TÉCNICO LISBOA

Multi-Objective Optimization for Sustainable Supply Chain Design and Planning

CEGIST
Centro de Estudos de Gestão do Instituto Superior Técnico

Ana Barbosa-Póvoa

Centre for Management Studies (CEG-IST),
Department of Engineering and Management
Instituto Superior Técnico (IST),
University of Lisbon, Portugal

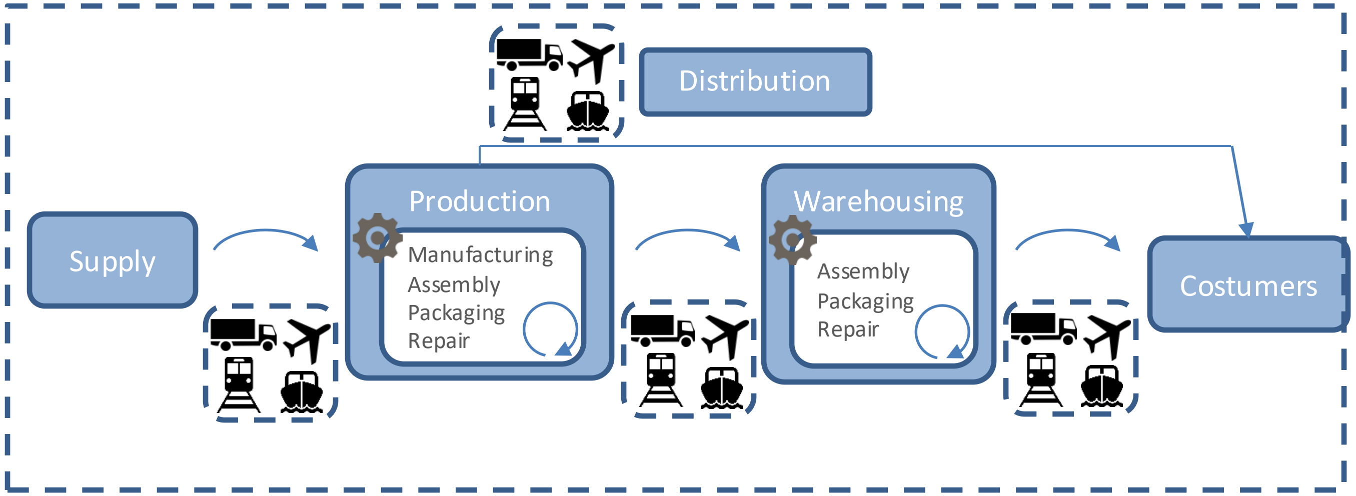
IMCDM2025, Coimbra

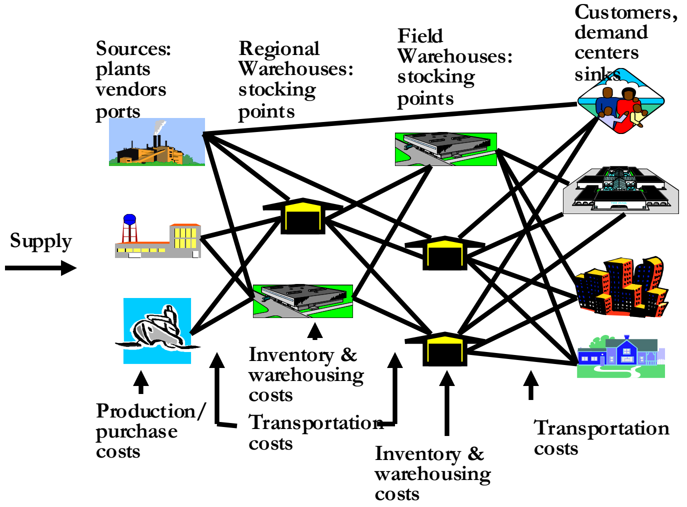
Agenda

- Supply Chain Evolution – from Traditional to Sustainable Supply Chain
- Design and Planning Sustainable Supply Chains – ToBLoOM
- New Multi-objective Approach – extending ToBLoOM
- Case Studies – Analyzing different strategic options
- Challenges & Future Work

Traditional a Supply Chain is…

A combination of processes aimed at fulfilling customers' requests, that include a set of network entities such as suppliers, manufacturers, transporters, warehouses, retailers and customers, whose main purpose is customer´s satisfaction at a minimum cost

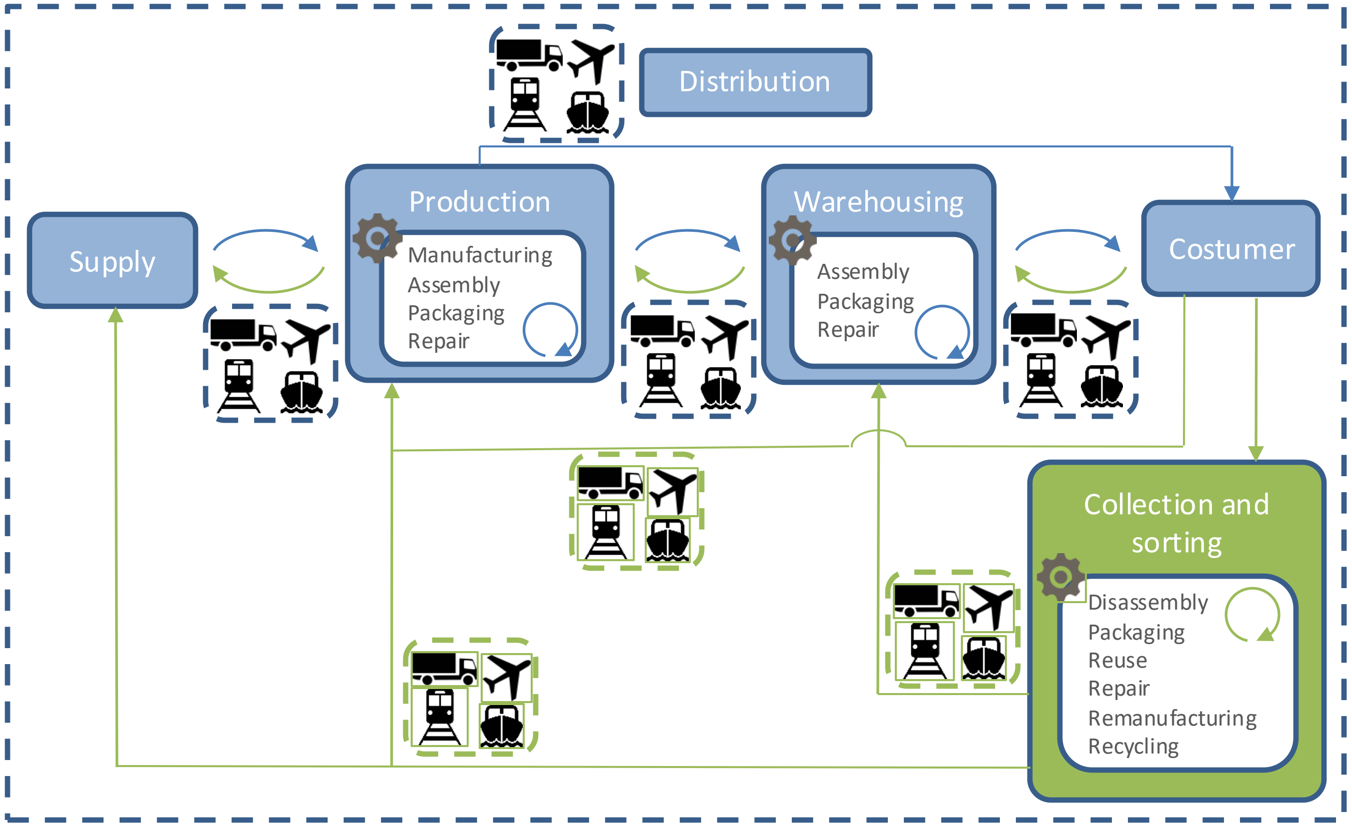




Closed-Loop Supply Chain

TÉCNICO LISBOA

+ Reverse logistics activities including the collection and treatment of non-conformed and end-of-life products through recycling, or remanufacturing, or repairing

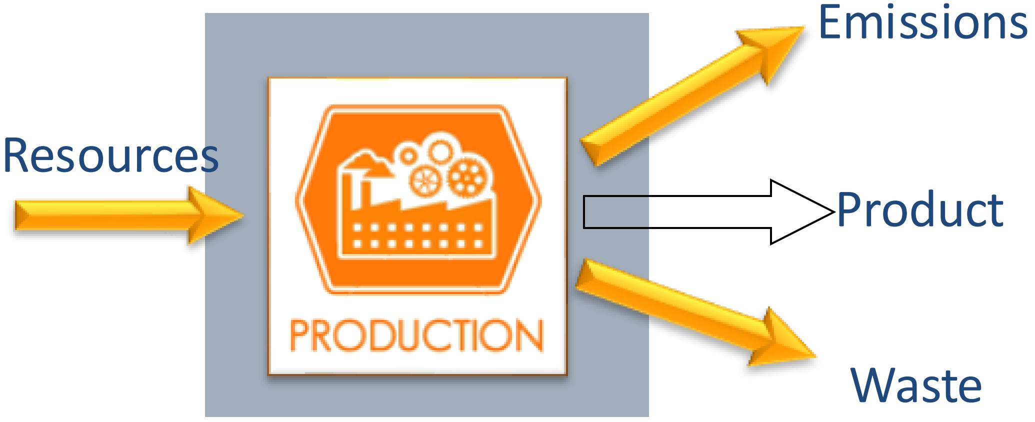


Closed-Loop Supply Chain

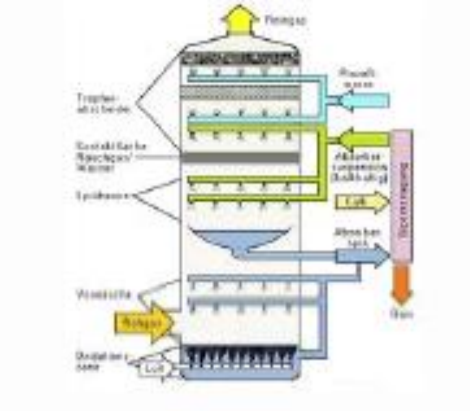
OpLog Research Group

Some in place Sustainable Strategies and Practices

Product and Processes measures ….



Filters, gas washer



Catalysts

Recycle and reuse

Treat Effluents

Diminish Waste

Some in place Sustainable Strategies and Practices

Processes measures ….

Reduce transportation footprint.

Use of cleaner transportation modes

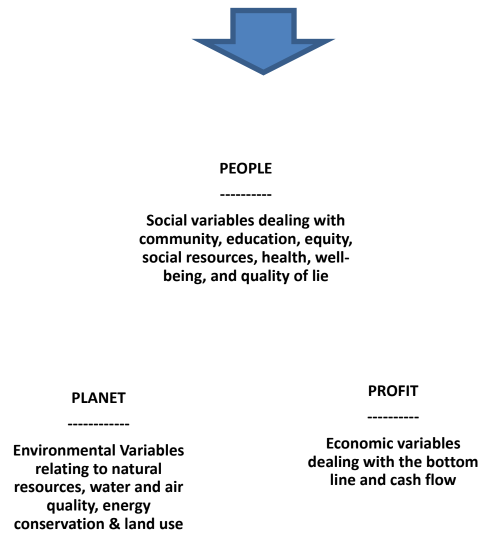
Eco driving.

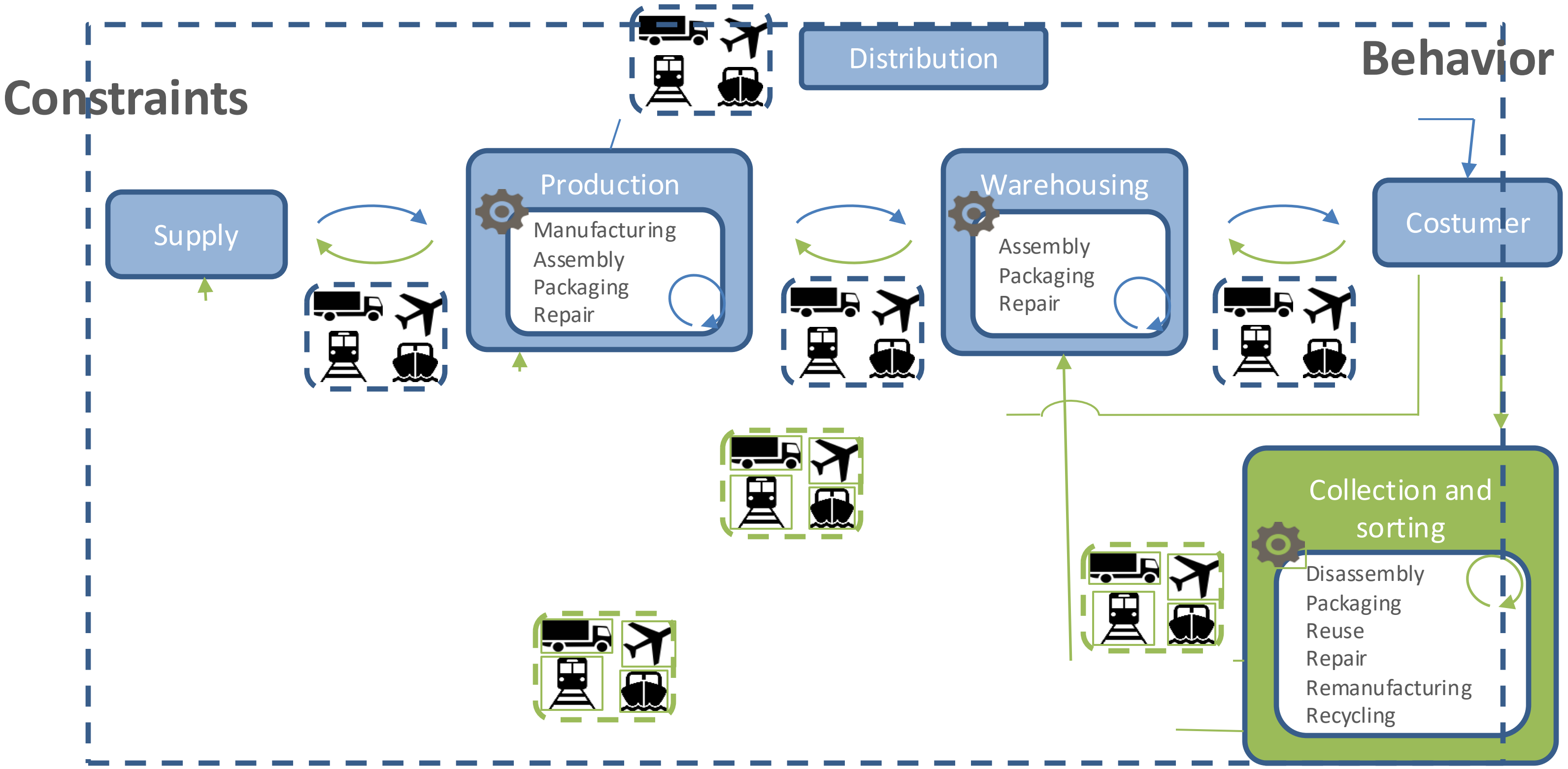
Reduce warehousing footprint.

Use of cleaner light/operation modes

But more is required …

- Integrated Product and Process oriented measures
- Resources availability
- Human resources conditions

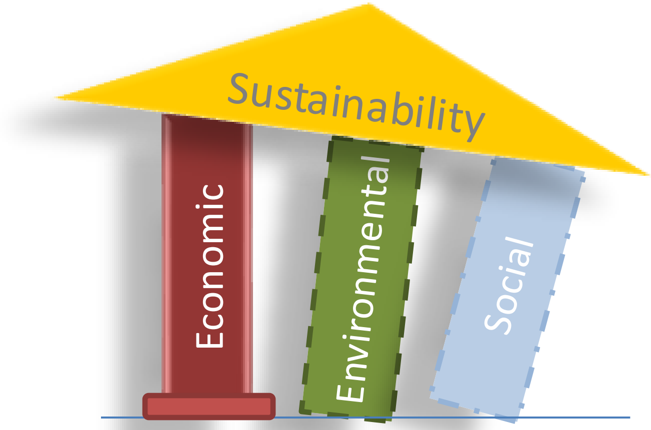




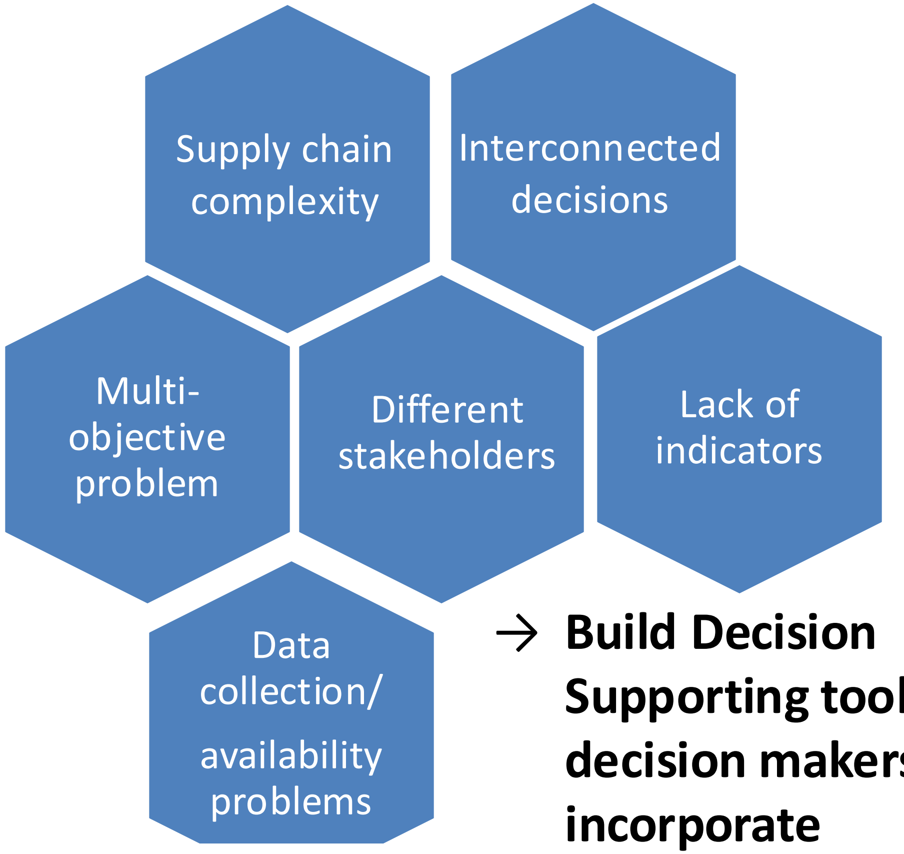
Sustainable Supply Chain - complex network system that involve a diverse set of entities that manage products from suppliers to customers and associated returns, accounting for **social, environmental and economic** impacts (Barbosa-Póvoa et al, 2018)

Sustainability
Should be part of Supply Chains' Strategy

- **Environmental assessment** in supply chains has been showing some growth
- Few to none research exists in quantitatively assessing the **social impact** of supply chains in the context of design and planning (Barbosa-Póvoa et al. 2018)



The challenge:



→ **Build Decision Supporting tools to help decision makers to incorporate Sustainability Goals in Supply Chains**

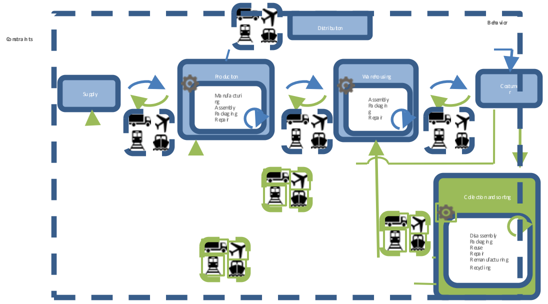
Barbosa-Póvoa, A.P, Carvalho A. Silva, C. "Sustainable supply chains: An integrated modeling approach under uncertainty", Opportunities and Challenges in Sustainable Supply Chain: An Operations Research Perspective, European Journal of Operational 268, 2, 399-431

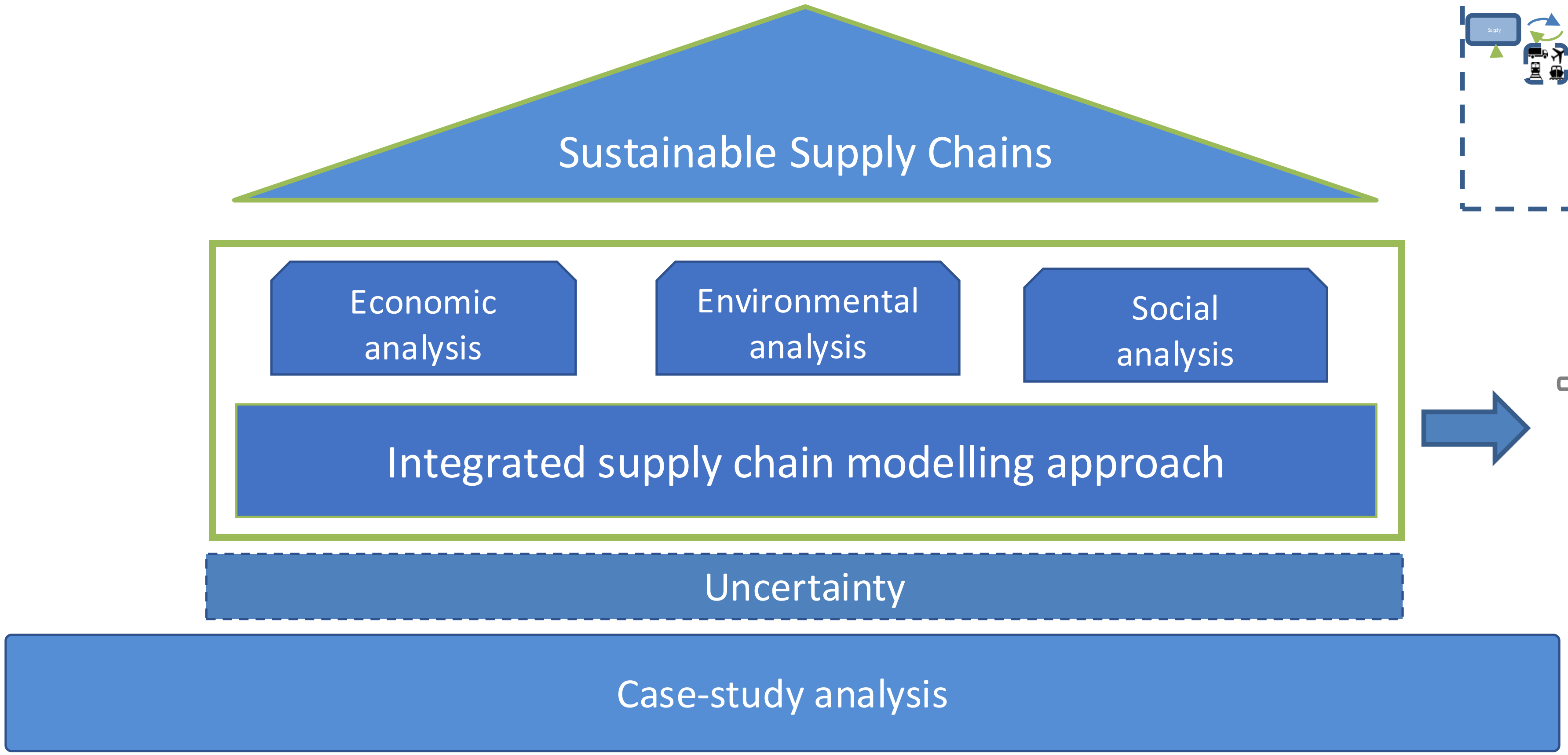
How to simultaneously incorporate economic, environmental and social concerns in the design and planning of supply chains?

How to adequately introduce environmental impact indicators in supply chain design and planning?

How to define social indicators that can be incorporated into an Optimisation-based tool?

Design and Planning Sustainable Supply Chains





ToBLoOM

Triple **B**ottom **L**ine **O**ptimization **M**odelling

Mota, B, Gomes, M.I, Carvalho, A, Barbosa-Póvoa, A.P, "Sustainable supply chains: An integrated modeling approach under uncertainty", **Omega**, Volume 77, Pages 32-57, June 2018, https://doi.org/10.1016/j.omega.2017.05.006

ToBLoOM

Triple **B**ottom **L**ine **O**ptimization **M**odelling

Supply → Production → Warehousing → Distribution → Use → Collection and sorting

INPUTS

	Supply	Production	Warehousing	Distribution	Use	Collection and sorting
General data	▪ Possible suppliers ▪ Supply capacity	▪ Possible locations ▪ Stock capacity ▪ Installation/renting area ▪ Production/remanufacturing capacities ▪ Labour needs ▪ Products' bill of materials	▪ Possible locations ▪ Stock capacity ▪ Installation/renting area ▪ Labour needs	▪ Possible hub terminals ▪ Flow capacities ▪ Labour needs ▪ Possible transportation modes ▪ Transportation capacitites ▪ Product weight/volume ▪ Distances between entities	▪ Product demand ▪ Market locations	▪ Possible locations ▪ Stock capacity ▪ Installation/renting area ▪ Labour needs ▪ Minimum return fraction of end-of-life products
Economic	▪ Raw material costs	▪ Entities investment costs ▪ Production/ remanufacturing technologies investment and operating costs ▪ Labour costs	▪ Investment costs of entities ▪ Labour costs ▪ Inventory costs	▪ Labour costs ▪ Investment/ outsourcing costs ▪ Variable costs ▪ Carrier contracted costs	▪ Price of final product	▪ Investment costs of entities ▪ Labour costs ▪ Recovered product costs ▪ Inventory costs
Environmental		▪ Entity environmental impact ▪ Production/ remanufacturing environmental impact	▪ Entity environmental impact	▪ Transportation environmental impact		▪ Entity environmental impact
Social	▪ Social factor of each location	• Social factor of each location • Labor intensity restrictions	▪ Social factor of each location ▪ Labor intensity restrictions	▪ Social factor of each location ▪ Labor intensity restrictions		▪ Social factor of each location ▪ Labor intensity restrictions

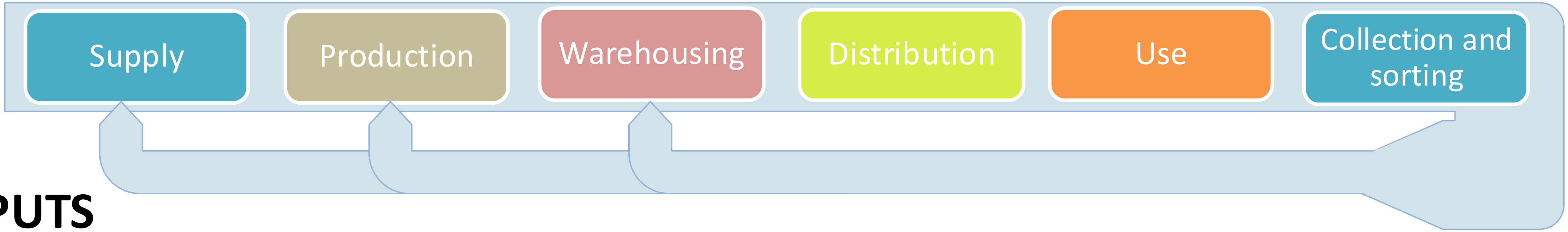
Economic analysis and indicators

Life cycle approach

Statistical analysis and socio-economic indicators

ToBLoOM

Triple Bottom Line Optimization Modelling



OUTPUTS

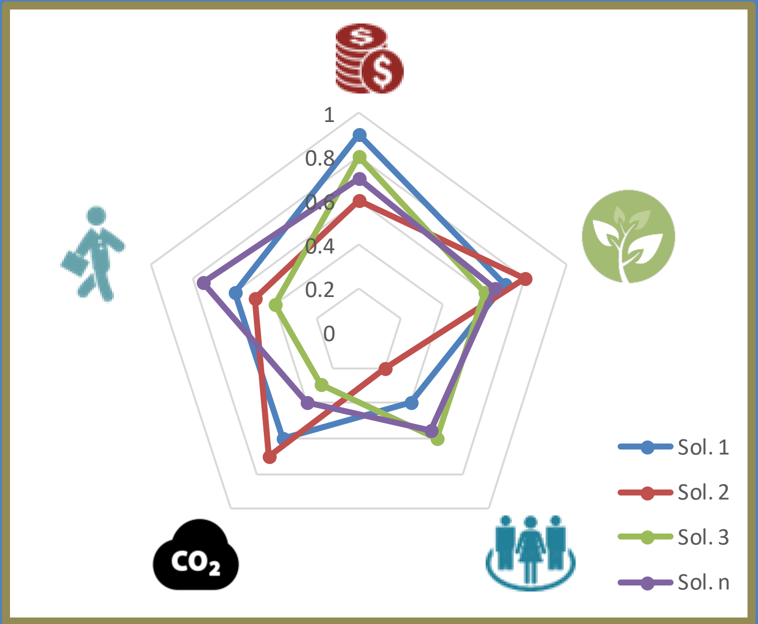
SC Decisions

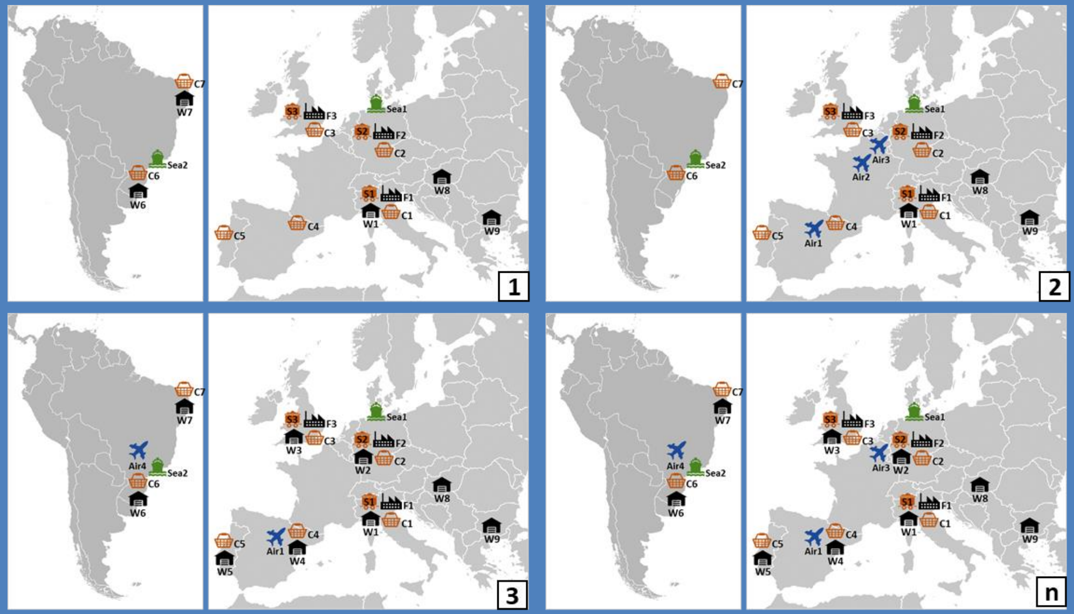
Economic

Environmental

Social

A pool of n-solutions



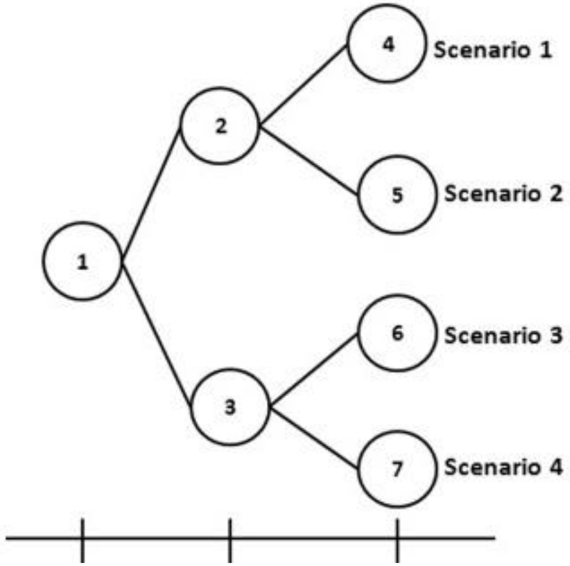


ToBLoOM
Triple Bottom Line Optimization Modelling

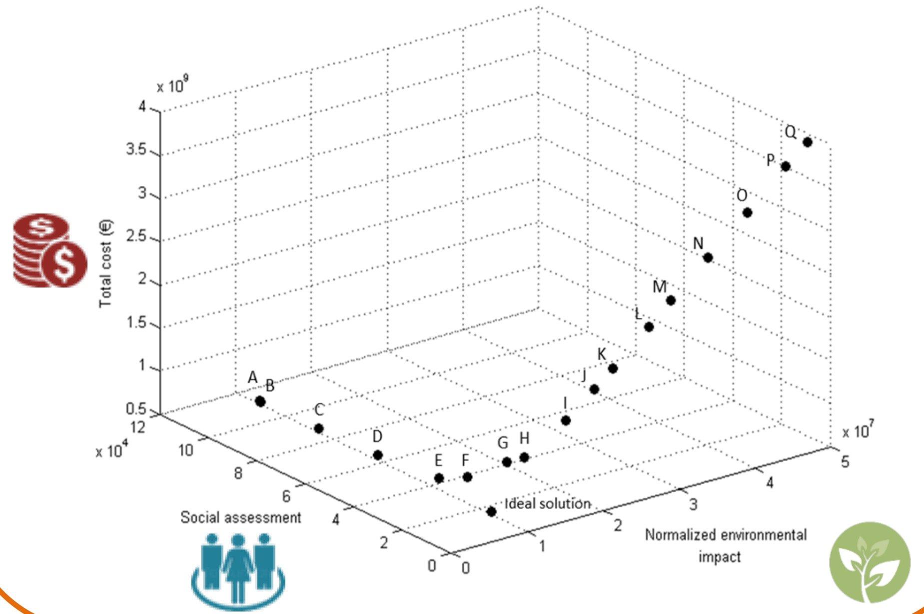
METHODOLOGY

Multi-objective mixed integer linear programming (MO-MILP)

Uncertainty – Stochastic Approch



Augmented ε-constraint method



Economic Objective

- **Max Net Present Value:** actualized cash flow: net earnings – fixed capital investment

Net earnings given by the difference between the incomes, defined by the amount of products sold, and the costs per time period:

- raw material costs
- production and remanufacturing costs
- recovered product costs
- transportation costs
- handling and contracted costs at the hub terminals
- inventory costs
- labour costs

Fixed capital investment given by:

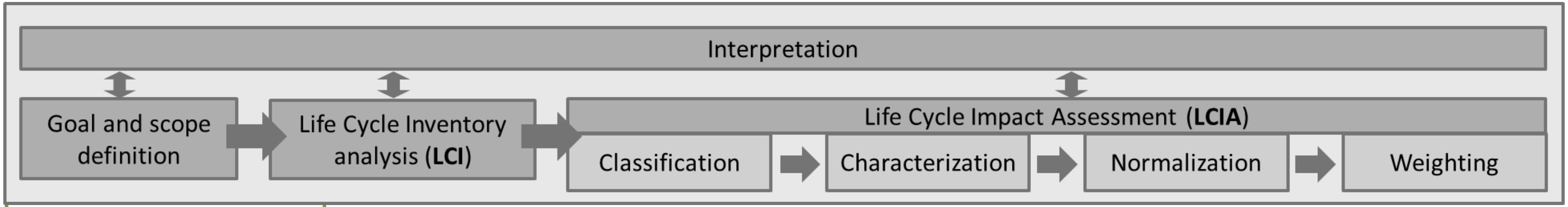
- the investment in facilities
- investment in production and remanufacturing technologies
- investment in transportation links

$$max\,NPV = \sum_{t \in T} \frac{CF_t}{(1+ir)^t} - \sum_{\gamma} FCI_\gamma$$

$$CF_t = \begin{cases} NE_t & t = 1, \dots, NT-1 \\ NE_t + \sum_{\gamma} \left(sv_\gamma FCI_\gamma \right) & t = NT \end{cases}$$

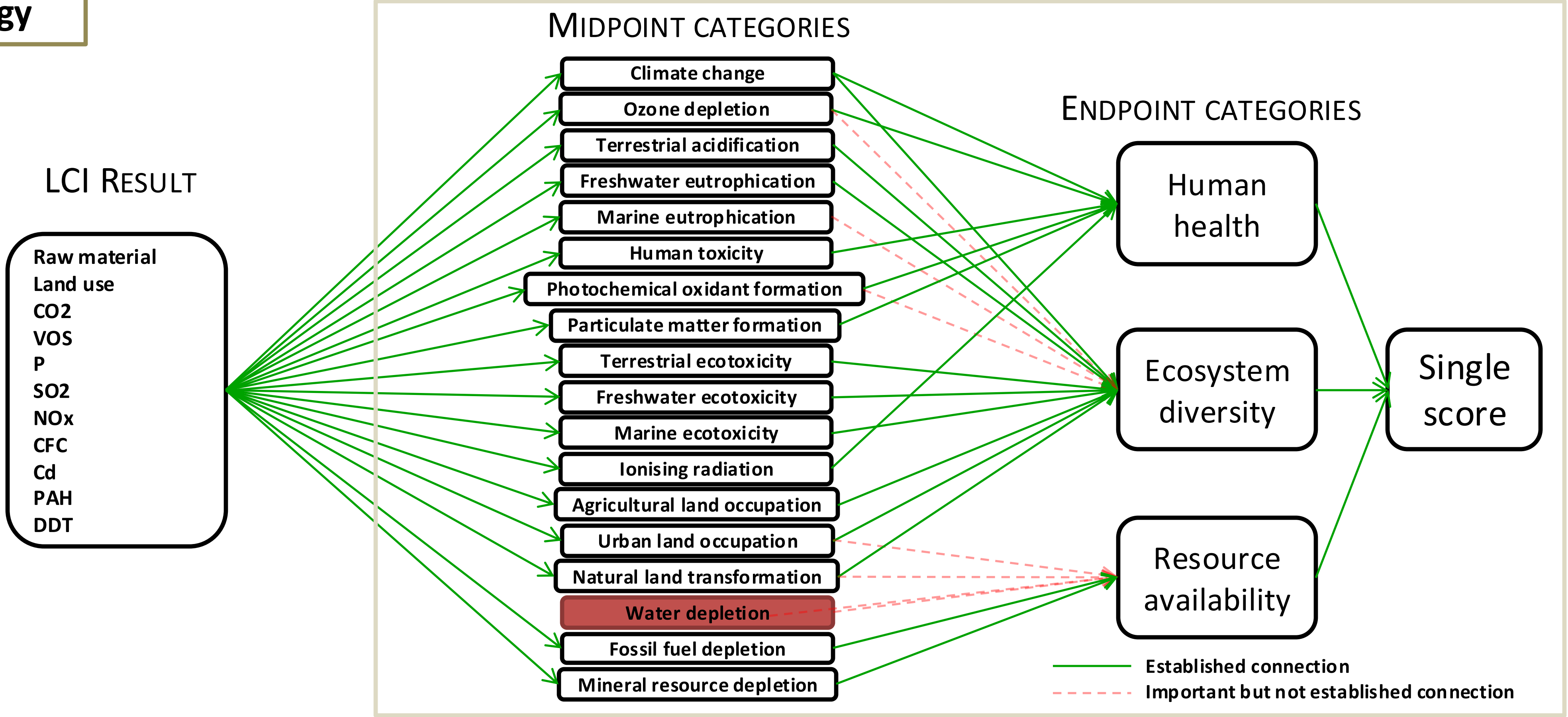
ToBLoOM
Triple Bottom Line Optimization Modelling

Environmental Objective



LCA methodology

ReCiPe LCIA method



Environmental Objective

- **Environmental objective function:** activities impact for each midpoint category

Environmental impact of production and remanufacturing

$$\min EnvImpact = \sum_{c}\left(\sum_{\substack{t\in T, i\in I_f\\(m,g)\in H}} ei_{mgc}\, pw_m (P_{mgit} + R_{mgit}) + \sum_{\substack{t\in T\\(a,m,i,j)\in NetP}} ei_{ac}\, pw_m d_{ij} X_{maijt} + \sum_{i\in I_f \cup I_w} ei_{ic}\, YC_i\right)\eta_c$$

Characterization factors of the methodology for each supply chain activity

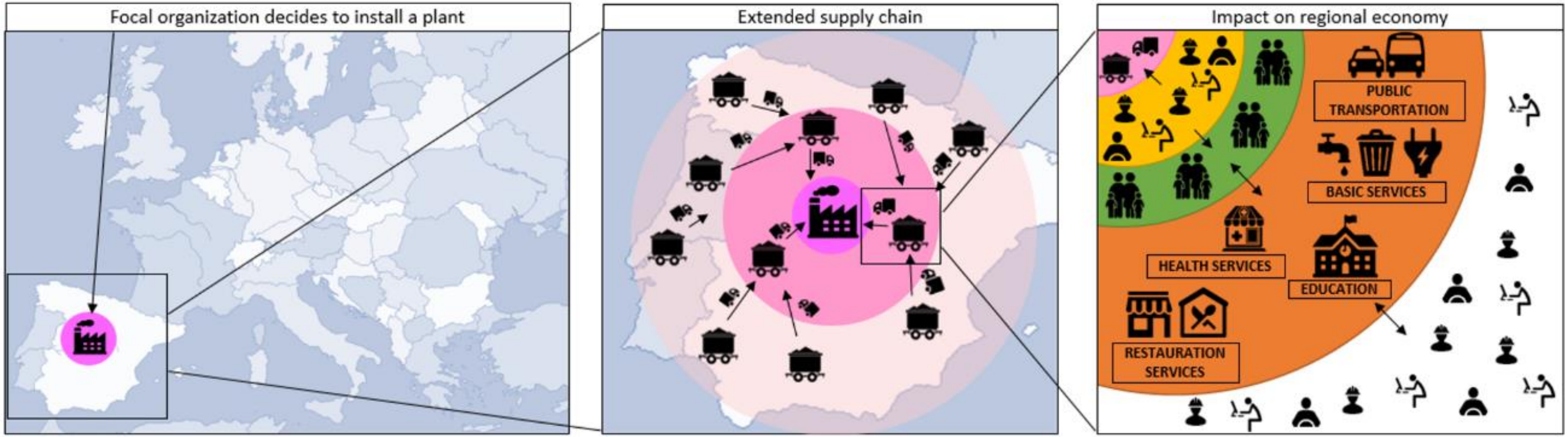
Environmental impact of transportation

Environmental impact of entity installation

Social Objective

Idea:

- To promote job creation in less developed regions
- To stimulate regional development
- To support access to critical products



Social Objective

- **Social objective function:** **create jobs in less developed regions**

Fixed workers at each entity

Workers per square meter of installed capacity

Workers at technologies

$$\max GDPInd = \sum_{i \in I_f \cup I_w} \mu_i^{GDP} w_i Y_i + \sum_{i \in I_f \cup I_w} \mu_i^{GDP} wpsqYC_i + \sum_{\substack{(m,g) \in H \\ i \in I_f}} \mu_i^{GDP} w_g Z_{gmi}$$

$$+ \sum_{\substack{(a,i,j) \in Net \\ a \in A_{truck}}} \mu_i^{GDP} w_a K_{ai} + \sum_{\substack{(a,m,i,j) \in NetP \\ a \in A_{plane} \cup A_{boat} \\ t \in T}} \mu_i^{GDP} \frac{w_a}{yth} . pw_m . d_{ij} . X_{maijt}$$

This is replaced according to the desired socio-economic indicator.

Workers at road transportation modes

Workers at air and sea transportation modes

Main Constraints

- **Material balances** at each of the supply chain entities
- **Entities & transportation capacities**
- **Flows** & **Supply** & **Demand** Restrictions
- **Inventory storage capacity and inventory policies**
- **Transportation modes** (for insourced and outsourced transportation)
- **Production and Remanufacturing** technology
- …

Material balance at the factories:

$$S_{mi(t-1)} + \sum_{g:(m,g)\in H_{prod}} P_{mgit} + \sum_{g:(m,g)\in H_{rem}} R_{mgit} = S_{mit} + \sum_{\substack{n,j:(n,i,j)\in F_{OUTFFP} \\ a:(a,n,i,j)\in NetP}} BOM^{f}_{mn} X_{naijt}, \quad t \in T \wedge m \in M_{fp} \wedge i \in I_f \tag{1}$$

$$\sum_{\substack{j\in I_{sup} \\ a:(a,m,j,i)\in NetP}} X_{majit} = \sum_{(n,g)\in H_{prod}} BOM^{prod}_{mng} P_{ngit}, \; m \in M_{rm} \wedge i \in I_f \wedge t \in T \tag{2}$$

$$\sum_{\substack{j:(m,j,i)\in F_{INFRP} \\ a:(a,m,j,i)\in NetP}} X_{majit} = \sum_{(n,g)\in H_{rem}} BOM^{rem}_{mn} R_{ngit}, \; m \in M_{rp} \wedge i \in I_f \wedge t \in T \tag{3}$$

Material balance at the warehouses:

$$S_{mi(t-1)} + \sum_{\substack{n,j:(n,j,i)\in F_{INW} \\ a:(a,n,j,i)\in NetP}} BOM_{mn} X_{najit} = S_{mit} + \sum_{\substack{n,j:(n,i,j)\in F_{OUTW} \\ a:(a,n,i,j)\in NetP}} BOM_{mn} X_{naijt}, \quad t \in T \wedge m \in (M_{fp} \cup M_{rp}) \wedge i \in I_w \tag{4}$$

Cross-docking at the seaports:

$$\sum_{\substack{n,j:(n,j,i)\in F_{INPORT} \\ a:(a,n,j,i)\in NetP}} BOM_{mn} X_{najit} = \sum_{\substack{n,j:(n,i,j)\in F_{OUTPORT} \\ a:(a,n,i,j)\in NetP}} BOM_{mn} X_{naijt}, \quad m \in (M_{fp} \cup M_{rp}) \wedge i \in I_{port} \wedge t \in T \tag{6}$$

Demand and return at the markets:

$$\sum_{\substack{j:(m,j,i)\in F_{INCFP} \\ a:(a,m,j,i)\in NetP}} X_{majit} = dmd_{mit}, \; i \in I_c, \; t \in T \tag{7}$$

$$\sum_{\substack{j:(m,i,j)\in F_{OUTCRP} \\ a:(a,m,i,j)\in NetP}} X_{maijt} \geq RetF_m \sum_{\substack{n,j:(n,j,i)\in F_{INCFP} \\ a:(a,n,j,i)\in NetP}} BOM^{recov}_{mn} X_{naji(t-1)}, \quad t > 1 \wedge m \in M_{rp} \wedge i \in I_c \tag{8}$$

$$\sum_{\substack{j:(m,i,j)\in F_{OUTCRP} \\ a:(a,m,i,j)\in NetP}} X_{maijt} \leq \sum_{\substack{n,j:(n,j,i)\in F_{INCFP} \\ a:(a,n,j,i)\in NetP}} BOM^{recov}_{mn} X_{naji(t-1)}, \quad t > 1 \wedge m \in M_{rp} \wedge i \in I_c \tag{9}$$

$$\sum_{\substack{a,j:(a,m,i,j)\in NetP \\ (m,i,j)\in F_{OUTSUP}}} X_{maijt} \geq sc^{min}_{mi} Y_i, \; i \in I_{sup} \wedge m \in M_{fp} \wedge t \in T \tag{11}$$

Flow capacity:

$$\sum_{a,m,j:(a,m,i,j)\in NetP} X_{maijt} \leq ec^{max}_i Y_i, \; i \in I \wedge t \in T \tag{12}$$

$$\sum_{a,m,i:(a,m,i,j)\in NetP} X_{maijt} \leq ec^{max}_j Y_j, \; j \in I \wedge t \in T \tag{13}$$

Stock capacity:

$$S_{mit} \leq ic^{max}_{mi} Y_i, \; m \in M_{fp} \wedge i \in (I_f \cup I_w) \wedge t \in T \tag{14}$$

$$S_{mit} \geq ic^{min}_{mi} Y_i, \; m \in M_{fp} \wedge i \in (I_f \cup I_w) \wedge t \in T \tag{15}$$

Entity capacity:

$$YCT_{it} = \sum_{maj:(m,a,j)\in NetP} apur_m X_{majit} + \sum_{m:(m,i)\in V} apu_m S_{mit}, \quad i \in I_f \cup I_w \wedge t \in T \tag{16}$$

$$YC_i \geq YCT_{it}, \; i \in I_f \cup I_w \tag{17}$$

$$YC_i \leq ea^{max}_i Y_i, \; i \in I_f \cup I_w \tag{18}$$

Case Studies

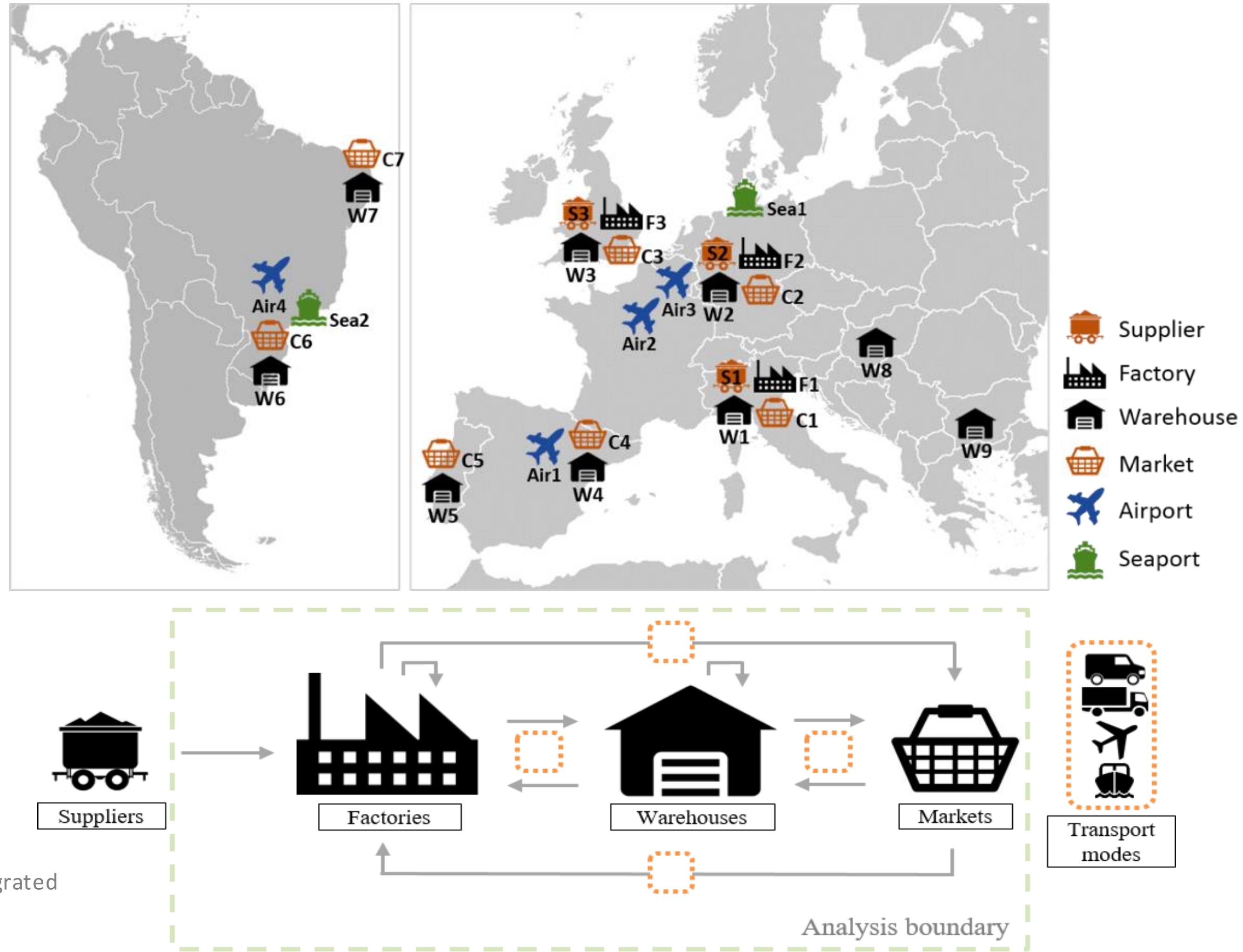
	Case-Study I	Case-Study II	Case-Study III
Industry	Electronic components	Pulp and paper	Automotive components
Sustainability indicators – **Economic**	NPV	NPV	NPV
Sustainability indicators – **Environmental**	ReCiPe (LCA)	ReCiPe PEF (LCA)	-
Sustainability indicators – **Social**	GDP	-	GDP Unemployment Rate Job creation
Look at:	The three pilars of Sustainability	Environmental Goal	Social Goal

Case Study II

Considers the three sustainability pillars when redesigning supply chains ?

TÉCNICO LISBOA

		Case-Study I
Industry		Electronic components
Sustainability indicators	Economic	NPV
	Environmental	ReCiPe (LCA)
	Social	GDP



Mota, B, Gomes, M.I, Carvalho, A, Barbosa-Póvoa, A.P, "Sustainable supply chains: An integrated modeling approach under uncertainty", **Omega**, Volume 77, Pages 32-57, June 2018, https://doi.org/10.1016/j.omega.2017.05.006

Results

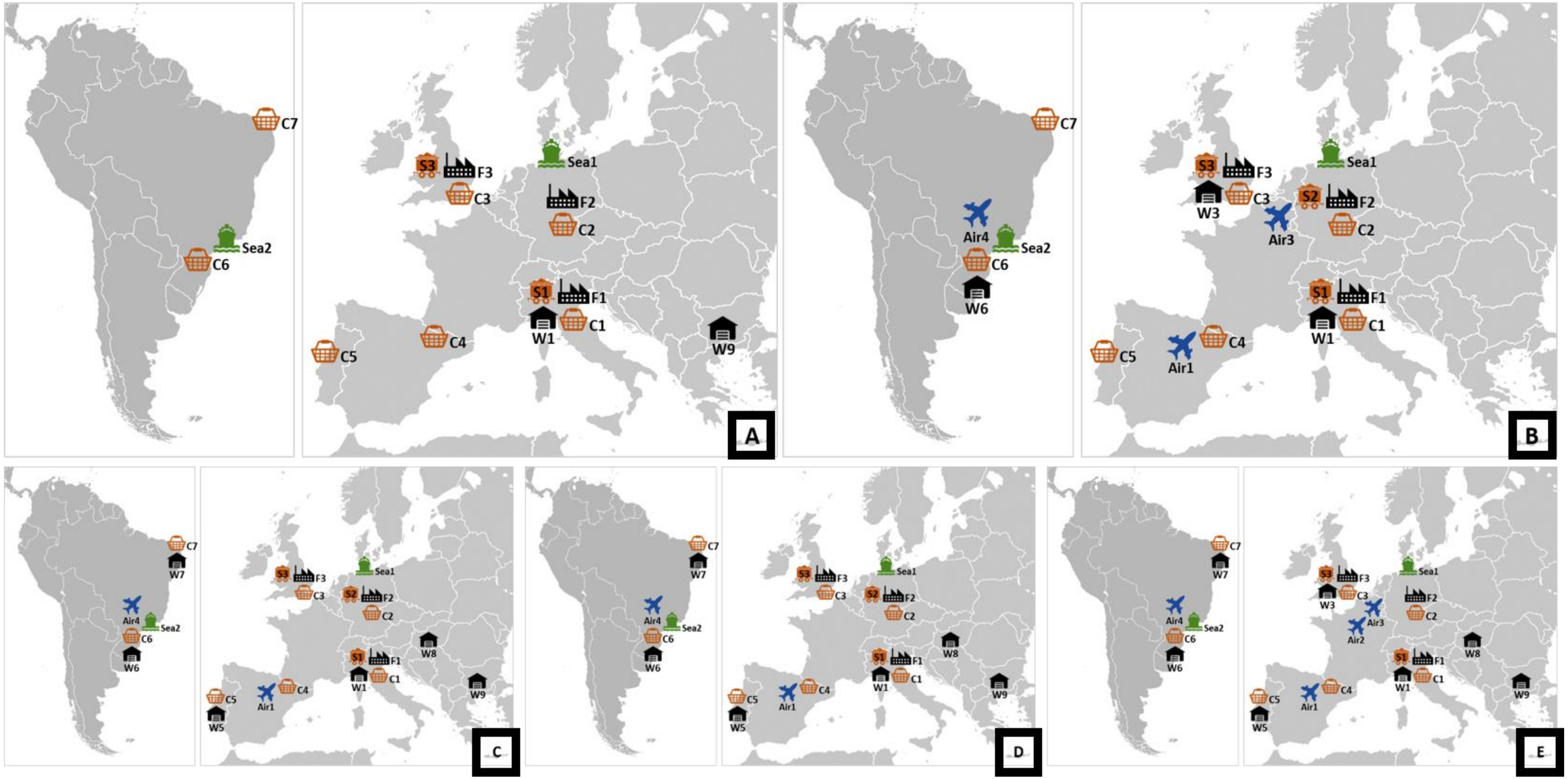
A: max NPV

B: min Env. Impact

C: max Social with 95% of max NPV

D: max Social with 85% of max NPV

E: max Social

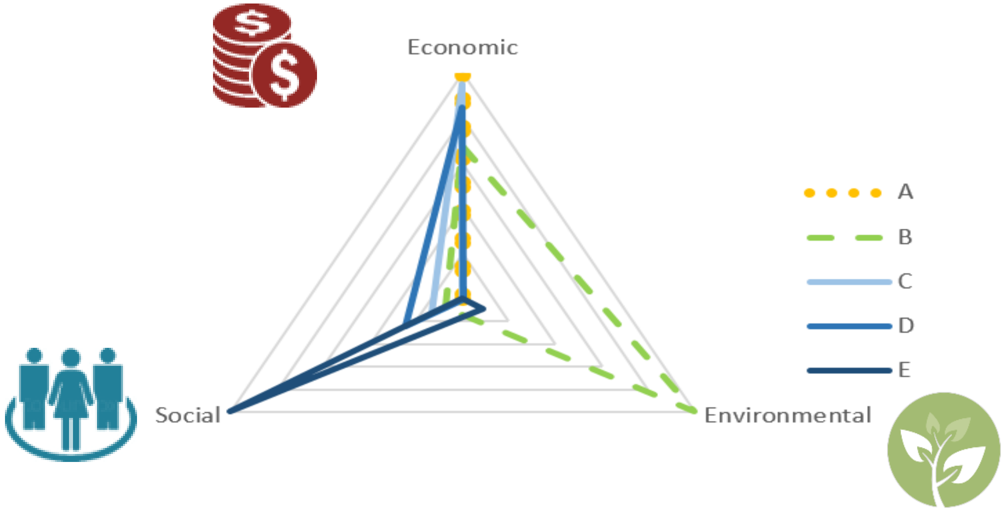


Changes in optimization objectives return significantly different strategic and tactical Supply Chains decisions

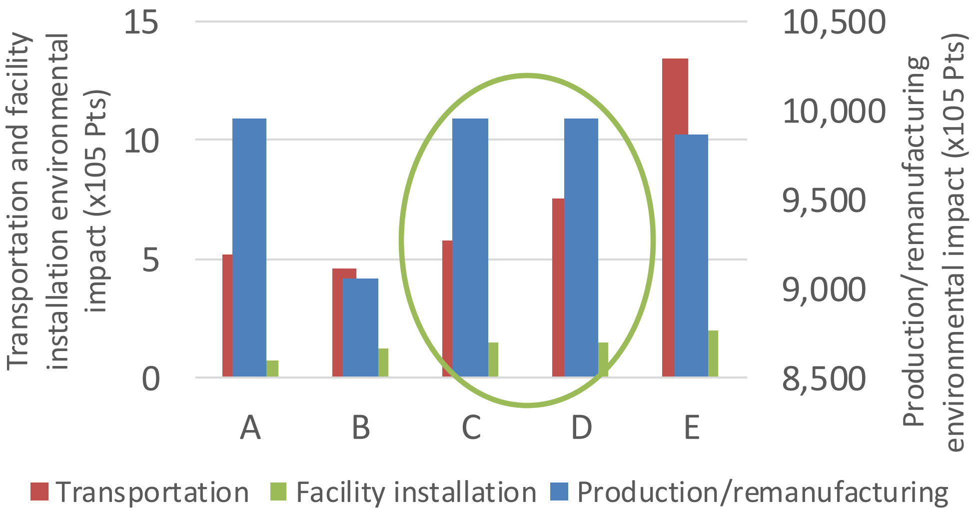
TÉCNICO LISBOA

Objectives:

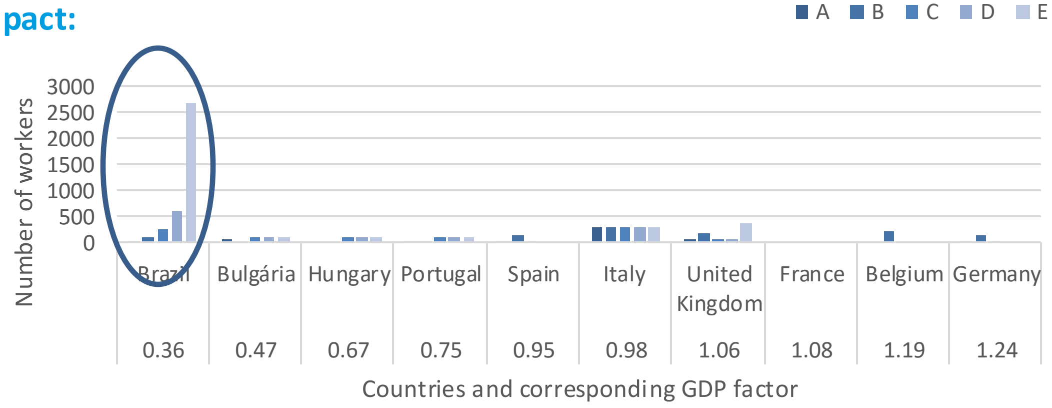
		Cases				
Indicator	**Units**	**A**	**B**	**C**	**D**	**E**
Economic	**€**	1,280,985,986	866,479,118	1,216,936,687	1,088,838,088	0
Environmental	**-**	996,589,688	905,849,526	996,522,581	995,990,099	988,465,182
Social	**-**	534	1,148	1,608	2,537	8,671



Environmental Impact



Social impact:



Importance of an **integrated framework** allows a **better performance** across the supply chain

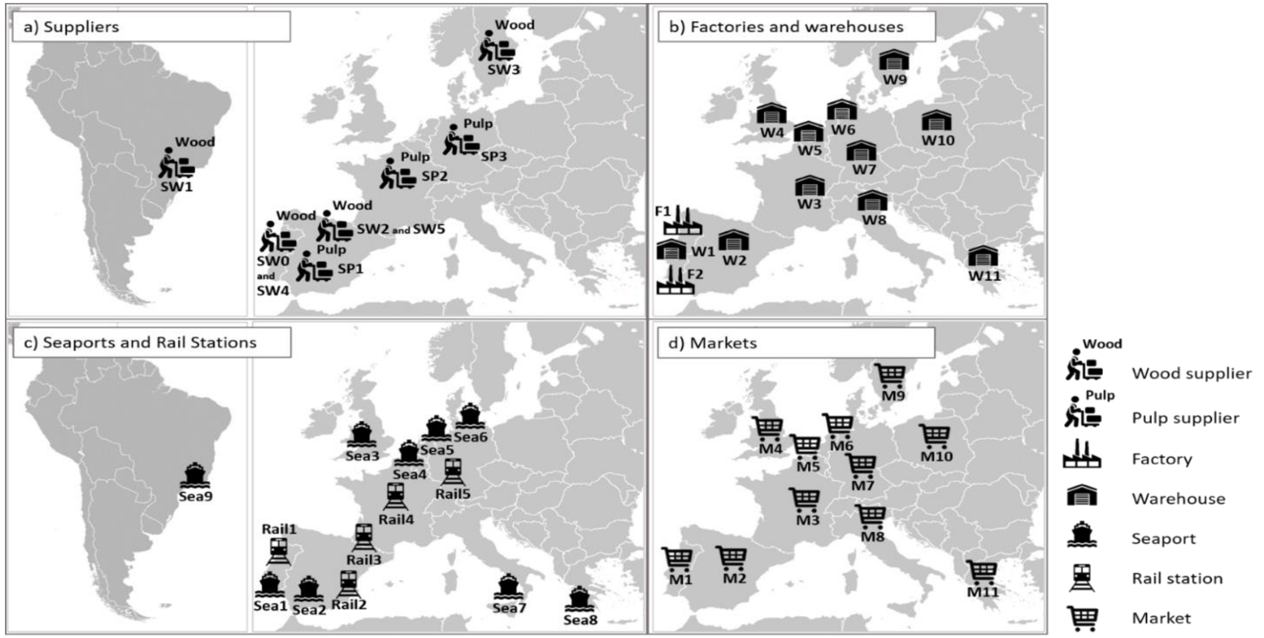
Indentification of sustainability hotspots

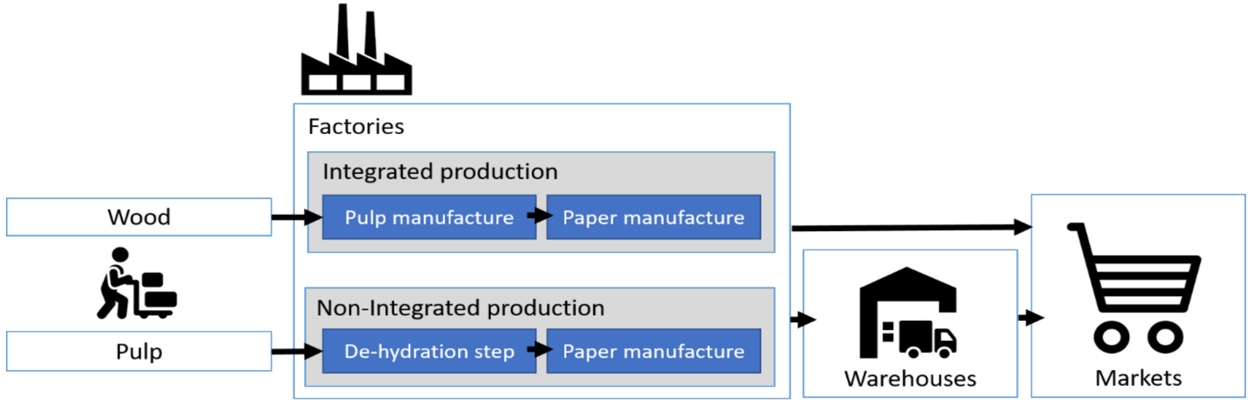
OpLog Research Group

Case-study II

How life cycle scope definition influences supply chains decisions ?

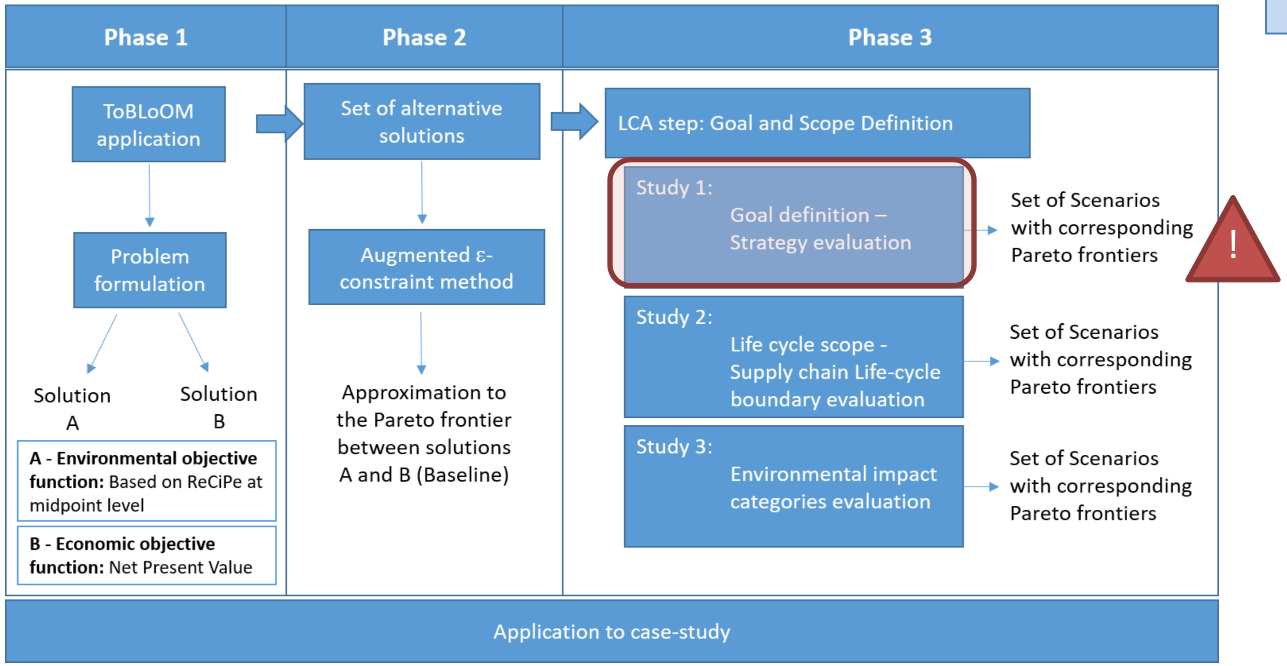
		Case-Study IV
Industry		Pulp and paper
Sustainability indicators	Economic	NPV
	Environmental	ReCiPe PEF (LCA)
	Social	-





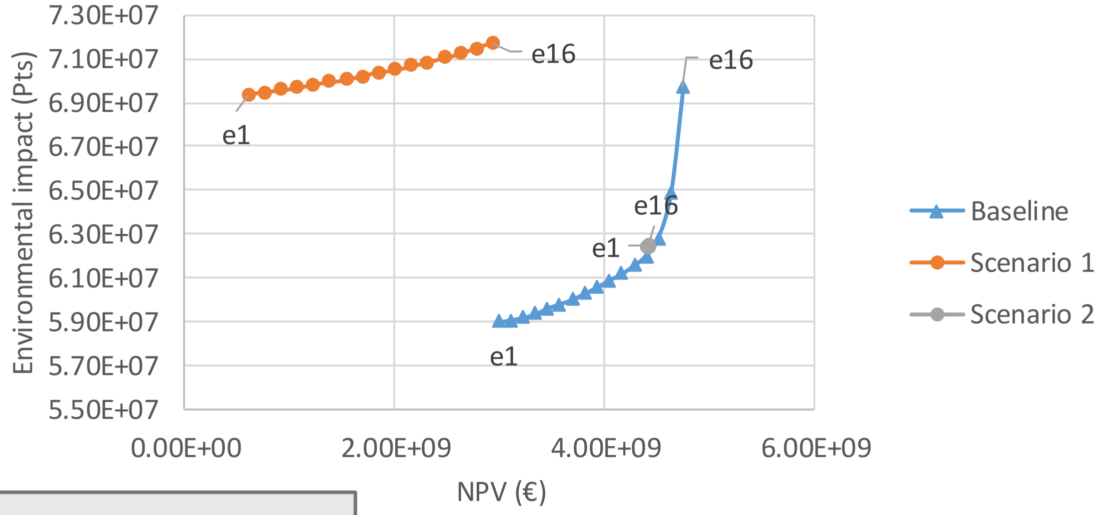
Forestry → Pulp manufacture → Paper manufacture → Distribution → Use → End-of-life

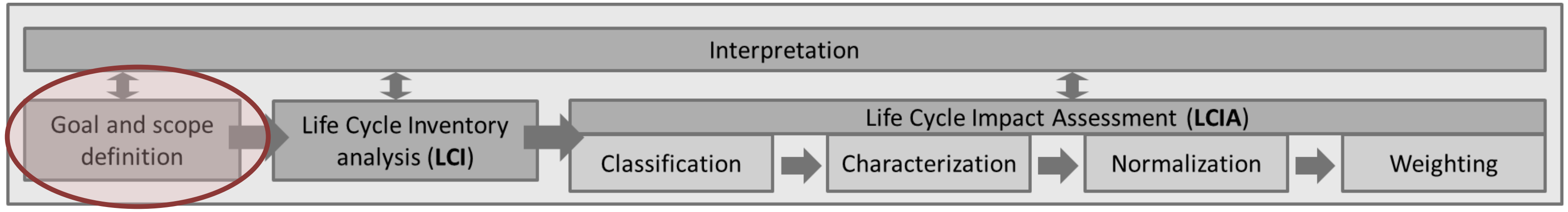
Case Study II – Goal and definition



Strategies thought to be sustainable <u>might not be</u> as sustainable as other alternatives

- scenario 1: 100% of certified raw-materials
- scenario 2: only road transportation



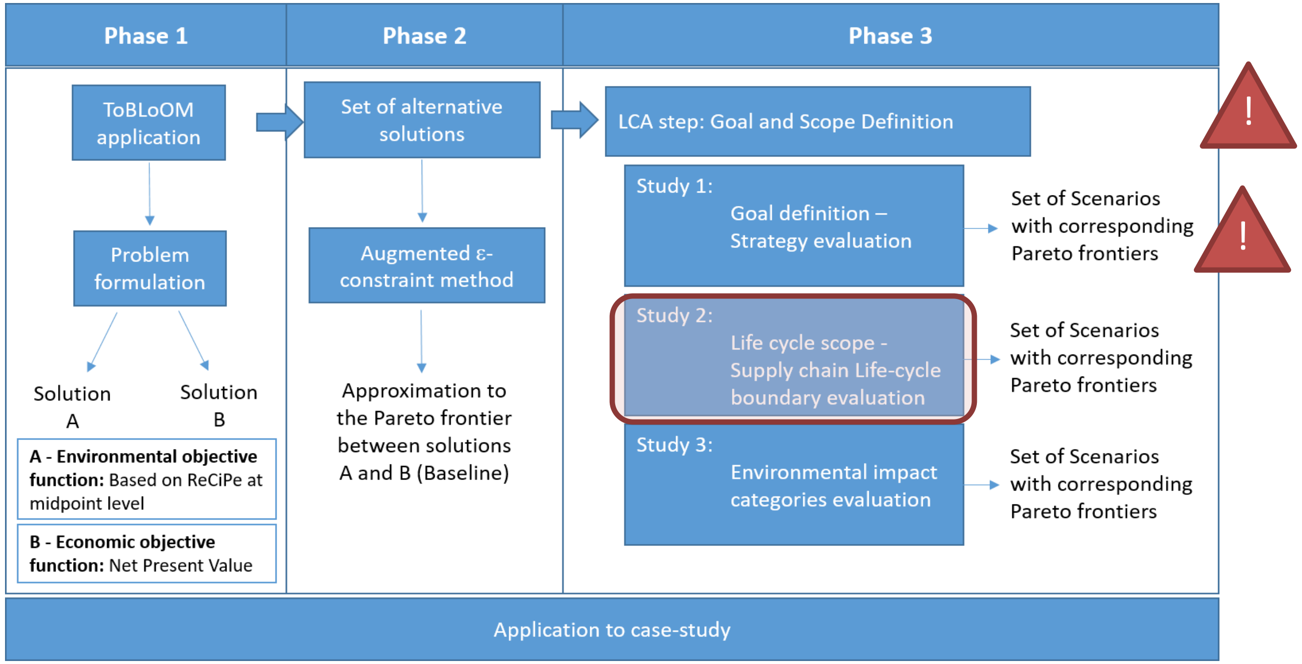


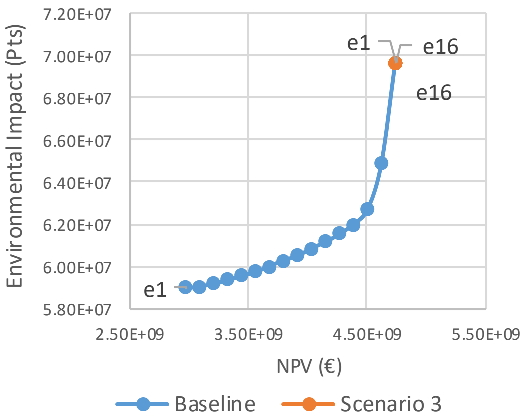
OpLog Research Group

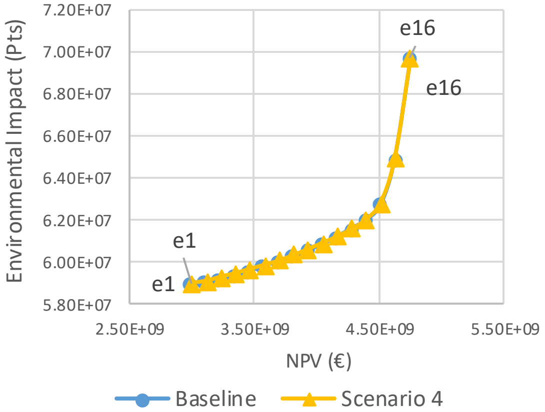
Case Study II – Lyfe Cycle Scope

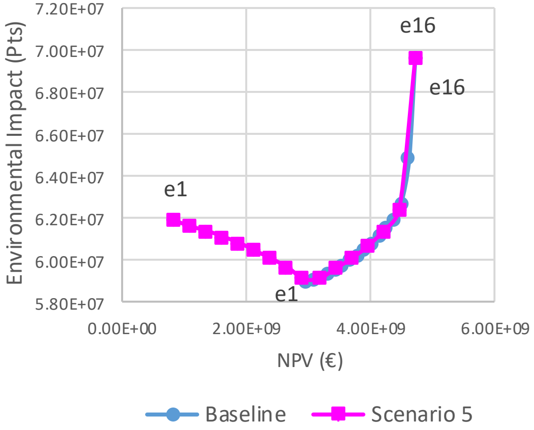
Narrower system boundaries can result in economically and environmentally worse solutions

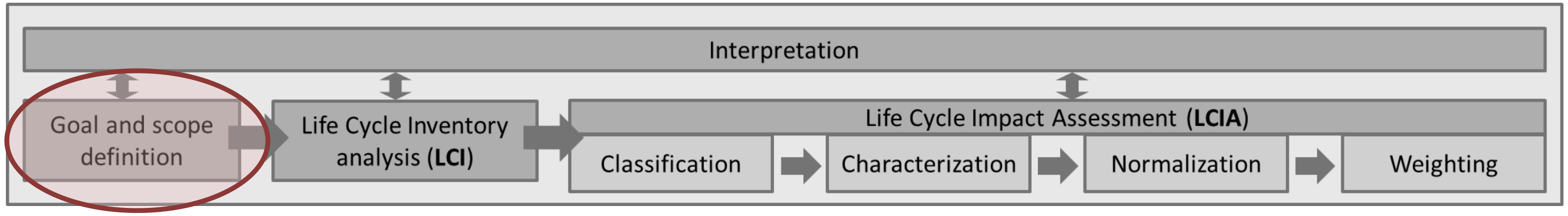
- scenario 3: only transportation activities
- scenario 4: only production and pulp production at the suppliers
- scenario 5: the impact of production, pulp production at the suppliers and carbon credits obtained from purchasing certified wood











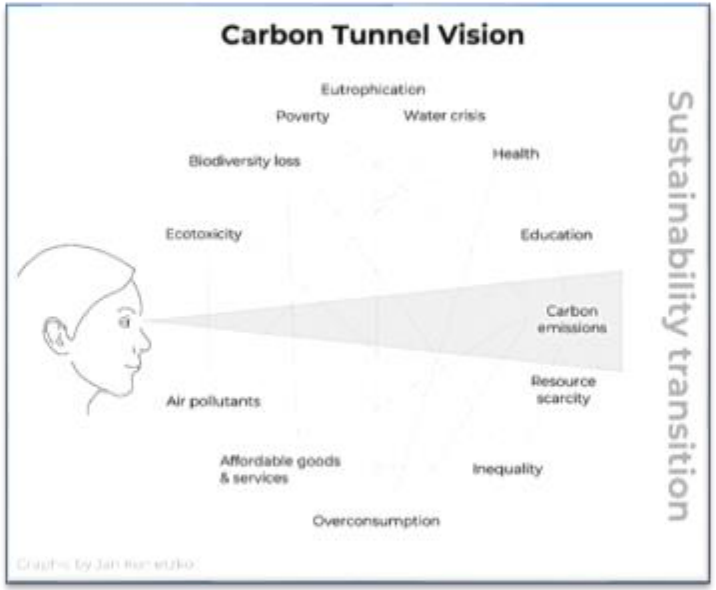
Environmental Analysis needs to be carefull done!

- Strategies thought to be sustainable might <u>not be</u> as sustainable as other alternatives
  - (e.g. certified suppliers only ….)

- <u>Narrowing</u> Systems Boundaries & Impacts Categories

may leads to a biased solution
  - (e.g focus on climate change)

- <u>…</u>



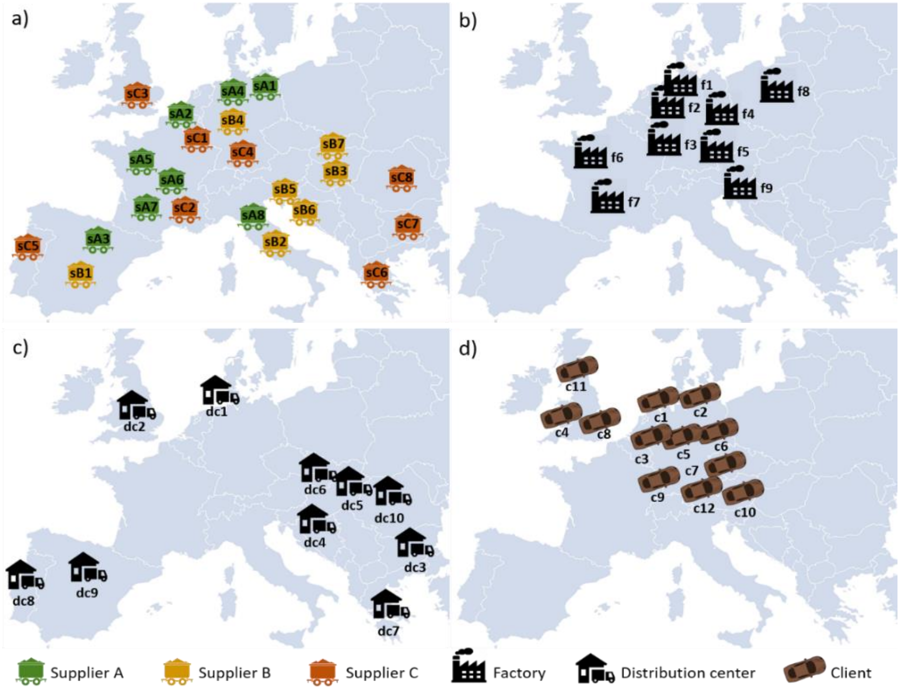
Carbon Tunel (Jan Konietzko, Moving beyong Carbon Tunel Vision with a Sustainability Data Strategy, Forbes, Apr 7, 2022

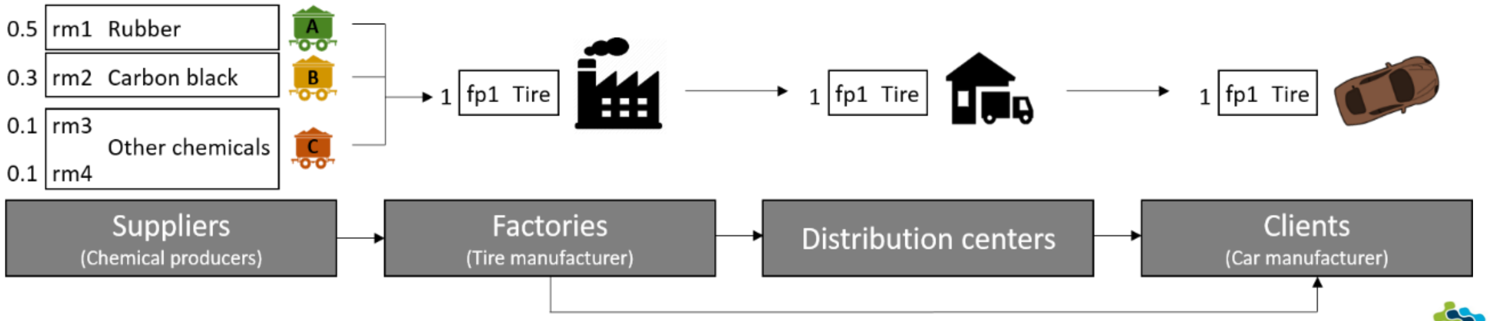
Case-study III

How different social indicators influence the Supply Chain Decisions ?

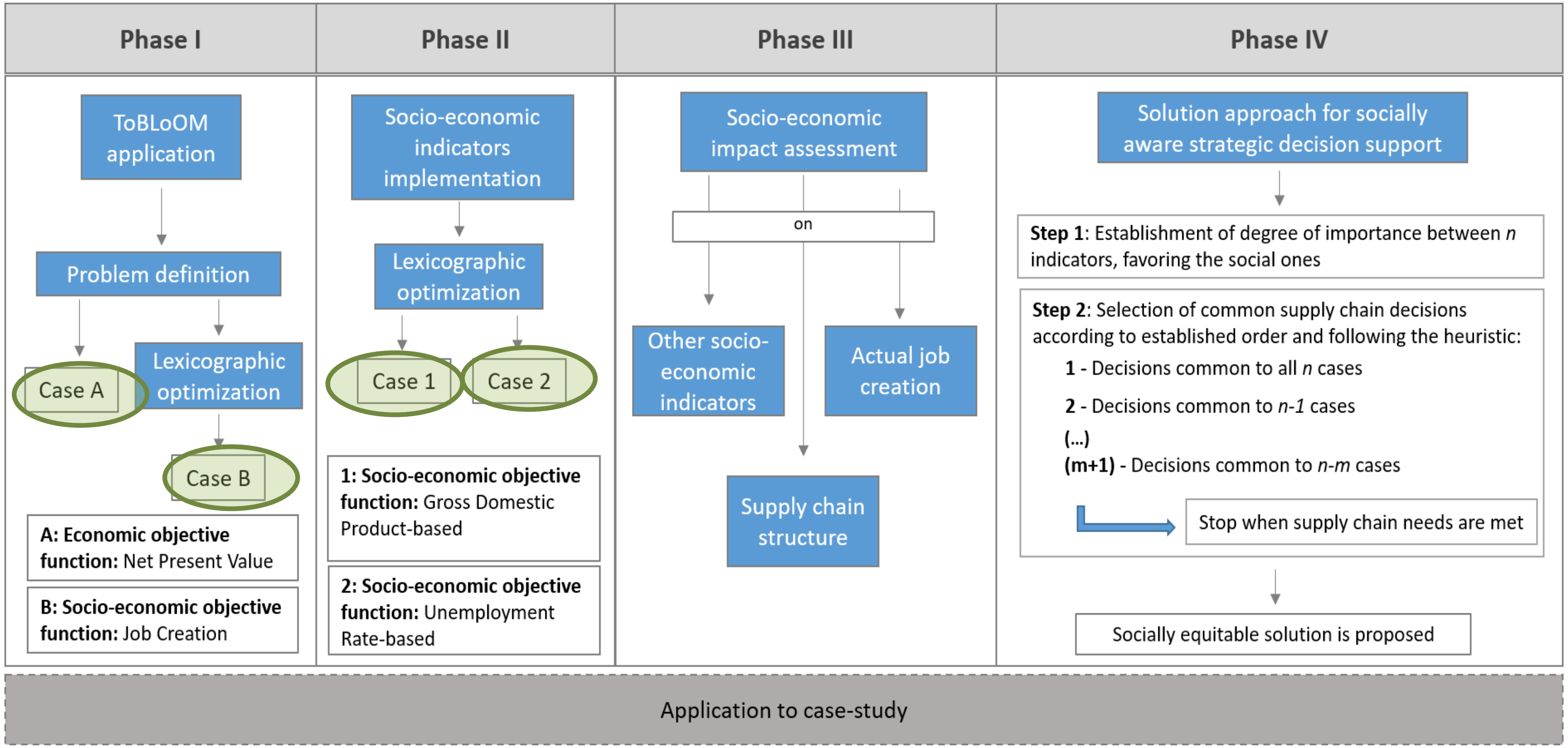
	Case-Study V
Industry	Automotive components
Sustainability indicators — Economic	NPV
Environmental	-
Social	GDP Unemployment Rate Job creation

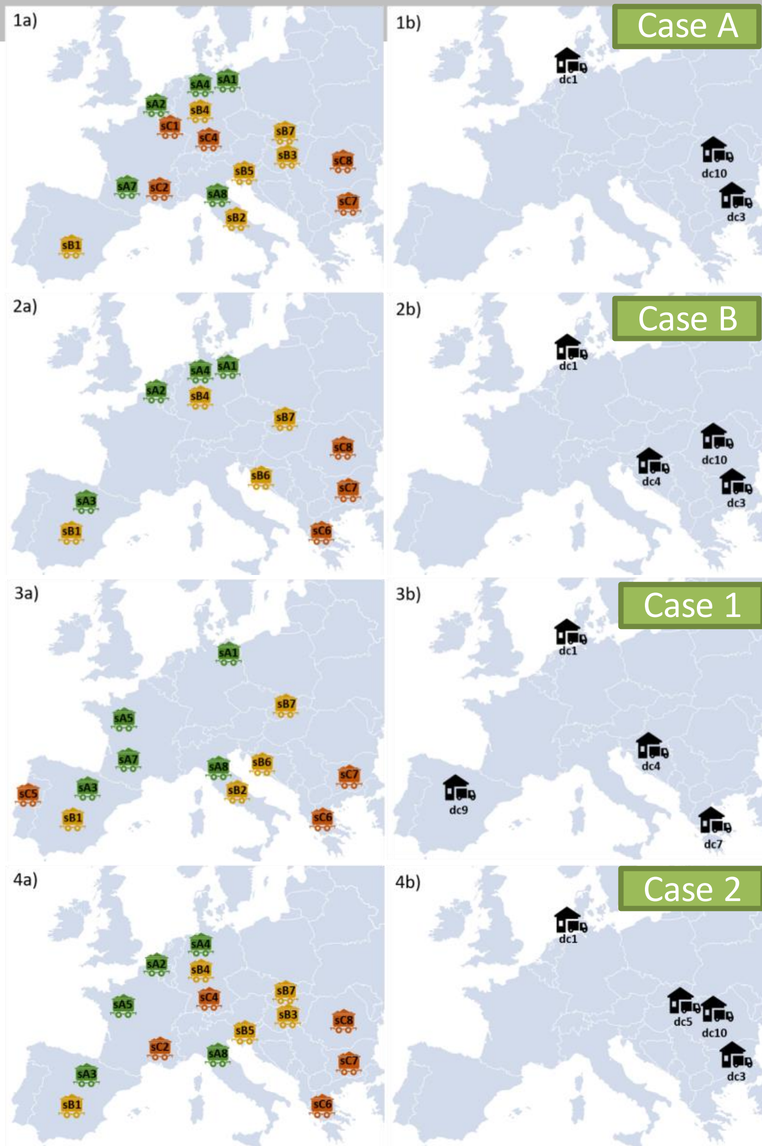
Mota, B, Gomes, M.I, Barbosa-Póvoa, A.P," Growth and jobs: supply chain design and planning towards socio-economic equity" (submitted)





Case-study III



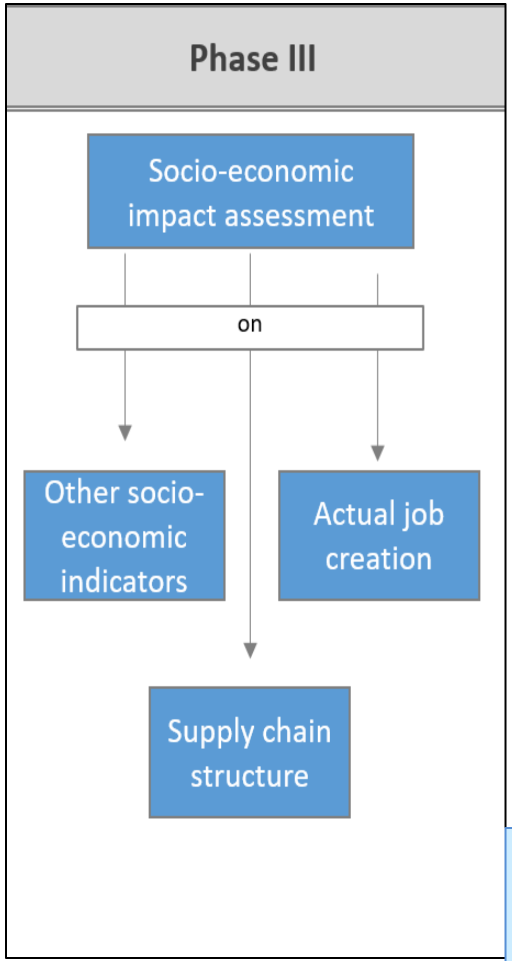


Different social indicators significantly influence supply chain structure

NEED FOR: careful analysis of contributions and relations between indicators and supply chain decisions is necessary

Case-study III

Having social concerns in mind
what is the most equitable solution?



Impact on other socio-economic indicators:

	Improvement* in GDP-based indicator (%)	Improvement* in Unemployment Rate-based indicator (%)	Improvement* in Job Creation (%)	Decrease in NPV (%)	Total Improvement in Social Indicators (%)
Case 1 (GDP-based)	**38**	47	34	12	120
Case 2 (Unemployment rate-based)	8	**98**	20	11	**126**
Case B (Job creation)	37	29	**35**	12	101

*compared to Case A

More Balanced Solutions

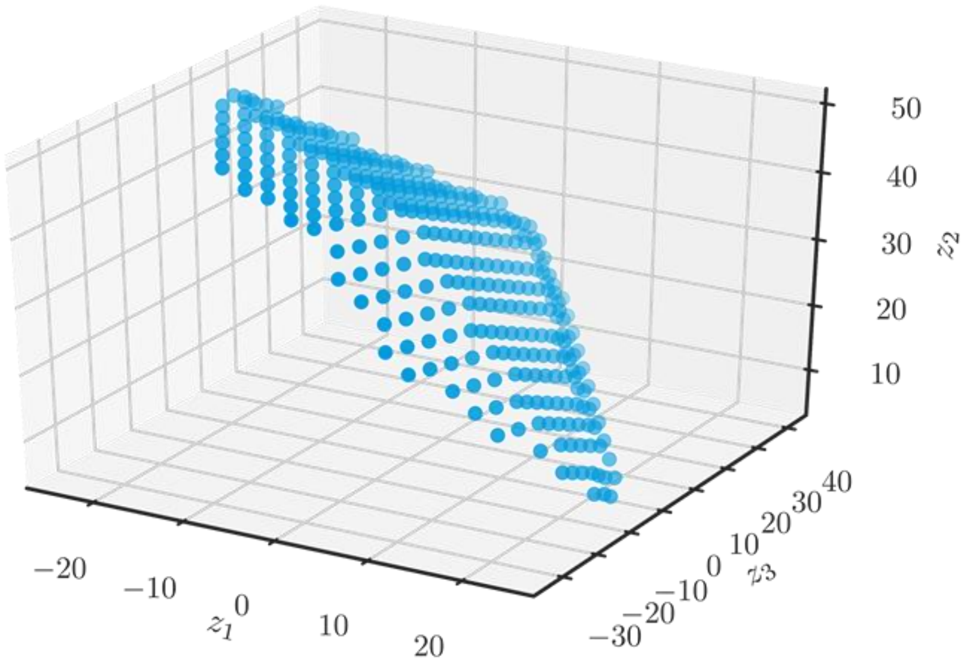
Application of certain indicators can result in a trade-off with other socio-economic indicators and the effective number of jobs created

NEED FOR: broader analysis with different social criteria supported by this type of methodologies

But …

- Solving Multi-objective objective problems in real cases results:

  - Overwhelming for the DM
  - Difficult to compute
  - Time consuming



New Methodology was proposed

COMBINE 3 STRATEGIES

1

Representation Method

Compute a subset of the Pareto front that:

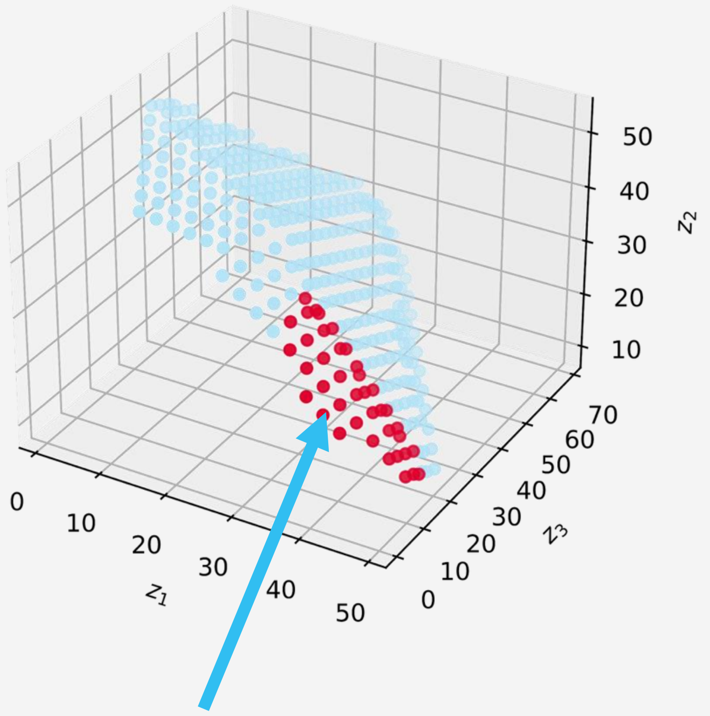
- Captures the traits of the Pareto front
- Is as small as possible
- Is well spread through the Pareto front

2

Pareto Front Decomposition Method

Restrict objective space based on DM's previous knowledge:

- Requires from the DM for simple preference statements
- Discards only solutions that would not be interesting to the DM
- Restricts the search region *a priori*



3

Interactive method

Guides the DM through the Pareto front to:

- Further refine the PF into a narrower ROI
- Help the DM converge on a satisfactory solution

Proposed methodology

1. Problem formulation

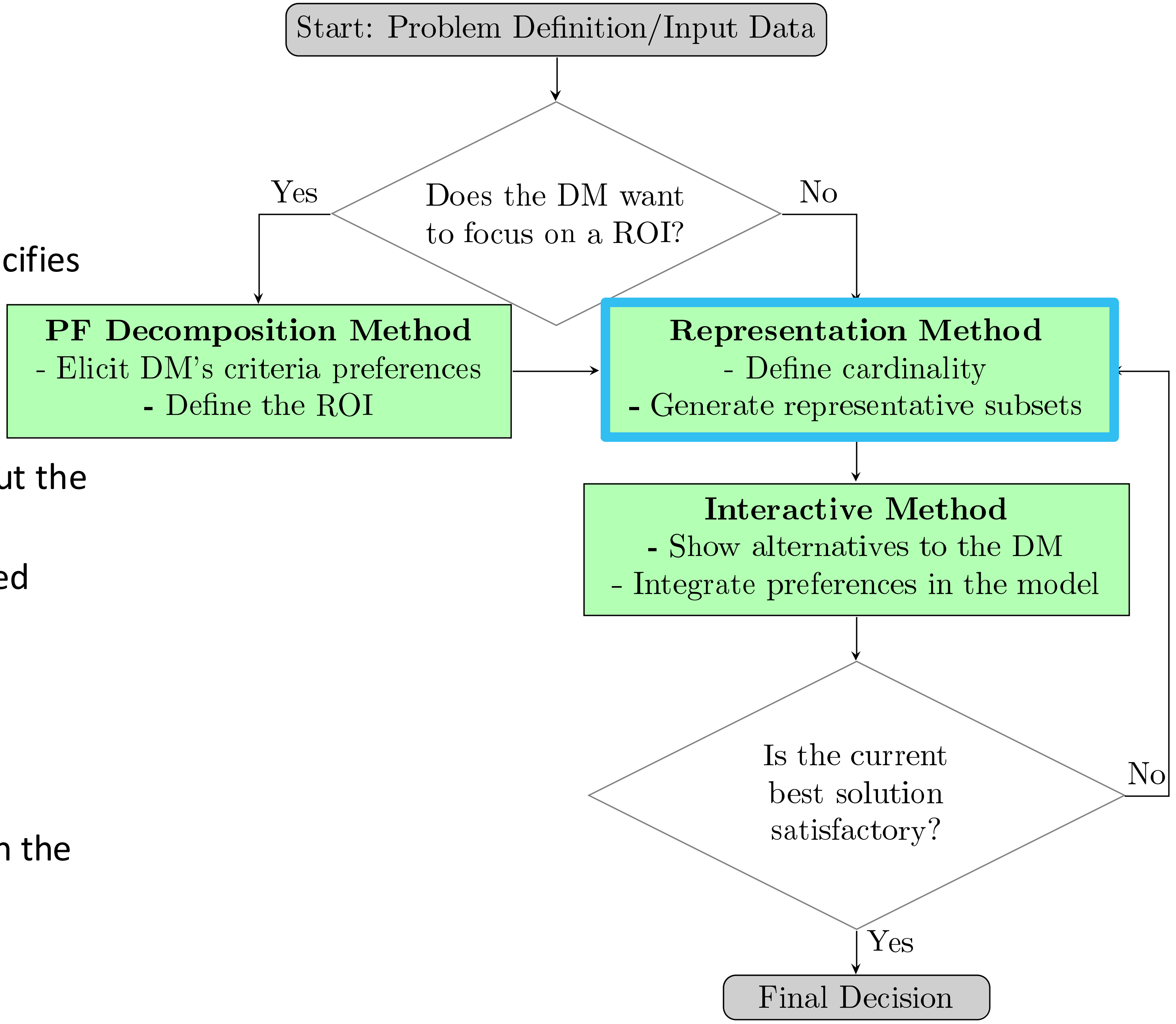
1. DM articulates problem statement and specifies relevant aspects

2. Initial Representation or ROI Definition

1. DM decides if we wants to learn more about the problem or focus on a ROI
2. DM is shown a PF representation and guided through the trade-offs

3. Interactive Refinement

1. DM wishes to find a satisfactory solution
2. The DM is shown alternatives and based on the DM's ranking the representation is refined



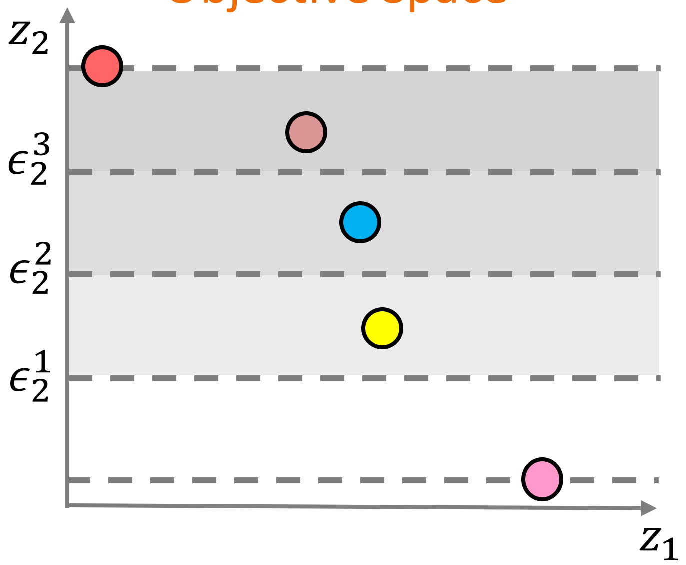
Representation Strategy

AUGMENCON2 method

$$\max_{x,s} \left\{ z_q(x) + \rho \sum_{k=1,\, k\neq q}^{p} 10^{k-1} \frac{s_k}{r_k} \right\}$$

$$\begin{aligned} \text{subject to:} \quad & z_k(x) - s_k = \epsilon_k, \quad k = 1, \dots, p, \ k \neq q \\ & s_k, \geqslant 0, \quad k = 1, \dots, p, \ k \neq q \\ & x \in X. \end{aligned}$$

Objective Space



Has some drawbacks

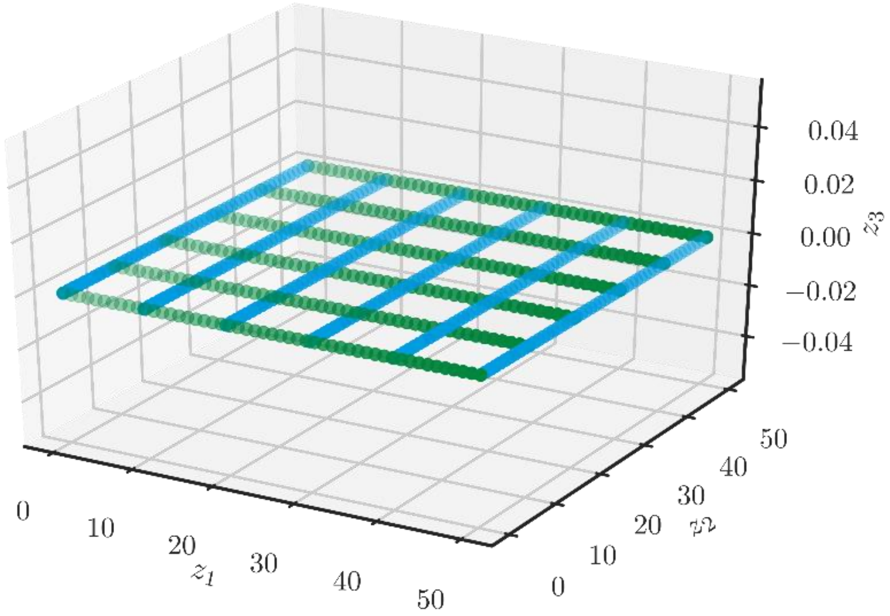
1. Is very dependent on the computation of the Pareto front's bounds
2. When in more than two objectives, many redundant computations are done
3. Representation quality is not considered

Representation Strategy - Proposed methodology

Grid-point based algorithm - GPBA-C

- ε-constraint based method

$$
\begin{aligned}
\max_{x,s} \quad & \left\{ z_q(x) + \rho \sum_{k=1,\, k\neq q}^{p} 10^{k-1} \frac{s_k}{r_k} \right\} \\
\text{subject to:} \quad & z_k(x) - s_k = \epsilon_k, \quad k = 1, \ldots, p, \ k \neq q \\
& s_k, \geqslant 0, \quad k = 1, \ldots, p, \ k \neq q \\
& x \in X.
\end{aligned}
$$



- Improved by:
  - The algorithm skips redundant computations
  - The algorithm is made independent on the quality of the Nadir estimation
  - Refines the search grid within the problem's feasible region whenever a grid step is skipped.

Mesquita-Cunha, M., Figueira, J.R., Barbosa-Póvoa, A.P., 2023. New ϵ-constraint methods for multi-objective integer linear programming: a Pareto front representation approach. European Journal of Operational Research 306, 286–307.

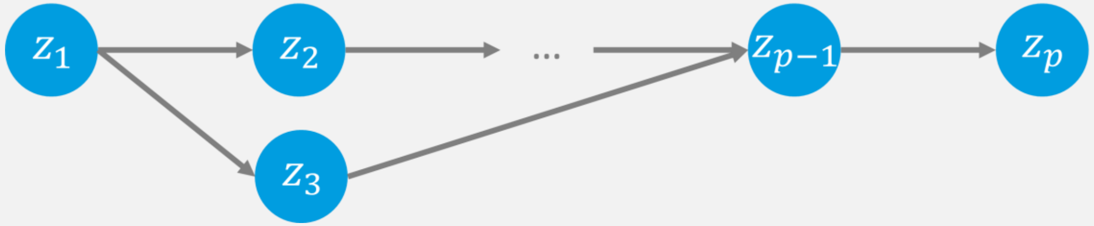
OpLog Research Group

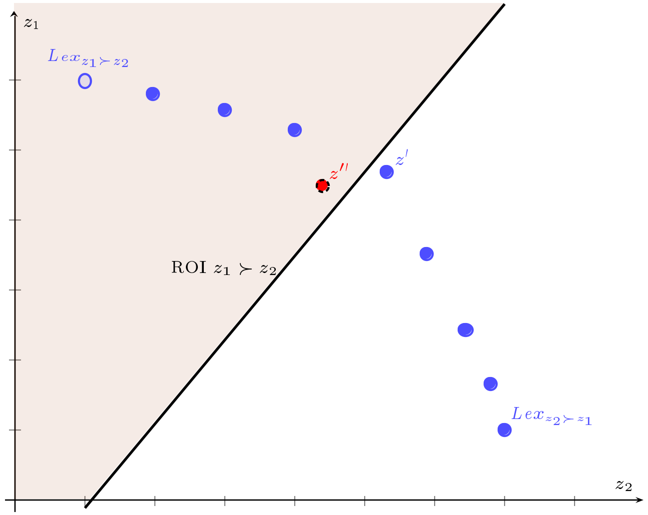
PF Decomposition Method

1. Elicit criteria preferences

1. **Total order:** All elements in the considered set are comparable

2. **Partial order:** An ordering of the elements in which not all elements are comparable



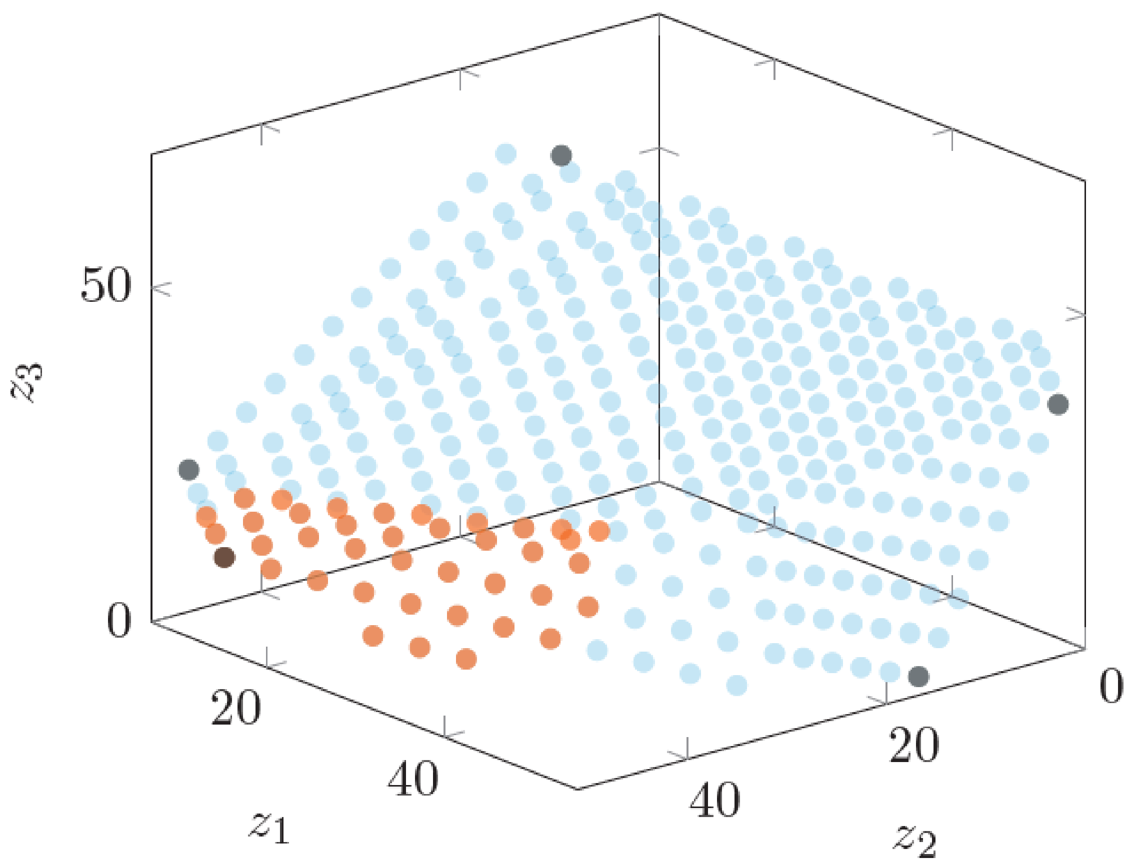


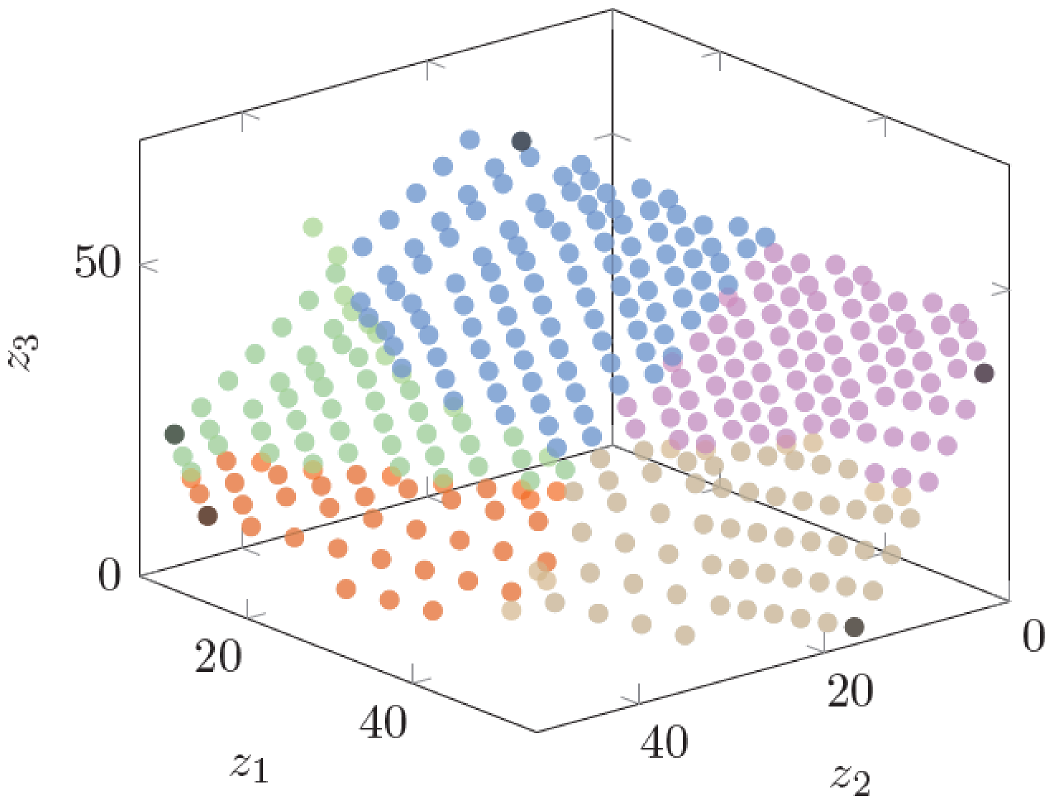
1. Create ordered sets of criteria respecting DM's preferences
2. Define the ROI using constraints

Mesquita-Cunha, M., Figueira, J.R., Barbosa-Póvoa, A.P., 2025, *Decomposing the Pareto Front using preferences provided by the decision-maker, under review*

PF Decomposition Method

PF partition for order $z_1 \succ z_2 \succ z_3$

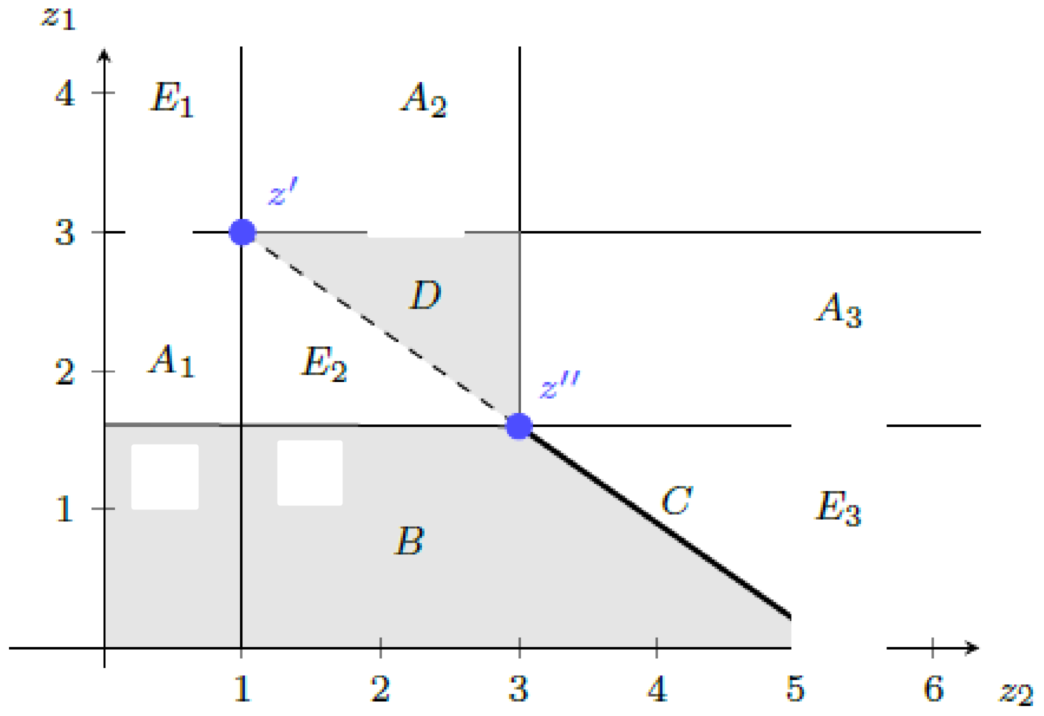


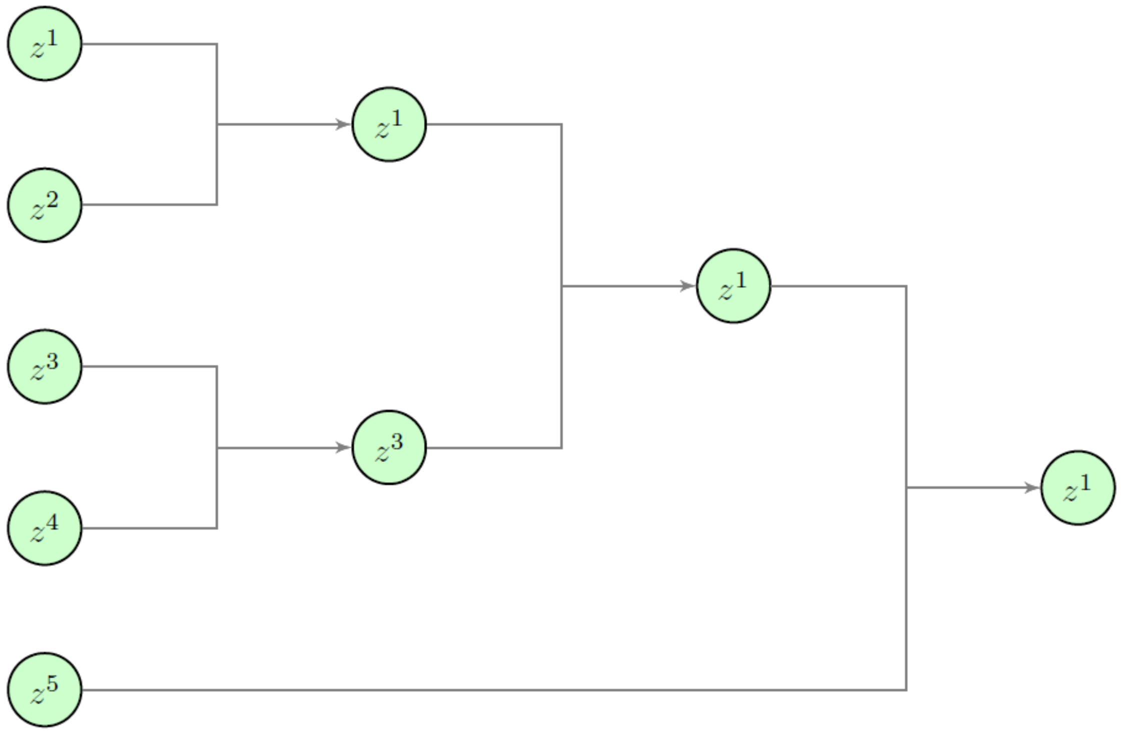


OpLog Research Group

Interactive Method

1. Select subset to analyse
2. Analyse solutions and define cones
3. Add cone dominated constraints





Mesquita-Cunha, M., Figueira, J.R., Barbosa-Póvoa, A.P., 2025, *An interactive method for multi-objective optimization: integrating preferences through convex cones, under review*

Design and Planning the Meningitis Vaccine SC

AVAILABILITY - Social Objective Function

Objectives' definition:

- Economic objective function
- Environmental objective function
- **Social objective functions**

Identification of Constraints:

- Material balance constraints
- Entity capacity constraints
- Transportation constraints
- Technology constraints

- The sum of mortality and morbidity is reflected to as the "**burden of disease**" and can be measured by a metric called DALYs.

The higher the disease burden in a country

The higher the p_i^{DALY}

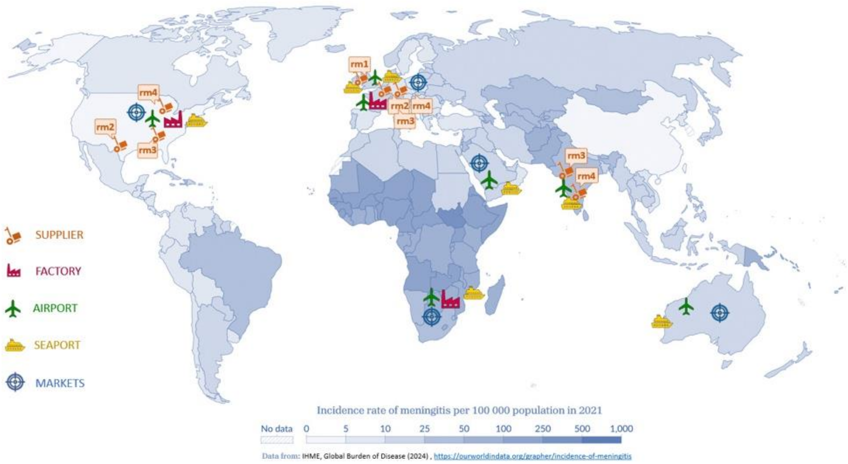
<u>Prioritizing the location of entity i in countries with higher disease burden</u>

DALYs : Disability Adjusted Life Years (rate per 100,000 population)

$$\max \text{PharmAccess} = \left(\sum p_i^{DALY} * Y_i\right)$$

Entity related parameter:
Social factor of location I based on DALY metric

Decision Variable:
1 => if entity i is installed



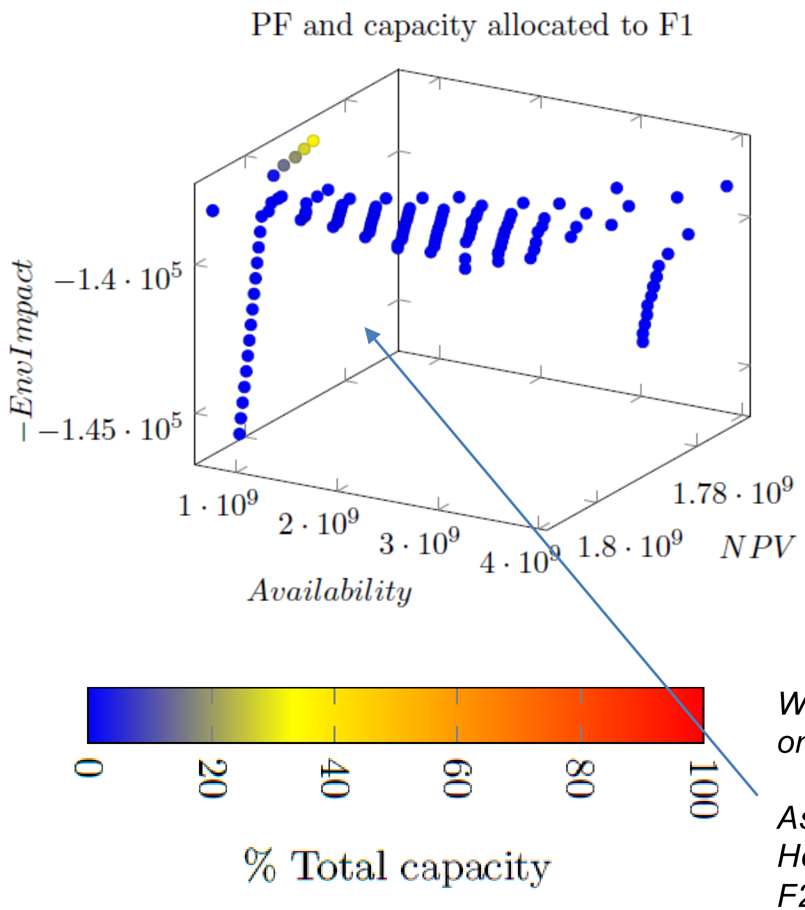
Duarte, I., Mota, B., Pinto-Varela, T., Figueira, J, Barbosa-Póvoa, A.P., 2025. Multi-objective sustainable pharmaceutical supply chain design and Planning, under review

Analysis

- Pareto front study

- Methodology assessment
  - Three preference scenarios for the DM:
    - Total order: $\mathrm{NPV} \succ Availability \succ Environmental\ Impact$
    - Hesitation regarding the first objective - Economic and Social: $\mathrm{NPV} \sim Availability \succ Environmental\ Impact$
    - Hesitation regarding the first objective - Economic and Social: $\mathrm{NPV} \sim Environmental\ Impact \succ Availability$
  - The DM is simulated through linear and Chebyshev value functions using weight vectors:
    - $w^1 = (0.7, 0.2, 0.1)$ and $w^2 = (0.5\ 0.3, 0.2)$ and $\mathrm{w}^3 = (0.45, 0.35, 0.2)$
    - Use the first PF to know the DM's preferred point
    - Stop when best solution is in the subset

Results – Factories capacity usage



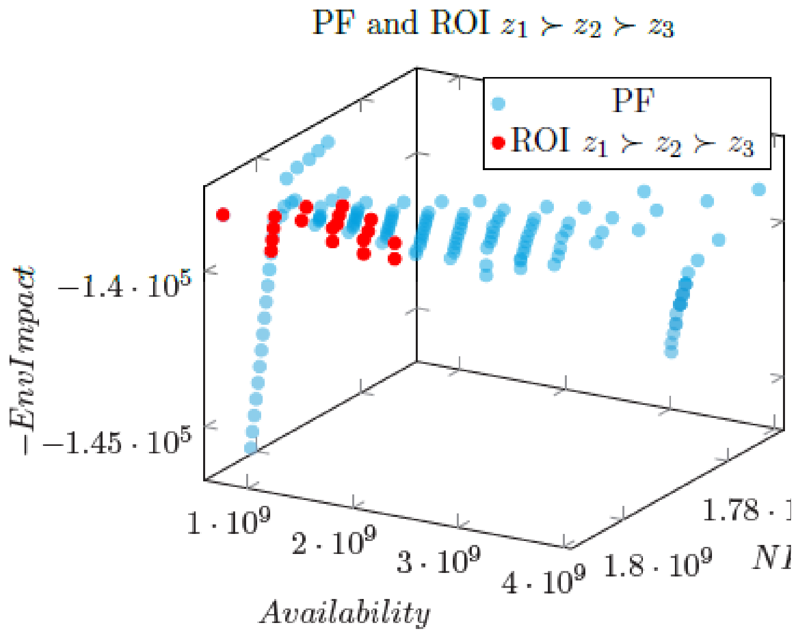
When maximizing the NPV , all production is allocated to factory F2 located in France and the suppliers chosen are the ones located closer to this factory

As we progress along the trade-off between NPV and EnvImpact, production in factory F1 located in US increases. However, this production does not exceed 36.5% of the total production level, being the remaining production in factory F2.

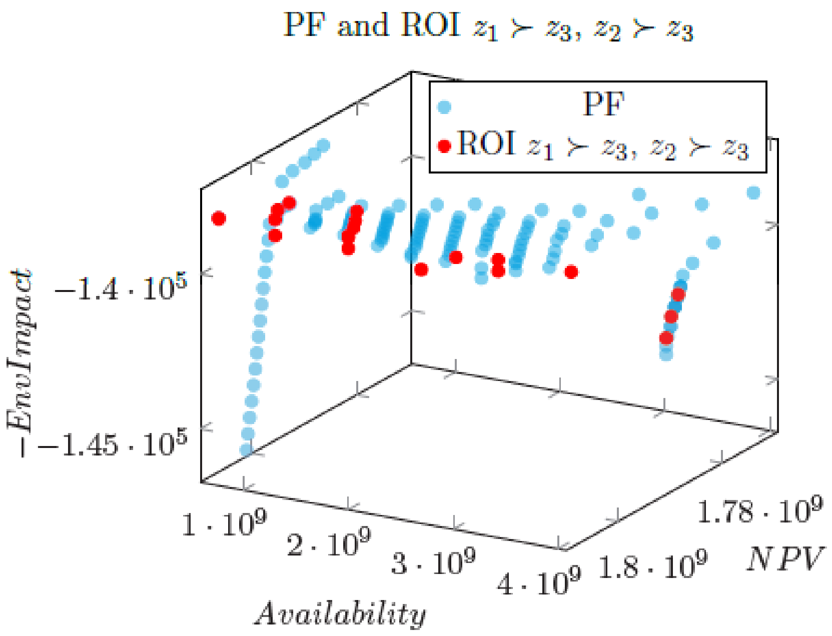
To improve the social impact, it is necessary to install a new factory, F3, in Africa. this improvement is associated with a gradual shift of production from factory F2 in France to factory F3 in Africa, while not producing at the US factory (F1).

Results - ROI

We evaluate this in terms of computational efficiency and the number of solutions analysed by the DM.

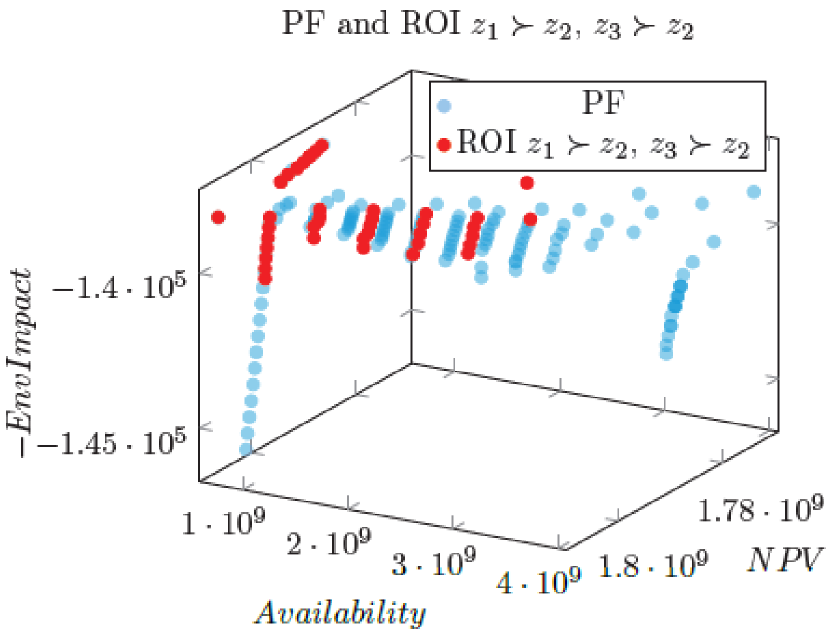


Total order scenario



hesitation between the

economic and social criteria in the first place



hesitation between economic and environmental objectives as the preferred objective

Results – Whole methodology

Algorithm	Scenario	Models solved	$\|PF\|$	CPU (s)
Represent. Method	No Pref. Info.	169	133	344.51
Decompos. & Represent.	Total order	24	18	93.10
Decompos. & Represent.	1st hes. - Econ. and Soc.	29	20	323.72
Decompos. & Represent.	1st hes. - Econ. and Env.	49	40	231.35

PF decomposition (ROI) provides a significant reduction in PF size
+
CPU reduction

Interactive method

w1NPV + w2Availability − w3EnvImpact

Weight vector	Included methods	Iter.	Nbr. Comp.	CPU (s)
$\mathbf{w}^1$	Represent.& Inter.	3	8	1146.23
	Decomp. & Represent. & Inter	1	4	460.15
$\mathbf{w}^2$	Represent.& Inter.	2	8	2091.19
	Decomp. & Represent. & Inter	2	4	459.87
$\mathbf{w}^3$	Represent.& Inter.	2	8	2077.71
	Decomp. & Represent. & Inter	1	4	961.49

Benefits of using the complete framework are clear

Main Conclusions

TÉCNICO LISBOA

- Importance of having an **integrated framework** allows **a systems view to** assess the impact of in supply chain decisions when considering:
  - different **options/decisions** taken within the application of each indicator
  - Importance of a **detailed understanding of the contributions of each environmental impact category** to the different supply chain activities and total environmental single score
  - **Different social indicators** can significantly influence supply chain structure

- **Further:**
  - Explore further **uncertainty** – not only on the problem characteristics (e.g. demand) but in the sustainability parameters – LCA and Social Indicators

- Importance of having a more **comprehensive multi-objective framework**, allow:
  - analysis of the trade-offs and the impact of different decisions on the objective functions providing insights on the problem
  - significant efficiency improvements were obtained regarding a posteriori analysis when using the PF decomposition with representation methods
  - there are significant efficiency improvements regarding interactive procedure when combining the whole methodology

- **Further:**
  - Integrate this process in a tool with an interface
  - Study the scalability of this approach to more complex and larger problems

Special Thanks to:

Ana Carvalho
Bruna Mota,
Cátia Silva
Inês Duarte
Mariana Cunha
Tânia Pinto-Varela

and

José Rui Figueira

Thank You

Contact: apovoa@tecnico.ulisboa.pt

Acknowledgments to the Portuguese National Science Foundation (FCT), under the projects PTDC/EME-SIS/6019/2020; UIDB/00097/2025 and UIDP/00097/2025

And research grants; SFRH/BD/149441/2019; 2022.11365.BD