

Are you running your plant like a hospital that forgot Covid?

Asset Management 5.0

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In the *Iliad*, both Cassandra and Paris perished

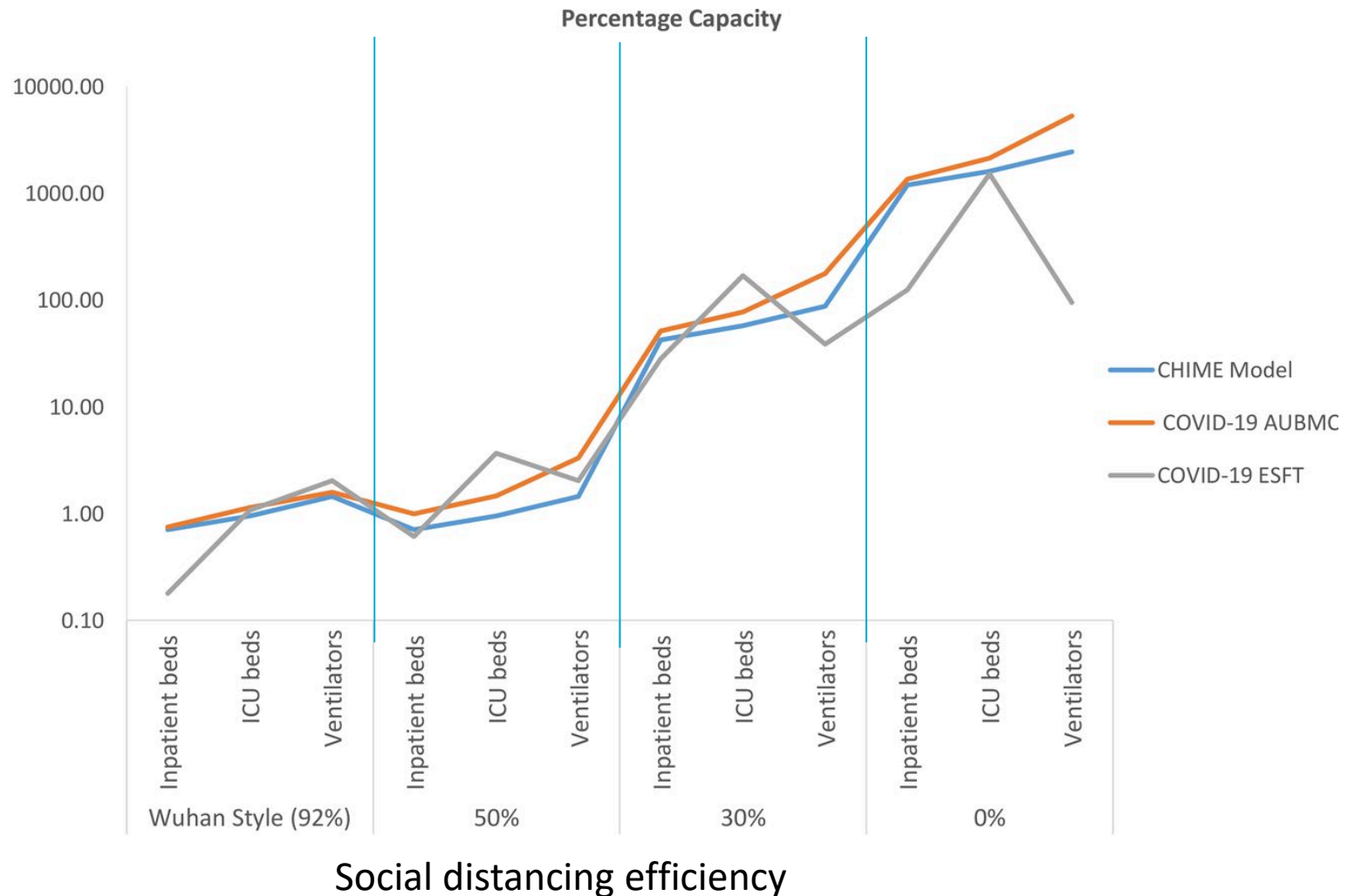
- Being a professional at [X] does not (always) make you better at predicting crises
- Wishful thinking has consequences
- And yet, one must resist the sirens of alarmism

And the rest is history

- Lack of ICU capacity
- Lack of trained staff
- Triage
- 7+ million deaths

World health organisation. (2026, September 28). *COVID-19 deaths*. WHO COVID-19 Dashboard. <https://data.who.int/dashboards/covid19/deaths>
Fjølner, J., Haaland, et al. (2022). Who gets the ventilator? A multicentre survey of intensivists' opinions of triage during the first wave of the COVID-19 pandemic. *Acta Anaesthesiologica Scandinavica*, 66(7), 859–868. <https://doi.org/10.1111/aas.14094>

The issue of ICU ventilators in crisis



Kamar, A., et al. (2021). Challenge of forecasting demand of medical resources and supplies during a pandemic: A comparative evaluation of three surge calculators for COVID-19. *Epidemiology and Infection*, 149, e51. <https://doi.org/10.1017/S095026882100025X>

The issue of ICU ventilators asset management

- How many ventilators?
- Internalized or outsourced maintenance?
- Fleet replacement periodicity?

**Engineers' instinct: maximize ROI, NPV, IRR, ...
while complying to standards and regulation**

- N+1 with N the nominal ICU capacity
- Outsourced
- Maximum given spare parts availability, machine availability, regulations and patient safety

What's hiding in the blind spot?



- N+1 does not give room for resiliency
 - Ability of a system to recover quickly to a stable state during or after a major mishap
 - E.g., $N_{\text{normal}}=38$; $N_{\text{COVID}}=44$
- On lockdowns, or if multi-crisis hits gas prices, etc., lack of internal knowledge
- No appeal to MDs.



How to avoid that crash?

1. Never neglect the human aspects of human systems
 - Doctors like novelty, nurses and technical staff like stuff that just works
2. Evaluate the resiliency of your systems
 - By simulating known or possible crises to your system
 - Crises are multifaceted, and ever more frequent
 - Are you ready for a new... COVID? Suez Canal blockage? A prolonged Ormuz/Bab-el-Mandeb blockade?
3. Don't forget the environmental aspects
 - They have true long-term benefits
 - European Sustainability Reporting Standard

Industry 5.0 is sustainable, resilient & human-centric

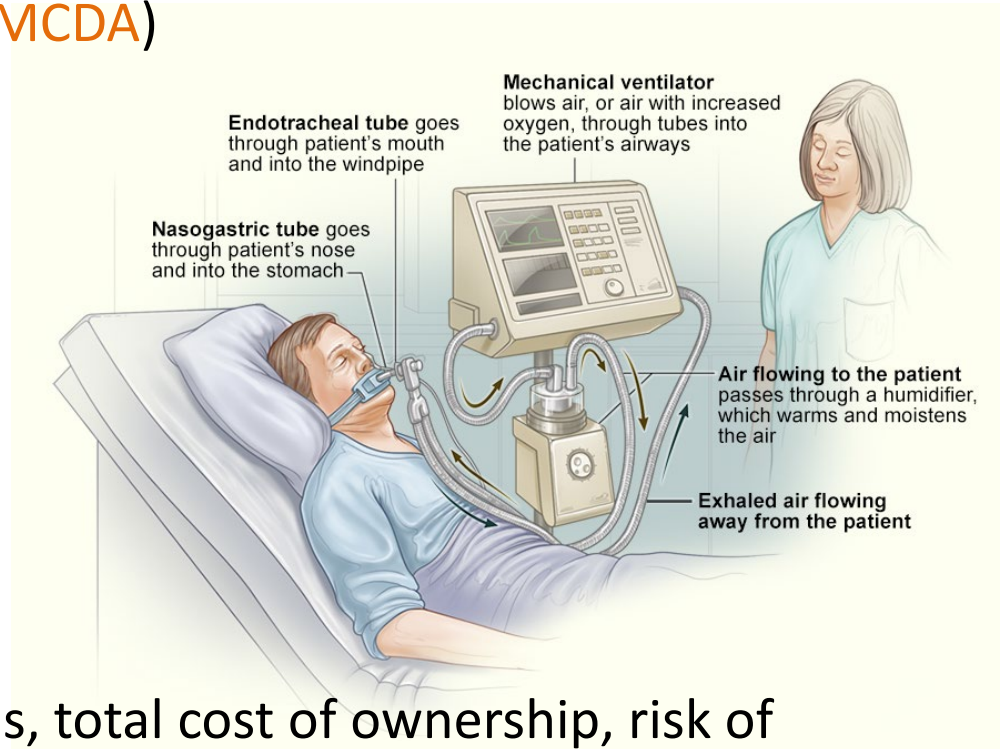
Can maintenance decisions really take all this into account?

Multi-criteria decision aid method (MCDA)

- ID criteria
- Rank/weights of criteria
- ID alternatives
- Score alternatives
- ID best alternative

Example: ventilators

- MCDA = AHP
- Criteria = {Availability rate in crisis, total cost of ownership, risk of obsolescence, fleet novelty, ease of procurement}
- Criteria ranked by ad hoc hospital committee
- Alternatives suggested w/ maintenance and procurement, checked for ethics & standards compliance
- Alternatives scored by committee



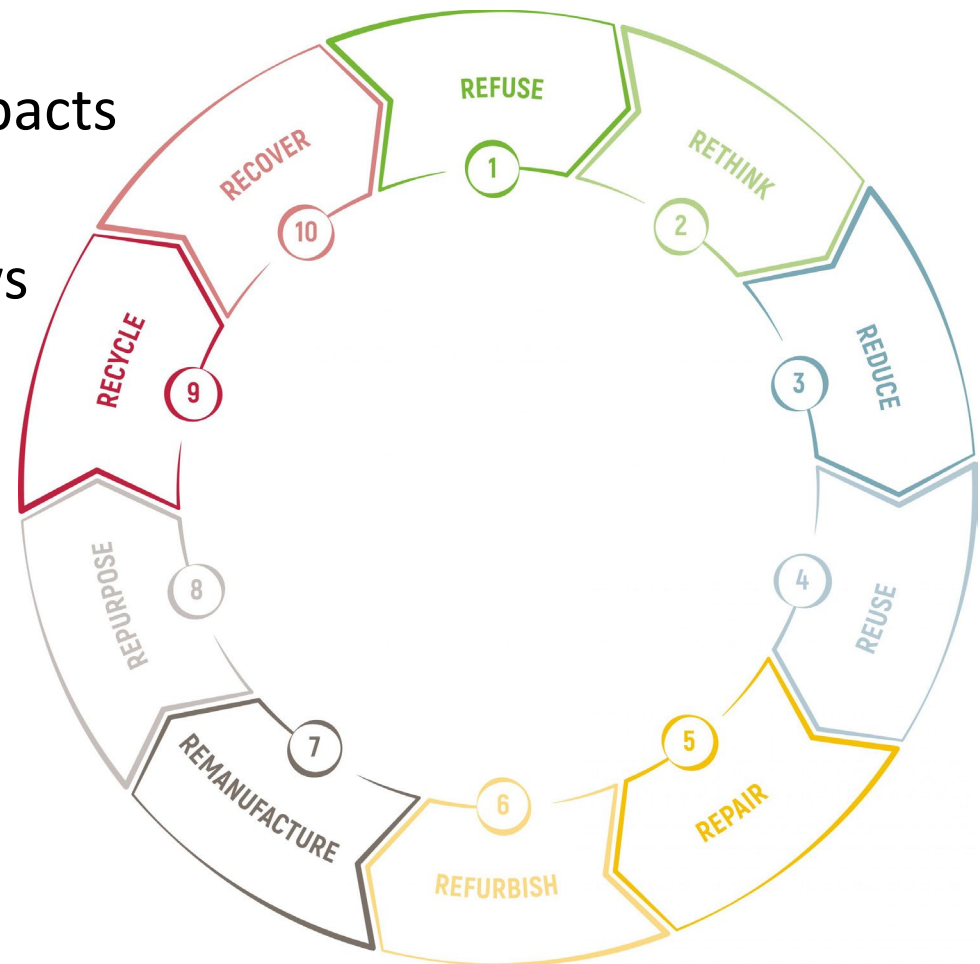
So we can have a multicriterion approach...

... We can evaluate the resilience of an operational decision...

But can we evaluate its environmental impact?

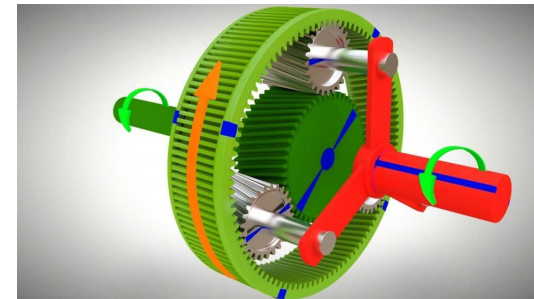
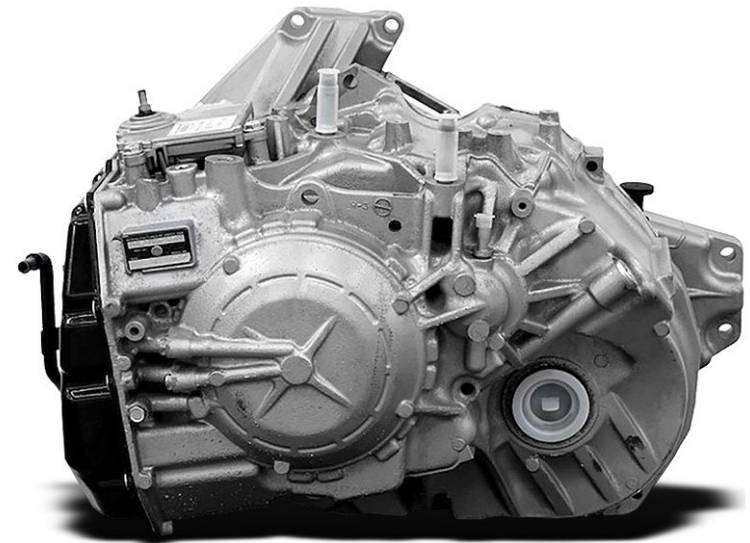
A sustainable maintenance?

- Maintenance is intrinsically sustainable
- Different levels of maintenance with different environmental impacts
- Life cycle assessment (LCA) allows quantifying environmental impacts



Spotlight: assessment of maintenance environmental impact

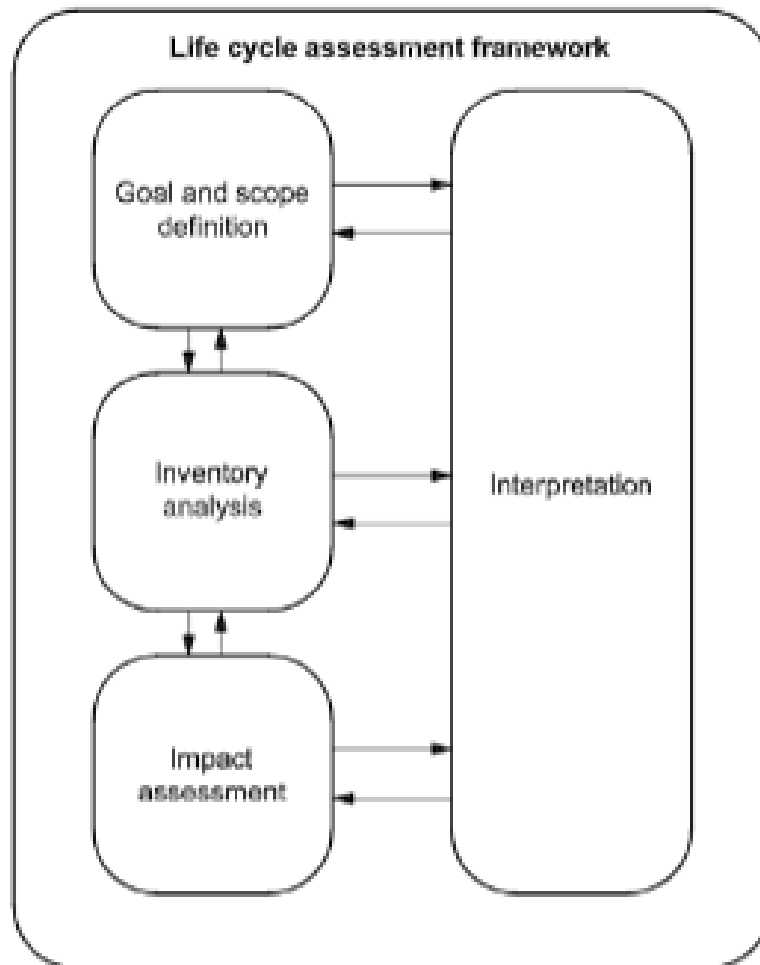
- Belgium-based Remanufacturing of used automatic transaxles that underwent a critical failure
- 3 main components
 - Transaxle
 - Valve body
 - Torque converter
- Principle: 2 planetary gear trains assembled in order to adapt the transmission ratio to the conditions



Comparison of the environmental impact of replacing a defective transaxle by a new one or a remanufactured one?

Life cycle assessment – Overview

- Goal
- Assumptions
- Boundaries of the system
- Functional unit
- Data collection
- Data calculation
- Allocation
- Indicators selection
- Classification
- Characterization



Defined by
ISO 14040-44

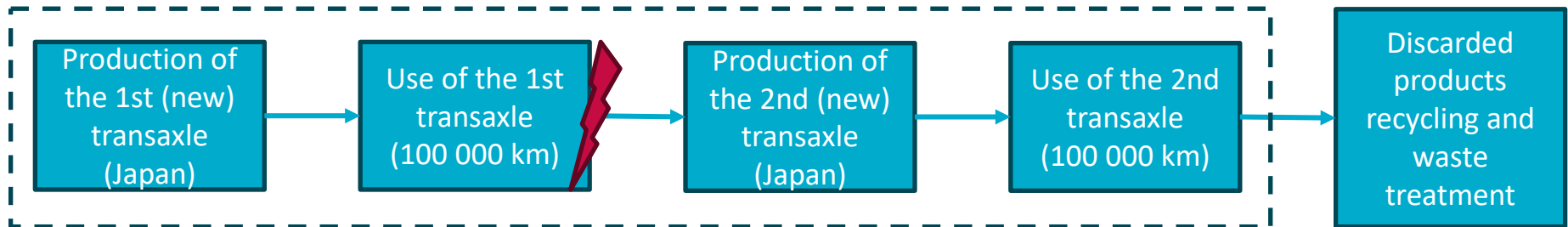
Direct applications:

- Product development and improvement
- Strategic planning
- Public policy making
- Marketing
- Other

Product systems

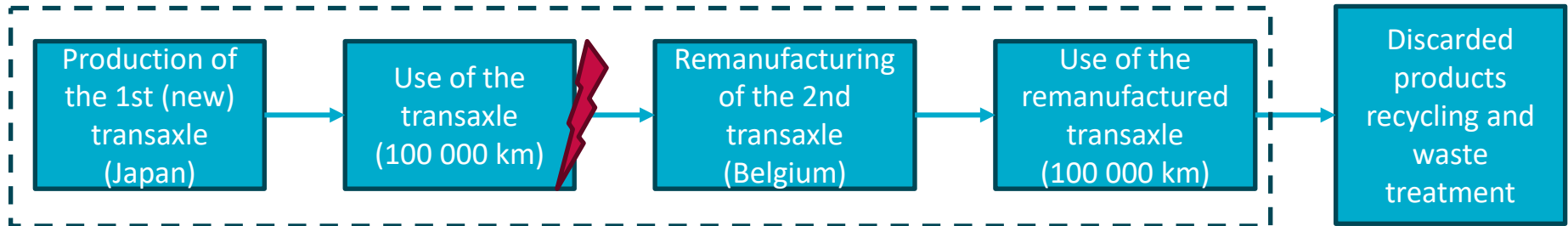
- 2 product systems: Cradle-to-gate
- Replacement by a new transaxle

System boundaries



- Replacement by a remanufactured transaxle

System boundaries



- Functional unit: 200 000 km

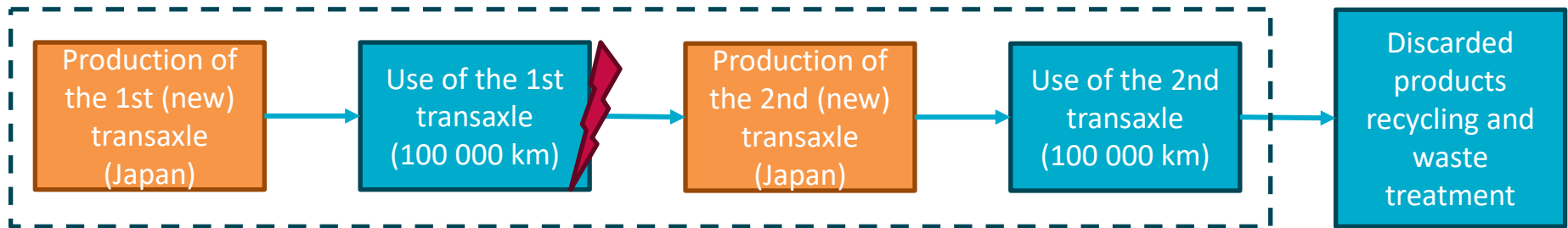
Scope definition

- Data
 - The mass of the parts constituting the transaxle is given by manufacturer
 - All the unit processes are taken or approximated by data of ecoinvent 3.9
- LCIA methodology and category indicators
 - ReCiPe 2016 (Global methodology)
 - All impact categories will be considered in a first iteration. However, water consumption is not relevant since all the contributions intervening in the life cycle are not known for this category indicator, and a focus will be made on Climate change
- Limitations
 - No consideration of the end of life of the transaxle, its parts, eventual recycling or discard
- Assumptions
 - Manufacturing line of the new transaxle = Spare parts line of Belgian factory

Product system

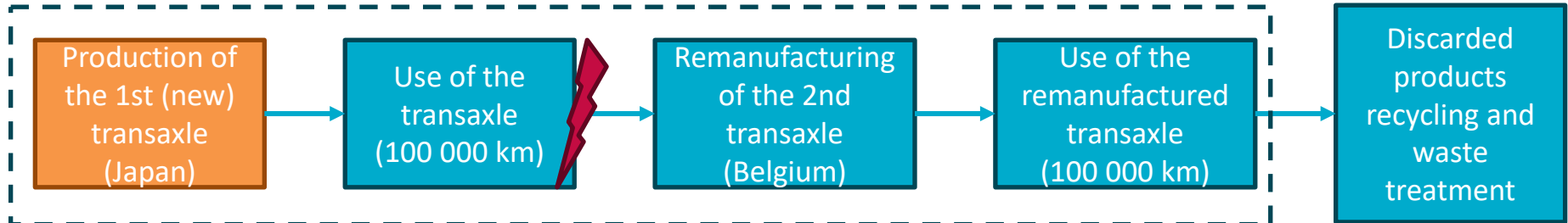
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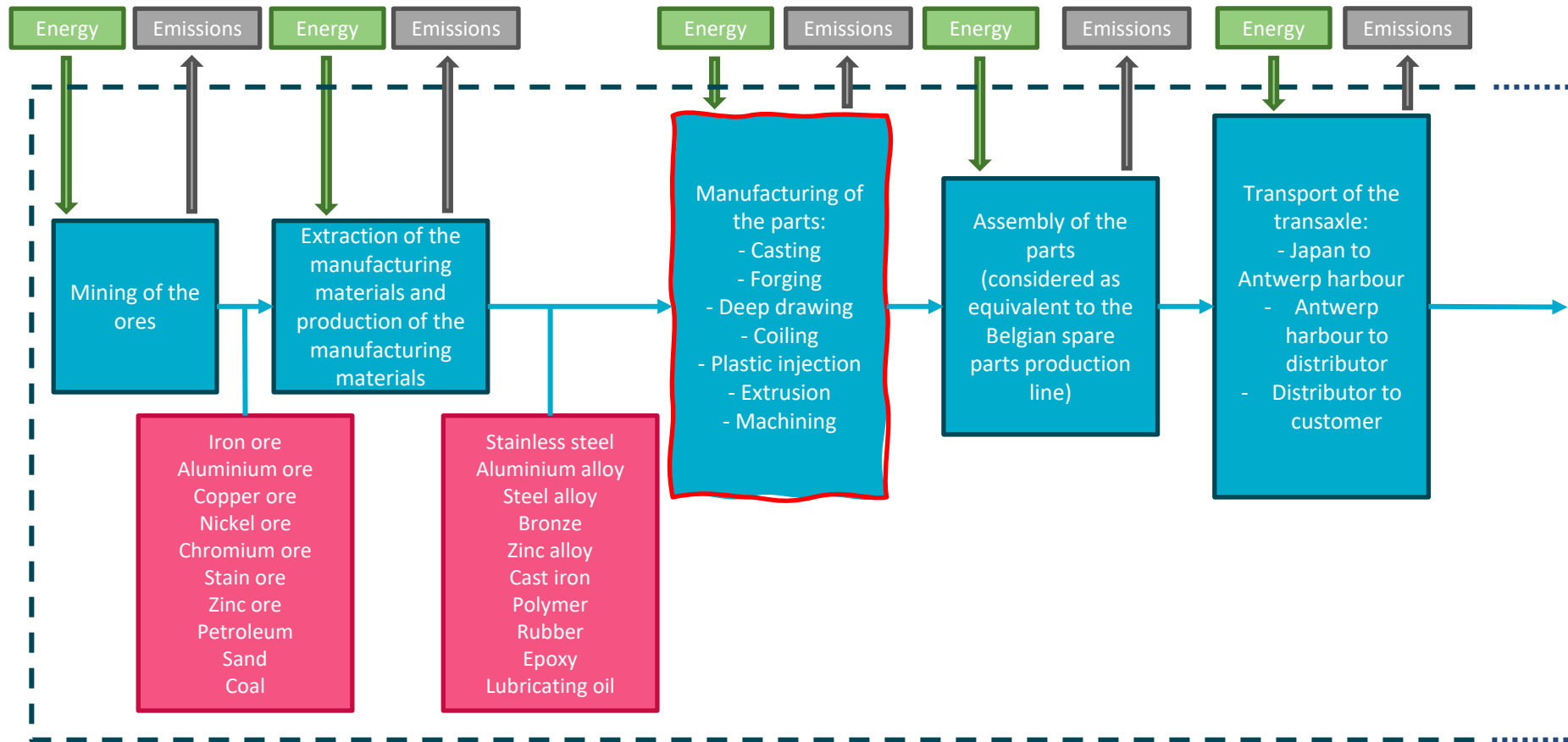
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System boundaries



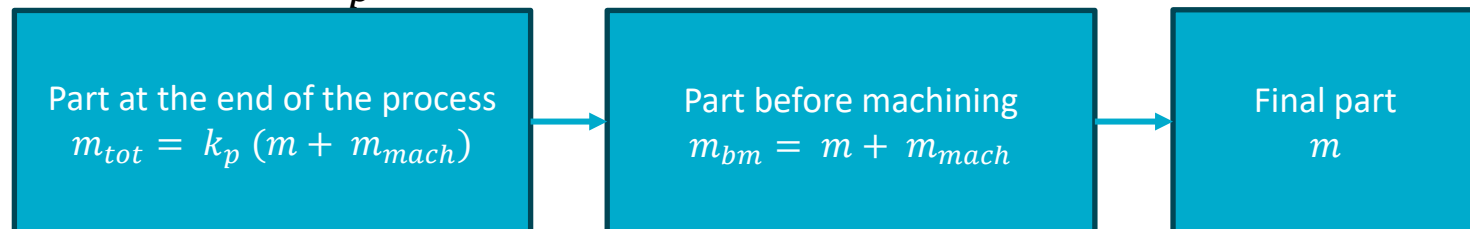
Production of the new transaxle (Japan)

- For all the parts



LCI of a new transaxle

- Access to the tree of the transaxle
 - Mass and quantity of each component
 - Analysis of the plans of the parts to extract the information relative to material and manufacturing process
 - After material inventory
 - Total mass of the transaxle (T/C + A/T + V/B + lubricating oil + ...): $O(100)$ kg
 - Difference: 99,905 % of mass accounted for
- For a given steel, aluminium or cast iron part
 - Casting and forging: $k_p = 10/7$
 - Deep drawing: $k_p = 10/9$
 - Other processes: $k_p = 1$



LCI of a new transaxle

Materials... For 100 kg of transaxle

Material	Manufacturing materials (kg)	Raw parts (kg)	Finished parts (kg)
Steel alloy	80.94	62.64	45.89
Cast iron	21.63	16.90	12.38
Stainless steel	10.08	7.03	5.15
Aluminium	41.20	29.66	27.26
Copper	0.86	0.86	0.86
Bronze	0.04	0.04	0.04
Composite	0.38	0.38	0.38
Zinc	0.00	0.00	0.00
Glass fiber	0.01	0.01	0.01
Rubber	0.28	0.28	0.28
Polymer	1.09	1.09	1.09
Oil	/	/	5.39
Others	/	/	1.27
Sum	/	/	100.00

LCI of a new transaxle

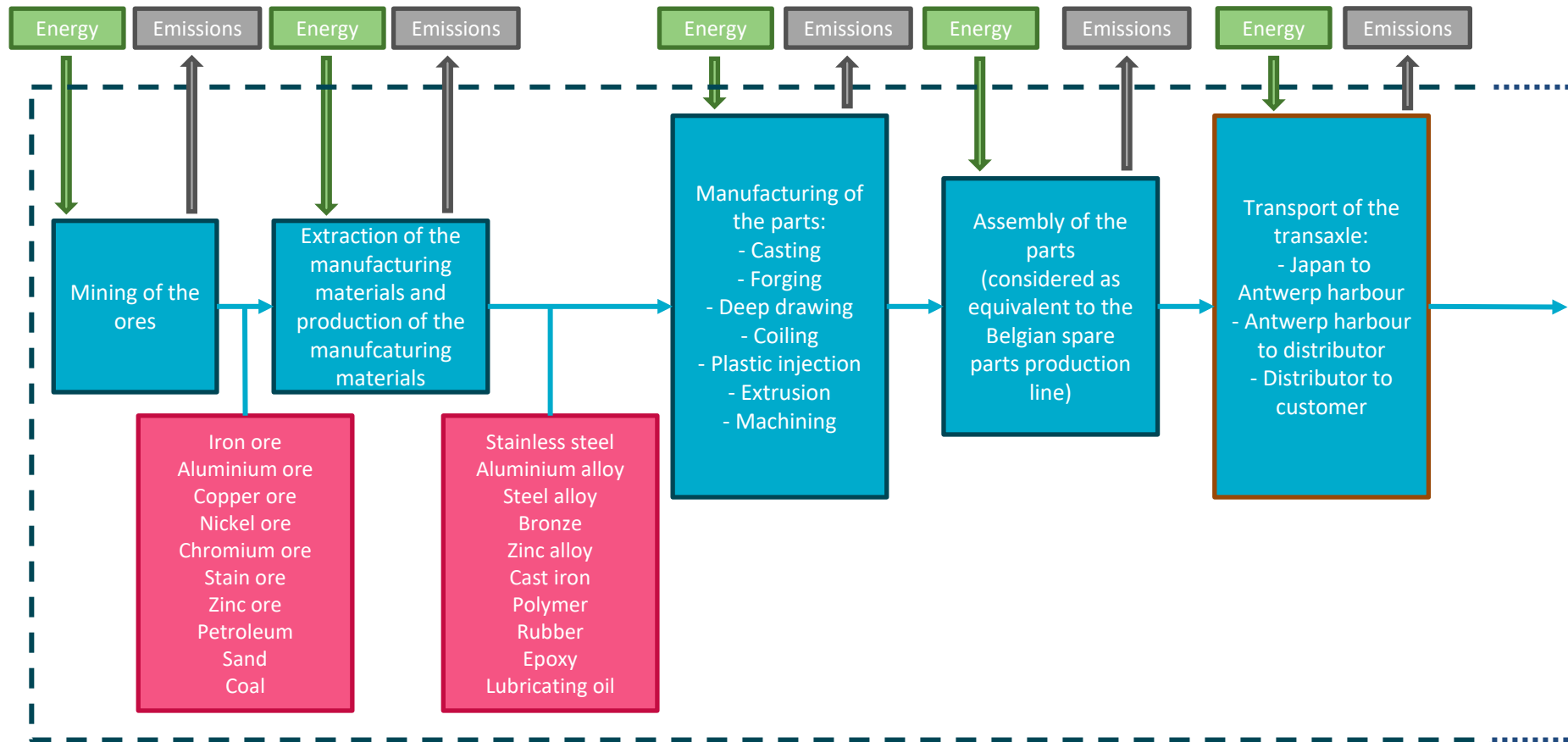
Processes for 100 kg of transaxle

Material	Process	Quantity of material (kg)
Steel alloy, Cast iron and Stainless steel	Casting	30.00
	Forging	51.27
	Deep drawing	16.92
	Rolling	2.00
	Coiling	1.02
	Tube bending	0.13
	Extrusion	9.79
	Bolt	1.50
	Machining	23.15
Aluminium	Casting	39.92
	Forging	0.17
	Rolling	1.11
	Machining	1.58

...Etc.

Production of the new transaxle (Japan)

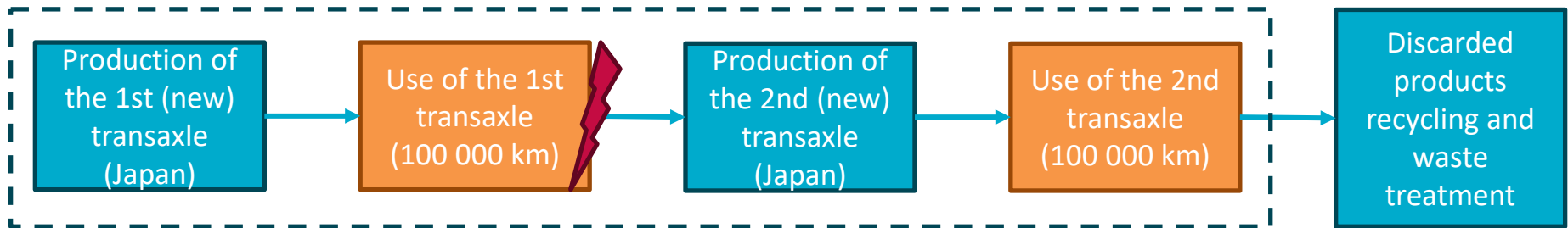
- For all the parts



Product system

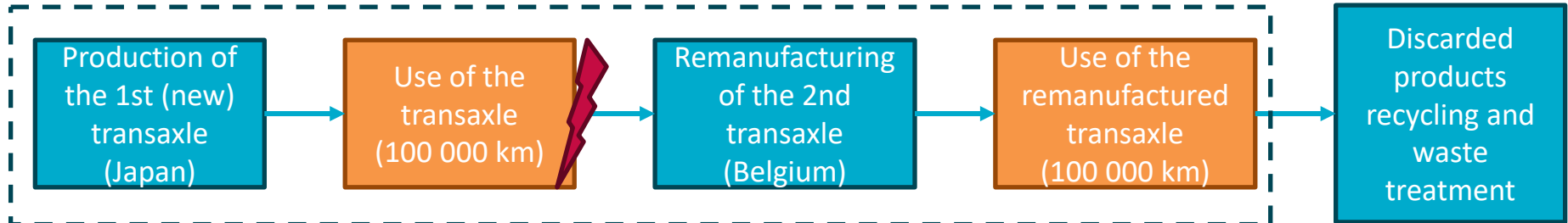
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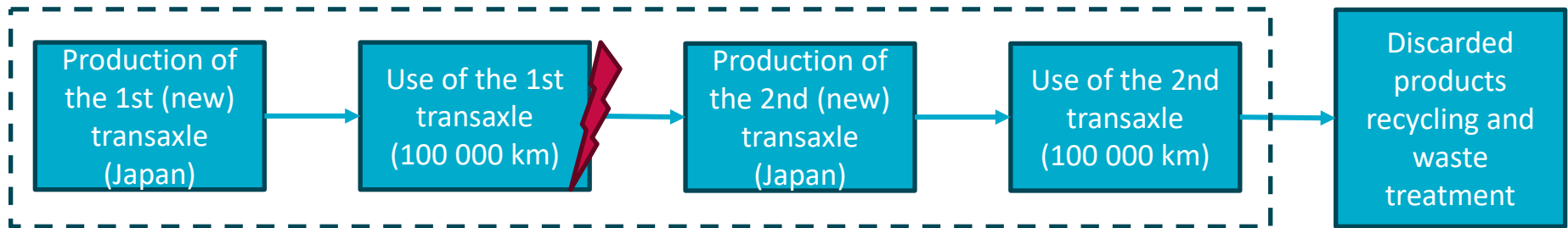
System boundaries



Product system

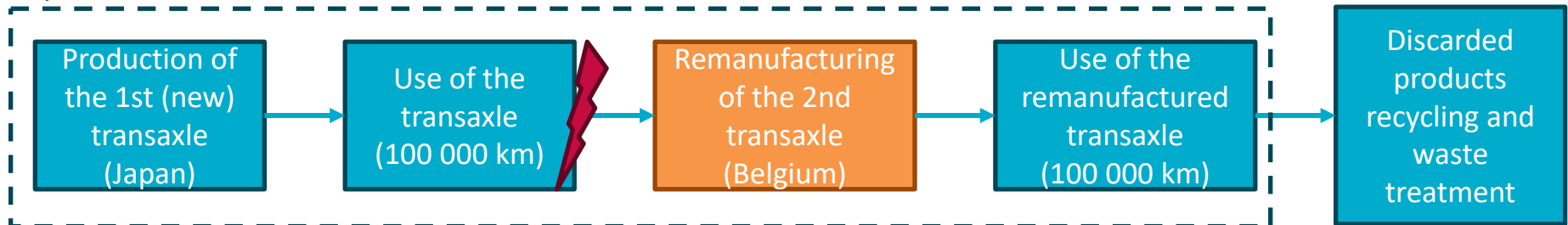
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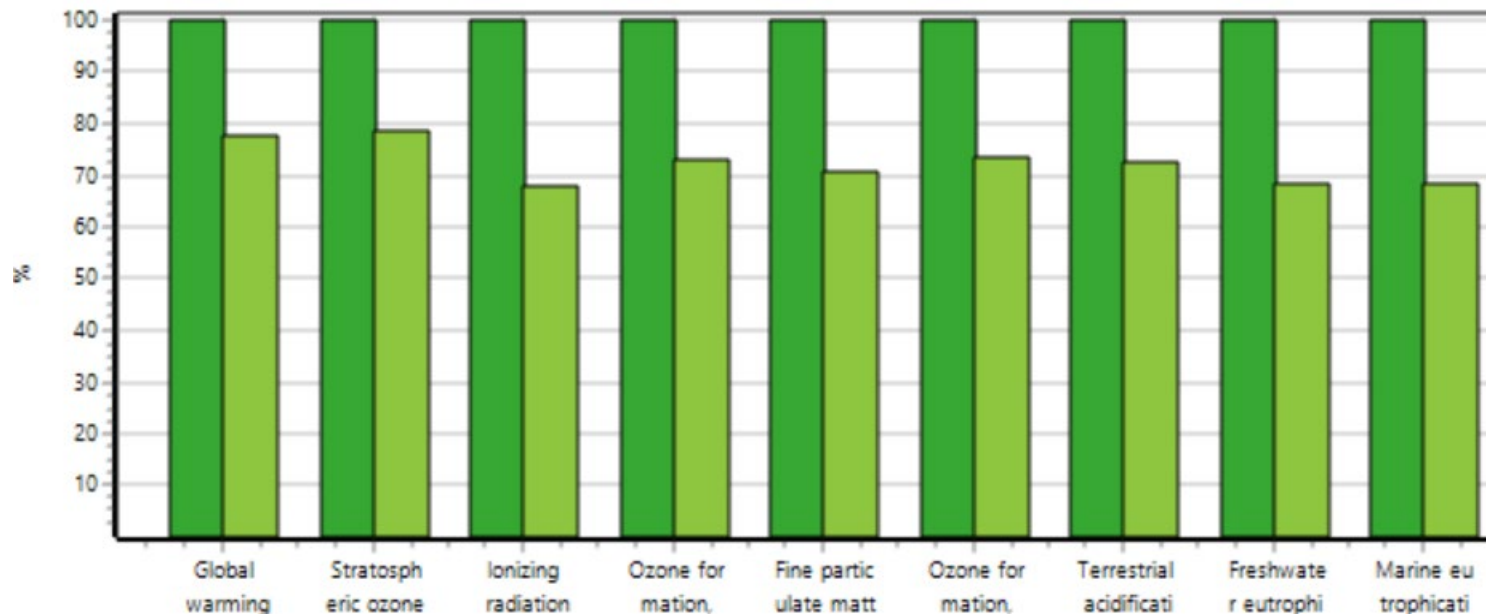
System boundaries



Impact assessment

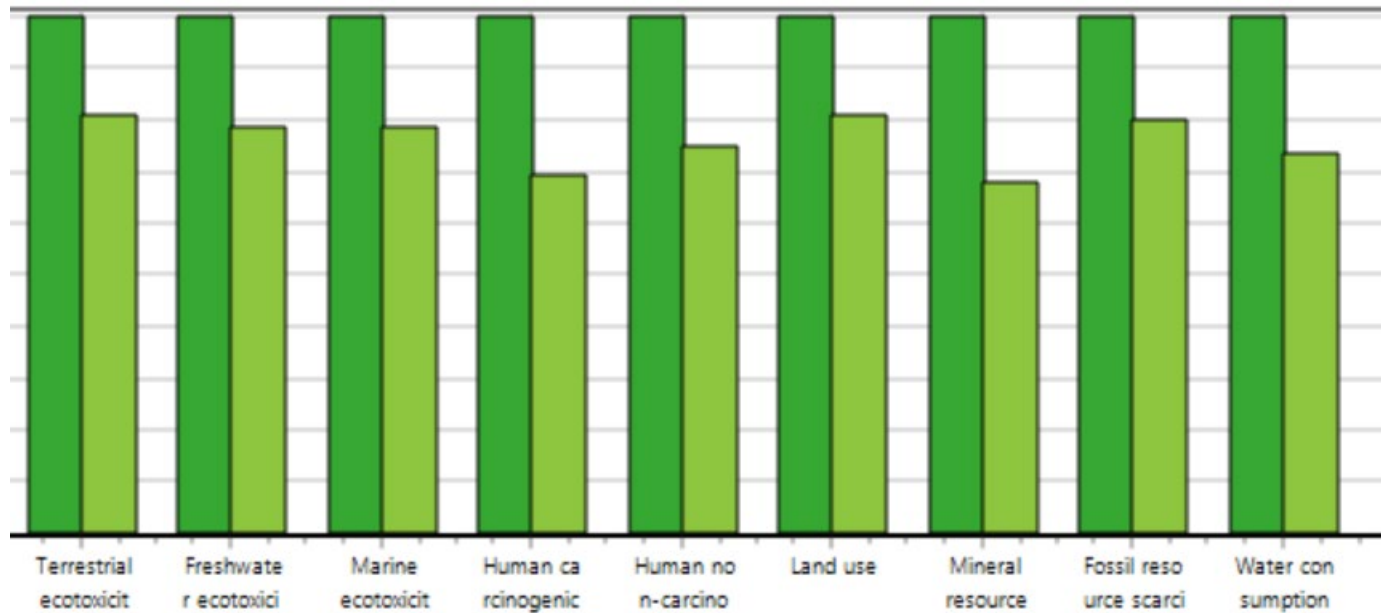
Global results

- First: As a global point of view
- Over the entire lifespan of the transaxle, choosing the remanufacturing reduces the environmental impact by 20-30%



Impact assessment

Global results (cont'd)



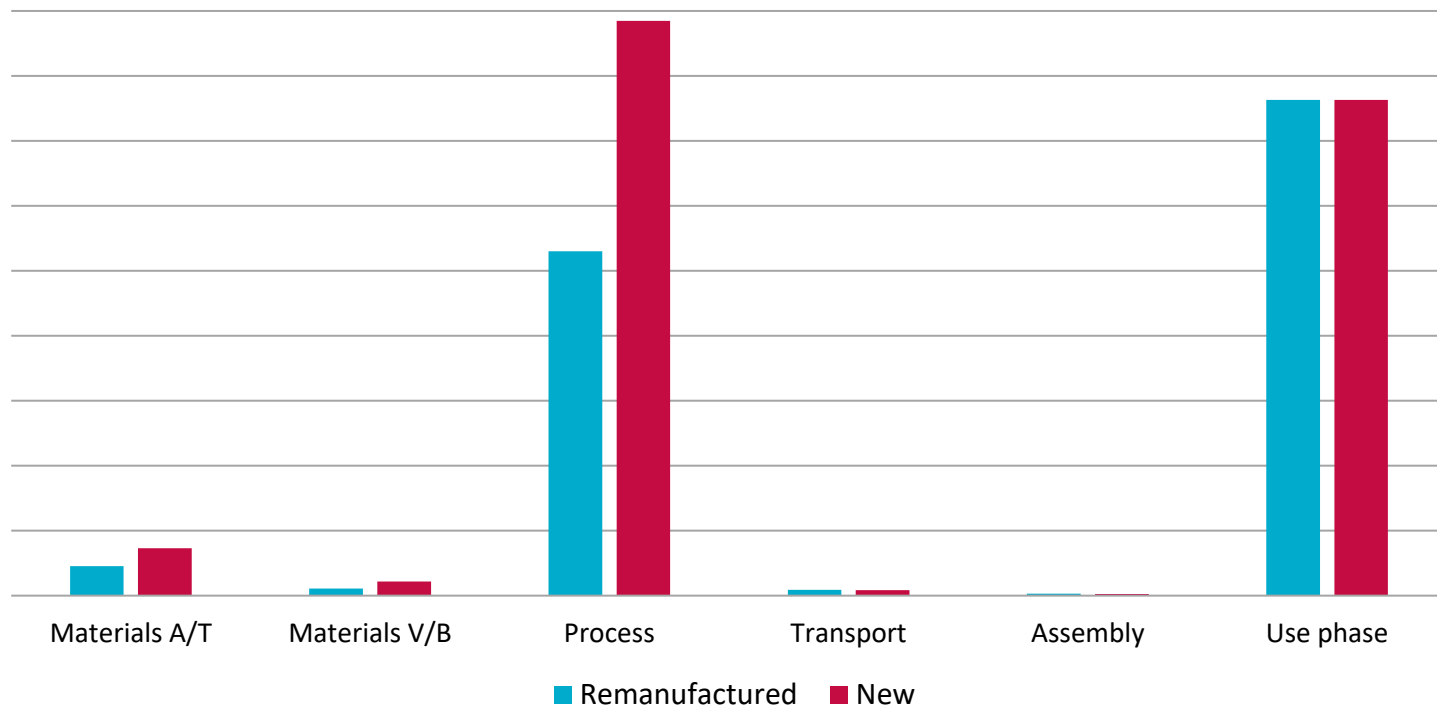
Impact assessment

Contributions of the steps

- Focus on Climate change (eq-kg CO₂) over full life (2 transaxles)

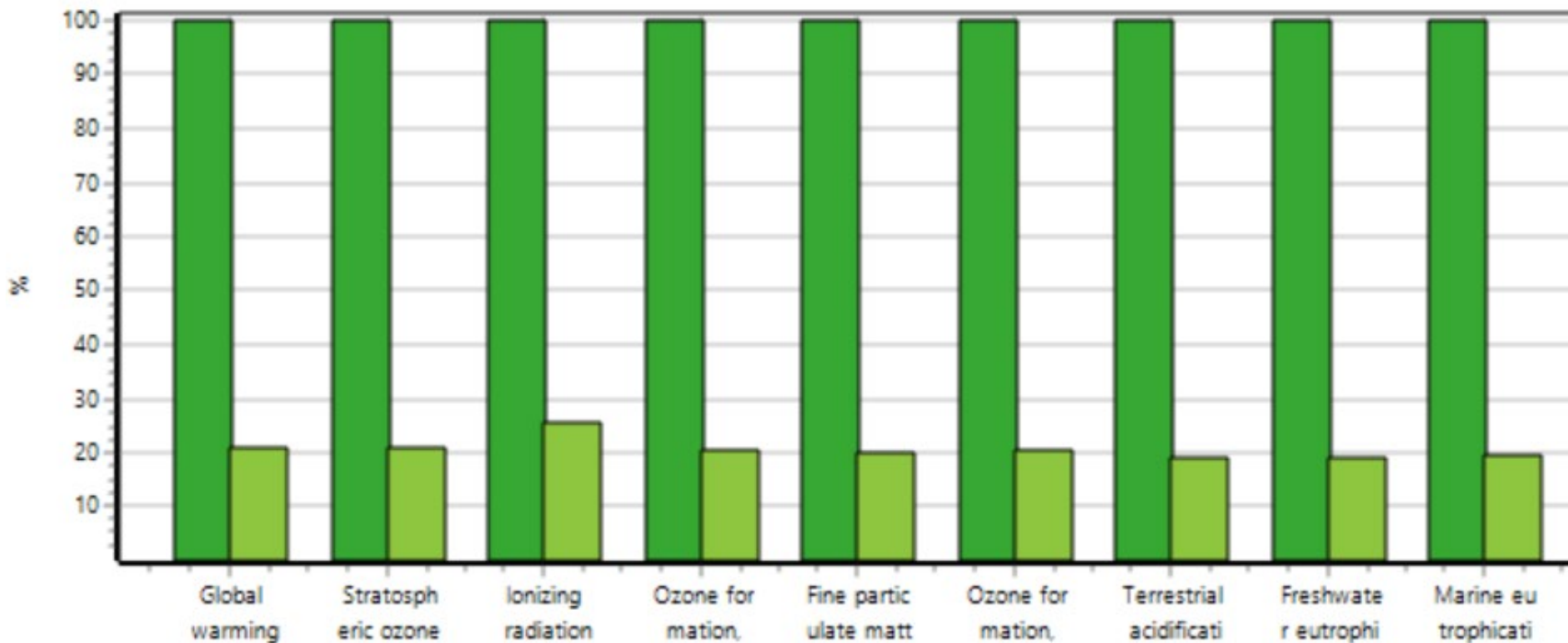
Impact on Climate Change (eq-kg CO₂) for each life cycle step of remanufactured and new transaxles

O(10k eq-kg CO₂)

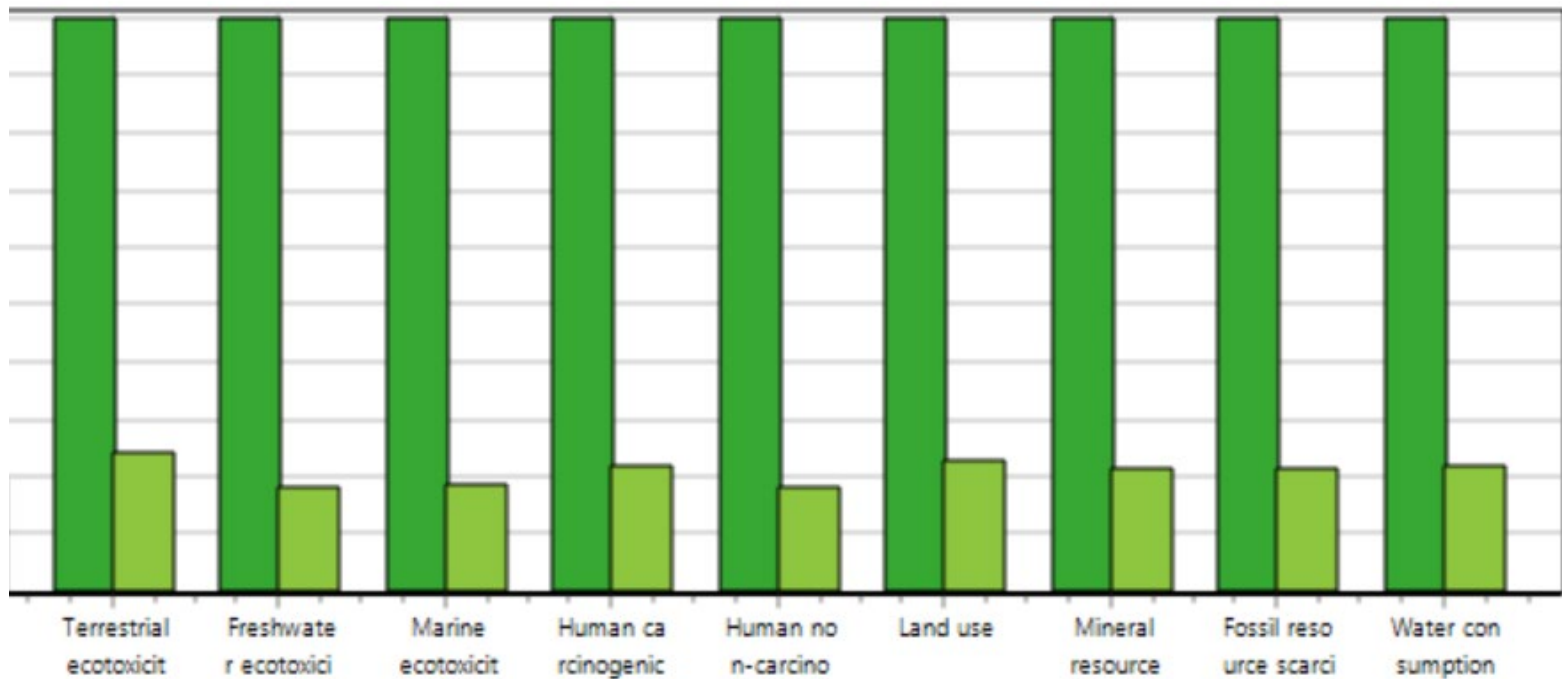


Impact assessment – Results

- Comparison: production of a 2nd transaxle, vs. reman of 1st
- Remanufacturing has approximately an environment impact 4 to 5 times lower than new transaxle production



Impact assessment – Results (cont'd)



So we can have a multicriterion approach...

... We can evaluate the resilience of an operational decision...

... We can evaluate its environmental impact...

But what's the human-centricity business?

A human-centric maintenance?



Factories



Hospitals



Emergency
responses

Reduced well-being: **turnover**, **absenteeism**, **burn-out**, **musculoskeletal disorders**, etc.

Prolonged cycle
times

Human error
probability

Increased
probability of
nursing errors

Can cost lives

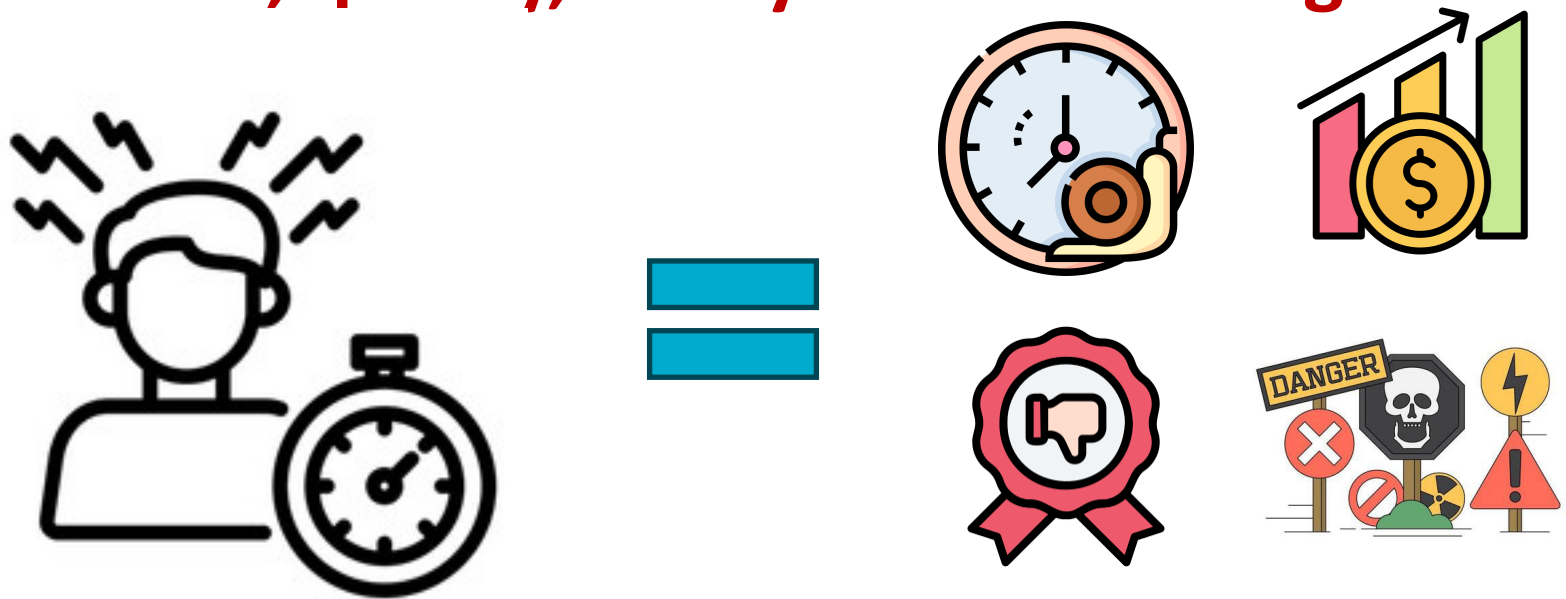
[1] Griffith, C. D. & Mahadevan, S. Inclusion of fatigue effects in human reliability analysis. *Reliab. Eng. Syst. Saf.* **96**, 1437–1447 (2011)

[5] Hafiz, W. S. et al. Developing a Fatigue Detection Model for Hospital Nurses Using HRV Measures and Machine Learning. *Safety* **11**, 48 (2025)

[6] Asadayoobi, N., Taghipour, S. & Jaber, M. Y. Optimising stochastic task allocation and scheduling plans for mission workers subject to learning-forgetting, fatigue-recovery, and stress-recovery effects. *Expert Syst. Appl.* **229**, 120524 (2023)

Images générées par Gemini

Treating a **worker** like a **robot** is not just an **ethical problem**: it is a **mistake** paid for in **time**, **cost**, **quality**, **safety** and **well-being**



[1] Griffith, C. D. & Mahadevan, S. Inclusion of fatigue effects in human reliability analysis. *Reliab.Eng. Syst. Saf.* **96**, 1437–1447 (2011)

[4] Philip, P. & Akerstedt, T. Transport and industrial safety, how are they affected by sleepiness and sleep restriction? *Sleep Med. Rev.* **10**, 347–356 (2006)

An ongoing work

Coming Soon! to your scheduling method

The need:

Scheduling based on an empirical **in-field** estimate of the operator's state

The method:

Ethically building a **digital operator twin** in the lab, and comparing **break-placement** strategies

The ambition:

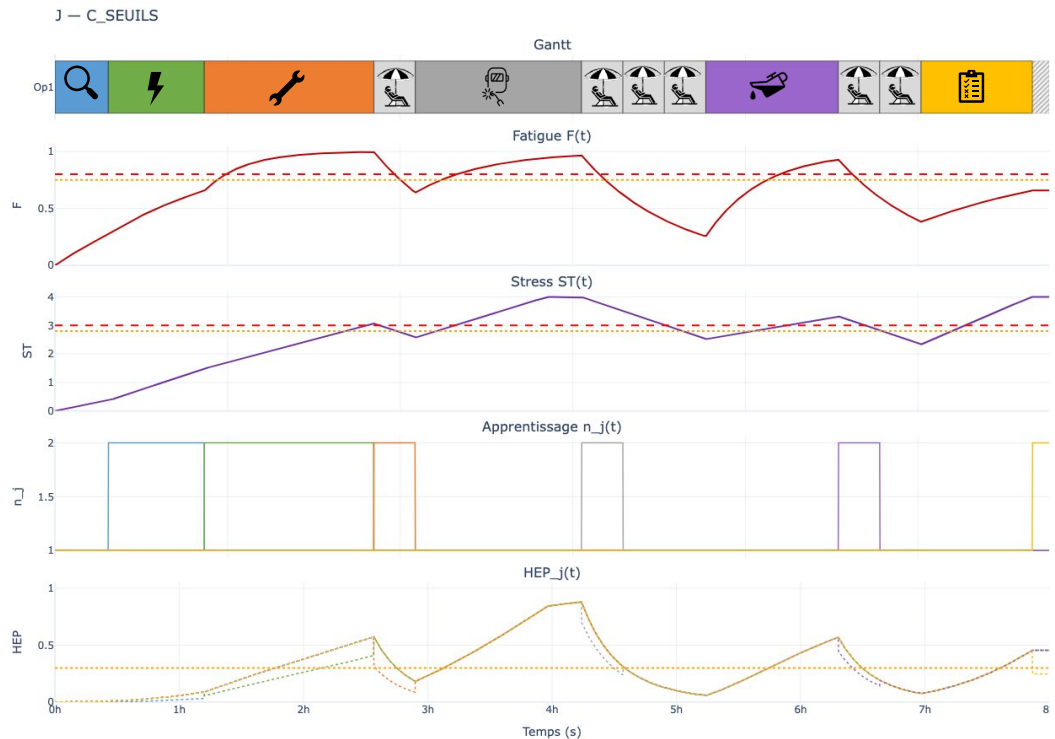
A **non-invasive** physiological **sensor** and control **software**, usable within the next 5 to 10 years

First numerical results

Numerical implementation of
three behavioral models
integrating learning, fatigue,
and stress

Transfer of the framework to
an industrial case:
maintenance of bogies in a
workshop

Design of a conditional
scheduling policy using **fatigue**
thresholds as break triggers



Human-aware conditional schedule for one maintenance worker
accompanied by fatigue, stress and learning rates and HEP
evolutions w.r.t time

Industry 5.0 is sustainable, resilient & human-centric

These are the characteristics of our future, built on our past and present experience.

So now, you can tell me...

Are you running your plant like a hospital that forgot COVID?



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