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How can process simulation be used to get more reliable data for LCA of mining emerging technologies?

S. Muller¹, J. Bodin¹, J. Segura Salazar², J. Villeneuve¹

SETAC Europe 29th annual meeting
29th May 2019

Session: Improving decision for support for sustainability
going beyond standard LCA

1: BRGM 2: Imperial College London

Context and objectives

Raw materials, a concern within the European context

In 2017: 88,6 billions tons of raw materials used



+ 100% from 2017 to 2050 (IRP, 2017)



Different issues:

- **Environmental consequences**
- **Sustainability**
- **Circular economy**
- **Criticality** (supply risks,...)



Resource access: a **strategic interest for nations**



In 2008, « Raw materials initiative »

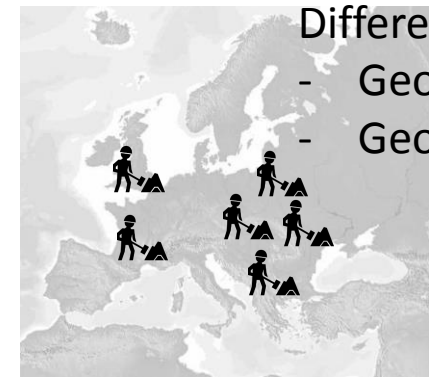
- Ensuring access to raw materials
- Fostering a sustainable supply of raw materials from European sources

IMP@CT project: Unlock the access to small complex mineral deposits in a more sustainable way

- Overall goal of the project:
 - Propose a new mining paradigm: the SOSO concept to improve the viability of small complex deposits



€ viable



Different contexts

- Geographical
- Geological

UNIVERSITY OF
EXETER



Géosciences pour une Terre durable

brgm

EPSE

**Metal
Innovations**



UNIVERSITY OF
EASTERN FINLAND

MINECO



**Imperial College
London**

Extractive
PROCESS DESIGNERS

MRE Institute of
Mineral
Resources
Engineering

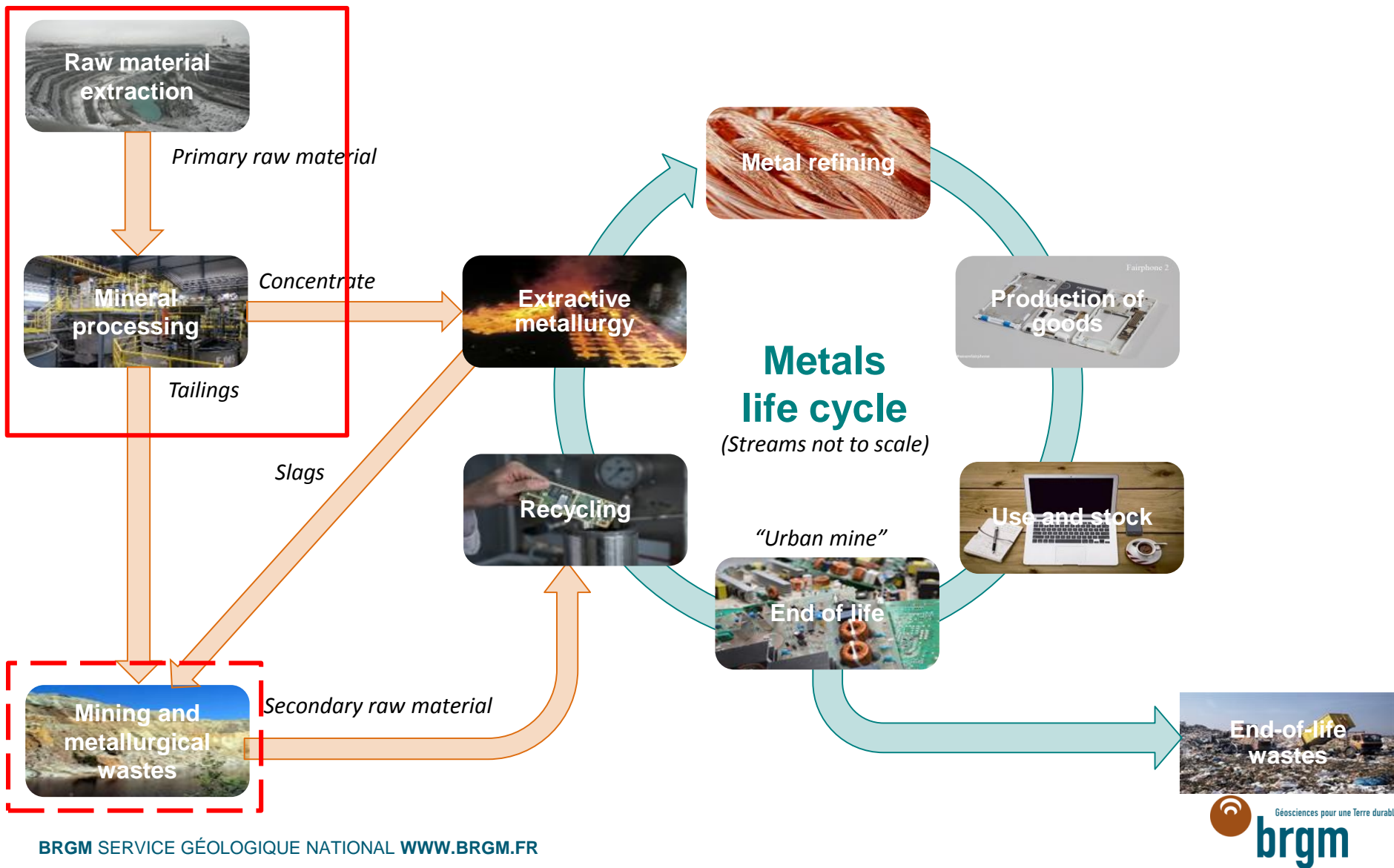
**RWTH AACHEN
UNIVERSITY**

RADOS

H2020 project : Started in January 2017, will end in May 2020 - Grant no 730411

Context and objectives

IMP@CT focus on the first phases of the metal life cycle



Context and objectives

Applying LCA in the framework of IMP@CT

OVERALL GOAL

- Address the environmental sustainability of the newly developed modularized mobile plant (MMP) solutions for small-scale mining operations through life cycle assessment



How to assess the potential environmental benefits against BAU of the newly developed MMP?



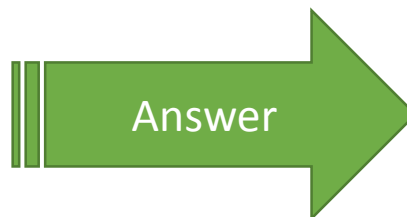
HAVING IN MIND MMP CHARACTERISTICS

- Should be mobile / flexible / modular
- Developed at a pilot scale

Validated in the mining and processing of small scale Pb and Sb deposits in the Balkans



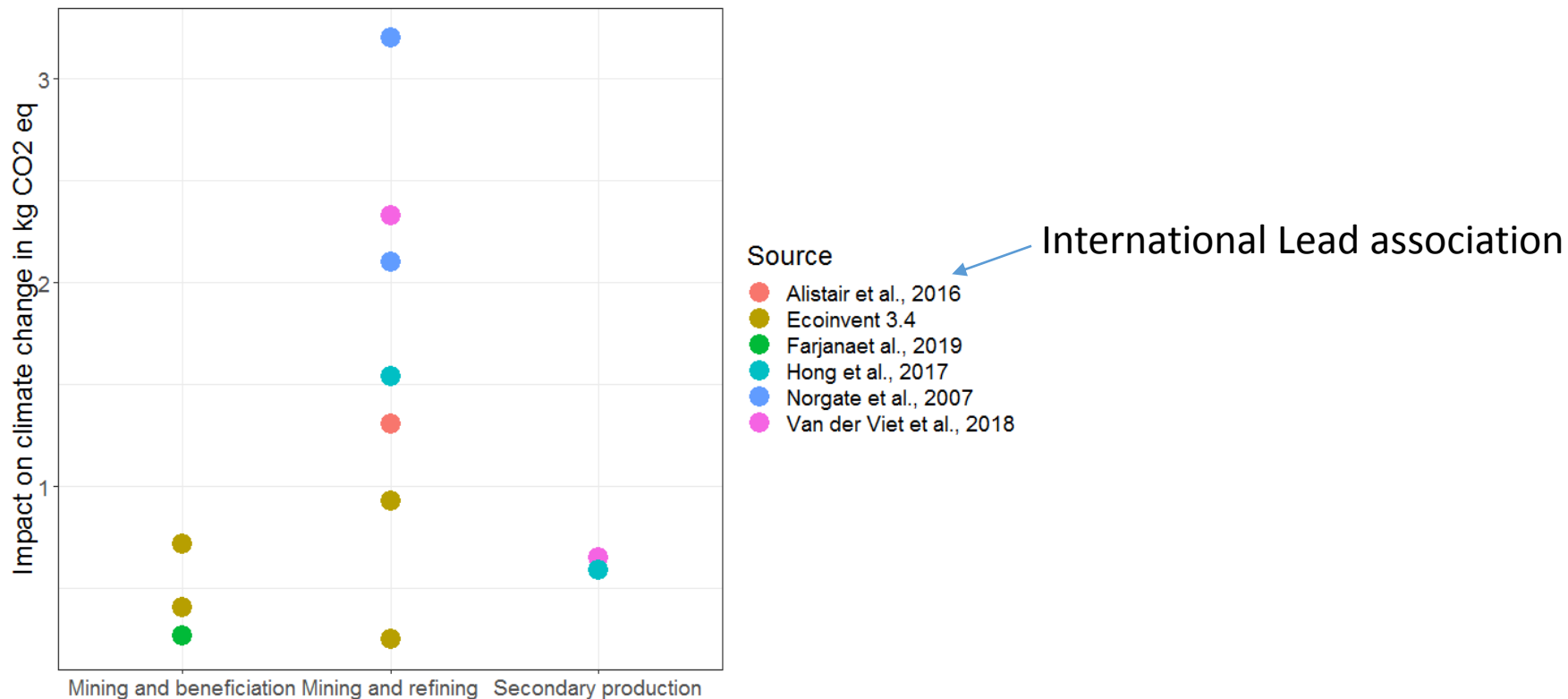
- Upscaling effect
- Contextual assessment



Use mineral process simulation **coupled** with LCA

First, what are the impacts of the BAU?

Assessing the climate change impacts of 1 kg of lead in different forms



What lead to
results
variability

GEOLOGY
CONTEXT

TECHNOLOGY

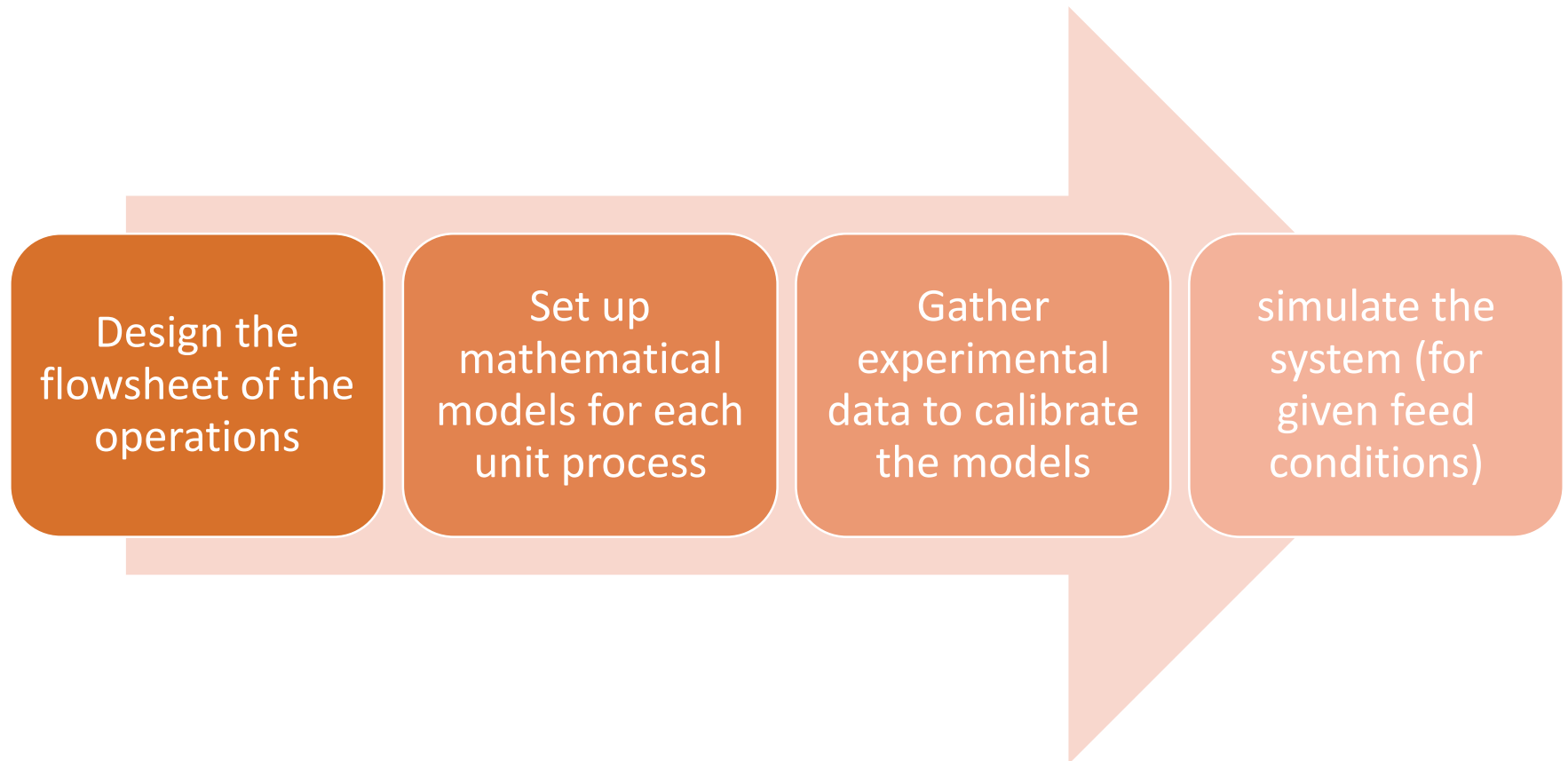
GEOGRAPHICAL
CONTEXT

LCA
METHODOLOGI-
CAL CHOICES

Get rid of the upscaling effect

Concept of process simulation

- Development starts in the 1960s
- Used to predict the performances of an industrial mineral processing plant
- Based on lab/pilot scale experimental data



Get rid of the upscaling effect

Design the
flowsheet of the
operations

Set up mathematical models for each unit process

Gather experimental data to calibrate the models

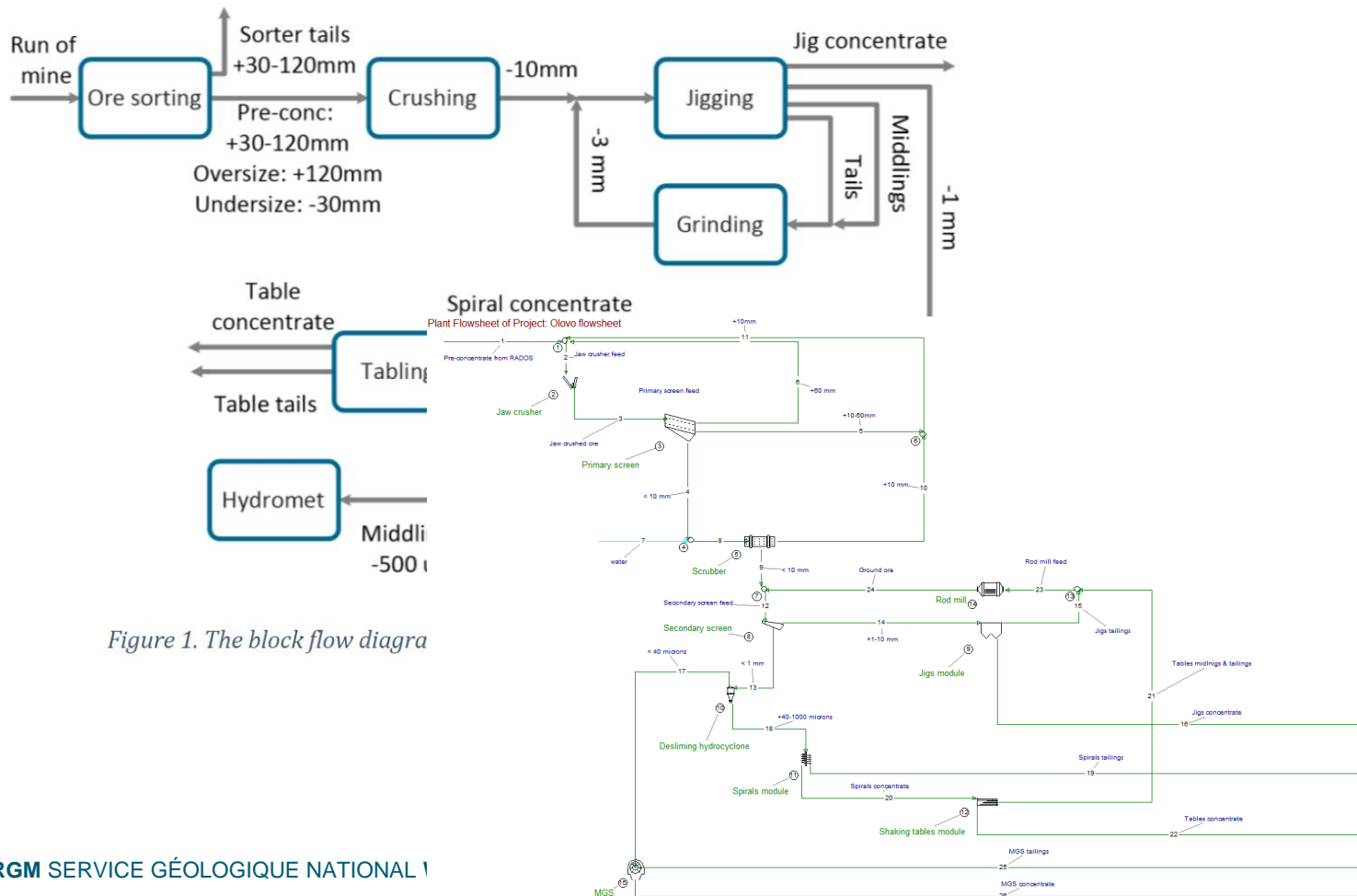


Figure 1. The block flow diagram

Get rid of the upscaling effect

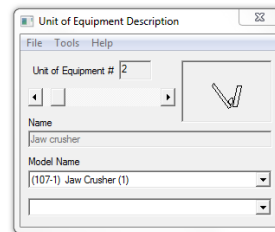
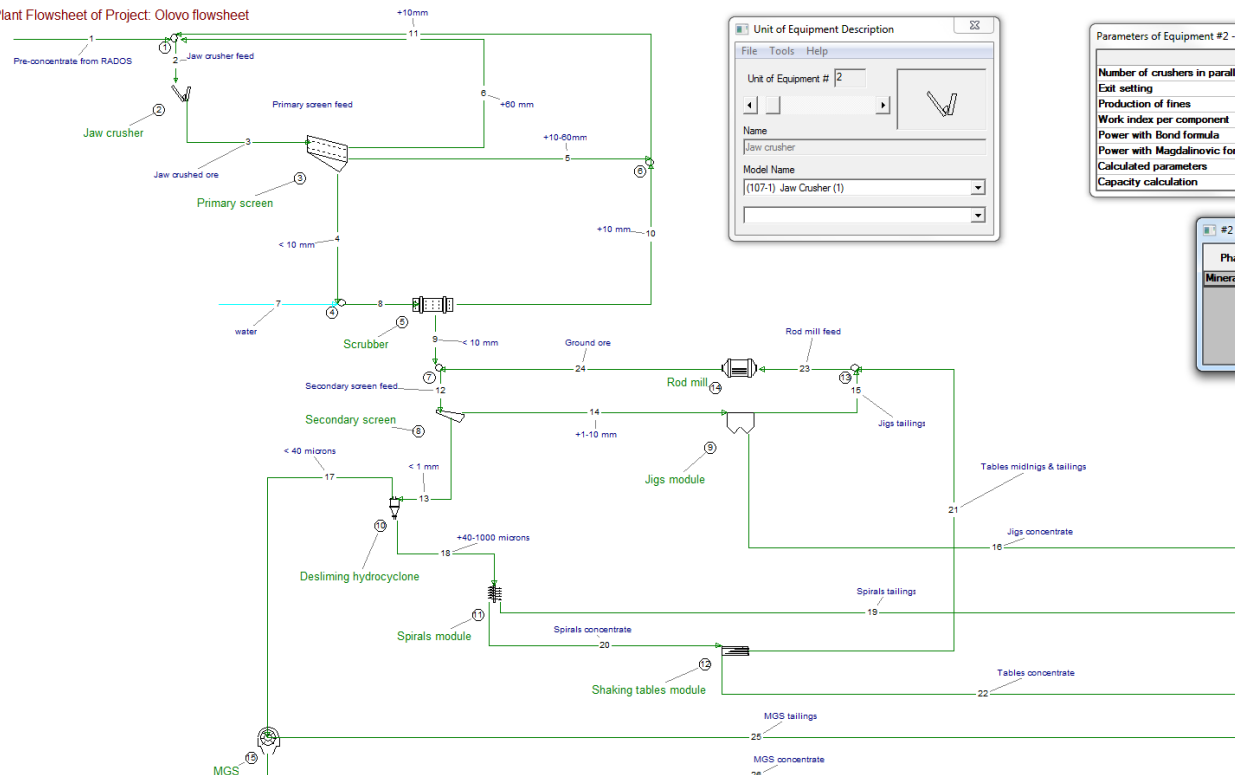
Design the flowsheet of the operations

Set up mathematical models for each unit process

Gather experimental data to calibrate the models

simulate the system (for given feed conditions)

Plant Flowsheet of Project: Olovo flowsheet



Parameters of Equipment #2 - Jaw crusher - Jaw Crusher (1)

Parameters	Values	Unit
Number of crushers in parallel	1	
Exit setting	16	mm
Production of fines	No	
Work index per component	Edit	
Power with Bond formula	Edit	
Power with Magdalinovic formula	Edit	
Calculated parameters	Edit	
Capacity calculation	Edit	

#2 - Jaw crusher - Jaw Crusher (1) - Wo...

Phases	Particle type	Work index per component	Units
Mineral liber	Free	14	kWh/t
	Liberated	14	kWh/t
	Middlings	14	kWh/t
	Sub-middlings	14	kWh/t
	Locked	14	kWh/t

USIM PAC

Example: Bond work index

$$W = \frac{\sqrt{100 \cdot W_i} - \sqrt{100 \cdot W_p}}{\sqrt{P}} - \frac{\sqrt{100 \cdot W_i} - \sqrt{100 \cdot W_p}}{\sqrt{F}}$$

where

W = predicted mill energy consumption, in kWh/st

W_i = Work Index, in kWh/st

100 = 100 μ m, which is the product size in the definition of Work Index

P, F = 80% passing sizes, in μ m of the feed (F) and product (P)

This equation is also commonly written as

$$W = 10 \cdot W_i \left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}} \right)$$

Get rid of the upscaling effect

Design the
flowsheet of the
operations

Set up
mathematical
models for each
unit process

Gather
experimental data
to calibrate the
models

simulate the
system (for given
feed conditions)

SOLID PHASE MODEL			Particle types distribution							Contact person
Size classes	units		Free %	Liberated %	Middlings %	Sub-middlings %	Locked %	Barren %	Total %	
20 mm	%ind								100	
10 mm	%ind								100	
5 mm	%ind								100	
2 mm	%ind								100	
1 mm	%ind								100	
0.5 mm	%ind								100	
Pan	%ind								100	
total		100								

Particle types definition			Particle types					
Grades	unit		Free	Liberated	Middlings	Sub-middlings	Locked	Barren
Cerrusite (PbCO ₃)	%		80-100	60-80	40-60	20-40	0-20	0
Carbonates (CaCO ₃)	%		0-20	20-40	40-60	60-80	80-100	100
Density	min	-	5.78	5.01	4.24	3.47	2.7	2.7
	max	-	6.55	5.78	5.01	4.24	3.47	2.7

USIM PAC

Mineral liberation/Variable composition			
Mass flowrate	5	th	
Volumetric flowrate	1.59299	m ³ /h	
Density	3.13872	kg/dm ³	

Particle types									
Size distribution				Free	Liberated	Middlings	Sub-middlings	Locked	Barren
Size classes	% Individual	% Passing	% Retained	%	%	%	%	%	%
150 mm	0	100	0	0	0	0	0	0	100
25 mm	27	73	27	0	0	5	10	15	70
12.5 mm	8	65	35	0	0	5	10	15	70
6 mm	13	52	48	25	5	5	5	5	55
2 mm	20	32	68	25	5	5	5	5	55
500 µm	15	17	83	26.5	4.8	4.2	5	5.7	53.8
100 µm	10	7	93	31.5	3.4	3	2.4	4.7	55
Pan	7	0	100	46.6	3.8	3.5	3.2	5	37.9
				18.637	2.976	4.575	6.364	8.575	58.873

Composition	
PbCO ₃	CaCO ₃
%	%
0	100
7	93
7	93
30.5	69.5
30.5	69.5
31.38	68.62
33.42	66.58
47.81	52.19
23.9107	76.0893

Composition of particle types			
Particle types		Grades	
Particle types	Grades	Units	
Free	18.637	%	90 10
Liberated	2.976	%	70 30
Middlings	4.575	%	50 50
Sub-middlings	6.364	%	30 70
Locked	8.575	%	10 90
Barren	58.873	%	0 100
	Means		23.9107 76.0893

Mineral liberation/Variable composition / Water & reagents			
Mass flowrate	5	th	
Volumetric flowrate	1.59299	m ³ /h	
Solid percent	100	%	
Density	3.13872	kg/dm ³	

Get rid of the upscaling effect

Outputs of process simulation and link with LCI

Process simulation with algorithms including:



- Mass balance calculations
- Data reconciliation

Operating
variables

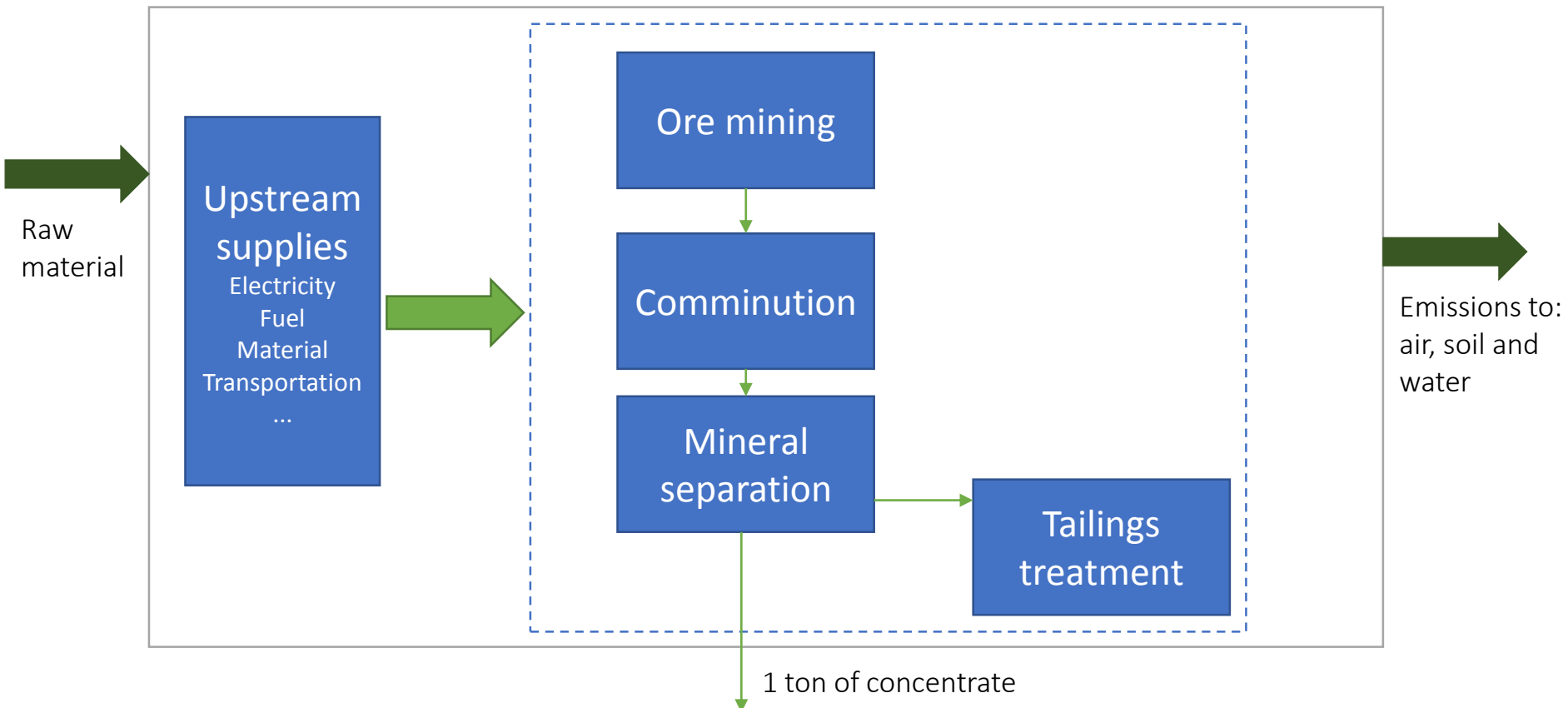
- Flow rates (liquids and solids)
- Energy and reagents consumption
- Mine wastes

Direct inputs for the
LCI phase

Performing a contextual assessment



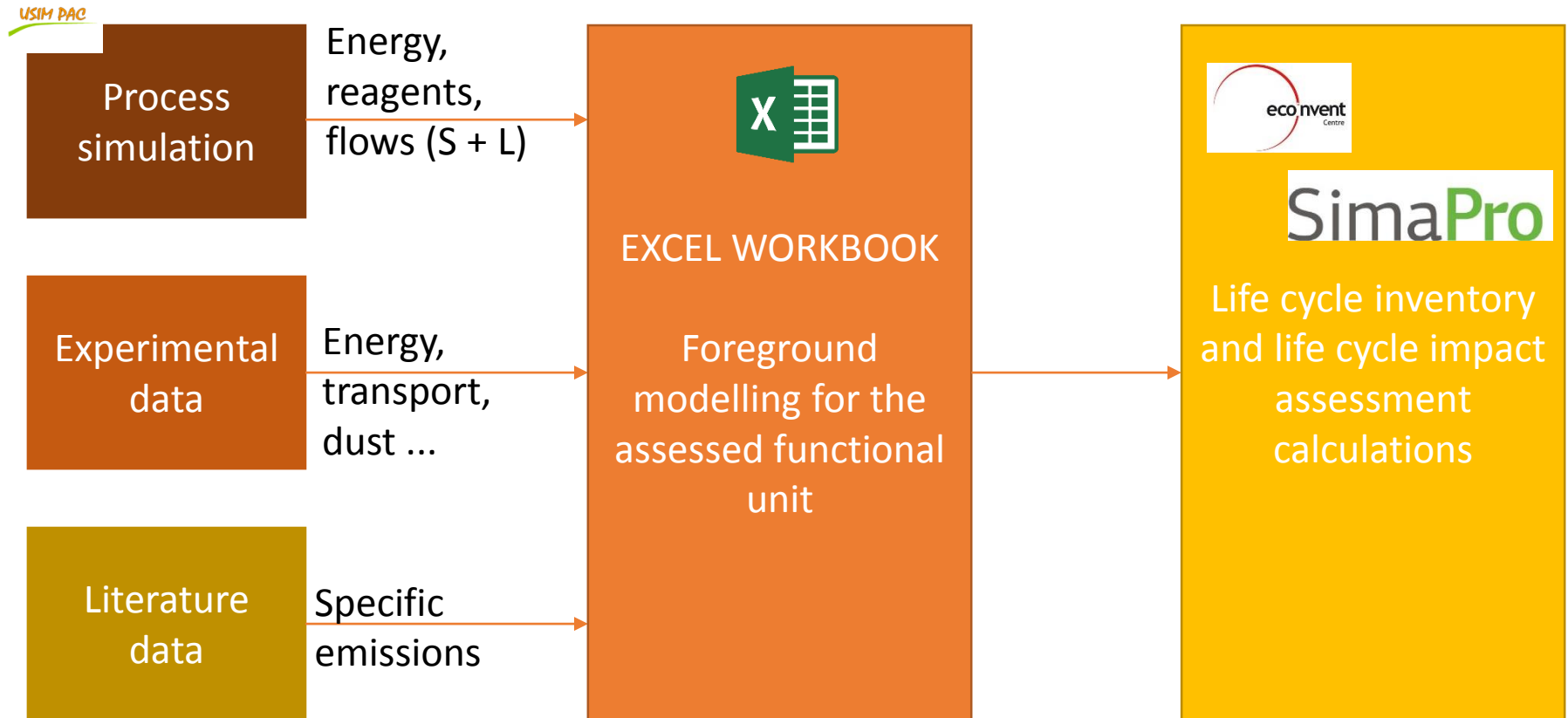
Generic functional unit for metal mining in the context of IMP@CT: “The production of 1 ton of concentrate containing x% of metal using the IMP@CT developed technologies”



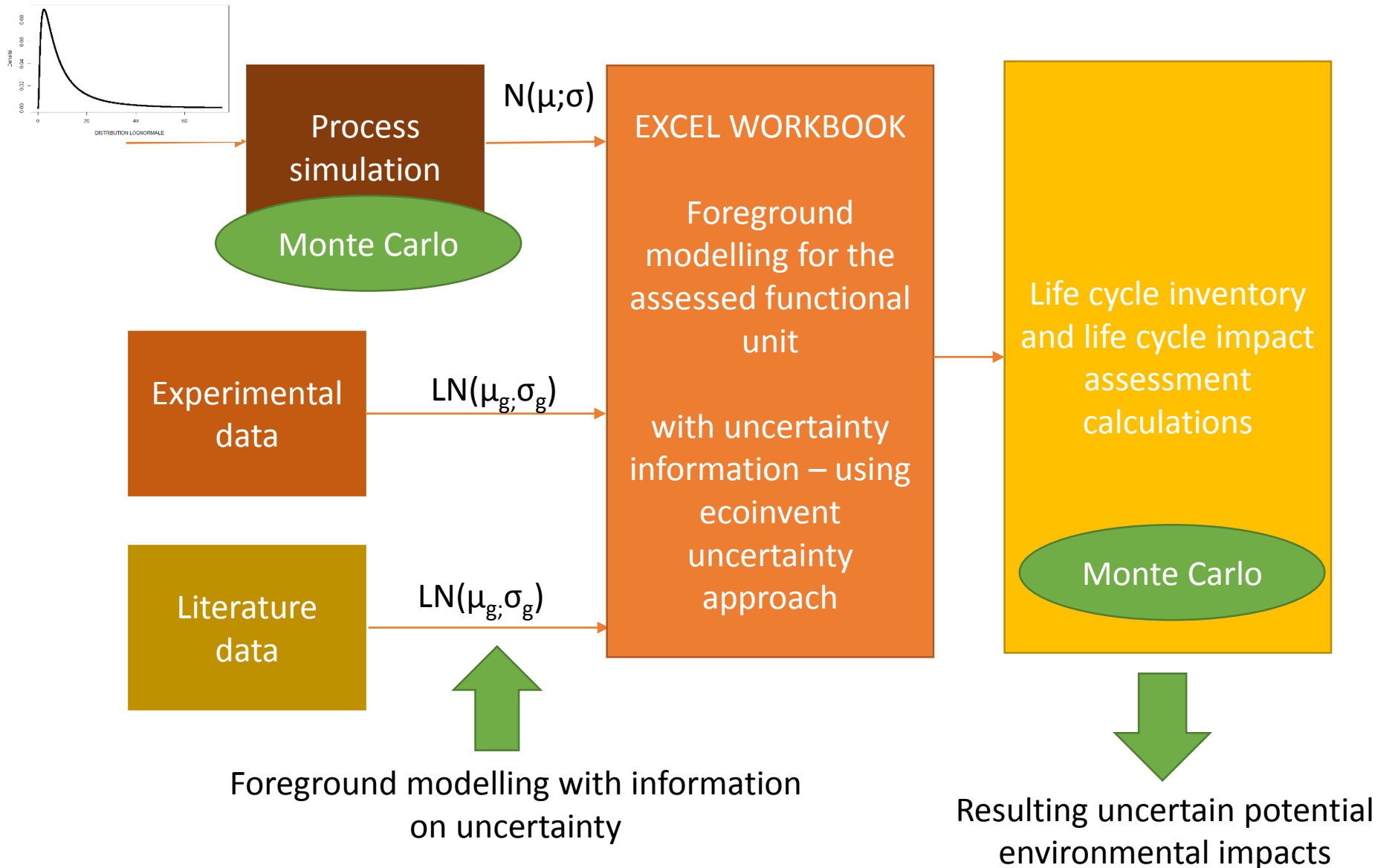
Performing a contextual assessment



Build a parametrized Excel tool that can be used whatever the context



Taking into account ore and process variability



Conclusions and perspectives

- Process simulation can enhance LCI data reliability
 - A way to model specific unit process inputs needed for LCI
 - Uncertainty can be quantified on these inputs
- Process simulation can specially be used on earlier process development stages
 - Coupling process simulation and LCA → a tool for ecodesign (see for example Reuter et al.)
- This coupling is not new in LCA
 - HSC can be linked to GaBi and there is discussions going on to link HSC to OpenLCA
- Specific ongoing work for IMPACT
 - Data collection
 - On field sampling
 - Couple results environmental LCA results to sLCA results

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Thank you for your attention
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