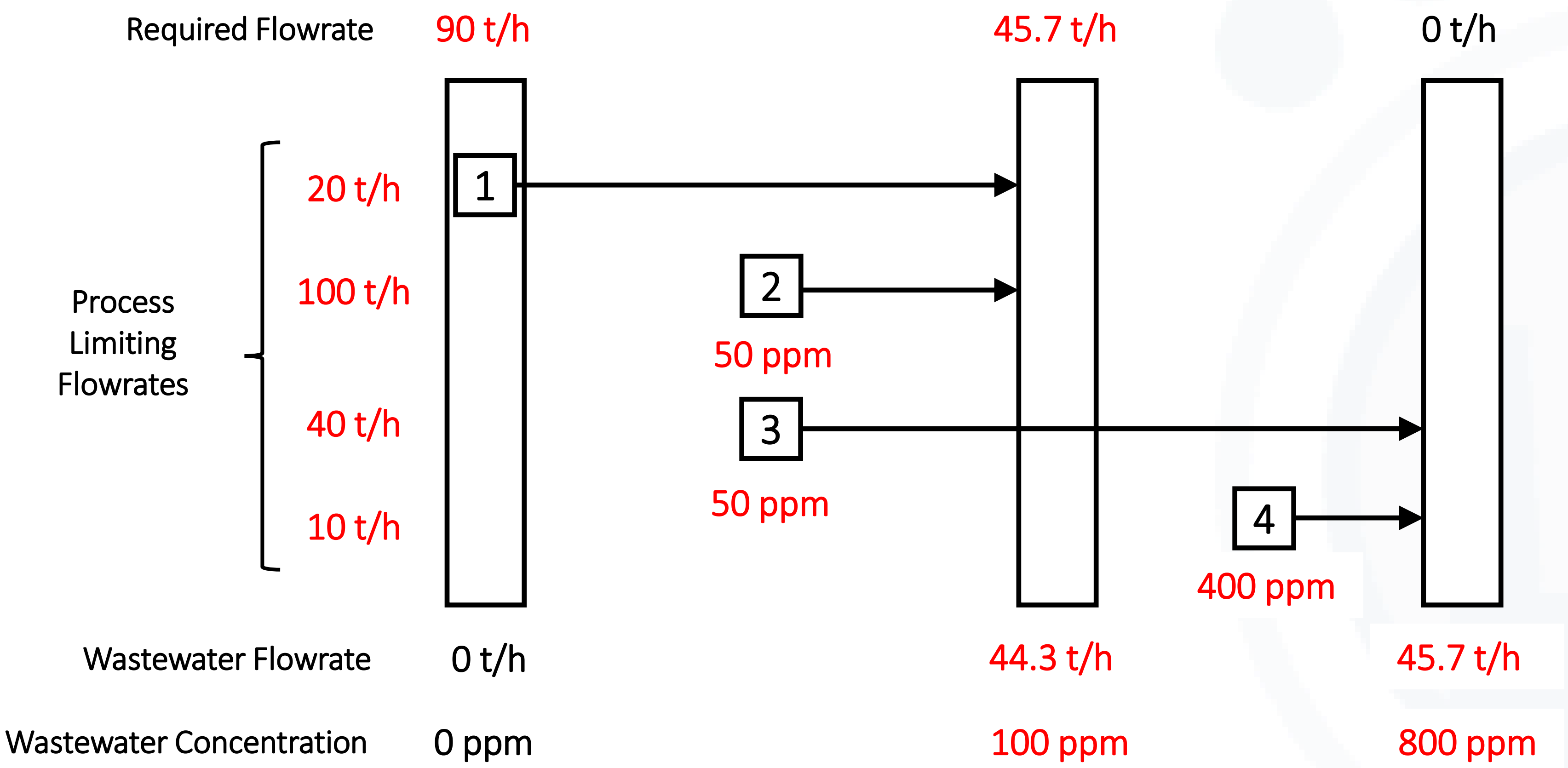
$$m_{w,I} = \frac{\Delta m_{C,pinch}}{\Delta C_{pinch}} = \frac{9000}{100} = 90 \text{ t/h}$$

  - Flow Rate in Design Region II

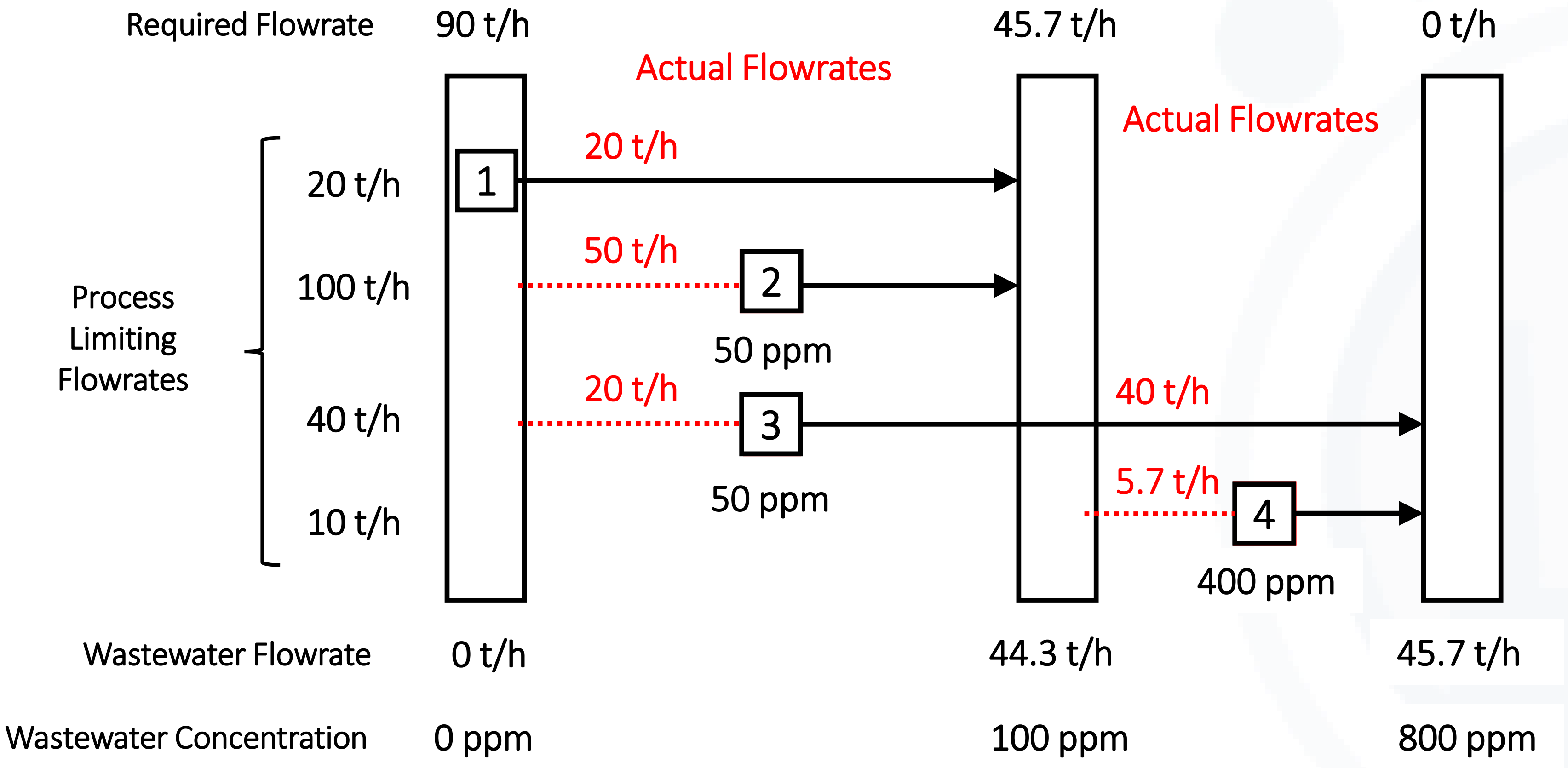
$$m_{w,II} = \frac{\Delta m_{C,II}}{\Delta C_{II}} = \frac{32000}{700} = 45.7 \text{ t/h}$$

Step 6. Design Grip Setup

Set up the design grid and include all the necessary water mains

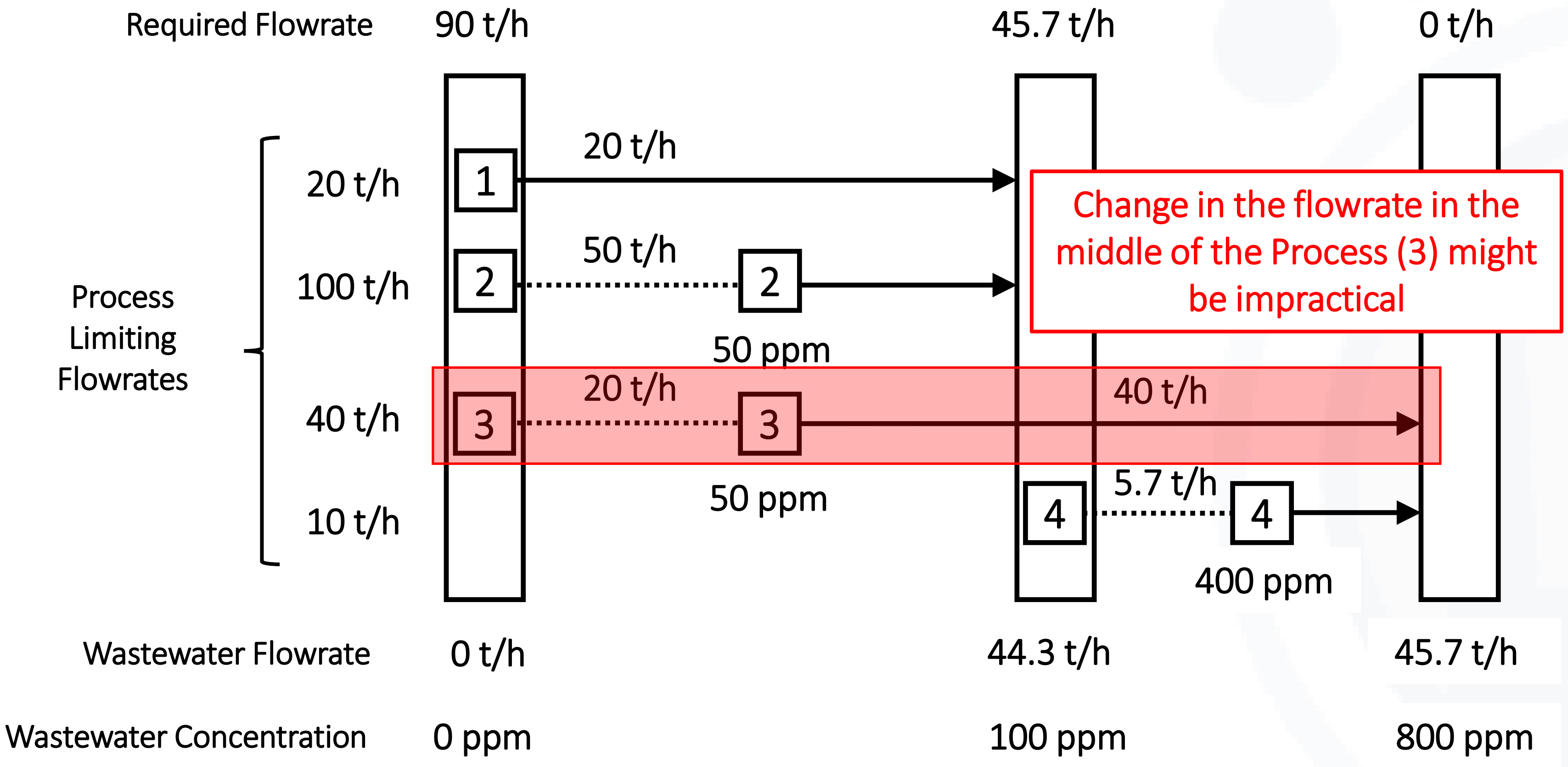


Step 7. Connect all the processes with water mains



Step 8. Amend flowrate where necessary

Amend the processes where the flowrate changes among water mains



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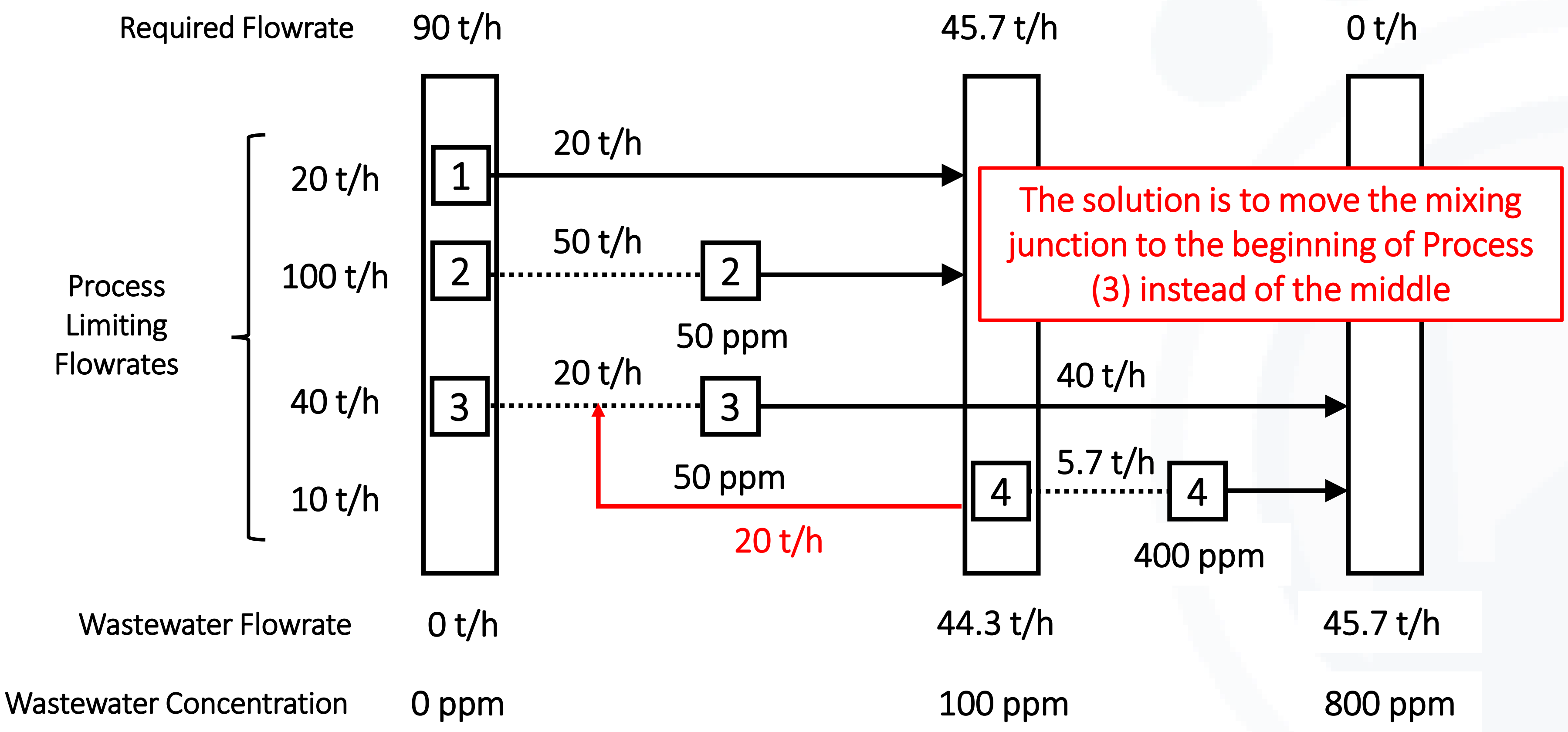
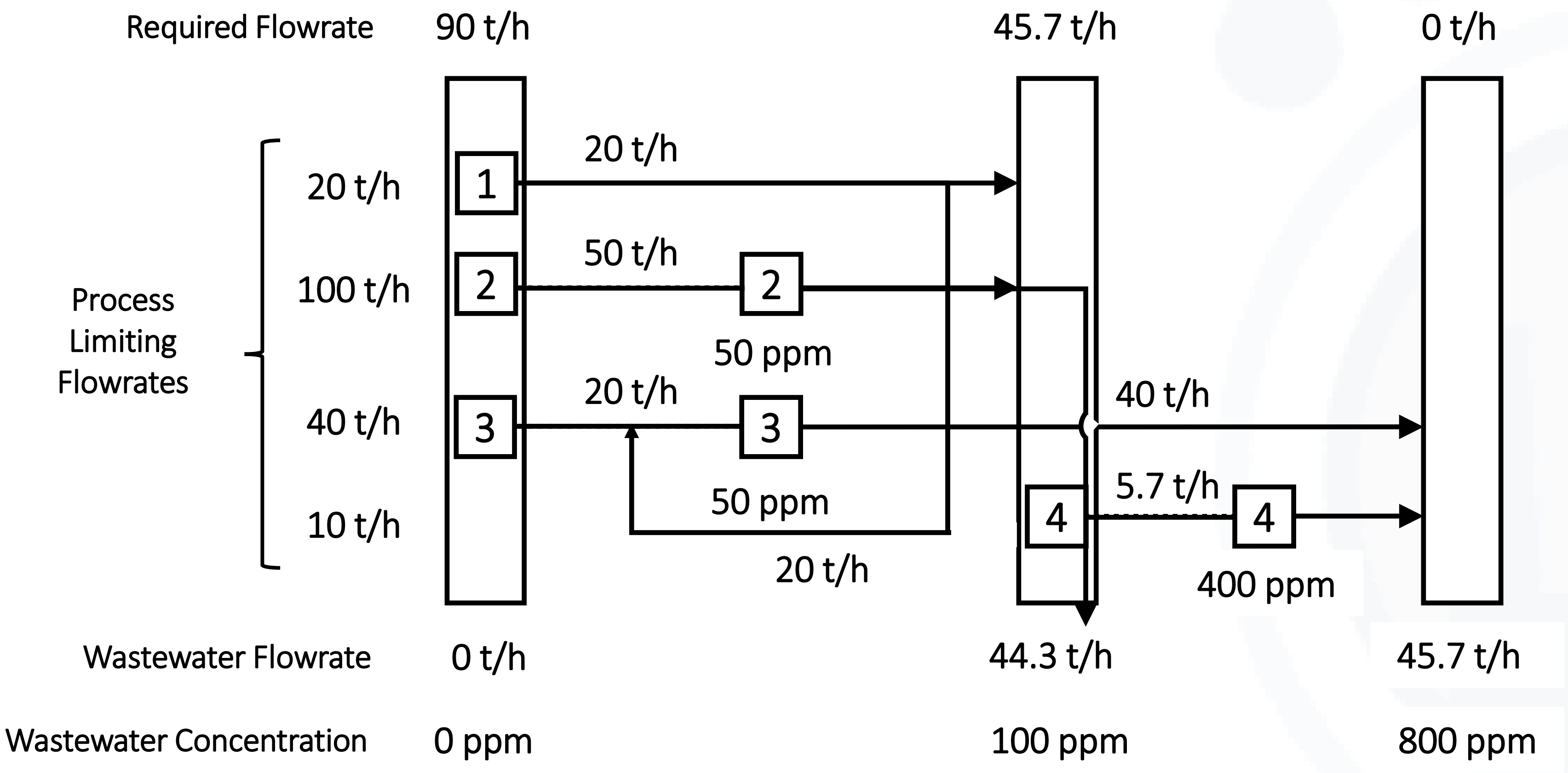
Amend the processes where the flowrate changes among water mains

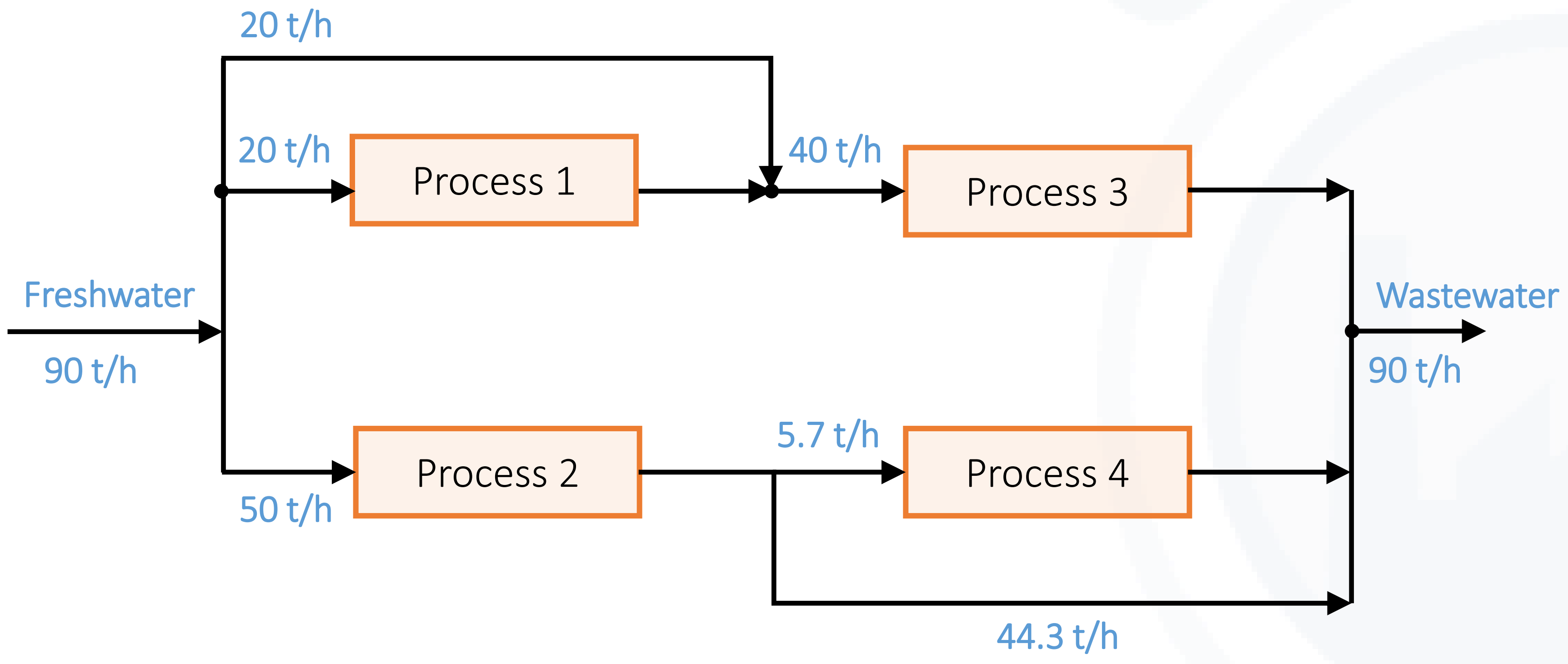


Step 9. Finalise the network

Remove the unnecessary water mains and connect all processes directly



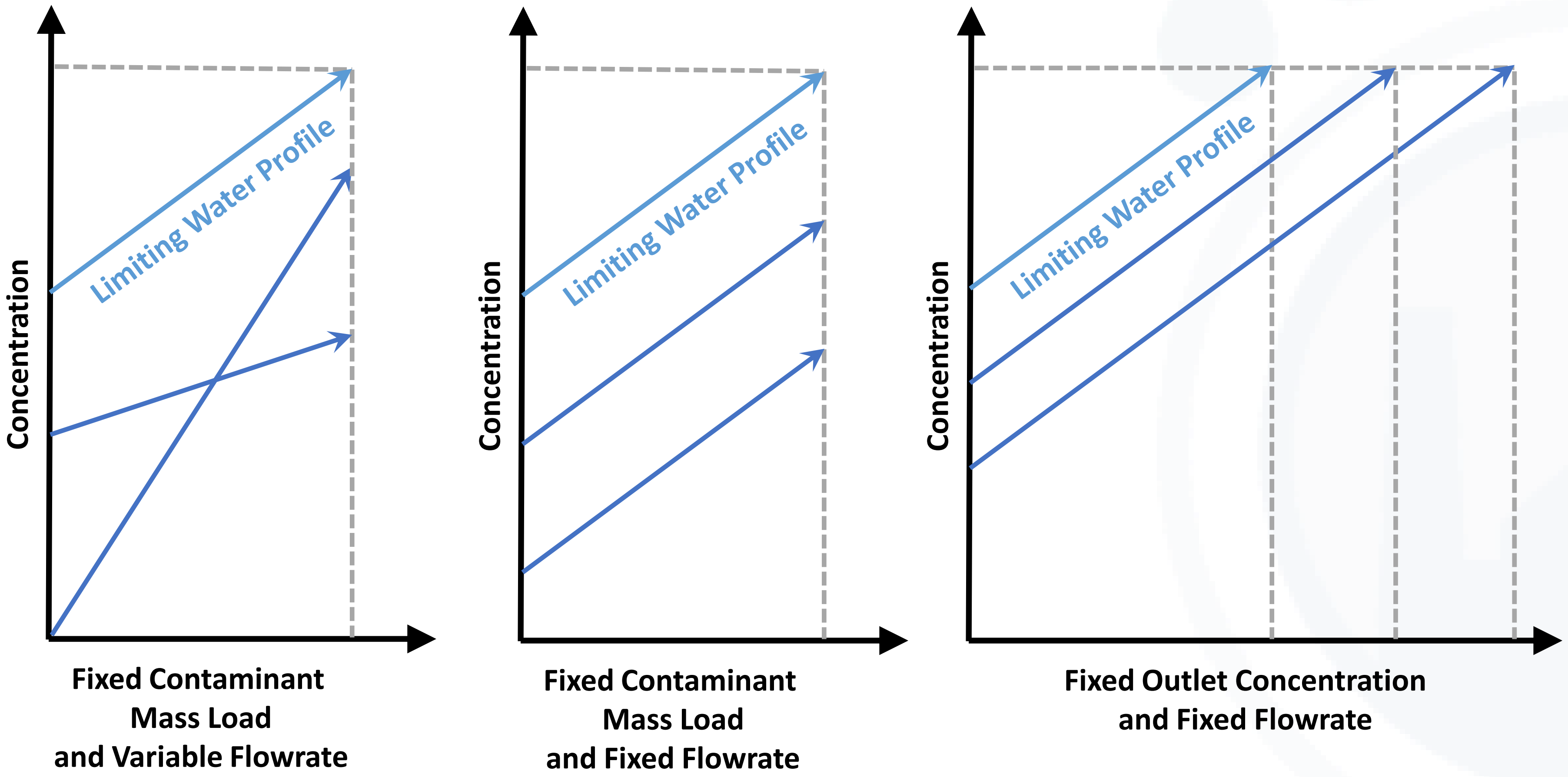
Step 10. Draw the flow diagram



Real Life Limitations

- Water losses in the systems
- More than one sources in the system (e.g. river, lake, potable, demineralized)
- More than one contaminants
- Different mass transfer models

Different Mass Transfer Models



References & Useful Resources

- Alwi, S, Varbanov, P.S., Manan, Z.A. & Klemes, J.J. (2014). *Process integration and intensification: saving energy and resources*, De Gruyter.
- Smith, R. (2016), *Chemical process design and integration,* 2nd Ed. Wiley Blackwell, Chichester, West Sussex.

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Design and Assessment of Water Reuse Systems

Part 2. Life Cycle Assessment

The AquaSPICE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958396.

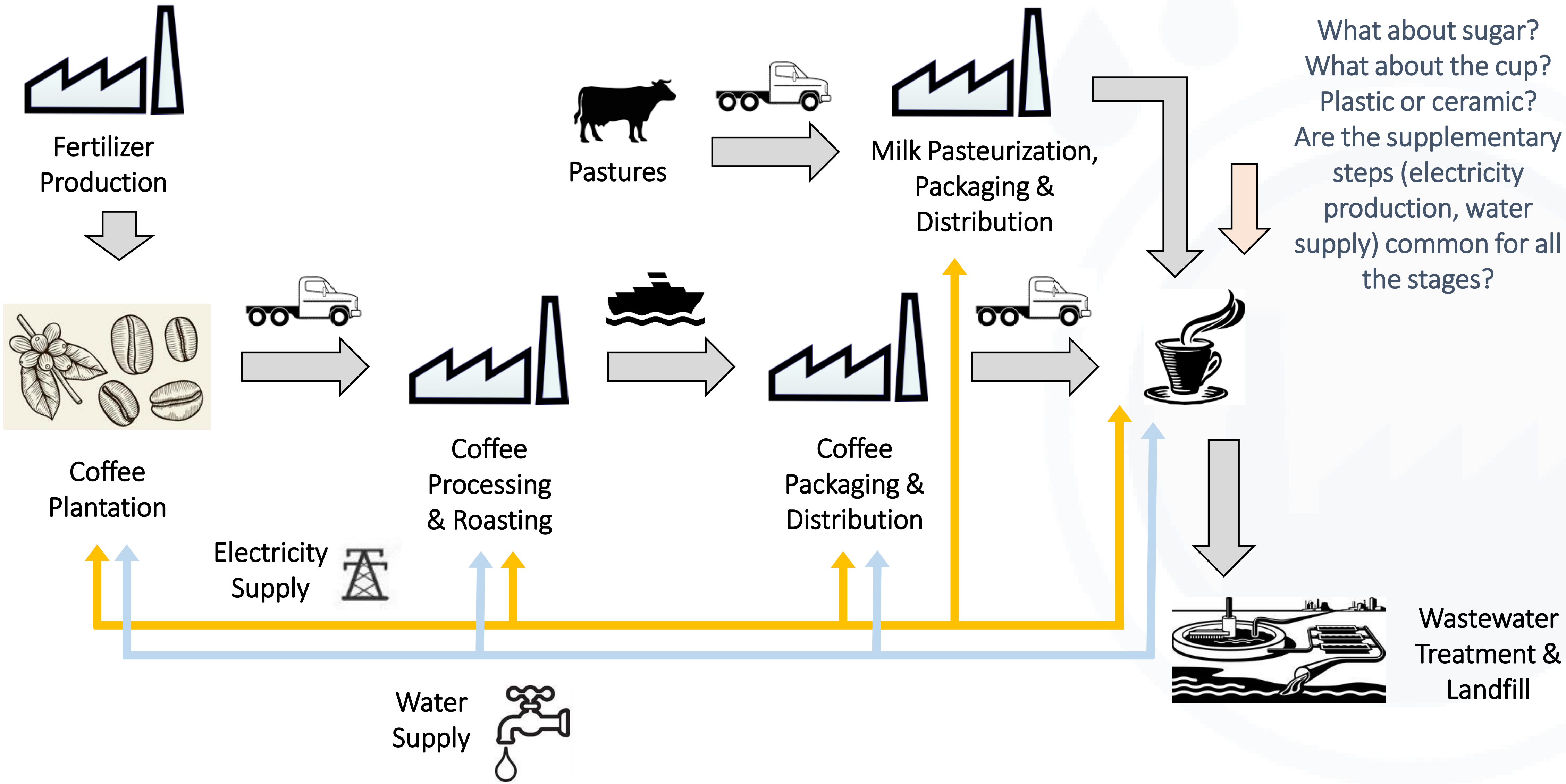
Life Cycle Assessment

A Brief Definition

- Systematic monitoring and accounting of the flows and stocks of materials and energy in physical units within a system defined in space and time throughout its entire life cycle, and assessment of the associated environmental impact.
- From raw material extraction through production, distribution, use, end-of-life treatment, recycling to final disposal

Life Cycle Assessment of a cup of coffee

Where do we set the boundaries?



What about sugar?
What about the cup?
Plastic or ceramic?
Are the supplementary steps (electricity production, water supply) common for all the stages?

Steps of a Life Cycle Assessment

According to ISO 14040:2006 - Environmental management

- What is the purpose of the study and the reference flow of the analysis?
- What are the boundaries of the system?

Step 1. Goal and Scope Definition

- What are the materials involved in the system
- What are the values of the corresponding flows?

Step 2. Life Cycle Inventory

- Which flows correspond to each environmental impact?
- What are the main environmental impacts?

Step 3. Life Cycle Impact Assessment

Step 4. Results Interpretation

- What do the results indicate?
- What should be the next actions?

Step 1. Goal And Scope Definition

- What is the purpose of the study?
  - Who will use the results?
  - Identification of hot spots? Comparison of alternative products? Comparison of alternative procedures? Assess the consequences?
- What are the boundaries of the system?
- What will be the reference flow of the analysis?
  - Reference Flow: The flow to which all other input and output flows quantitatively relate
  - Functional Unit: The numeric value of the reference flow, a reference to which results are normalized and compared

Life Cycle Boundaries

Common variants that can be used

- Cradle-to-grave
  - From resource extraction ('cradle') to the disposal stage ('grave')
- Cradle-to-gate
  - From resource extraction (cradle) to the factory gate (i.e., before it is transported to the consumer). The use and disposal stages are not included
- Cradle-to-cradle or closed loop production
  - Specific type of cradle-to-grave assessment, where the disposal stage for the product is a recycling process.
- Gate-to-gate
  - Specific type of LCA focusing on one value-added process in the entire production chain
- Well-to-wheel
  - Specific LCA used for transport fuels and vehicles

Life Cycle Boundaries

Foreground vs Background System

- An important element in the life cycle approach is the distinction between “foreground” and “background” systems
  - Foreground System: The set of processes whose selection or mode of operation is affected directly by decisions based on the study
  - Background System: Includes all other activities, which deliver energy and materials to the foreground system, usually via a homogeneous market

Functional Unit

- The functional unit provides a reference to which results are normalized and compared
- Appropriate definition of functional unit to allow comparisons
- For a beverage bottling company possible functional units can include:
  - 1 bottle of beverage
  - 1 litre of beverage
  - 1 day/year of operation
  - …
- What about multiple products?

Step 2. Life Cycle Inventory

- Life cycle inventory (LCI) analysis involves creating an inventory of flows entering and leaving every process in the foreground system, i.e. the system within the defined system boundaries
- In a typical LCA methodology, the inventory of flows must be related to the functional unit defined in the goal and scope definition

Step 3. Life Cycle Impact Assessment

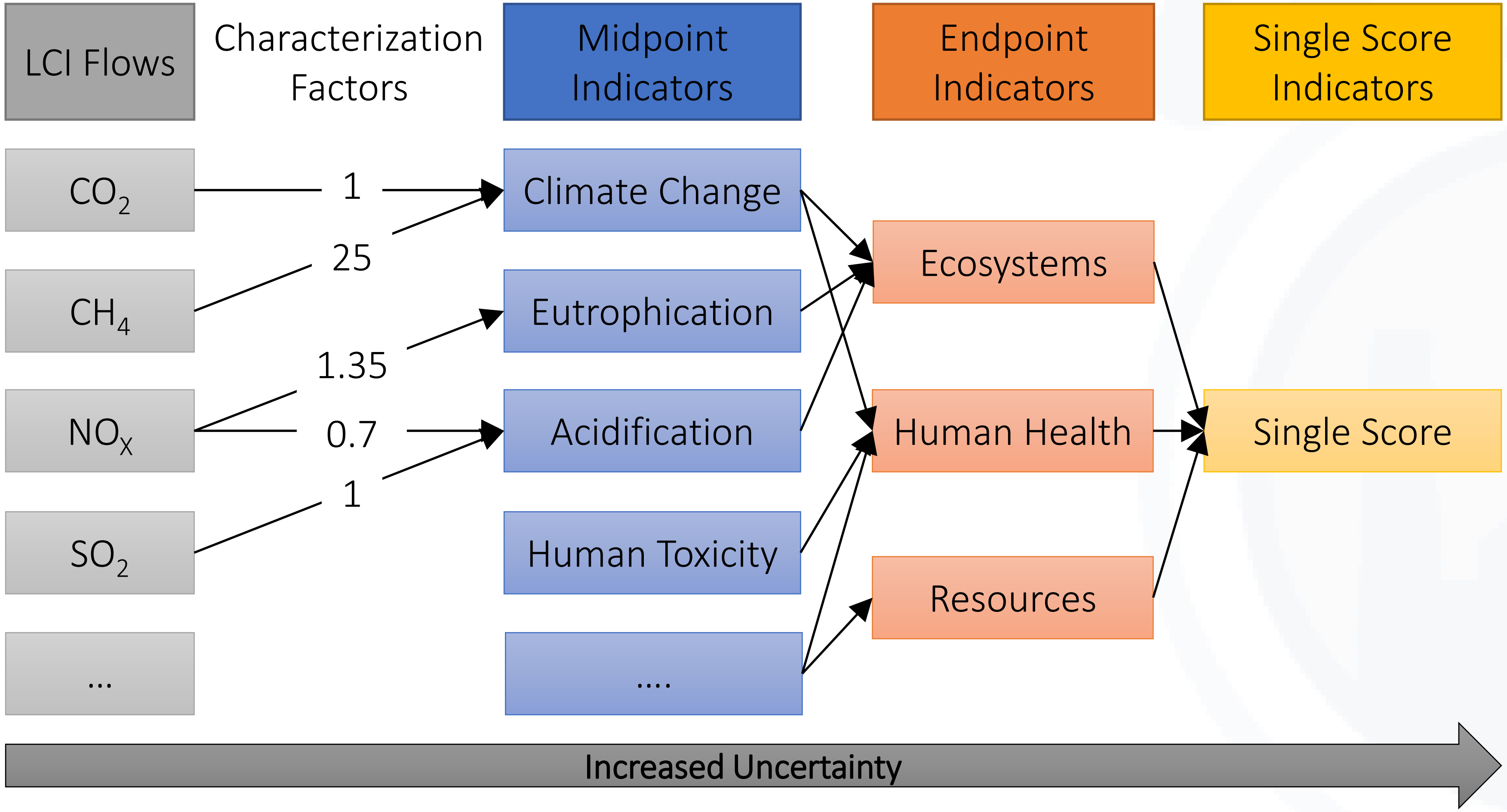
Three mandatory elements

- Selection of relevant impact categories and the corresponding indicators
- Classification and characterization
  - Inventory flows are assigned to specific impact categories and are characterized into common equivalence units
- Impact calculation
  - Inventory flows are used to provide an overall environmental impact score per category

Selecting Impact Categories

- An impact category represents a certain environmental issue of concern, to which the life-cycle inventory flow can contribute and thus a value may be assigned
- The selection of the most appropriate ones is case specific and is directly related to the information required to make concrete proposals for specific policies
- Distinction between midpoint and endpoint categories
    - Midpoint impact categories refer to specific environmental issues (such as climate change, acidification, eutrophication, human toxicity, etc.)
    - Endpoint categories refer to the three generally recognized issues of concerns (degradation of ecosystems, negative impact in human health and depletion of natural resources)

Midpoint vs Endpoint



Classification and characterization

- Quantify the impact of the elementary flows by aggregating the inventory flows into a limited number of midpoint or endpoint indicators
  - Classification: Organize and, if possible, combine the life cycle inventory flows into impact categories
  - Characterization: Quantify the extent to which each resource/emission contributes to different environmental impact categories
- The environmental impact for a given category (c) is expressed as a score (ESc) in the common unit for all contributions within the category

Characterisation Factors

- Factors for Foreground Systems
  - Retrieved from LCA databases
    - A widely used one (CML-IA) can be retrieved from the University of Leiden Department of Industrial Ecology webpage
  - Vary based on the method used
- Factors for Foreground Systems
  - More difficult to retrieve
  - The background system is usually considered as a homogeneous market, so that individual plants and operations normally cannot be identified
  - Environmental impact factors are usually retrieved from databases, mainly provided with commercial and publicly available LCA software
  - Selection of which ones to include

Step 4 – Results Interpretation

- Many numbers/tables/charts!
- Identify the most significant issues based on the results of the environmental assessment
- Identify the stages/processes/flows that mainly contribute to the environmental impact
- Formulate conclusions and recommendations, according to the goal and scope of the study
- Explain the limitations of the analysis
- Provide recommendations for progressively improving the performance of the system

Dynamic Life Cycle Assessment

- In general, the term “dynamic” is used to express a system which is characterized by constant change.
- The changes that characterize a dynamic system can be:
  - directly linked to the operation of the system itself, affecting its performance in the short term
  - linked to the environment, which will affect the system and its performance indirectly, and probably in the longer term.
- However, usually these changes are not considered when assessing the system’s environmental impact through a traditional static LCA.

LCA in the context of I4.0

- Static LCA, based on data from historical time series, enables the stakeholders to better understand the environmental impacts caused by the product system under consideration.
- At the same time though the digital transformation of the industry is one of the biggest shifts we see moving forward.
- Production processes are in the throes of Industry 4.0 transformation, towards a more agile, resilient, and flexible way of operation which increases their capacity to response rapidly to challenges

LCA in the context of I4.0

- New tools based on real-time modelling as well as robust data-driven approaches, enable the formation of Cyber-Physical Systems (CPS) and allow to better monitor processes and to operate systems much more efficiently.
- Thus, in the context of Industry 4.0 and the CPSs, static LCA is inflexible, providing only a single static snapshot in the time of the complex interactions of a product system.
- That means, it cannot be used to identify hotspots and trade-offs in real-time and support operational actions. The developed concept of Dynamic LCA could overcome these barriers.

Dynamic Life Cycle Assessment

- Dynamic Life Cycle Assessment can be defined as the LCA that incorporates elements of temporally induced changes that affect the results and the interpretation of the modeled system
- However:
  - Can we use the same framework for Dynamic LCA?
  - Which part of LCA will be dynamic?
  - Are there any differences regarding indicators/data requirements?

Steps of a Static Life Cycle Assessment

According to ISO 14040:2006 - Environmental management

Step 1. Goal and Scope Definition

- What is the purpose of the study and the reference flow of the analysis?
- What are the boundaries of the system?

Step 2. Life Cycle Inventory

- What are the materials involved in the system
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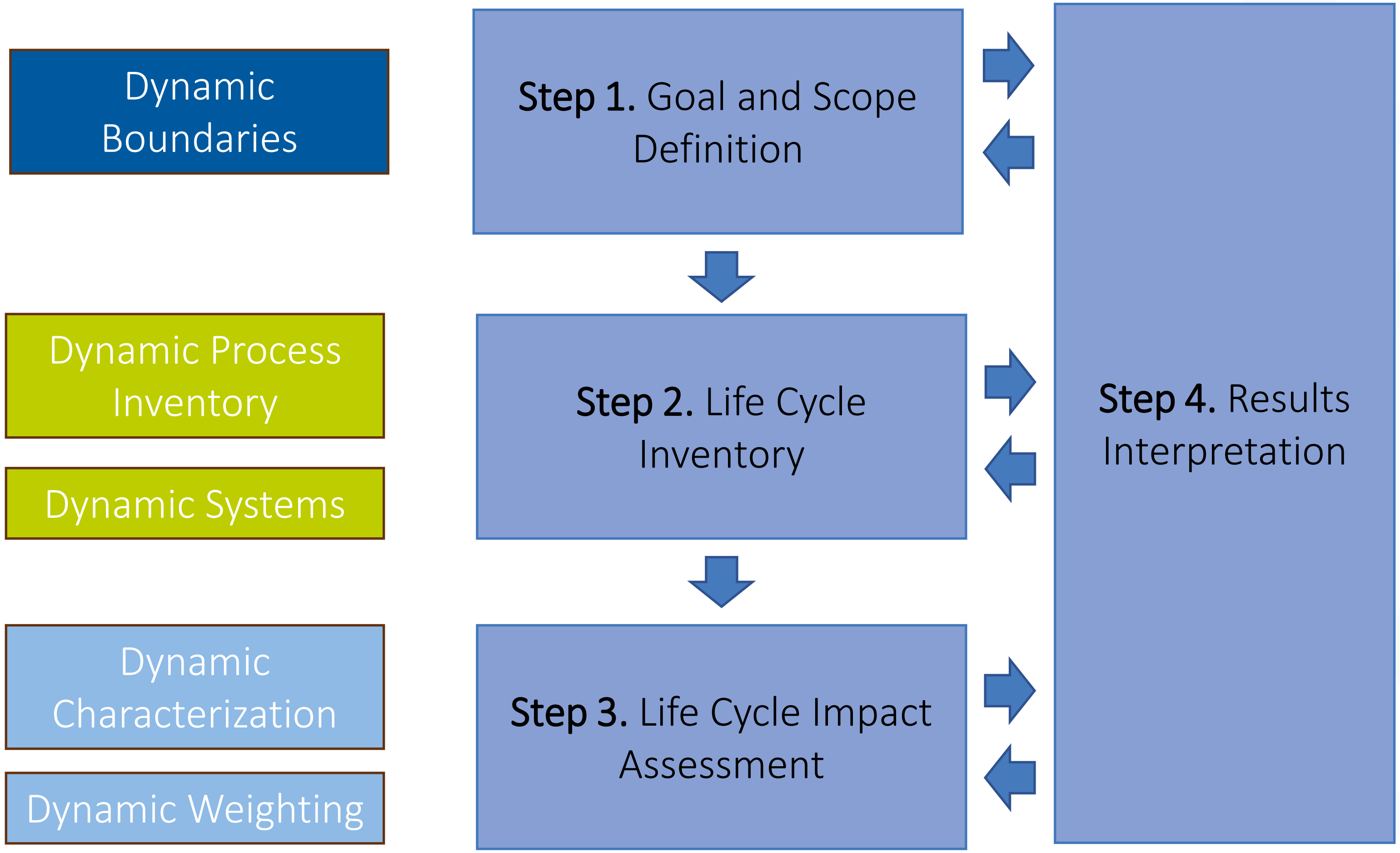
From LCA to Dynamic LCA

A proposed methodological framework

- Sohn et al (2020) suggested an adapted methodological approach where, the first and last steps remain unchanged but the other can be converted into dynamic.
- Three different types of dynamism are described:
  - Dynamic Process Inventory (DPI), which is the most frequently applied type of dynamism, implements temporal changes in input and/or output flows.
  - Dynamic Systems (DSys), where changes are implemented in unit processes within the modelled systems.
  - Dynamic Characterization (DChar), where the characterization factors change temporally.
- DPI and DSys are the dynamic variations of the LCI, whereas DChar is the dynamic implementation of LCIA.

Steps of a Dynamic Life Cycle Assessment



Dynamic Characterization

- Characterization factors change temporally
- Dynamic characterization based on the expected global temperature changes and time-adjusted cumulative radiative forcing (CRF), as defined by the IPCC to express the global warming potential
- Time-horizon-dependent ecotoxicity characterization factors, developed based on the USEtox fate model
- Time horizon-adjusted CFs for acidification, ozone depletion
- Long term consideration: 100-500 years' time horizon

Dynamic Inventory

Long Term Scenarios vs Real Time Monitoring

- Using Scenarios
  - The most frequently applied type of dynamism, implementing temporal changes in input and/or output flows
  - Most common application is based on the development of future scenarios
- Real Time
  - In conjunction with real time monitoring systems
  - Real time data collection to continuously update the inventory
  - Why would you need to do that? Which sectors?

Dynamic Systems

Examples from Literature

- Dynamic Process Modelling, where changes are implemented in unit processes within the modelled systems
- Used in conjunction with/incorporated into existing process modelling tools
- Common application in the building sector with the Building Information Model (BIM), a tool developed for monitoring the building over its entire life cycle, by collecting an interoperable data set

Dynamic Life Cycle Assessment

The AquaSPICE Approach

- From the four steps of LCA, three have been incorporated in the Dynamic Life Cycle Assessment AquaSPICE framework:
  - Dynamic Goal and Scope (via link to Process Simulation and Modelling tool)
  - Dynamic Life Cycle Inventory (via link to Real Time Monitoring platform and Process Simulation and Modelling tool)
  - Dynamic Interpretation (via link to a Cyber Physical System)
- Dynamic Characterisation is not suitable for short-term (near real time) life cycle assessment
  - Characterisation Factors will only change in the long term (50 or 100 years), and definitely not in a very short time horizon

Let's try an example…

Slaughterhouse Wastewater Treatment

- A slaughterhouse in Romania wants to assess the environmental impact of alternative options for their wastewater treatment facilities.
- A volume-based unit is the most common functional unit in the LCA of wastewater treatment and, for this study, 1 m^3 of wastewater effluent prior to entering the wastewater treatment system is chosen.
- The focus of the study was the operational Life Cycle Assessment on the water line, which implies that the design, building and maintenance of different process equipment have not been included.

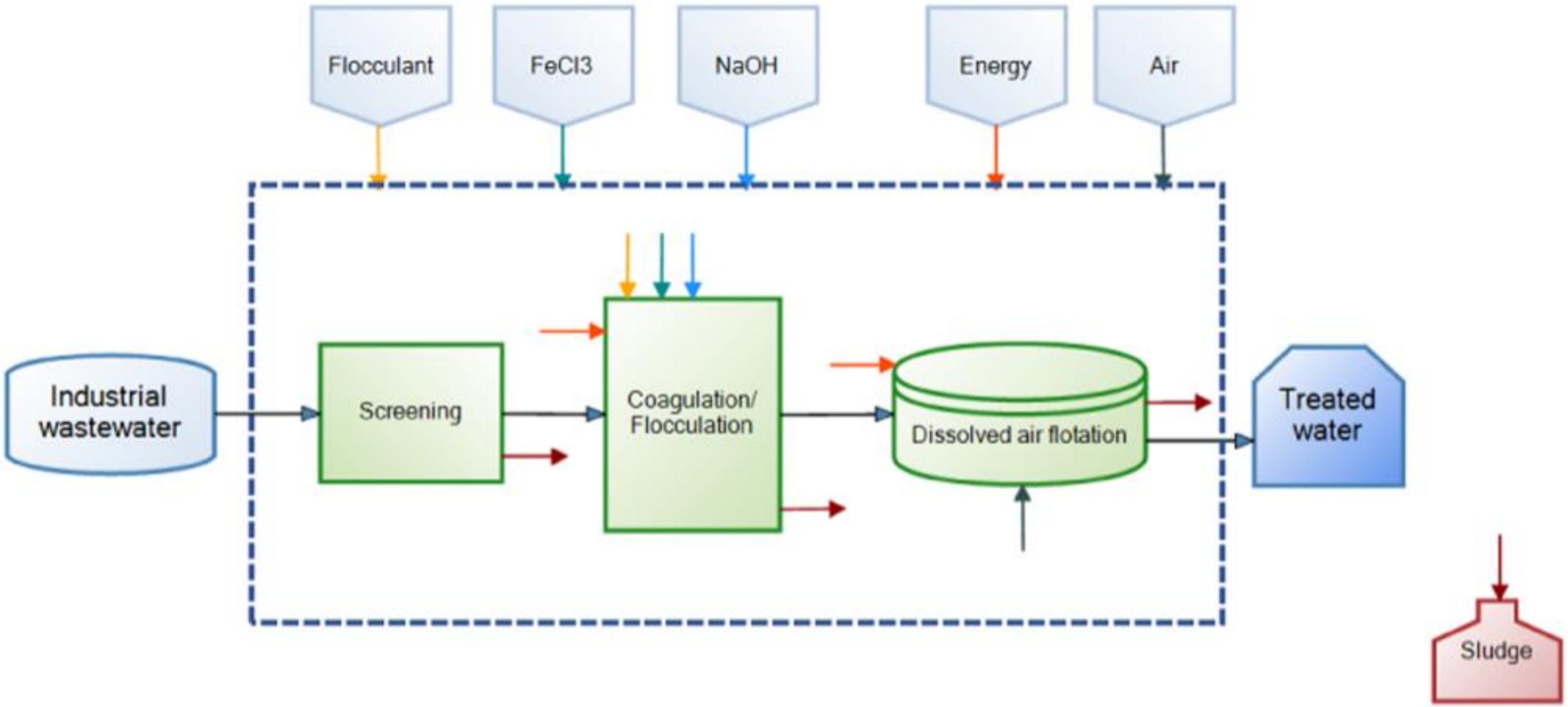
Life Cycle Assessment

Main Assumptions

- The Environmental Footprint (EF) impact assessment method has been selected for the impact assessment of the alternative scenarios.
- The EF is an LCA methodology, adopted by the European Commission in the Environmental Footprint transition phase of the commission to incentivise industries manufacturing products with improved environmental performance, based on reliable, verifiable, and comparable information.
- Version 3.7.1 of the ecoinvent database was used for the assessment.

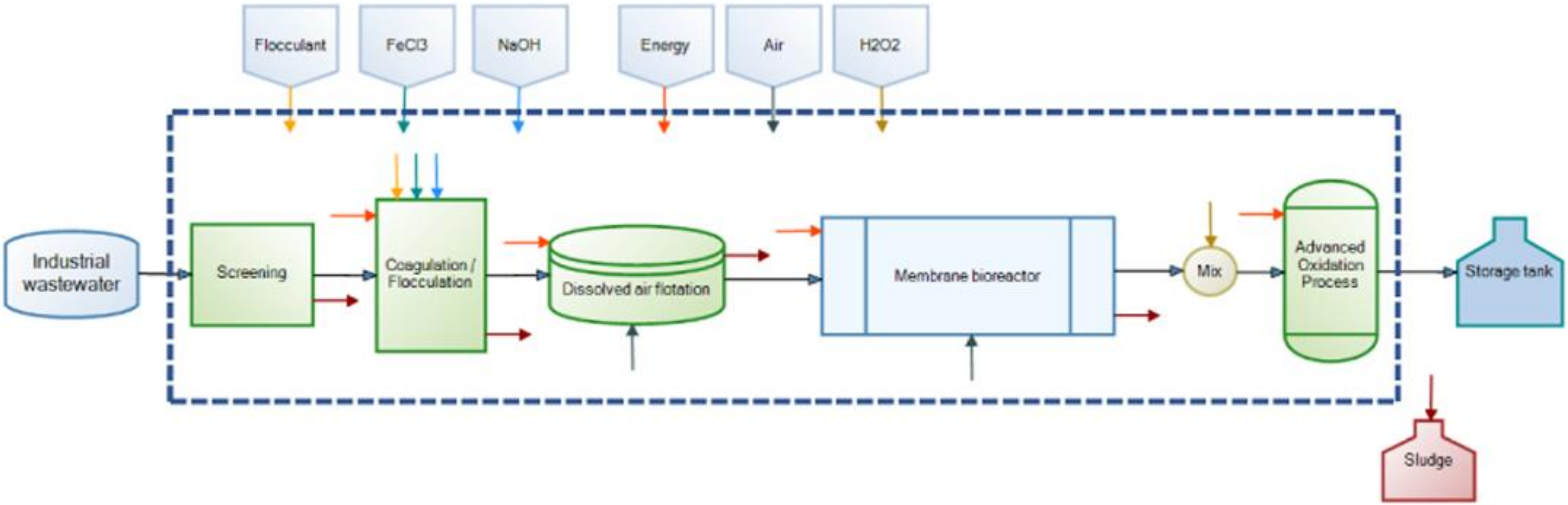
Option 1 for Wastewater Treatment

As modelled and illustrated using the PSM tool developed by TUC



Option 2 for Wastewater Treatment

As modelled and illustrated using the PSM tool developed by TUC



Life Cycle Inventory

Inputs and Outputs

The Life Cycle Inventory has been populated using: (a) real-time data from online sensors and (b) outputs from a process simulation and modelling tool (digital twin of the process)

Life Cycle Inventory – Input with the functional unit as 1 m^3 of wastewater prior to entering the wastewater treatment system.

Resource	Scenario 1	Scenario 2	Scenario 3
Ferric (III) Chloride	-	462 g/m^3	462 g/m^3
Sodium Hydroxide	-	270 g/m^3	277 g/m^3
Flocculant	-	5.05 g/m^3	5.05 g/m^3
Hydrogen peroxide	-	-	50.0 g/m^3
Electricity (for coagulation)	-	0.276 kWh/m^3	0.276 kWh/m^3
Electricity (for DAF)	-	0.170 kWh/m^3	0.170 kWh/m^3
Electricity (for MBR)	-		2.95 kWh/m^3
Electricity (for AOP)	-		0.420 kWh/m^3

Life Cycle Inventory – Output with the functional unit as 1 m^3 of wastewater prior to entering the wastewater treatment system.

Resource	Scenario 1 *	Scenario 2	Scenario 3
Alkalinity	85.0 g/m^3	54.2 g/m^3	57.1 g/m^3
pH	7.10	7.51	7.62
Chemical Oxygen Demand	1288 g/m^3	146 g/m^3	0.010 g/m^3
Biological Oxygen Demand	525 g/m^3	363 g/m^3	24.3 g/m^3
Total Organic Carbon	1570 g/m^3	160 g/m^3	0.160 g/m^3
Total Suspended Solids	686 g/m^3	103 g/m^3	1.03 g/m^3
FGO	183 g/m^3	4.80 g/m^3	4.80 g/m^3
Total Nitrogen	215 g/m^3	215 g/m^3	157 g/m^3
Total Phosphorus	33.5 g/m^3	33.5 g/m^3	0.000 g/m^3
Sulphate	622 g/m^3	622 g/m^3	617 g/m^3
Nickel	3.28 g/m^3	3.28 g/m^3	3.28 g/m^3
Lead	1.36 g/m^3	1.36 g/m^3	0.0300 g/m^3
Zinc	1.88 g/m^3	1.88 g/m^3	0.430 g/m^3
Copper	10.6 g/m^3	10.6 g/m^3	0.530 g/m^3
Cadmium	0.750 g/m^3	0.740 g/m^3	0.240 g/m^3
Sludge	-	0.510 m^3_{sludge}/h	1.37 m^3_{sludge}/h
Sludge (normalised per functional unit)	-	0.0124 $m^3_{sludge}/h/m^3$	0.0333 $m^3_{sludge}/h/m^3$
Wastewater	41.1 m^3/h	40.6 m^3/h	39.3 m^3/h

*Indicates experimental data, provided by an industrial unit

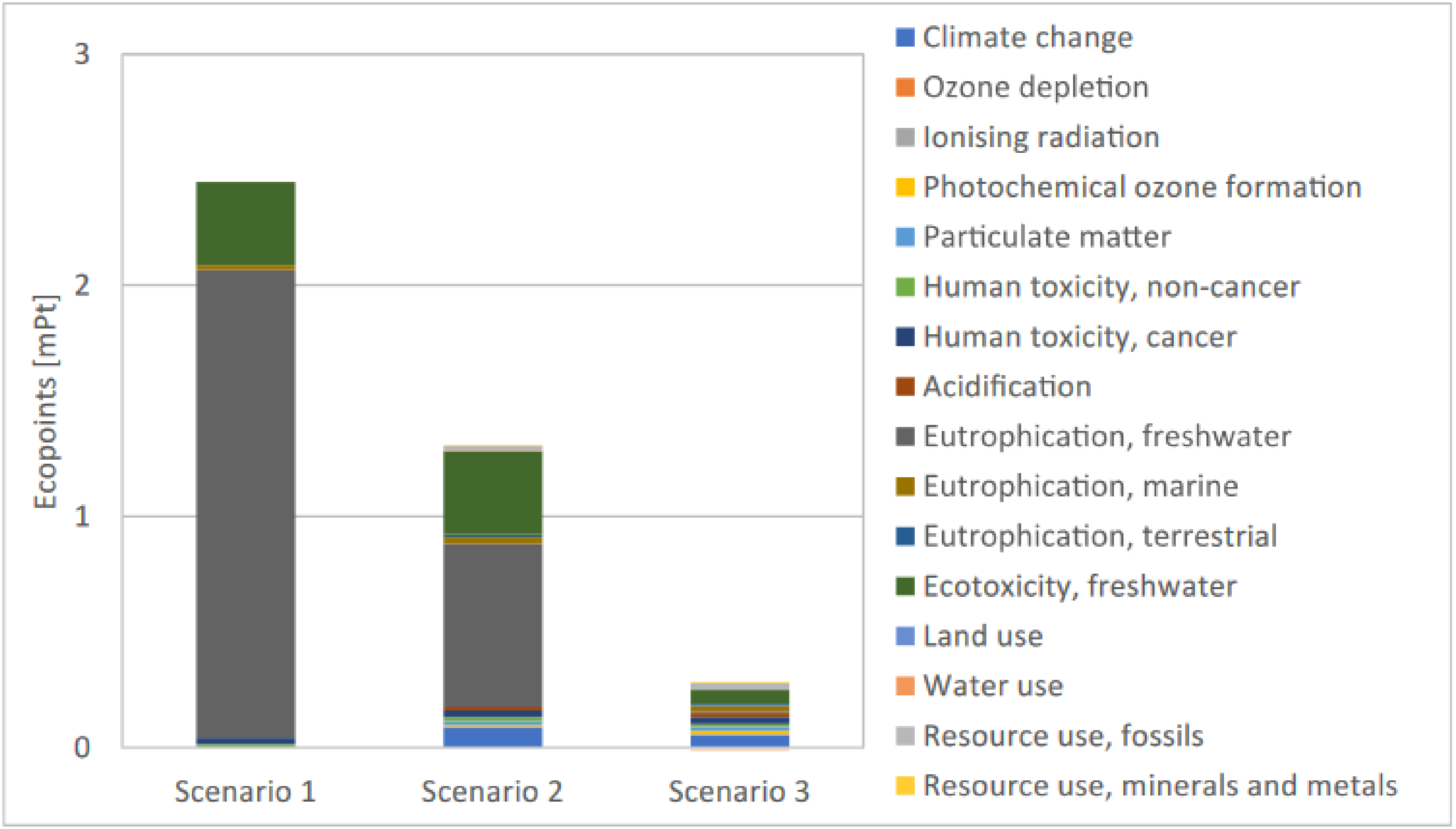
Life Cycle Impact Assessment

Retrieval of Characterisation Factors

Resource	Ecoinvent Entry
Citric Acid	1 kg Citric acid {GLO}| market for | APOS, U (of project Ecoinvent 3 - allocation at point of substitution - unit)
Sodium Hypochlorite	1 kg Sodium hypochlorite, without water, in 15% solution state {RER}| market for sodium hypochlorite, without water, in 15% solution state | APOS, U (of project Ecoinvent 3 - allocation at point of substitution - unit)
Electricity	1 MJ Electricity, medium voltage {RO}| market for | APOS, U (of project Ecoinvent 3 - allocation at point of substitution - unit)
Water	1 m^3 Water, deionised {Europe without Switzerland} | market for water, deionised | APOS, U
Sludge Treatment	1kg Digester sludge {GLO}| treatment of digester sludge, municipal incineration | APOS, U

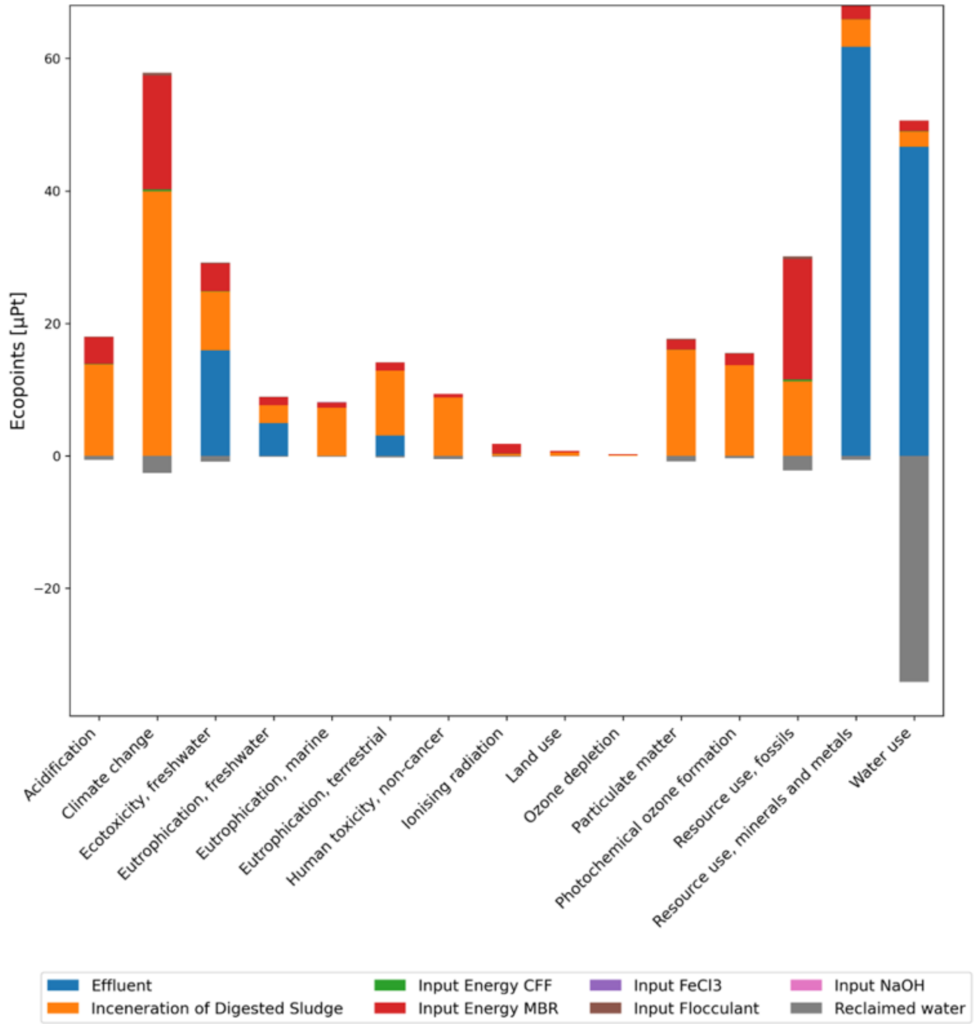
Life Cycle Impact Assessment

Environmental Footprint Calculation



Life Cycle Impact Assessment

Interpretation of Results



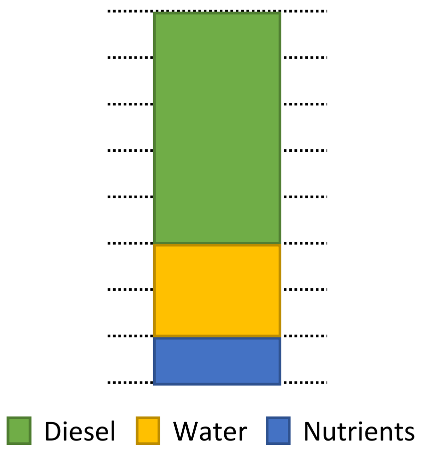
Finding the environmental hotspots, i.e. the processes/flows/stages with the highest contribution to the environmental impacts

Identifying further potential improvements to reduce the environmental impact

What can LCA offer?

Identify Hot Spots

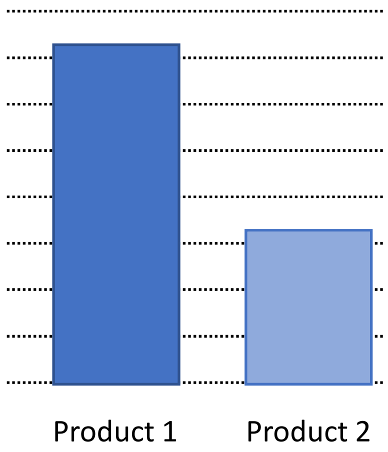
Identify the stage or the flow that is responsible for the higher share of environmental impact



Breakdown of the environmental performance of process X

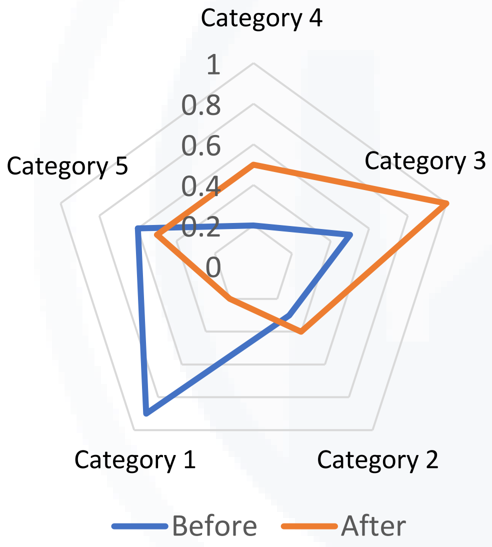
Compare Alternative Processes/Products

Compare the environmental performance of two similar products, with different production methods



Estimate the Consequences

Assess the environmental performance of a process before and after certain interventions



Marketing Tool

The entire lifecycle of **one pair** of Levi's® 501® jeans equates to:

Climate Change:
33.4 kg CO_2-e…

- 69 miles driven by the average US car
- 246 hours of TV on a plasma big-screen

Water Consumed:
3,781 liters…

3 days worth of one US household's total water needs

Eutrophication:
48.9 g PO_4-e…

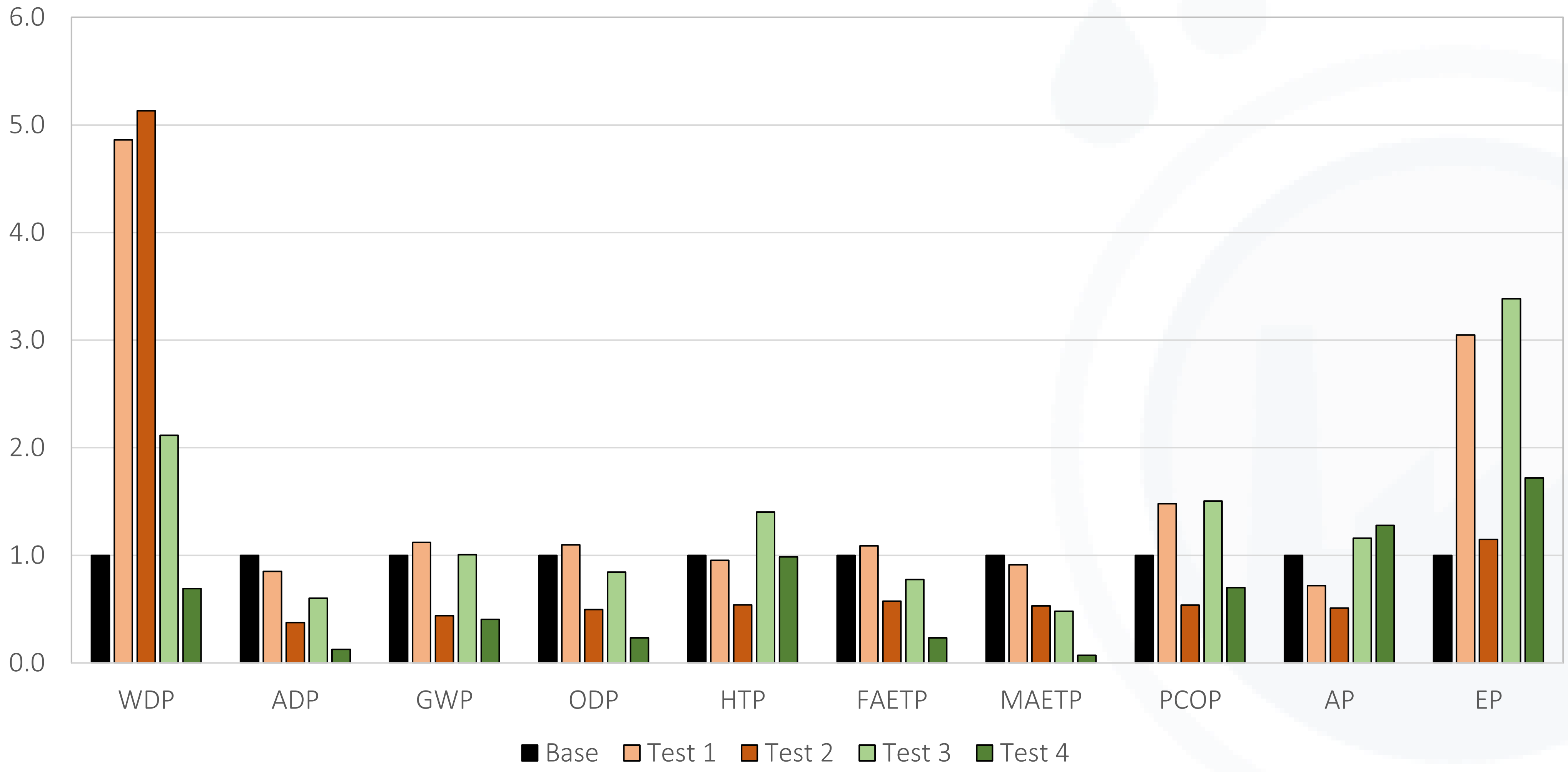
The total amount of phosphorous found in 1,700 tomatoes

Land Occupation:
12 m^2/year…

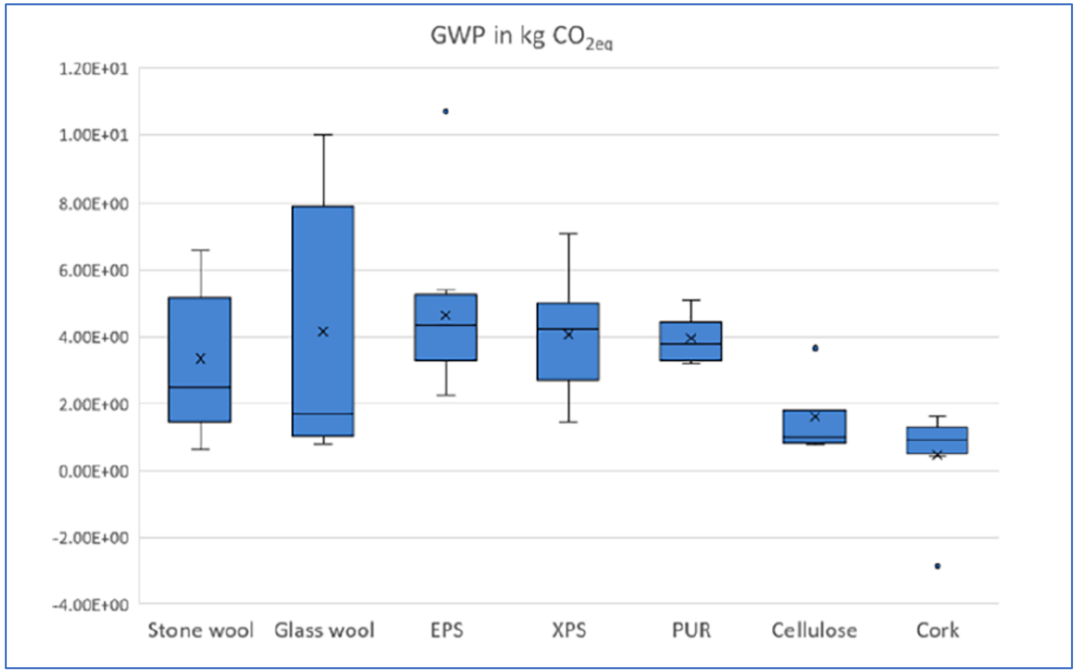
Seven people standing with arms outstretched, fingertips touching, would form one side of a square this size

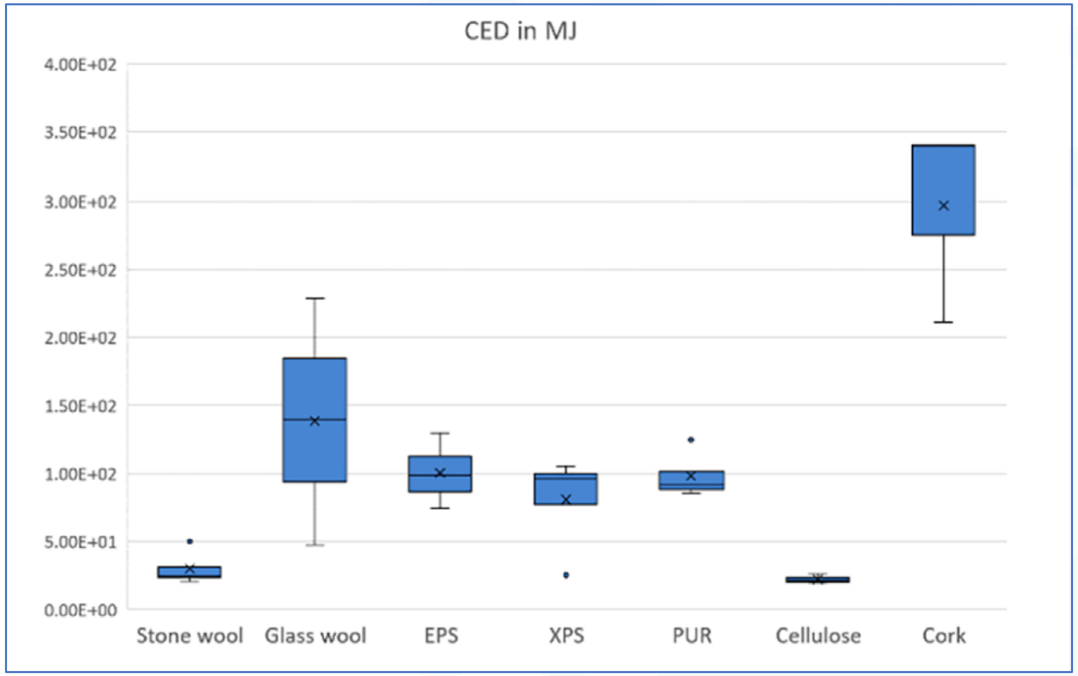
Source: The Life Cycle of a Jean – Understanding the environmental impact of a pair of Levi's 501 jeans
https://www.levistrauss.com/wp-content/uploads/2015/03/Full-LCA-Results-Deck-FINAL.pdf

Product Development



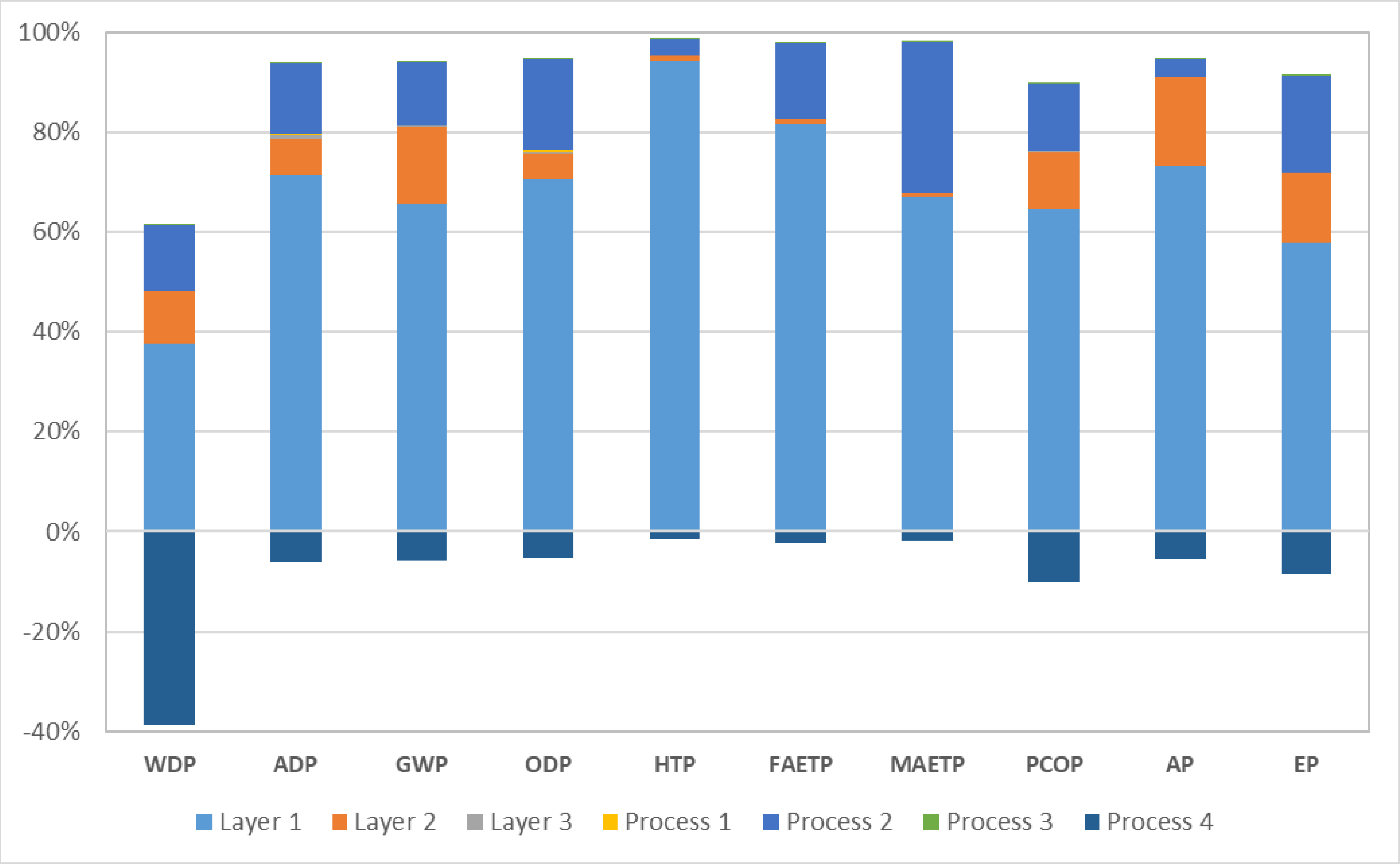
Benchmarking Products





Source: Füchs, S., Rheude, F., Roder, H. Life cycle assessment (LCA) of thermal insulation materials: A critical review, *Cleaner Materials*, 5 (2022) 100119

Identify the hot spots



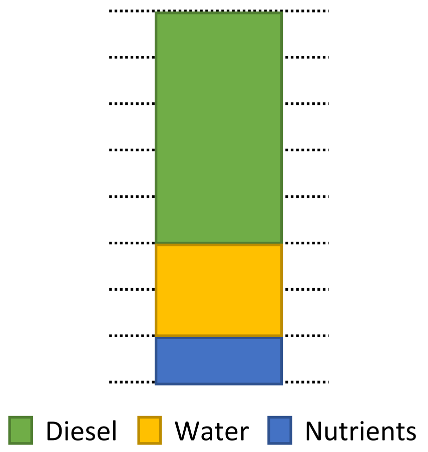
Compare alternative products

		Product with Recycled Raw Material	Product with Virgin Raw Material	
	Carbon Footprint	8.2 $kgCO_{2, eq}/kg$	10.5 $kgCO_{2, eq}/kg$	⇩ -21.9%
	Water Footprint	0.67 m^3/kg	0.71 m^3/kg	⇩ -4.5%
	Eutrophication Potential	0.014 $kgPO_4/kg$	0.014 $kgPO_4/kg$	⇩ -0.8%
	Resource Depletion	102.4 MJ/kg	162.7 MJ/kg	⇩ -37.1%

What can Dynamic LCA offer?

Identify Hot Spots

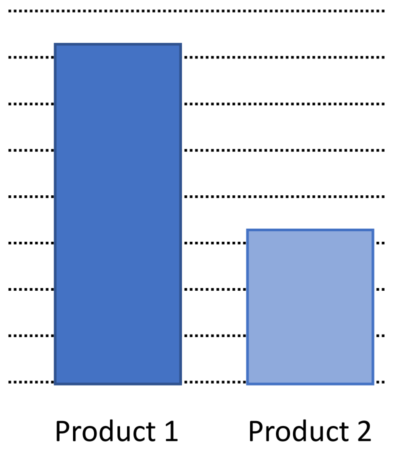
Identify the stage or the flow that is responsible for the higher share of environmental impact



Breakdown of the environmental performance of process X

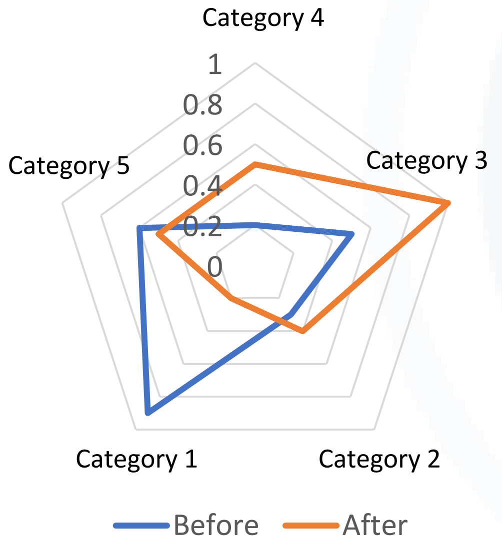
Compare Alternative Processes/Products

Compare the environmental performance of two similar products, with different production methods



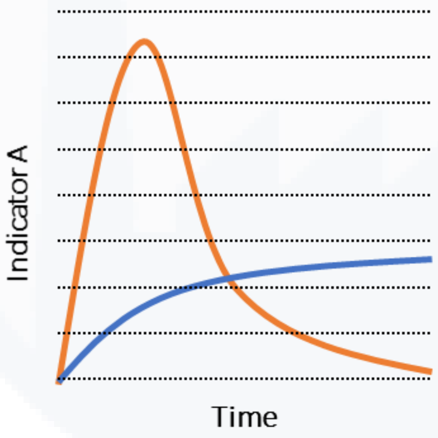
Estimate the Consequences

Assess the environmental performance of a process before and after certain interventions



Assess Impact Over Time

Monitor or estimate the environmental impact variation over time, under different assumptions



AquaSPICE

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Design and Assessment of Water Reuse Systems

Dr Athanasios Angelis-Dimakis, University of Huddersfield

AquaSPICE Summer School 2024

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