LIFE-CYCLE ASSESSMENT OF AN OFFICE BUILDING: INFLUENCE OF THE STRUCTURAL DESIGN ON THE EMBODIED CARBON EMISSIONS

Global Research and Development

06/06/2024

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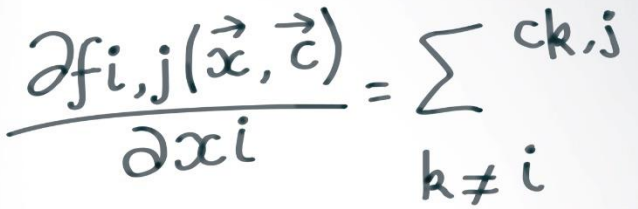


SUSTAINABLE PLACES 2024

Presentation Outline:

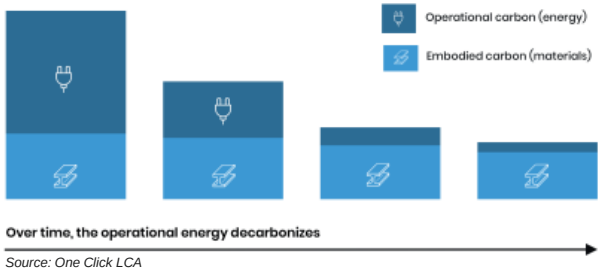
SUSTAINABLE PLACES 2024

1. INTRODUCTION
2. METHODOLOGY
3. RESULTS AND INTERPRETATION
4. CONCLUSION

INTRODUCTION:

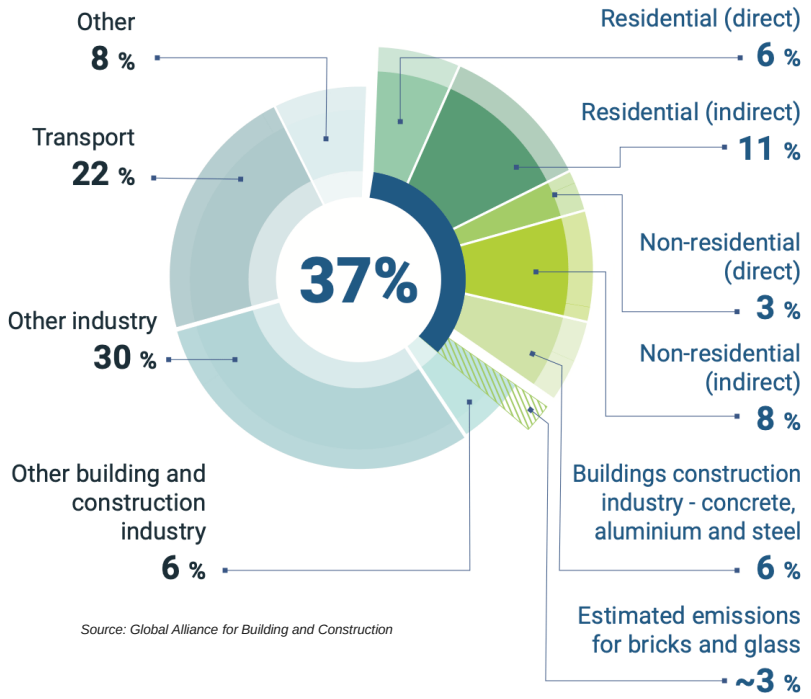
Environmental emergency

- 37% of the global share of energy-related CO_2e emissions were attributed to buildings and the construction sector.
- Efforts have been brought to reduce the operational carbon footprint of buildings by improving their energy efficiency



Source: One Click LCA

- Awareness has also been raised on embodied carbon. Emissions from materials and products must be urgently addressed to ensure constructions are optimized as low-carbon solutions.



Source: Global Alliance for Building and Construction

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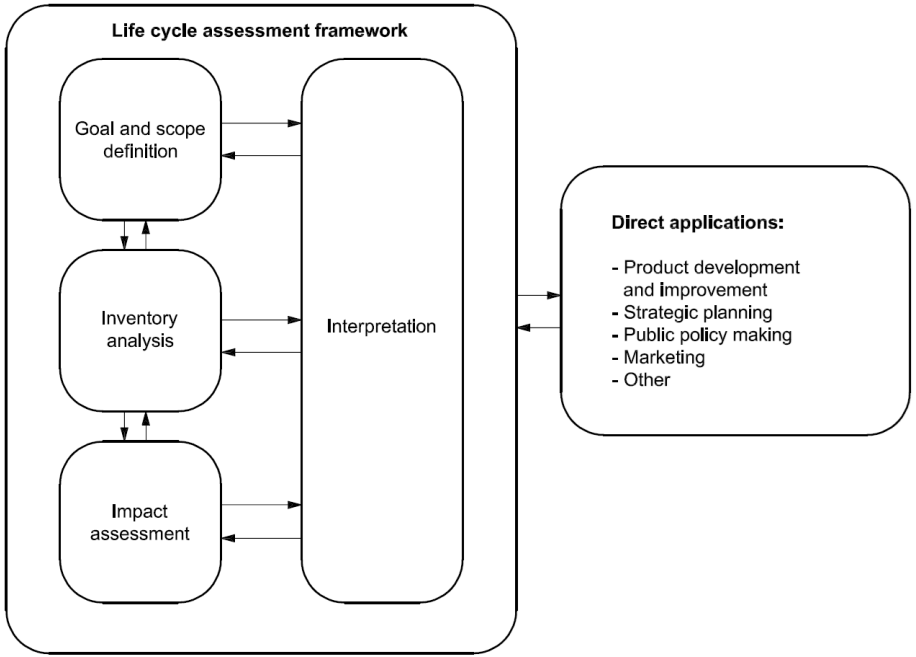
METHODOLOGY:

Life-cycle Assessment (LCA):

- LCA is a scientific and quantitative method for determining and assessing environmentally relevant processes.

- The ISO 14044 Environmental management — Life cycle assessment — Requirements and guidelines define the steps that shall be followed for LCA:
  - Goal and Scope;
  - Life Cycle Inventory (LCI)
  - Life Cycle Impact Assessment (LCIA);
  - LCA Interpretation;



Source: ISO 14040

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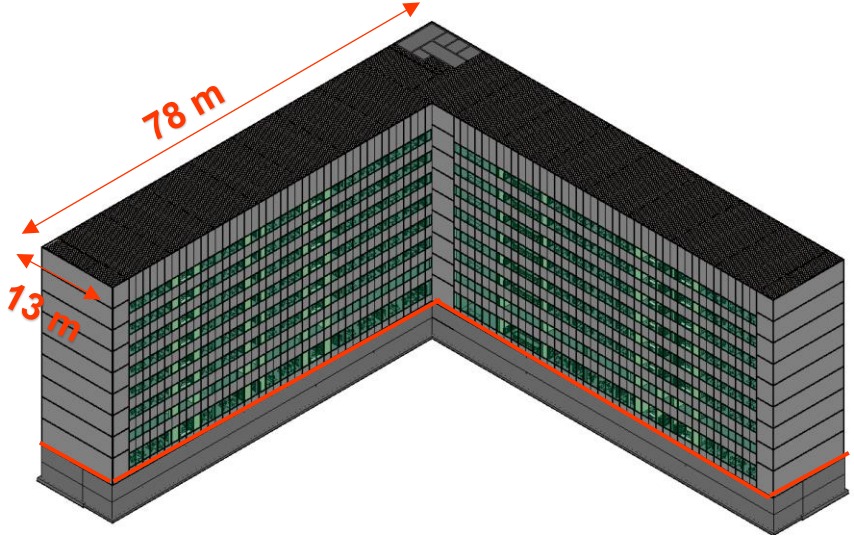
Goal and Scope:

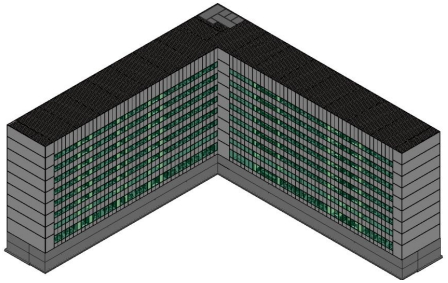
- **Goal:**
  - The goal of this study is to assess the embodied carbon of equivalent structural options, composed of different materials, of a given office building located in Luxembourg for a reference service life of 50 years.

Functional unit	One L shaped office building with a gross floor total area (GFA) of 15552 m^2 located in Luxembourg over a 50-year analysis period
Reference unit	m^2.
Location	LU
Quantification	Material content as defined by the design office Schroeder & Associés.

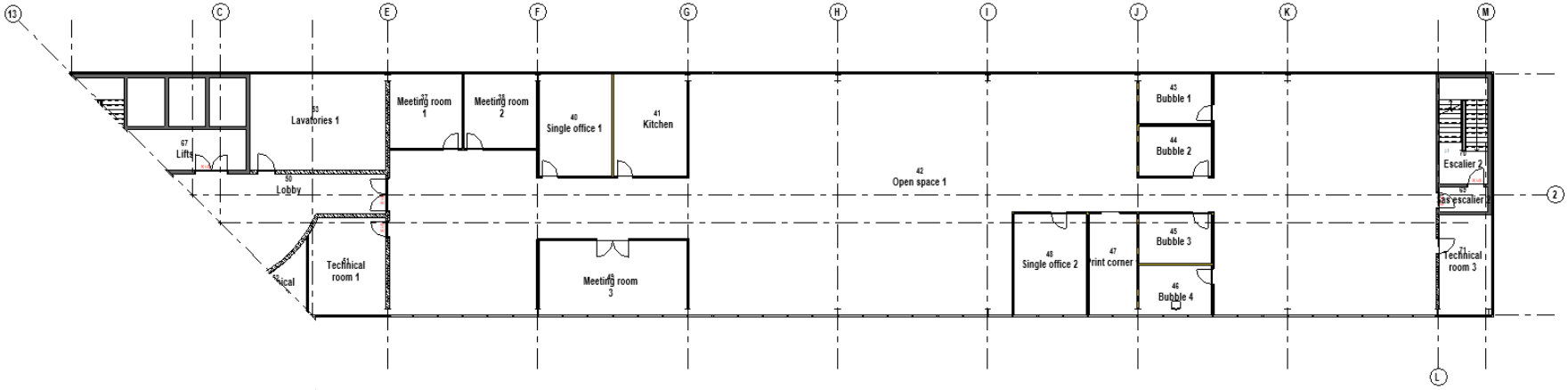


Dimension	Value
Building depth [m]	13.60
Building length [m]	78.15
Superstructure number of levels	R + 8
Infrastructure number of levels	2
Free height on the ground floor [m]	3.5
Free height on the intermediate floors [m]	2.7

Goal and Scope:



- **Object of assessment (Product description):**



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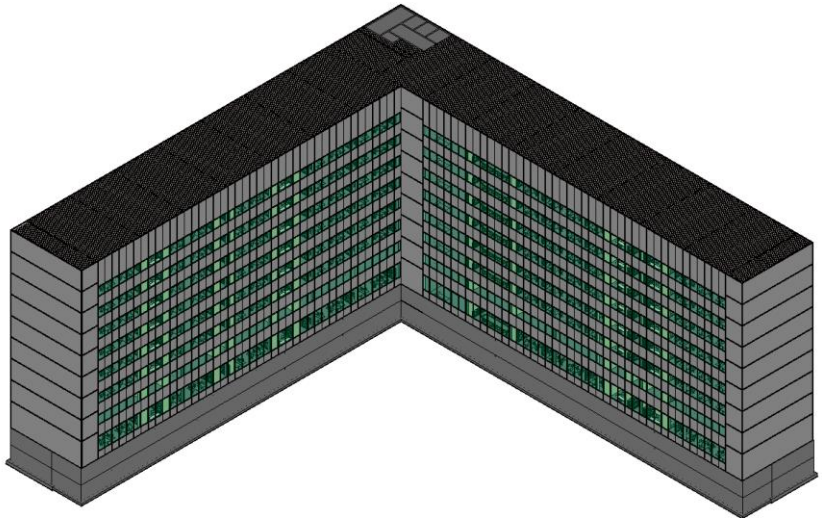
Goal and Scope:

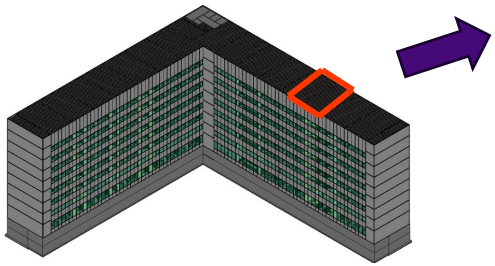
- **Object of assessment (Product description):**
  - Three structural alternatives for the office building structure were studied:
    - Composite steel-concrete option;
    - Prefabricated reinforced concrete option;
    - Timber option;
  - The structural design was conducted by the Luxembourgish office Schroeder & Associés;
  - The functional equivalency of these solutions is ensured by adopting the same boundary conditions such as design assumptions, building location, soil condition, safety requirements, and actions on the structure;

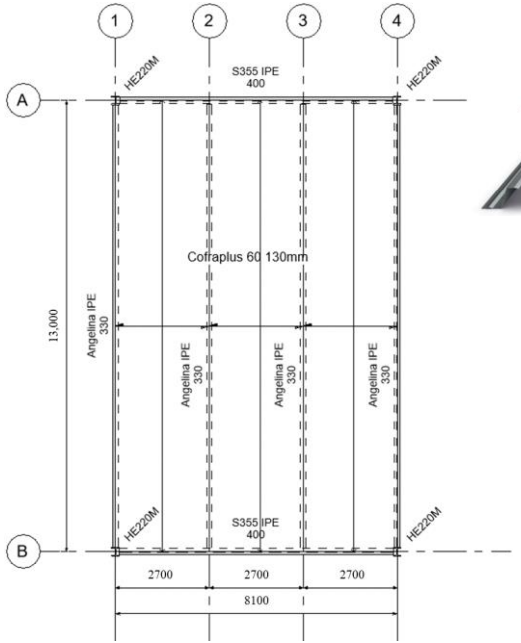


Goal and Scope:

- **Object of assessment (Product description):**
  - 8.1 m by 13 m (clear span) for the composite steel–concrete option;

Structural Elements	Steel Composite
Slab	Cofraplus® 60 [1] 130 mm
Beams	A/B [1]: IPE 400 1/2/3/4 [2]: Angelina IPE 300
Columns	A/B [1]: HEM 200
Grid	8.1 × 13 m





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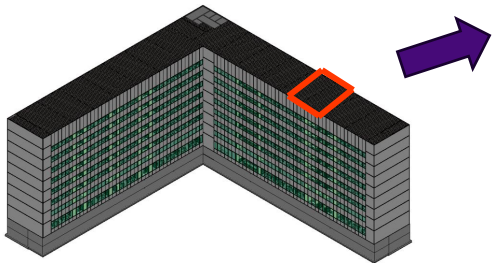
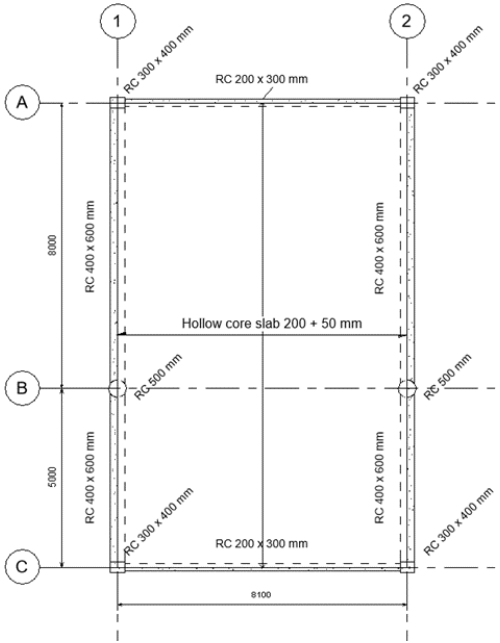
Goal and Scope:

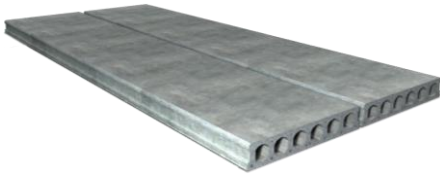
- **Object of assessment (Product description):**
  - 8.1 m by 5 m + 8 m (with intermediate columns) for the prefabricated reinforced concrete option;

Structural Elements	Reinforced Concrete
Slab	Prestressed prefab hollow core slab 200 + 50 mm
Beams	A/C [2]: 200 × 300 mm 1/2 [3]: 400 × 600 mm
Columns	A/C [2]: 300 × 400 mm B [4]: d = 500 mm
Grid	8.1 × 5 + 8 m





Echo Precast Engineering



EPD Ireland: Quinn Hollowcore Slabs

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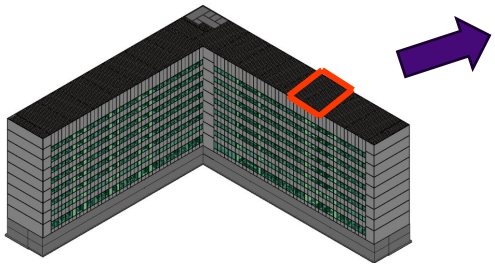
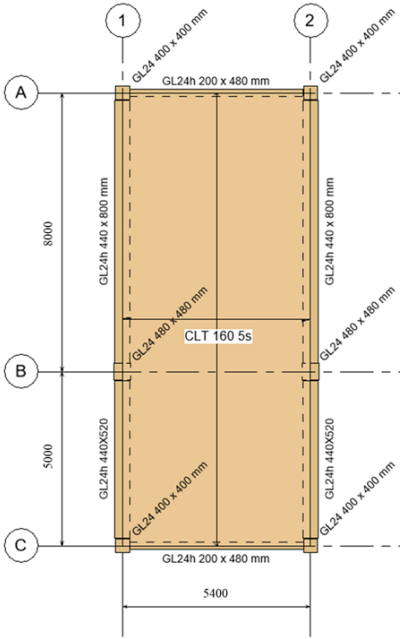
Goal and Scope:

- **Object of assessment (Product description):**
  - 5.4 m by 5 m + 8 m (with intermediate columns) for the timber options;

Structural Elements	Timber
Slab	CLT panel 160 mm
Beams	A/C [2]: 200 × 480 1/2 [3]: 440 × 800
Columns	A/C [2]: 400 × 400 mm B [4]: 480 × 480 mm
Grid	5.4 × 5 + 8 m





LEVER Architecture

https://oxleytrade.com.au/product/clt-cross-laminated-timber/

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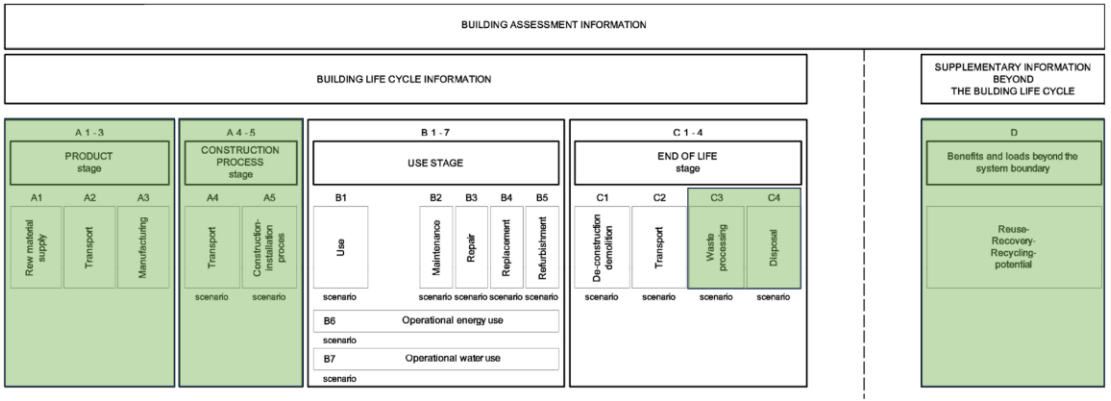
Goal and Scope:

- **System Boundaries:**
  - The EN 15978 set out a common life cycle model for construction works. The life cycle model includes modular definitions for the life cycle stages, allowing each stage to be compared in isolation with other projects.
  - Product Stage – A1-A3;
  - Construction Process Stage – A4-A5;
  - End of Life – C3-C4
  - Benefits and loads outside the systems boundaries – D.



Source: EN 15978

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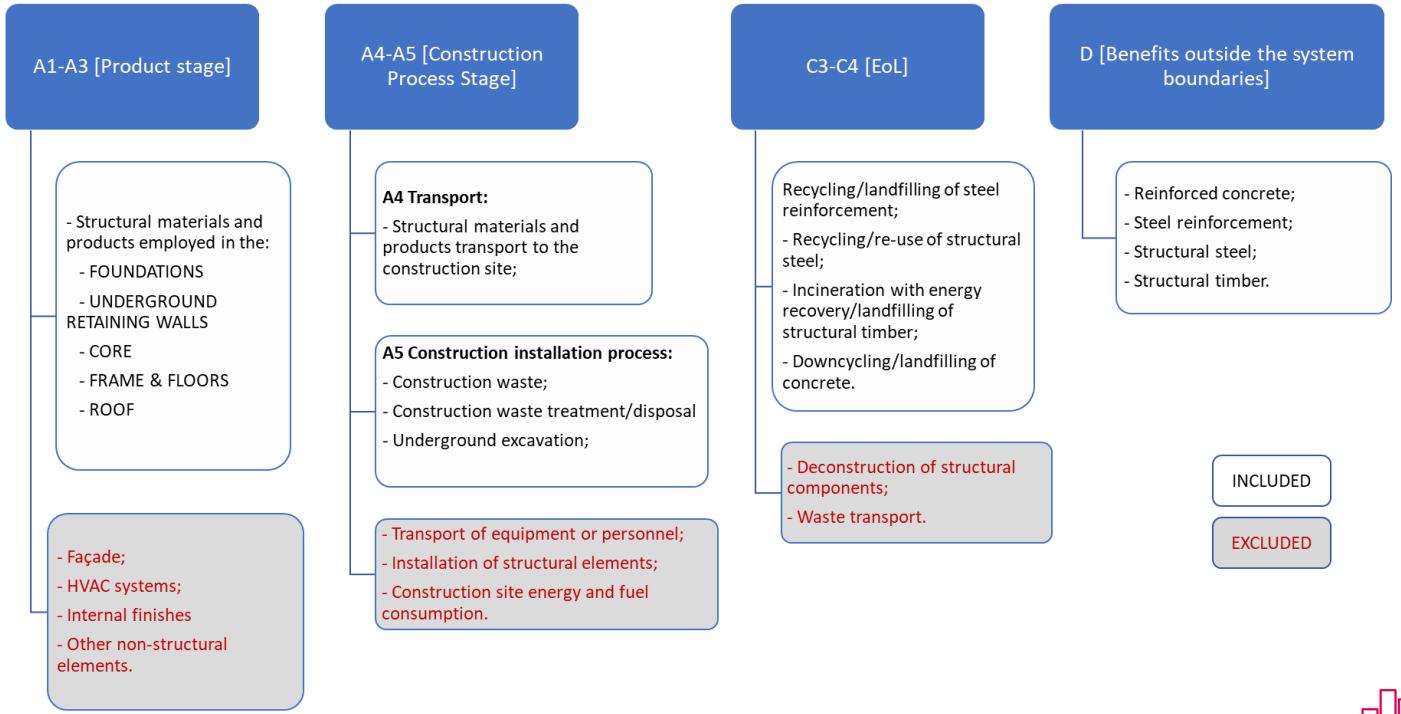
Goal and Scope:

- **System Boundaries:**



Goal and Scope:

- **Time coverage:**
  - The study represents a hypothetical initial construction in 2022 and continued use of the office building for 50 years.
- **Technology Coverage:**
  - Technologies are representative of Luxembourg and Europe for manufacturing the structural materials, and the construction of the office building. Current technologies have been applied to future end-of-life.
- **Geographical Coverage:**
  - Design assumptions, background data on environmental impacts, and life cycle assessment scenarios were intended to represent an office building construction in Luxembourg. The results of this study are only applicable to the location, the boundary conditions and LCA scenarios considered.

- **Allocation**
  - Co-product allocation was not necessary for the foreground processes, as there are no co-products known or considered in the construction of the office building.
  - For all background data used in the model, the standard allocation assumptions of the used datasets were maintained.
- **Cut-off criteria:**
  - No cut-off criteria were applied in this study.

Goal and Scope:

- **Selection of Life Cycle Impact Assessment Methodology and Types of Impacts:**
  - Global warming potential (GWP) was chosen because of its relevance to climate change. Climate change is of high public and institutional interest and is deemed to be one of the most pressing environmental issues of our times.
  - For GWP, the characterization factors from EC-JRC were applied (EN15804+A1/A2). (Environmental Footprint (EF).
  - In EN 15804+A1, GWP is presented as a single indicator, whereas in EN 15804+A2, GWP-total is divided into three sub-indicators: GWP-Fossil, GWP-Biogenic, and GWP-luluc.
  - A partial compatibility is guaranteed by:
    - The global warming potential impacts caused by fossil fuels are remarkably similar between the different standards and characterization methodologies;
    - Biogenic carbon storage (negative carbon impact) is separated from the GWP in EN 15804+A1 data.
    - Then:
      - If and EPD as per EN 15804+A2 is used, then: GWP = GWP-fossil
      - If an EPD as per EN 15804+A1 is used, then: GWP = GWP – biogenic carbon storage.

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Goal and Scope:

- **Assumptions (scenarios):**
  - **Transport A4**

Material	Transport Type	Distance [km]
Structural steel	Trailer combination, 40-ton capacity, 100% fill rate	370
Steel rebars	Trailer combination, 40-ton capacity, 100% fill rate	370
Reinforced concrete	Concrete mixer truck, appr. 8 m^3, 100% fill rate	60
Timber	Trailer combination, 40-ton capacity, 100% fill rate	220

  - **Construction A5 (waste)**

Material	Percentage %
Structural steel	3.3
Steel rebar	4.85
Reinforced concrete	4
Timber	16.7

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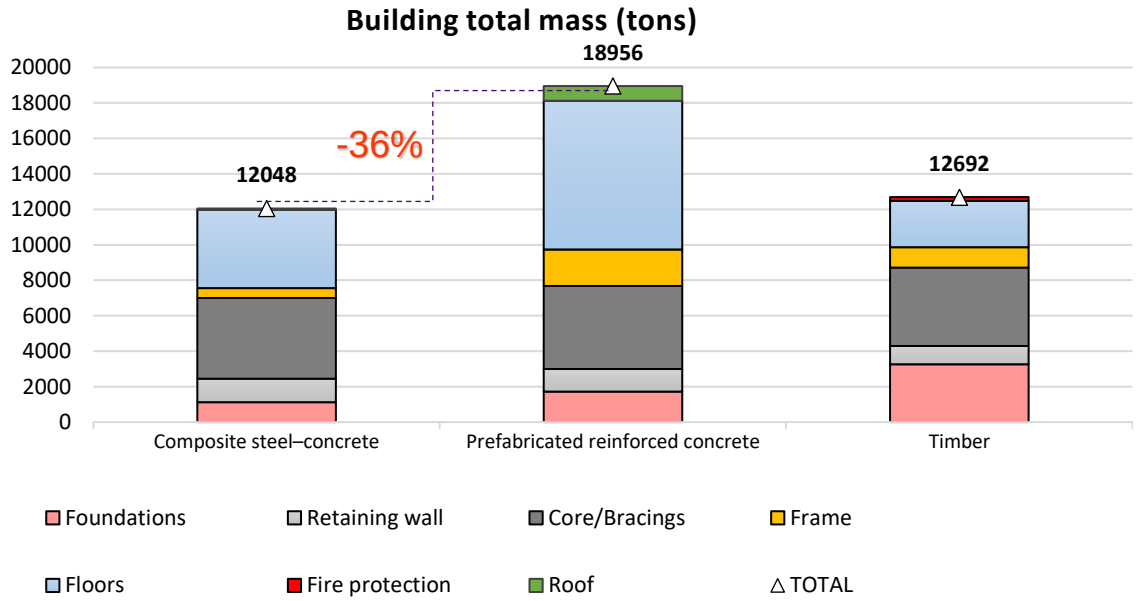
Goal and Scope:

- **Assumptions:**
  - **EOL C3-C4**

Structural Elements	Landfill %	Re-Use %	Recycling %	Downcycling %	Incineration with Energy Recovery %
Structural steel sections	1	11	88	-	-
Hot-dip galvanized carbon steel	2	-	98	-	-
Steel reinforcement bars	10	-	90	-	-
Reinforced concrete	25	-	-	75	-
Timber	-	-	-	-	100

Life Cycle Inventory (LCI):

- **Building mass:**



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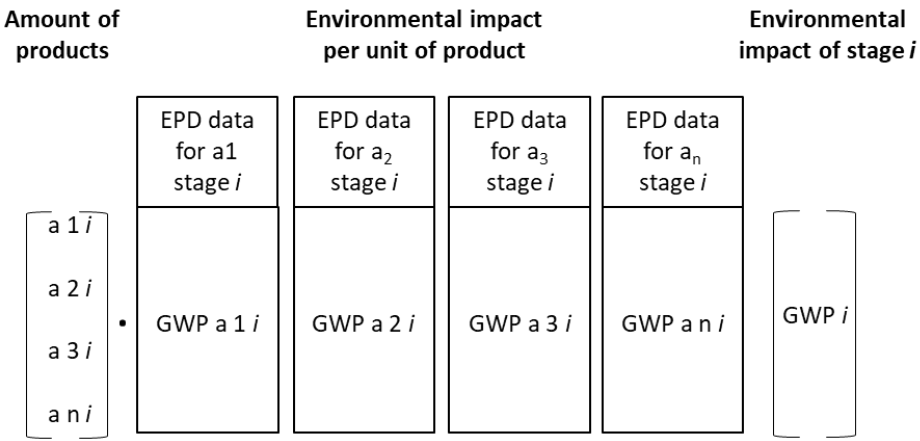
Life Cycle Inventory (LCI):

- **Material and Products – Datasets (Environmental Product Declaration):**

Product/Material	Dataset name	Compliance system name	Year	Geography	Upstream database
Structural steel sections	EPD, XCarb® recycled and renewably produced structural steel sections and merchant bars, ArcelorMittal Europe	EN 15804+A1	2023	RER	GaBi
Structural steel sections	EPD, structural steel sections in HISTAR grades, ArcelorMittal	EN 15804+A1	2017	RER	GaBi
Hot-dip galvanized carbon steel	EPD, XCarb® recycled and renewably produced hot dip galvanized steel with Magnelis® coating, ArcelorMittal	EN 15804+A2	2023	RER	GaBi
Steel rebar	EPD, XCarb® reinforcing steel in bars, ArcelorMittal Europe	EN 15804+A1	2021	RER	GaBi
Steel rebar	EPD, reinforcing steel in bars, ArcelorMittal	EN 15804+A1	2016	RER	GaBi
Ready-mix concrete C30/37	One Click LCA	EN 15804+A2	2022	LU	Ecoinvent
Ready-mix concrete C40/50	One Click LCA	EN 15804+A2	2022	LU	Ecoinvent
Ready-mix concrete C50/60	One Click LCA	EN 15804+A2	2022	LU	Ecoinvent
CLT	EPD, cross-laminated timber (X-Lam), Studiengemeinschaft Holzleimbau e.V.	EN 15804+A1	2017	DE	GaBi
GluLam	EPD, binderholz Glulam—binderholz Bois lamelle-colle BSH—Legno lamellare BSH binderholz—binderholz BSH glulam	EN 15804+A1	2019	DE	GaBi

Life Cycle Impact assessment (LCIA):

- **Calculation matrix & GWP emission factors:**



Data Source	Material	FU	A1–A3 GWP [kg CO_2eq./FU]
EPD, XCarb® recycled and renewably produced structural steel sections and merchant bars, ArcelorMittal Europe	Structural steel sections	kg	0.33
EPD, structural steel sections in HISTAR grades, ArcelorMittal	Structural steel sections	kg	0.52
EPD, XCarb® recycled and renewably produced hot dip galvanized steel with Magnelis® coating, ArcelorMittal	Hot-dip galvanized carbon steel	kg	0.794
EPD, XCarb® reinforcing steel in bars, ArcelorMittal Europe	Steel rebar	kg	0.30
EPD, reinforcing steel in bars, ArcelorMittal	Steel rebar	kg	1.23
One Click LCA	Ready-mix concrete C30/37	m^3	270.88
One Click LCA	Ready-mix concrete C40/50	m^3	355.83
One Click LCA	Ready-mix concrete C50/60	m^3	429.00
EPD, cross-laminated timber (X-Lam), Studiengemeinschaft Holzleimbau e.V.	CLT	m^3	187.23
EPD, binderholz Glulam—binderholz Bois lamelle-colle BSH—Legno lamellare BSH binderholz—binderholz BSH glulam	GluLam	m^3	205.3

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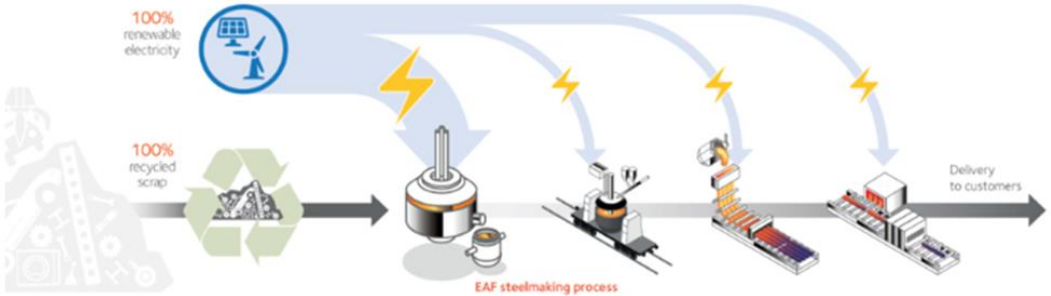
Life Cycle Impact assessment (LCIA):

- **XCarb™:**
  - ArcelorMittal's XCarb™ initiative, which emphasizes recycled and renewably sourced steel, is centered around the Electric Arc Furnace (EAF) route.
  - This approach involves using 100% recycled material combined with 100% renewable electricity.

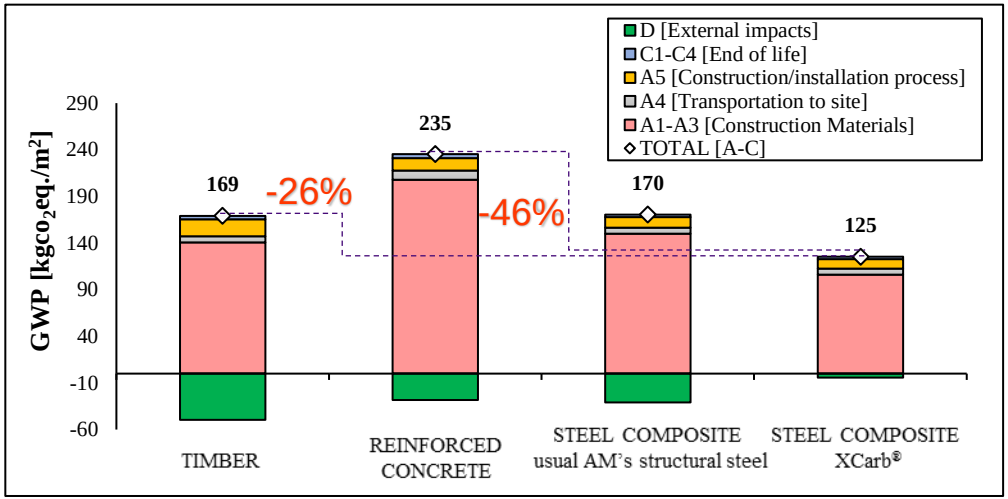


Material/Product	XCarb™ A1-A3 kgCO_2eq./kg	WorldSteel association kgCO_2eq./kg	Reduction %
Hot Rolled Steel Sections	0,33	1,91 (global production)	82,72
Steel reinforcement (rebars)	0,30	1,94 (global production)	84,53
Hot Rolled Coil	0,532	2,28 (global production)*	82,72
Metallic Coated Coil	0,797	-	-

RESULTS AND INTERPRETATION:

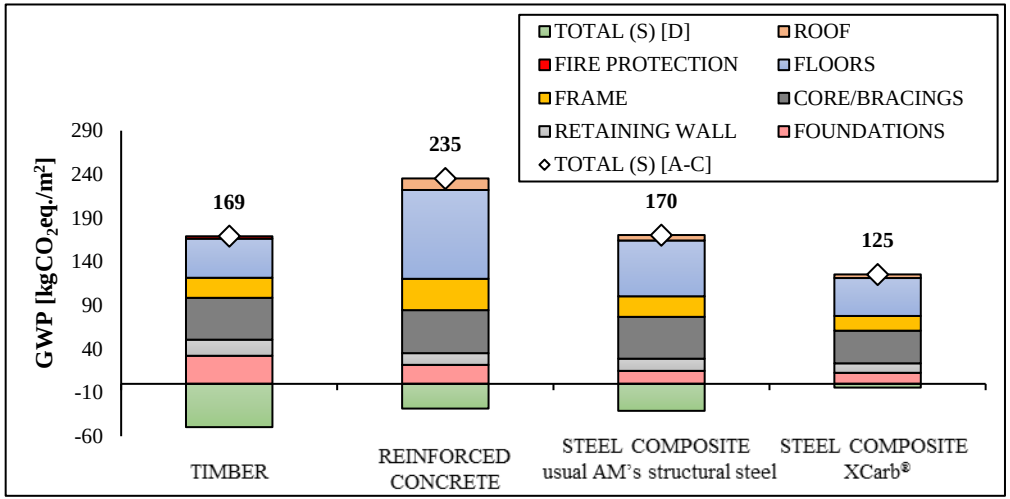
Results and Interpretation:

- The results are presented in terms of FU (m^2):



Results and Interpretation:

- The results are presented in terms of FU (m^2):



CONCLUSIONS:

Conclusions:

- The whole life cycle GWP is calculated for all structural options. The steel-concrete composite option outperforms the:
  - Reinforced concrete option reducing by 46% when comparing to the XCarb® steel-concrete composite option;
  - Timber option reducing by 26% the overall GWP for the XCarb® steel-concrete composite option.
  - The steel-concrete composite option profits from having a high content of recycled steel (scrap), up to 100%. In addition, a greater reduction is achieved for the use of XCarb® steel since it is produced with 100% renewable electricity.

- The production stage (modules A1-A3) is the major responsible for the CO_2e emissions.
  - Because of that the reduction of raw material extraction using high-recycled content materials is key to the reduction of embodied carbon.

- Floors are identified as the building part that contributes the most to the overall GWP. Ready-mix concrete is the main responsible for the impacts related to the floors for the steel and reinforced concrete options.

THANK YOU!!

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S-LCA OF RECYCLED PVC PRODUCTS
CIRCUSTAIN PROJECT

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September 25th, 2024

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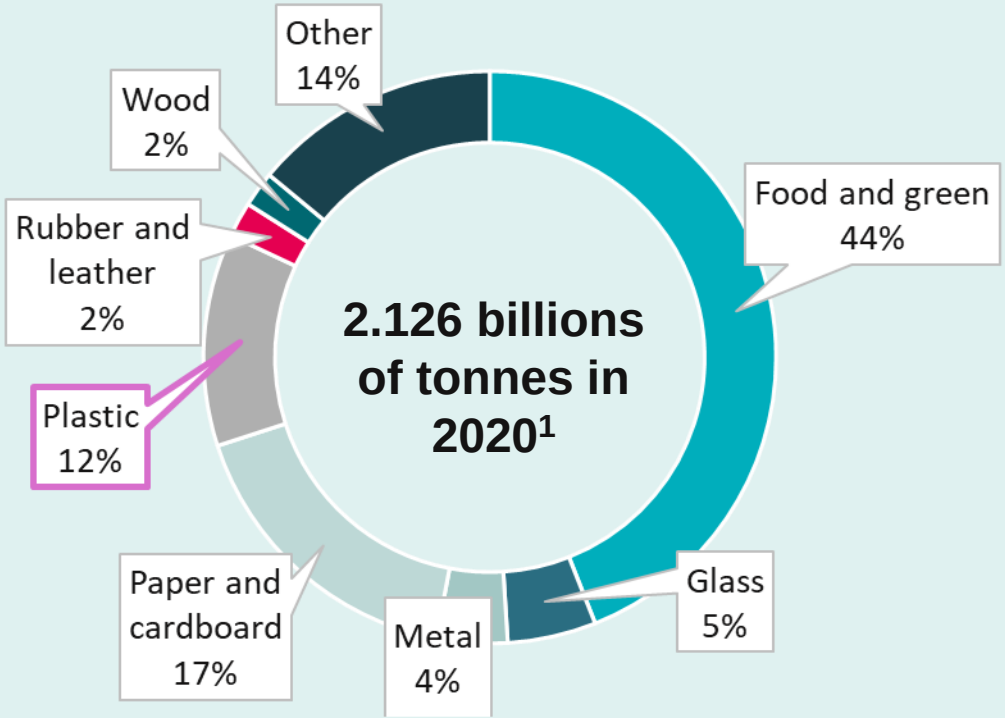
CONTENT

- Motivation: PVC value chain
- CIRCUSTAIN project: Objectives and scope
- Methodology: Social Life Cycle Assessment
- Preliminary results
- Outlook

SOLID WASTE PRODUCED GLOBALLY



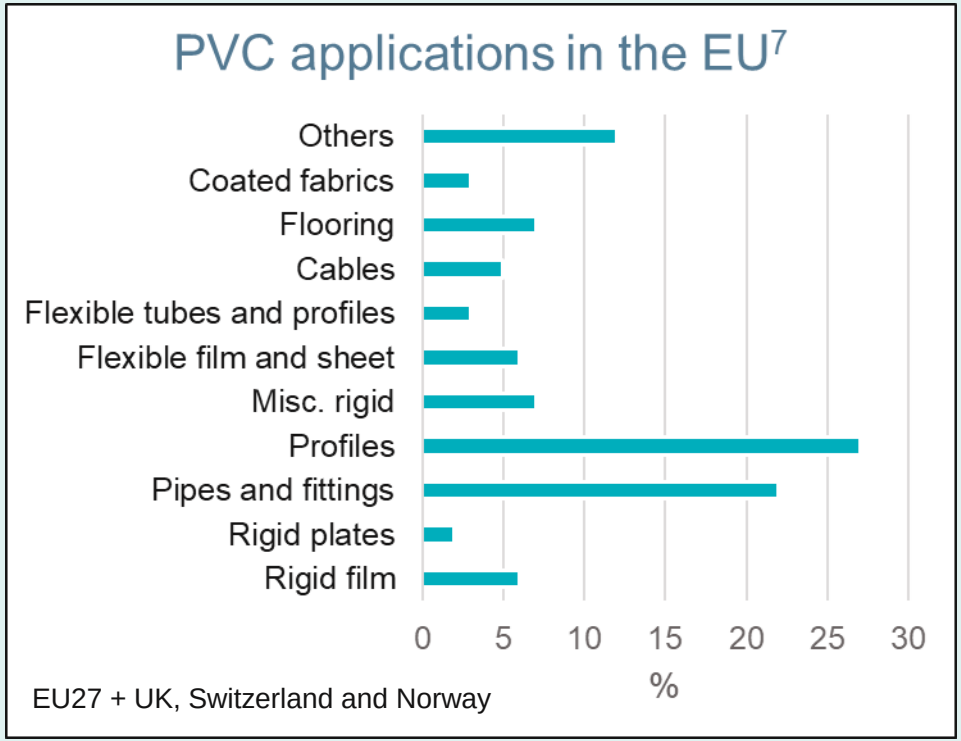
Global plastic waste accounted for 353 Mt in 2019[2].

Approx. 16 Mt of plastic **waste** were generated in the EU in 2021[3].

1. UNEP, 2024 2. OECD, 2022 3 EUROSTAT, 2021

PVC FIGURES

- **Production:** In the EU in 2022 fossil-based PVC represented 9.1% or **5.3 Mt** of a total of 58.7 Mt plastics (fossil-based + recycled)[4].
- **Waste: 2.4 Mt** of post-consumer PVC waste in the EU, 44% generated in the construction sector[5].
- 70% of PVC is used for products used in the building sector[6].



4. Plastics Europe, 2023
5. European commission, 2022
6. VinylPlus, 2023
7. ECVM

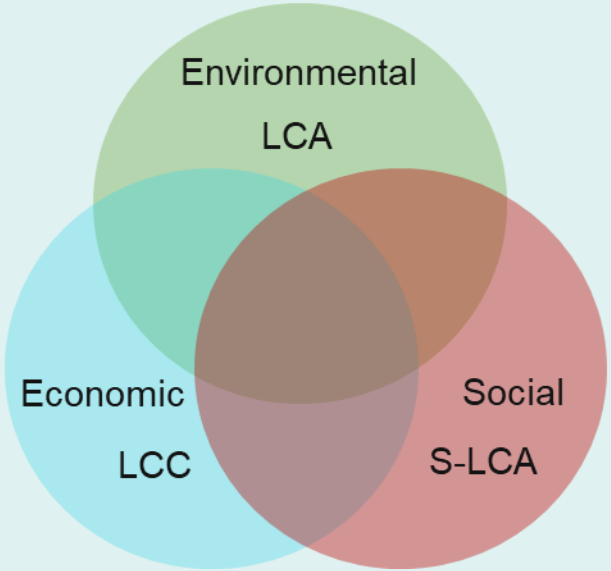
PVC FIGURES

- The plastic processing sector employs 338000 employees □ 5.3% of the manufacturing sector in Germany[8].
- Around 41% of companies in this sector contain <50 employees.
- Only 1% of companies >1000 employees[8].
- In 2019: 73% male, 27% female[8].
- 92% full-time, 8% part-time[8].

8. Dispan and Mendler, 2020

CIRCUSTAIN PROJECT

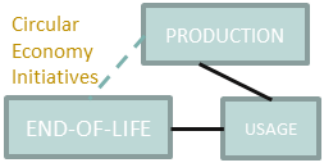
- Circular economy (CE) strategies, like plastic recycling
- Sustainability of CE practices is not guaranteed better than conventional ones.
- LCSA (social, economic and environmental)



CIRCUSTAIN: Integrated sustainability assessment across all three sustainability pillars of circular economy initiatives

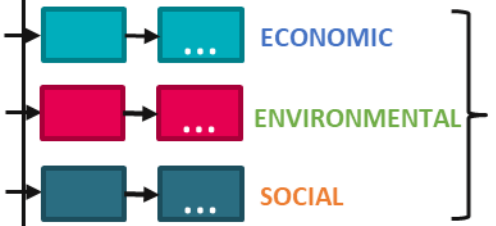
Conventional Life cycle sustainability assessment of circular vs. linear economy

Life cycle inventory of circular & linear product systems



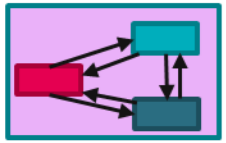
Life cycle impact assessment:
with conventional methods

WP1



Novel integrated life cycle impact assessment

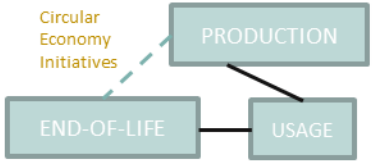
Two new impact pathway models:
with integrated cause-effect chains for topics: healthy labour force & rebound effect



WP2

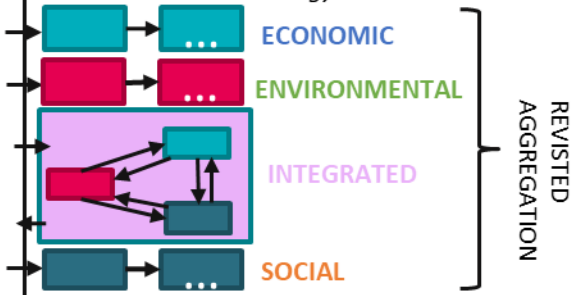
***Updated** CIRCUSTAIN approach*

Life cycle inventory of circular & linear product system



<u>Revisited & novel</u> life cycle impact assessment:
combining the new impact pathway models with the conventional methodology

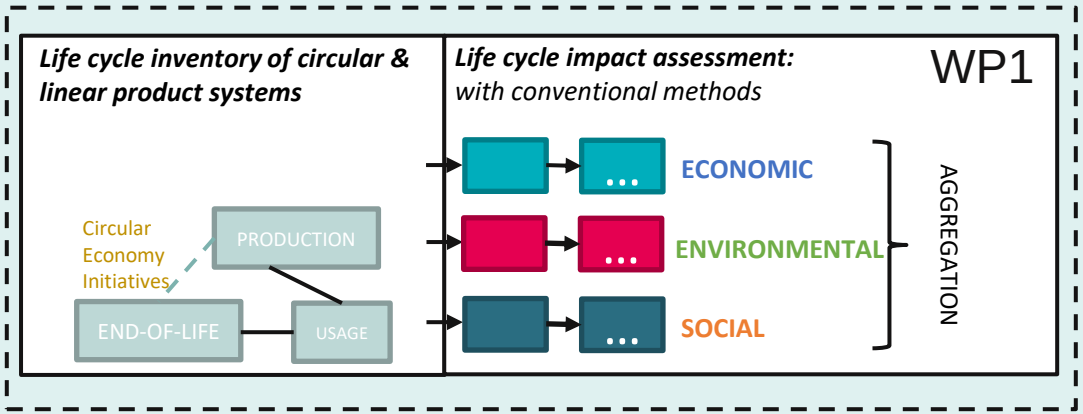
WP3



Period:
2024-2027

LIST

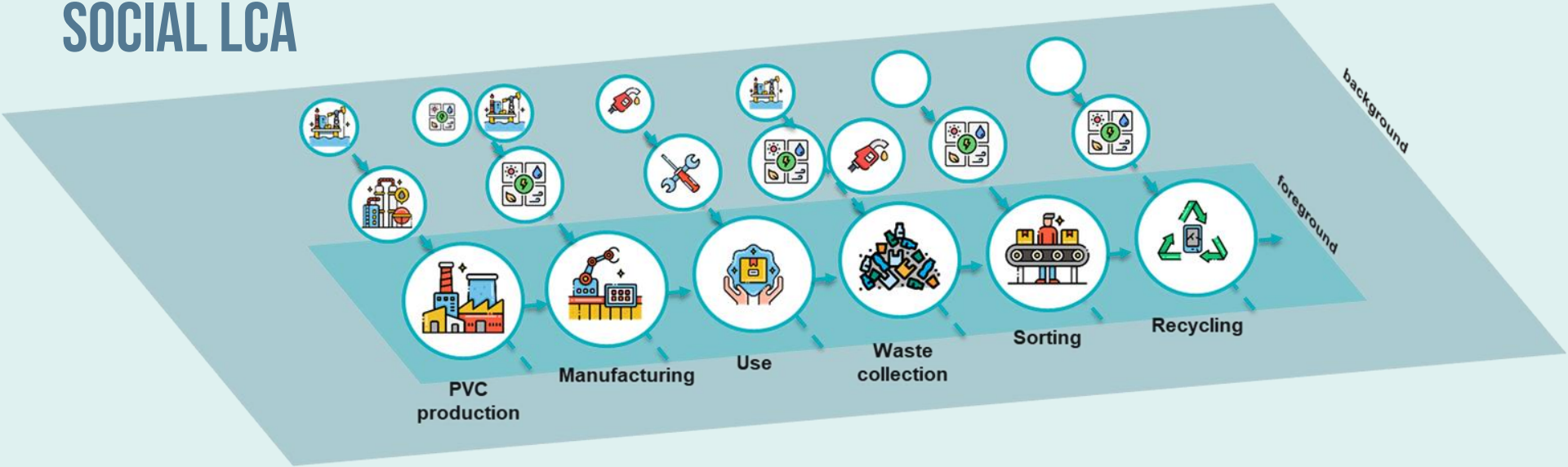
OBJECTIVE



To quantify the **social issues, focusing on labour aspects**, alongside economic and environmental impacts of identified circular versus linear product systems using conventional LCSA.

LIST

SOCIAL LCA

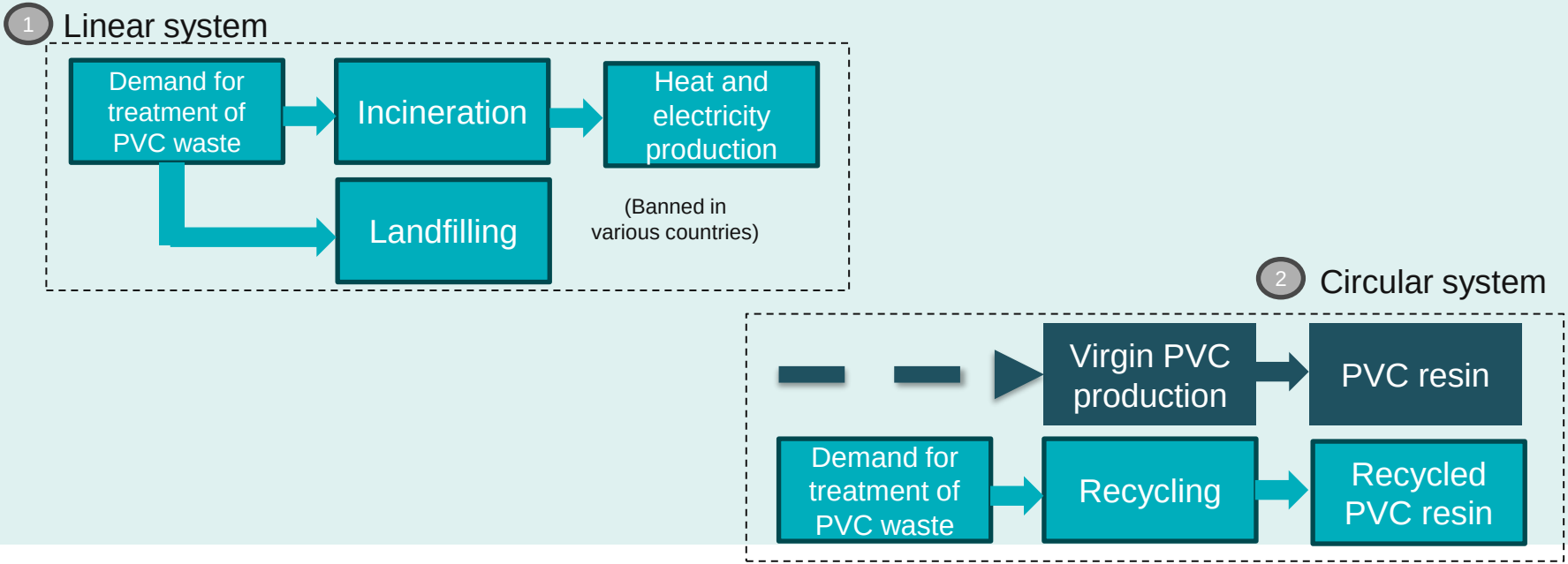

background
foreground
PVC production
Manufacturing
Use
Waste collection
Sorting
Recycling
Workers
Local community
Value chains actors

SOCIAL LCA FRAMEWORK

Complete framework in the UNEP Guidelines for S-LCA of products and organizations[9], 2020

LIST

CASE STUDY: PRODUCT SYSTEM



CASE STUDY: SCOPE

- **Geographical delimitation:** PVC production and recycling in Germany and Luxembourg
- **Stakeholder covered:** Workers, local community
- **Impact categories addressed:** job creation potential and health and safety
- **Sectors in the foreground system:** construction (installation and unmounting of PVC products) and manufacturing (plastics, chemicals production)

CASE STUDY: METHODOLOGY

- **Job Creation**
  - Input-Output Tables
    - PSILCA[10]
    - EXIOBASE v3 monetary[11]

- **Health and safety**
  - Exposure to chemical substances
  - Rate of fatal and non-fatal accidents

10. Stadler et al.,2018

11. Ciroth, A., & Eisfeldt, F. (2016).

INPUT-OUTPUT TABLES

- Input–output analysis is an analytical framework that provides data of the structure of the economy based on the interdependence of industries[10] presented in input–output tables.

- The input–output table of a country contains information on monetary transactions between industries in a specific location. It shows the flows of products that industries purchase (inputs) and sell (outputs) [10].

- Industries are related to each other because they buy products from other industries to produce their own products and in turn, provide products to other industries, which use them in their own production[10].

	Country 1 – sector 1	Country 1 – sector 2	Country 2 – sector 1	Country 2 – sector 2
Country 1 – sector 1				
Country 1 – sector 2				
Country 2 – sector 1				
Country 2 – sector 2				

12. Miller and Blair, 2009

CASE STUDY: METHODOLOGY

- **PSILCA**
  - Based on EORA MRIO
  - 189 countries
  - It contains worker-hours by sector and country
  - Aim of the database: to conduct Social Risk Assessment
- **EXIOBASE**
  - MRIO
  - 49 countries + regions
  - Worker-hours and employment accounts by sector and country

WORKER HOURS ESTIMATION

PSILCA estimated worker-hours based on EORA following:

$$\text{Worker hours } [h] = \frac{\text{Unit labor costs}}{\text{Mean hourly labor costs per employee } [USD/h]}$$

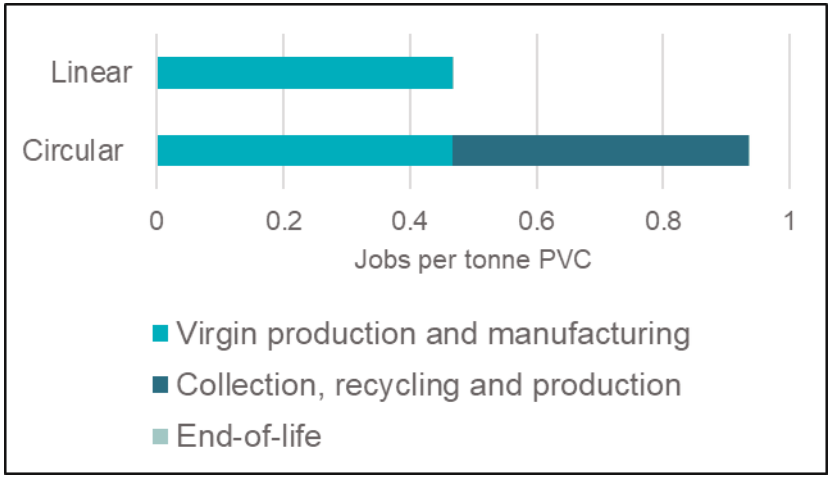
$$\text{Unit labor costs} = \frac{\text{Compensation of employees by sector and country } [€]}{\text{Gross output by sector and country } [€]}$$

EXIOBASE contains total employment and worker-hours accounts

	Country 1 – sector 1	Country 1 – sector 2	Country 2 – sector 1	Country 2 – sector 2
Compensation of employees				
Total employment				
Vulnerable employment				

INVENTORY WORKER HOURS – FOREGROUND SYSTEM - PRELIMINARY

Process units	Total wh per tonne PVC	Unit
PVC production	2.68	wh/PVC tonne
Profile production	4.50	wh/PVC tonne
Windows assembly	58.38	wh/PVC tonne
Montage	224.72	wh/PVC tonne
Use in B&I		
Unmounting	337.08	wh/PVC tonne
Sorting	1.00	wh/PVC tonne
Mechanical recycling		
Profile production	4.50	wh/PVC tonne
Windows assembly	58.38	wh/PVC tonne
Montage	224.72	wh/PVC tonne
Use in B&I		
Unmounting	337.08	wh/PVC tonne
Sorting	1.00	wh/PVC tonne



- Manual activities require more hours per functional unit.
- EXIOBASE: Windows assembly and PVC production
- Costs variation
- Mechanical recycling
- Technologies

WORKER HOURS IN THE LIFE CYCLE[12]

- Direct jobs.- Jobs provided by a project
- **Direct induced jobs**.- Jobs provided by a supplier and created to serve the project
- **Indirect induced jobs**.- Jobs provided by the supplier of a supplier to develop an input for the project
- Secondary jobs.- Jobs created incentivise consumption creating in turn other jobs

$$\mathbf{A = aij = Xij/Xj}$$

- A: Matrix of technical coefficients
- aij: Technical coefficient of a sector by total sector output
- Xij: Quantity of monetary units from sector (i) necessary to the sector (j)
- Xj: Total monetary output of sector (j)

$$\mathbf{f = S\ (I\text{-}A)^{-1}}$$

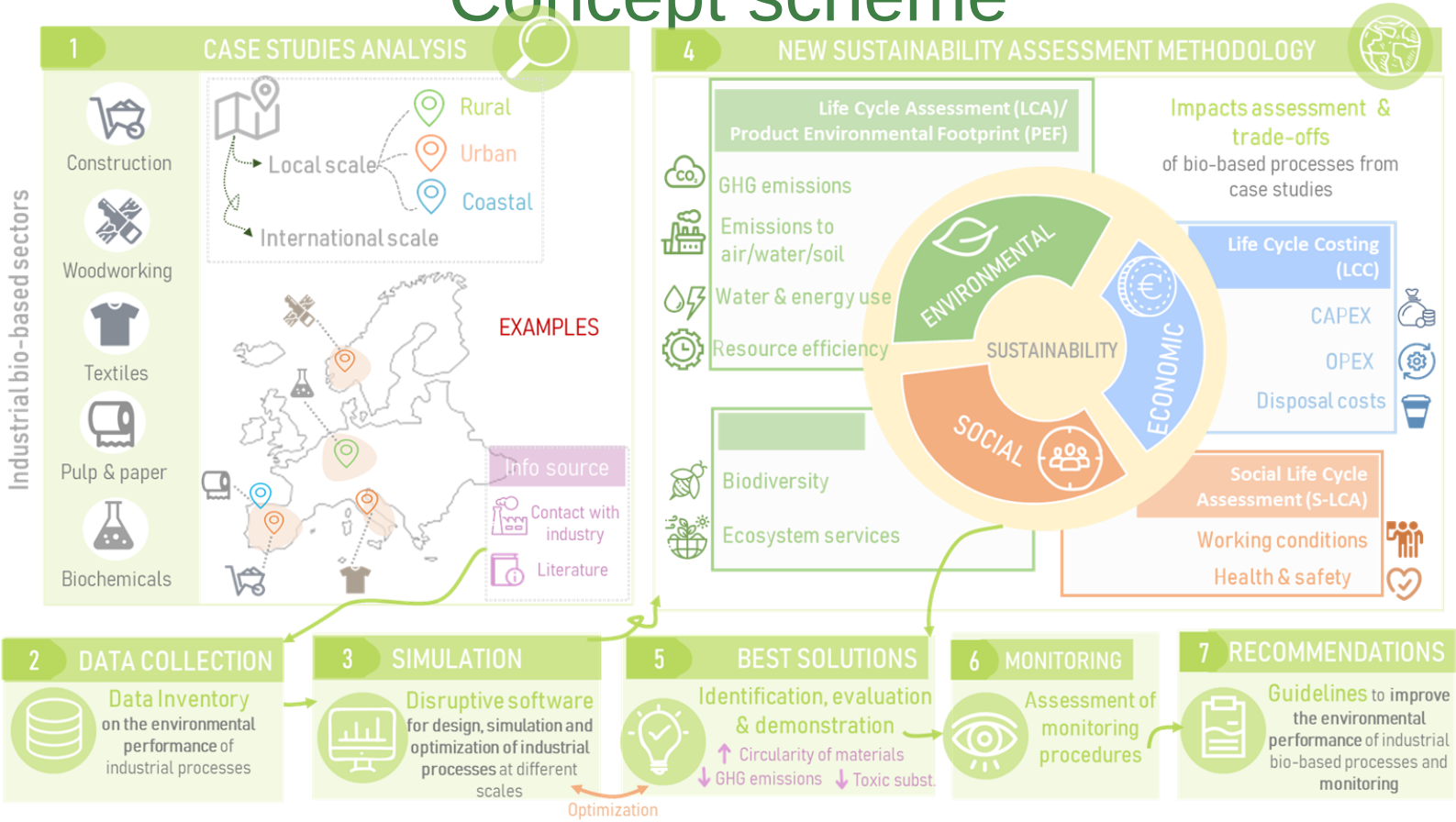
- f: direct and indirect worker hours to produced one monetary unit
- S: social matrix in hours per monetary unit
- I: identity
- A: technical coefficients matrix

12. Pillain, 2019

LIST

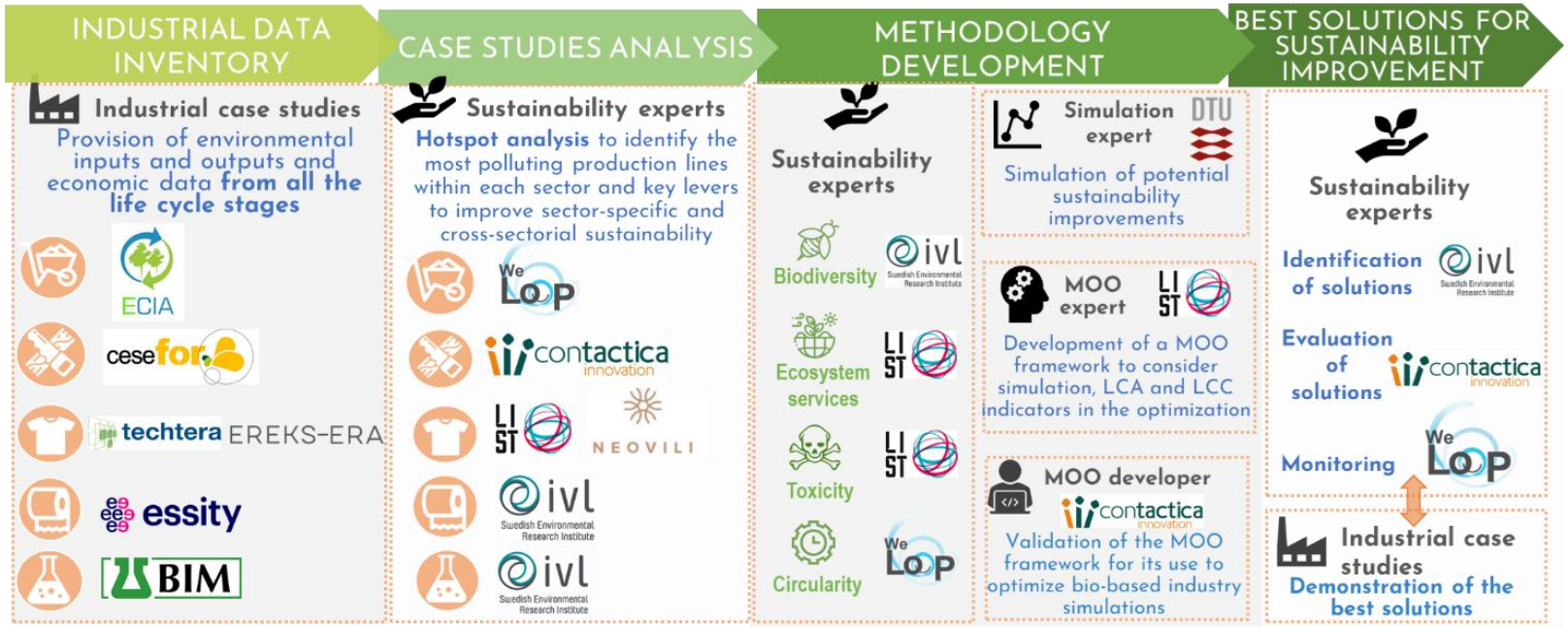
Project funded by the European Union with the number 101060546 (CALIMERO)
https://calimeroproject.eu/

Concept scheme

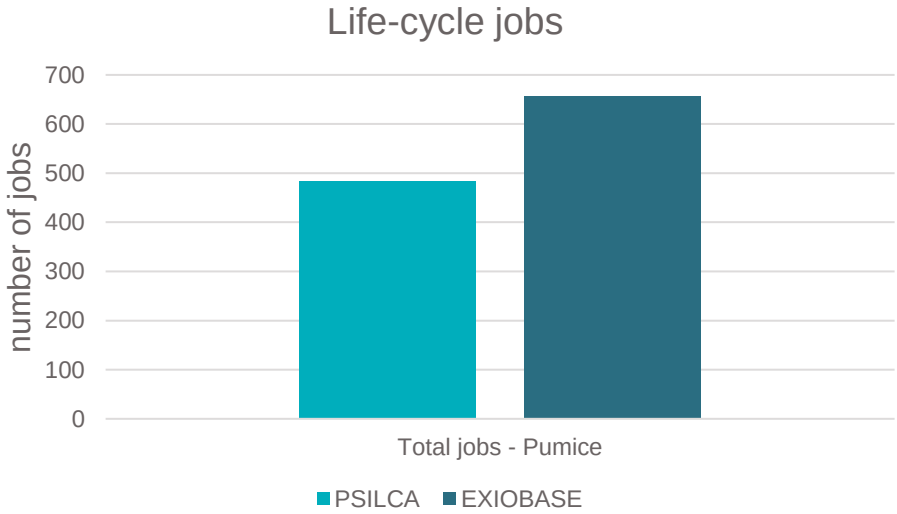


Project funded by the European Union with the number 101060546 (CALIMERO)
https://calimeroproject.eu/

Implementation



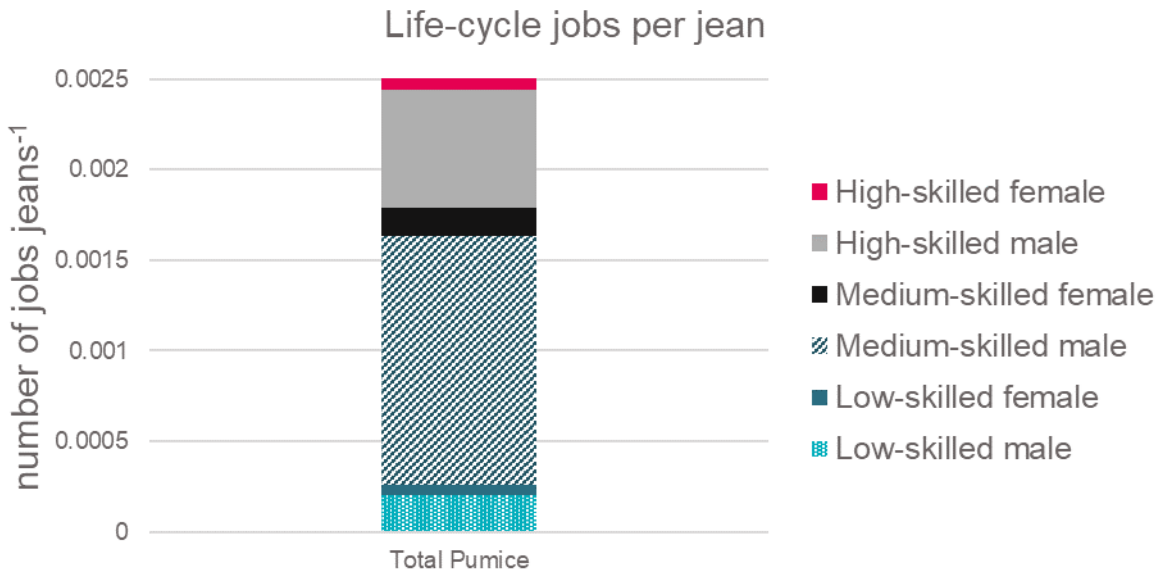
DATABASE COMPARISON (EXAMPLE)



Databases comparison

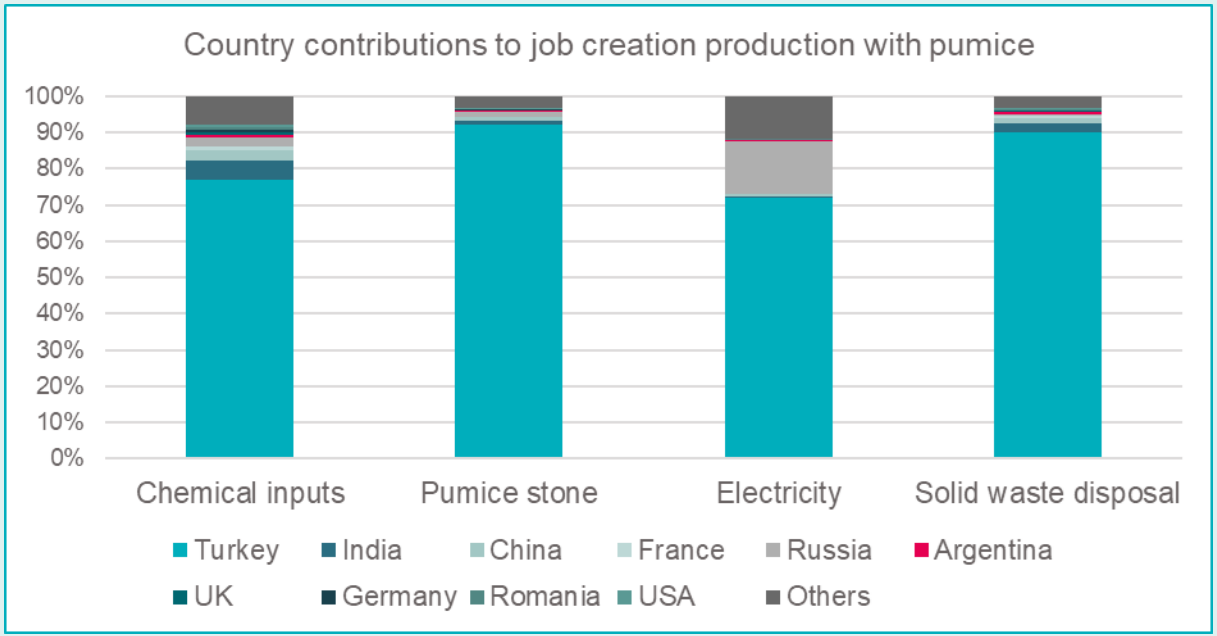
- 30-35%

SKILL-LEVELS (EXAMPLE)



- Skill-level

REGIONALIZATION (EXAMPLE)



- PSILCA
- Job creation by region

OUTLOOK

- Data quality
- Health Human toxicity of different chemicals workers are exposed to along the value chain using USEtox.
- Physical hazards Rate of accidents in the plastics and construction sectors.

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[9] Benoît Norris, C., Traverzo, M., Neugebauer, S., Ekener, E., Schaubroeck, T., & Russo Garrido, S. (2020). Guidelines for social life cycle assessment of products and organizations 2020.

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[11] Stadler, K., Wood, R., Bulavskaya, T., Södersten, C. J., Simas, M., Schmidt, S., ... & Tukker, A. (2018). EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input-output tables. Journal of Industrial Ecology, 22(3), 502-515.

[12] Miller, R. E., & Blair, P. D. (2009). Input–output analysis: Foundations and extensions. Cambridge University Press.

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- https://www.flaticon.com/free-icons/fuel" title="fuel icons">Fuel icons created by Freepik – Flaticon
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thank you

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nirvana.marting@list.lu

SUSTAINABLE PLACES 2024

LIST


QUESTION
ANSWER
QUESTION
QUESTION
ANSWER
QUESTION
ANSWER

SUSTAIN

SUSTAINABLE PLACES 2024

PREMISES

PREMISES project: impact of predictive maintenance and IoT on the SRI

Igor PEREVOZCHIKOV, R2M Solution France

Sustainable Places 2024
25 September 2024
Luxembourg, Luxembourg

OSMOSE Génie climatique et énergétique

R2M FRANCE SOLUTION

Why the predictive maintenance?

How to avoid the breakdown of building assets?

How to reduce the budget of maintenance?

How to manage building in more smarter way?

The cooling unit on the 3rd floor is not more working

Distribution pump 2 in the 9th heat distribution circuit is not more working

One solar shading blind' motor is not more working from 1 month

We pay higher cost for maintenance

The cost for maintenance are higher from one year to another

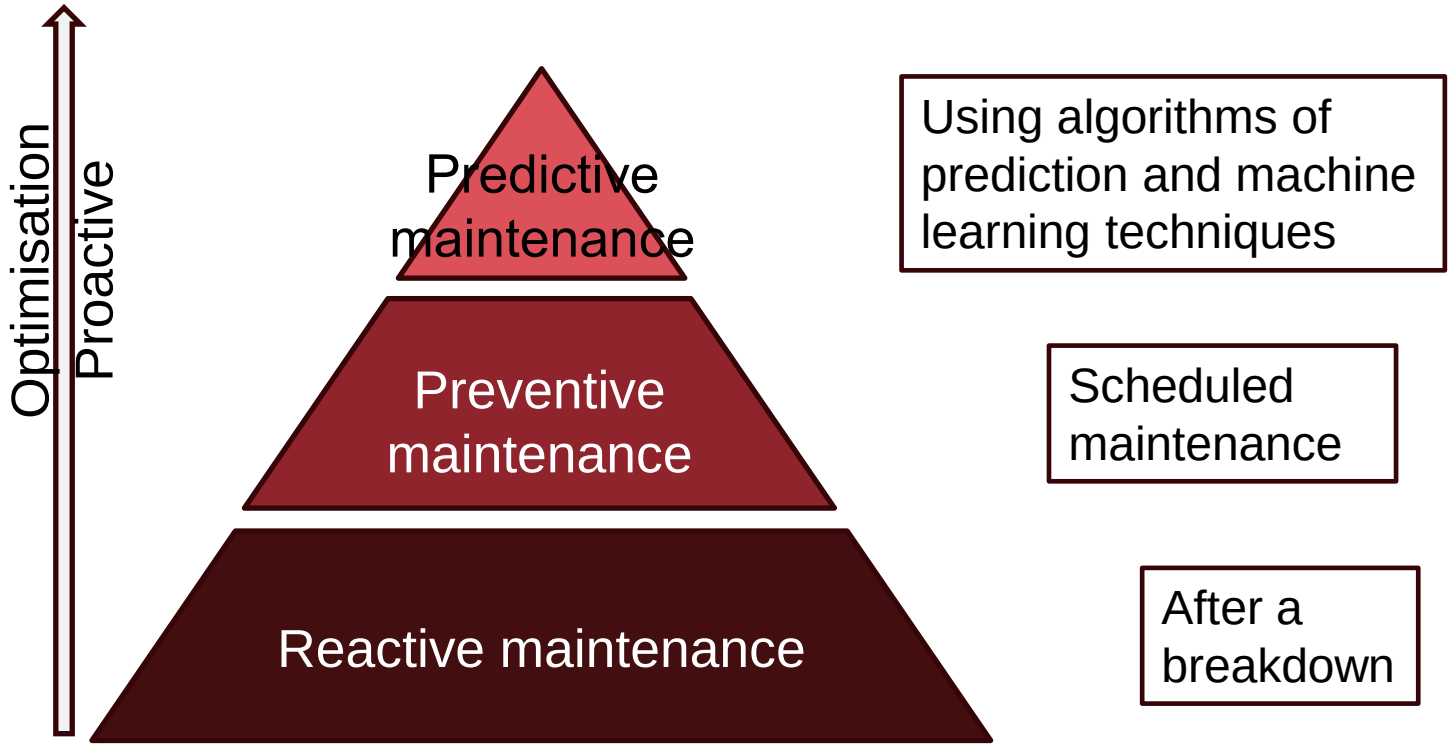
One opening window motor is not more working

The ambient lighting on the 2nd floor is not more switched on automatically

Solar thermal panels are not producing expected quantity of energy

What is the predictive maintenance?

Predictive maintenance **uses data analysis to identify operational anomalies and potential equipment defects, enabling timely repairs before failures occur**. It is often based on sensor and meter data.

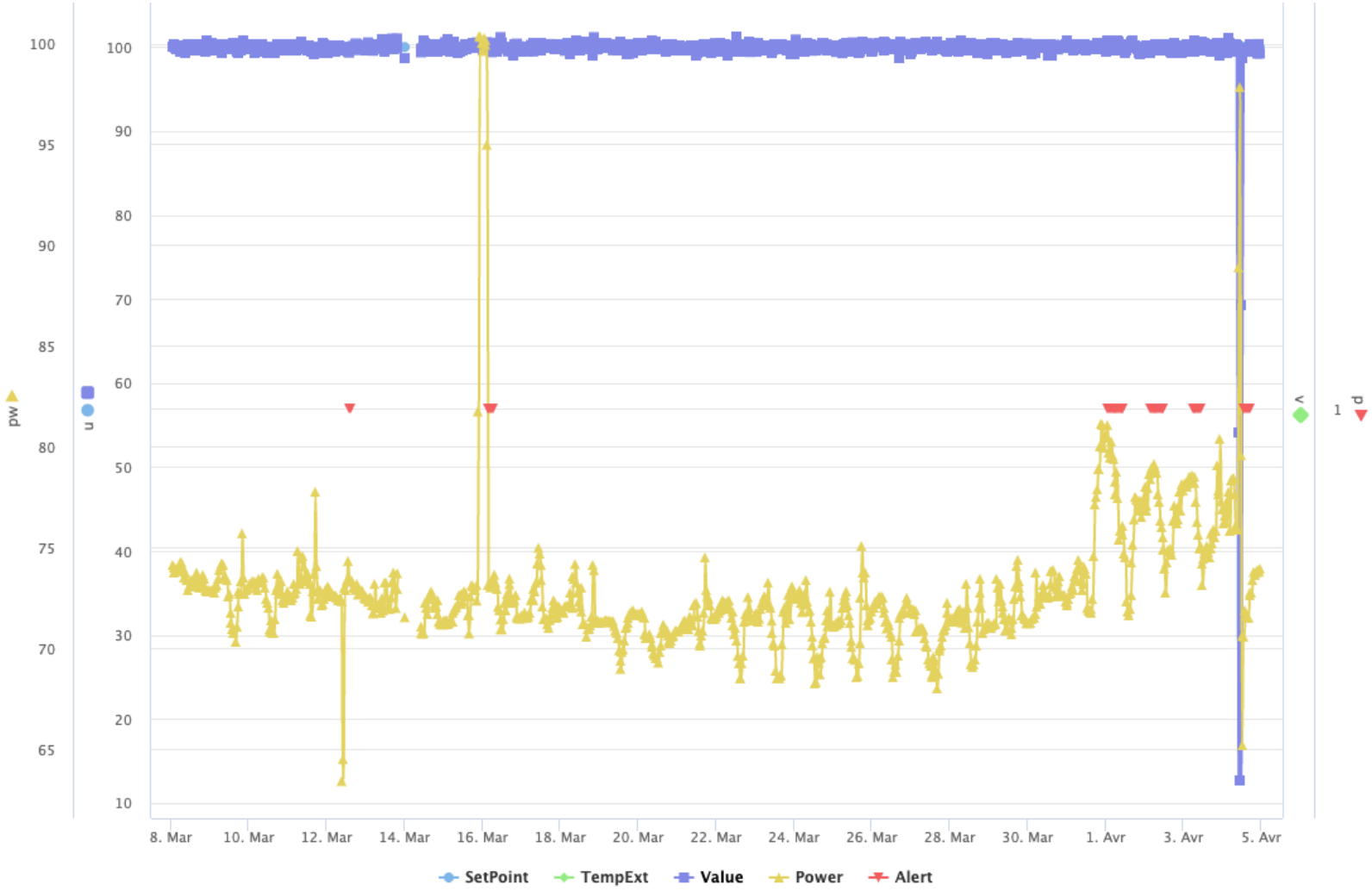


Challenges of predictive maintenance

Predictive maintenance **uses data analysis to identify operational anomalies and potential equipment defects, enabling timely repairs before failures occur**. It is often based on sensor and meter data.

Predictive maintenance for energy optimization

- Most **deviations** involve **over-consumption**.
- **Anticipating** deviations automatically increases the **energy performance** of installations.
- **Contextualizing** data is the only way to interpret it.



Objective, innovations, KPIs

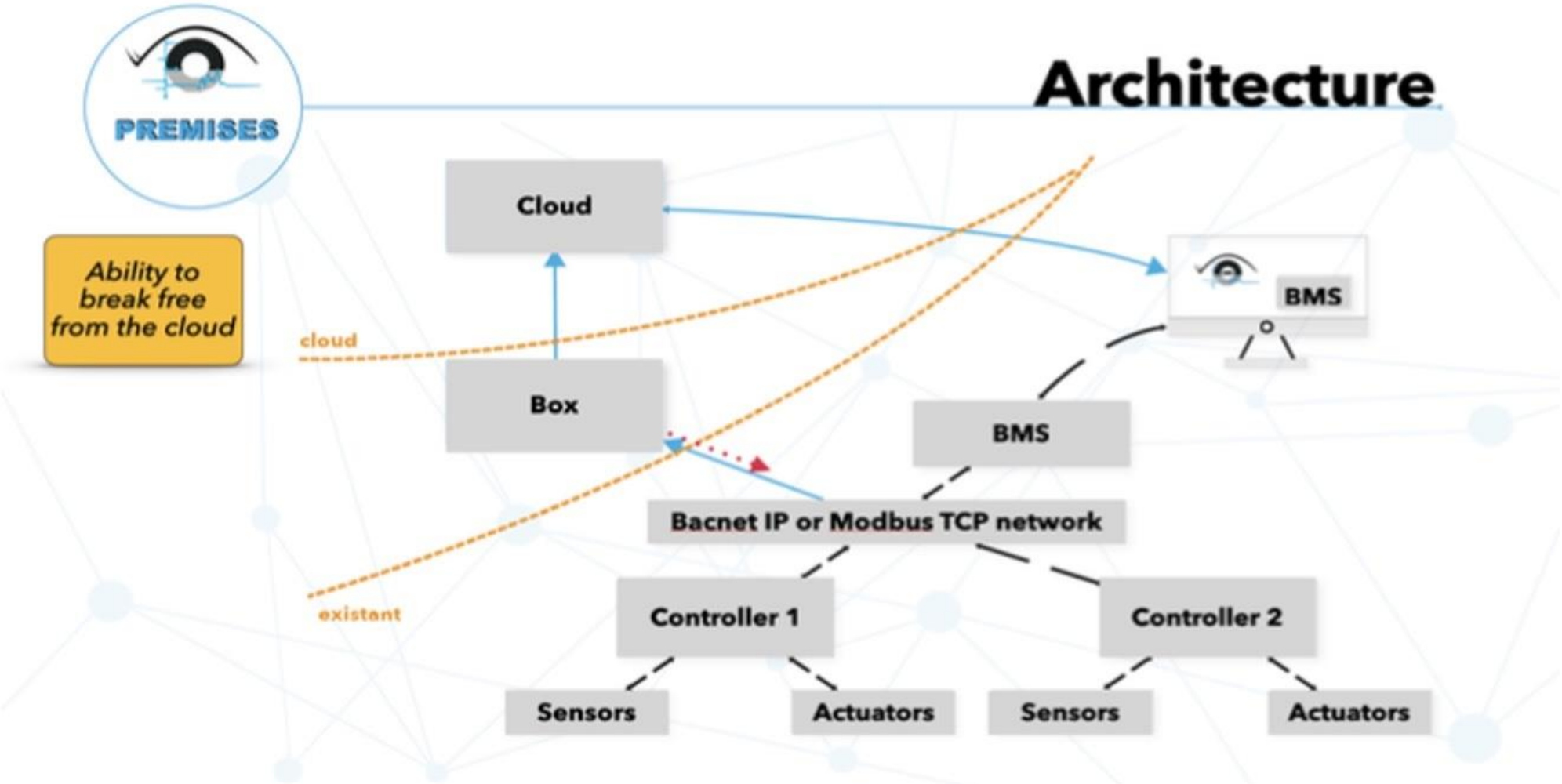
PREMISES reimagines smart building management by introducing a groundbreaking approach to HVAC predictive maintenance and energy optimization. Traditional systems offer data without context, while PREMISES introduces decentralized control, seamlessly integrating **self-learning AI algorithms** with **IoT** devices. This approach promotes cooperation among building equipment, enhancing energy efficiency, reducing costs, and improving comfort. Initial focus will be on **industrial buildings**. PREMISES targets a shift from TRL4 to TRL6 through lab testing in a small building.

- Duration: **9 months**
- Budget: **50k€**
- Start date: **1st April 2024**
- End date : **31st December 2024**

Key innovations:

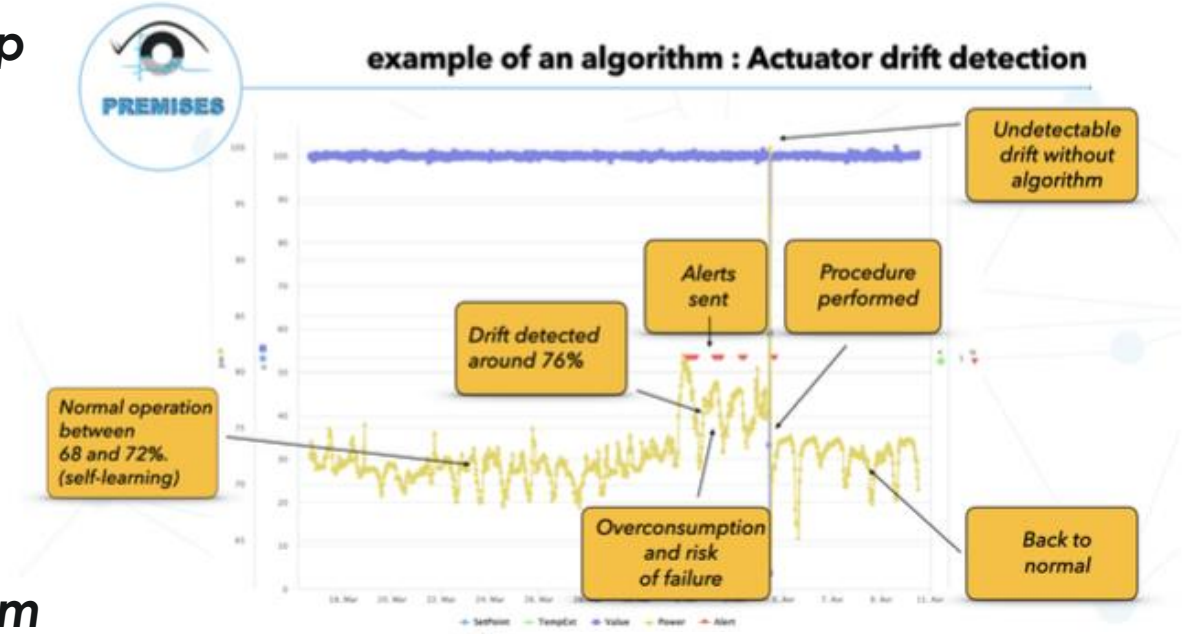
- Low installation costs
- Efficient integration with existing systems
- AI-driven predictive maintenance
- ROI of under 1.5 years.
- SRI score enhancement

Architecture of PREMISES solution



Algorithms and KPIs

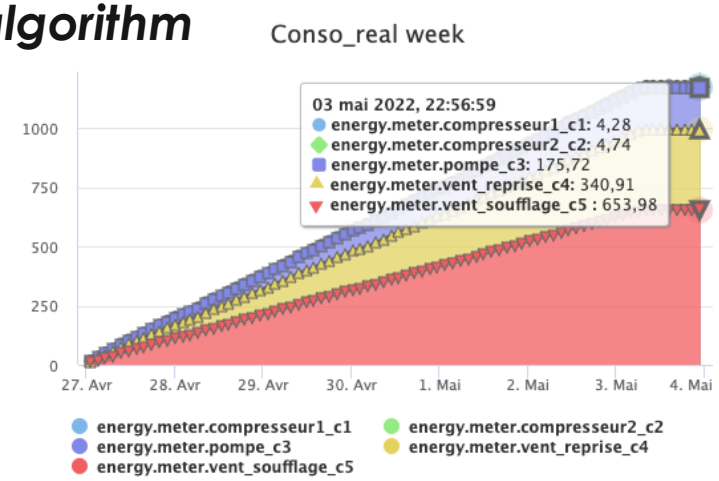
ControlLoop algorithm

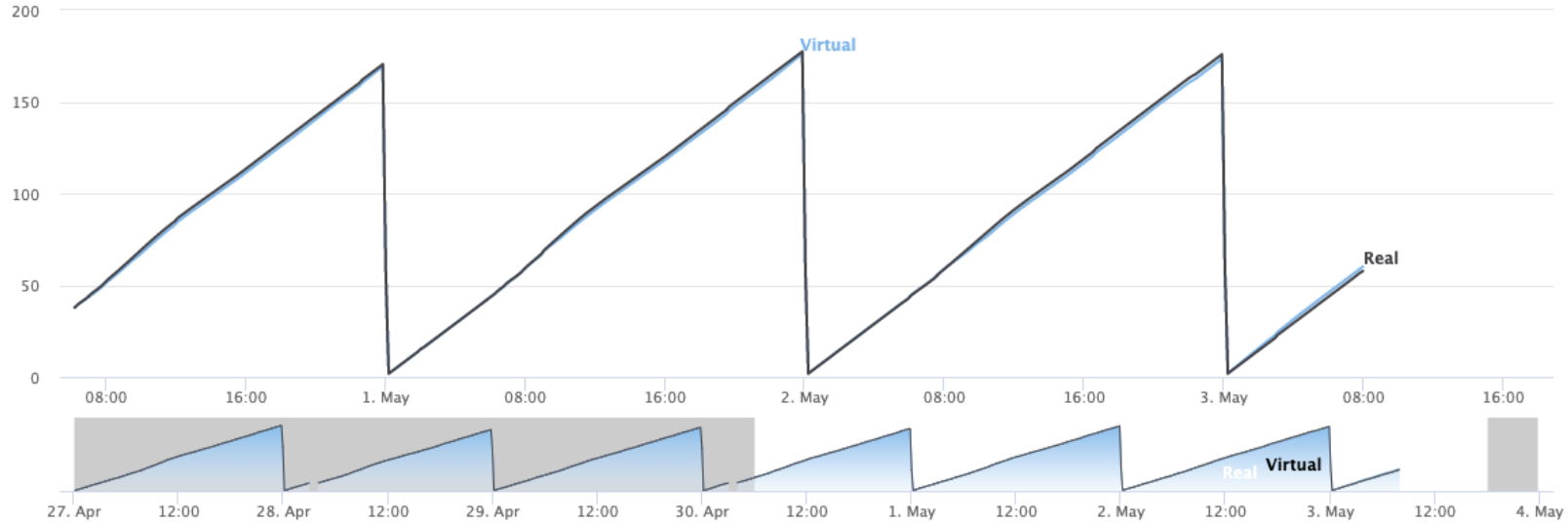


3 KPIs:

1. Algorithm reliability: up to 85%
2. ROI: <1,5 years
3. SRI score improvement: >15%

MeterSystem algorithm





Demo building

Location: South-East of France
Area of building: 1100 m2
Age of building : 2019
Use of building: office + manufacture + warehouse
Number of floors: 2 + basement
Number of users: 35

Project workplan

Technical requirements, installation and implementation:

- Selection and installation of the required IoT devices
- Setup of Home Assistant and Windows with the Oris BMS on the server
- Connection of all equipment via MQTT, Zigbee and Modbus-TCP communication protocol
- Implementation of the AI-driven algorithms

Lab testing:

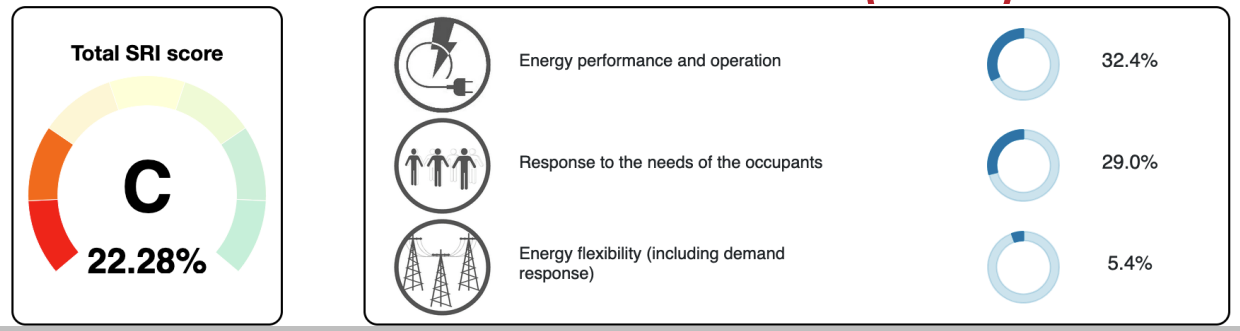
- AI-driven algorithms setup

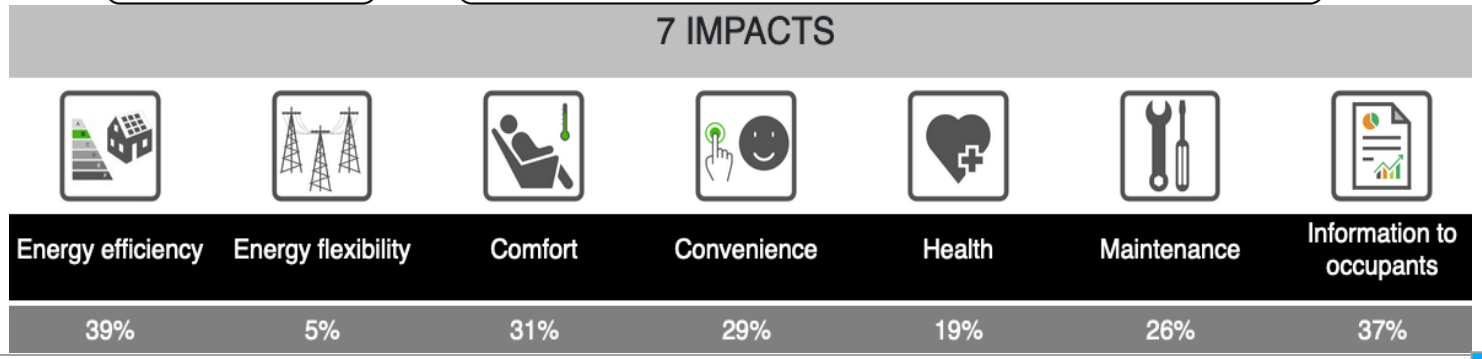
SRI analysis:

- SRI assessment of pilot building realized
- SRI results analysis, recommendations and simulation performed

KPI's assessment.

Smart Readiness Indicator (SRI) initial score





Heating	34%
DHW	47%
Cooling	29%
Ventilation	12%
Lighting	23%
Dynamic envelope	2%
Electricity	56%
eVehicle	0%
M&C	20%

Smart Readiness Indicator (SRI) improvements

SRI score improvements recommended:

1) Equip the building with IoT sensors for measurement of ambient parameters (T, RH, IAQ sensors) and implement a BMS of classes B or A in order to:

1. Centralize monitoring and control of all building technical systems (heating, cooling, ventilation, DHW, lighting and electrical outlets).
2. Implement building management based on real-time data from local weather station to be installed.
3. Collect next-day local weather forecasts to prepare the predictive control of building systems.

2) Implement a PREMISES solution for predictive maintenance of HVAC systems.

3) Provide flexibility capabilities by connecting BMS supervision server to electrical grid signals (RTE, Enedis) via an API allowing to adjust HVAC operation based on grid status.

Optional Measures:

- **Install renewable energy production systems (PV panels, solar thermal, mini wind turbines) with storage.**
- **Connect these systems to grid commands (RTE, Enedis) via an API.**

Installation and implementation of IoT

12 temperature and humidity sensors

Zigbee gateway

Web interface

Server smart-Box

Home Assistant

mosquitto

Windows with Oris BMS

Modbus-TCP

HVAC unit

40 smart plugs

Motion sensor

E-mail

Cloud

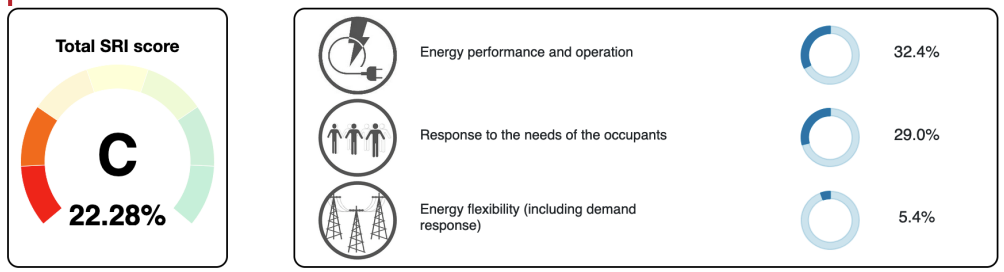
mosquitto

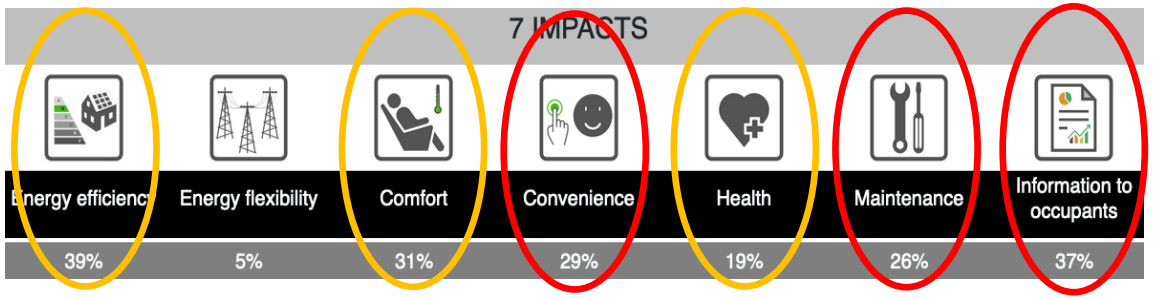
PREMISES

PREMISES server

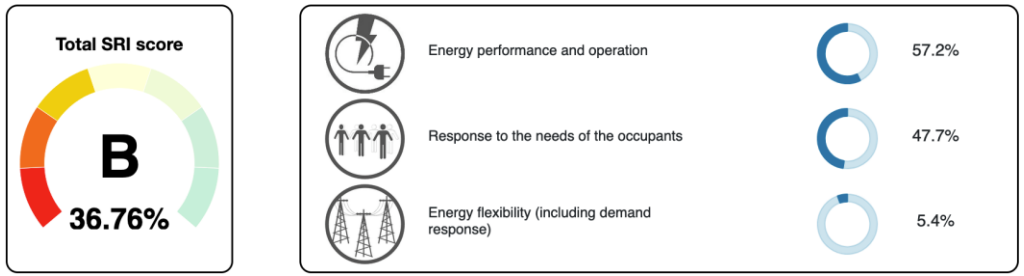
Smart Readiness Indicator (SRI) analysis

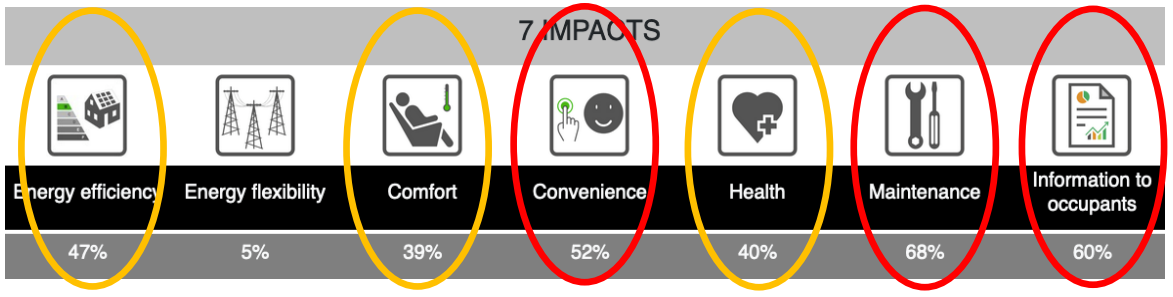
SRI of the building in its current state with scores by main functionality and detailed scores by domain and impact criterion





Simulated SRI of the OSMOSE building with recommended intelligence improvement measures





R2M Solution

Heating	34%		46%
DHW	47%		47%
Cooling	29%		41%
Ventilation	12%		26%
Lighting	23%		23%
Dynamic envelope	2%		2%
Electricity	56%		56%
eVehicle	0%		0%
M&C	20%		53%

Main outcomes

The PREMISES predictive maintenance associated with IoT measurement devices installed in a non-residential building without TABS impacts mainly **detecting faults of TBS** SRI service and **reporting of performances** services associated to ***Heating***, ***Cooling***, ***Ventilation*** and ***Monitoring&Control*** domains. The impact of PREMISES solution is equal to **14,48**%.

The technical domain of ***Monitoring&Control*** is the mostly impacted by proposed measures. Its associated SRI score raised up by **33**%. This is followed by ***Ventilation*** domain whose score is raised up by **14**%.

The SRI criteria the more impacted by improvements proposed is the ***Maintenance*** criteria, raised by 42%. It is directly related to the predictive maintenance functionality of the PREMISES solution. It is followed by ***Information to occupants*** and ***Convenience*** criterias, raised by 23%.

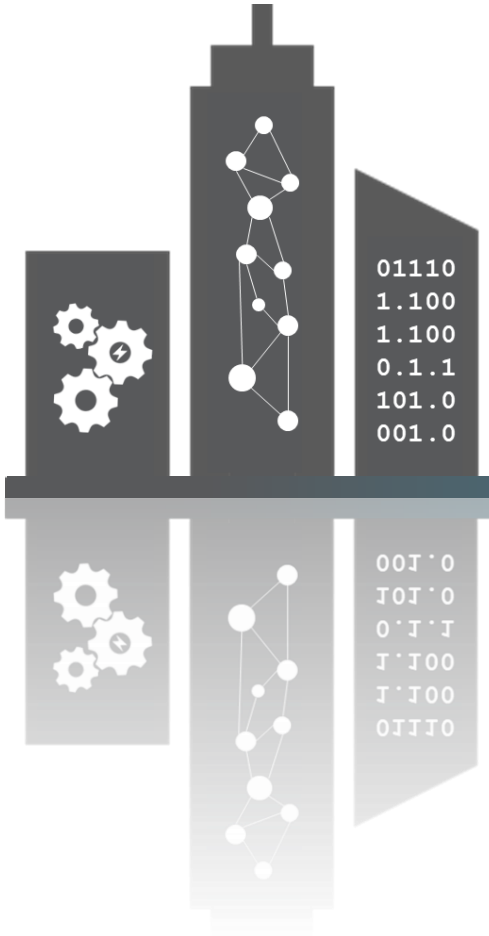
The optional measure related to connection of technical building systems (heating and cooling) to signals from grid in order to provide flexibility control based on grid signals has a big impact on the SRI score, +11,63%.

PREMISES project

THANK YOU!

Igor PEREVOZCHIKOV, R2M Solution France

Sustainable Places 2024
25 September 2024
Luxembourg, Luxembourg



Increasing transferability for automated fault detection and diagnosis in HVAC systems through a hybrid AI methodology

Nicolas Réhault (Fraunhofer ISE)

Sebastian Dietz (University of Luxembourg)

Sustainable Places Conference 2024

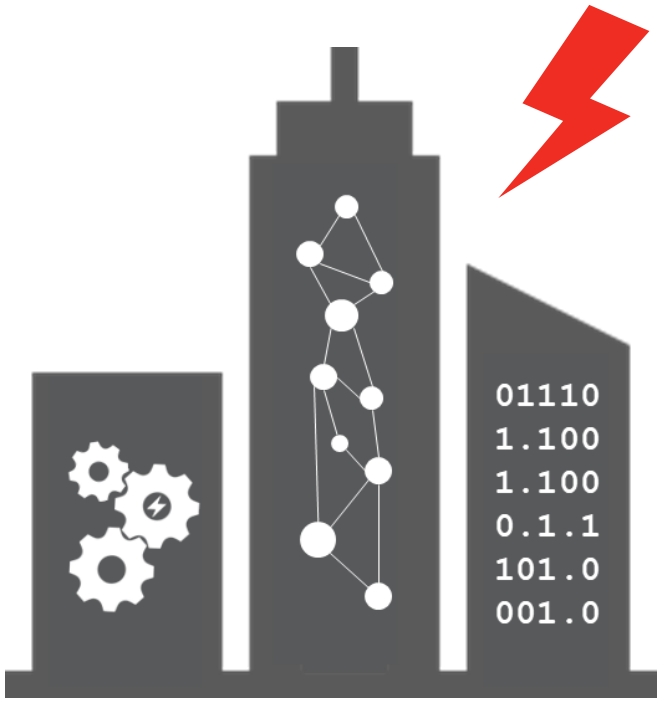
Content

- Background and objective
- Residual generating FDD
- Hybrid AI methodology for FDD
- Case studies
- Summary

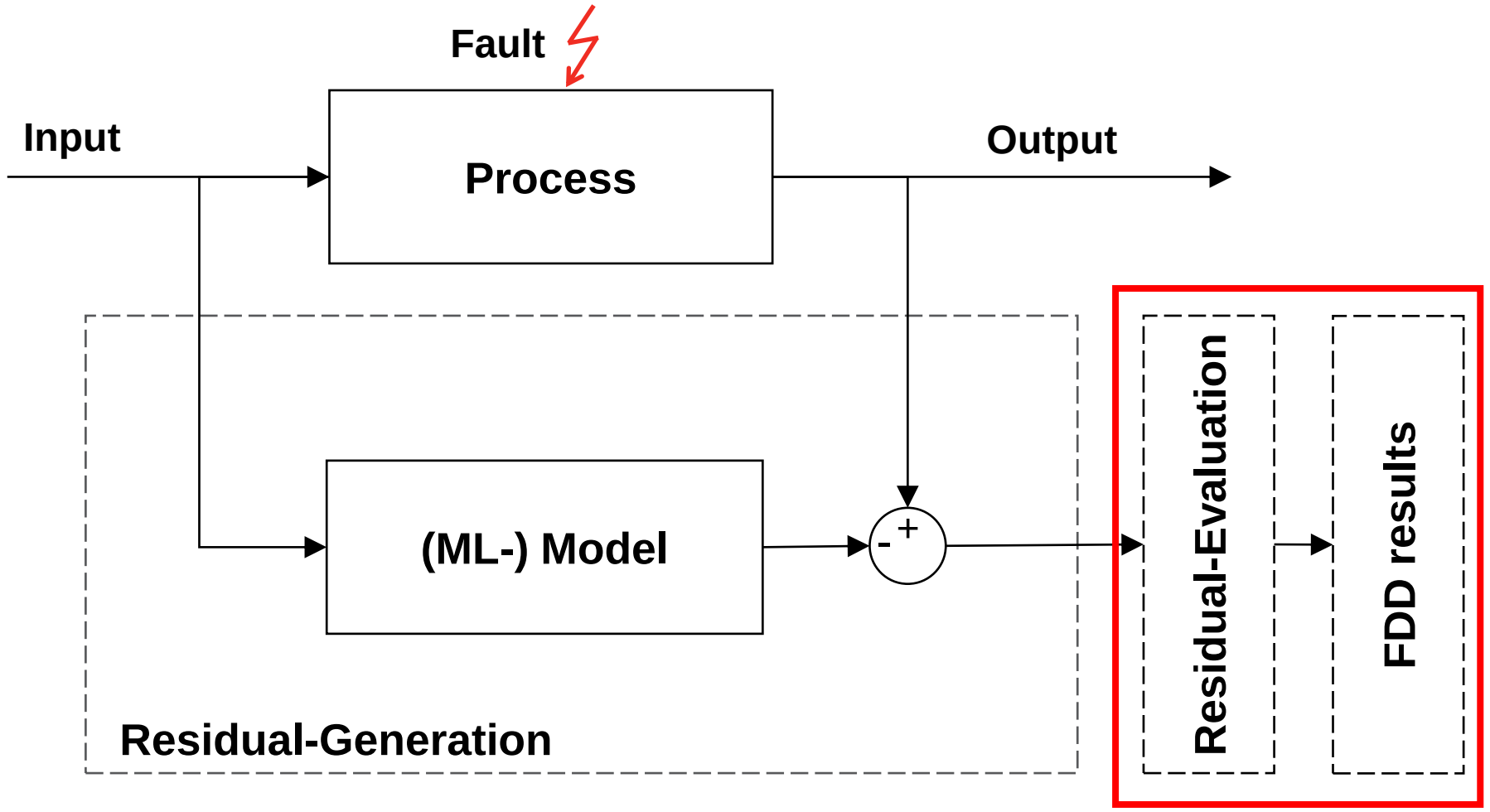
Background and objective

- Building services operation is often degraded by faults
- Automated fault detection and diagnosis (FDD) can save up to 20% energy
- High implementation and parametrization effort required for FDD methods

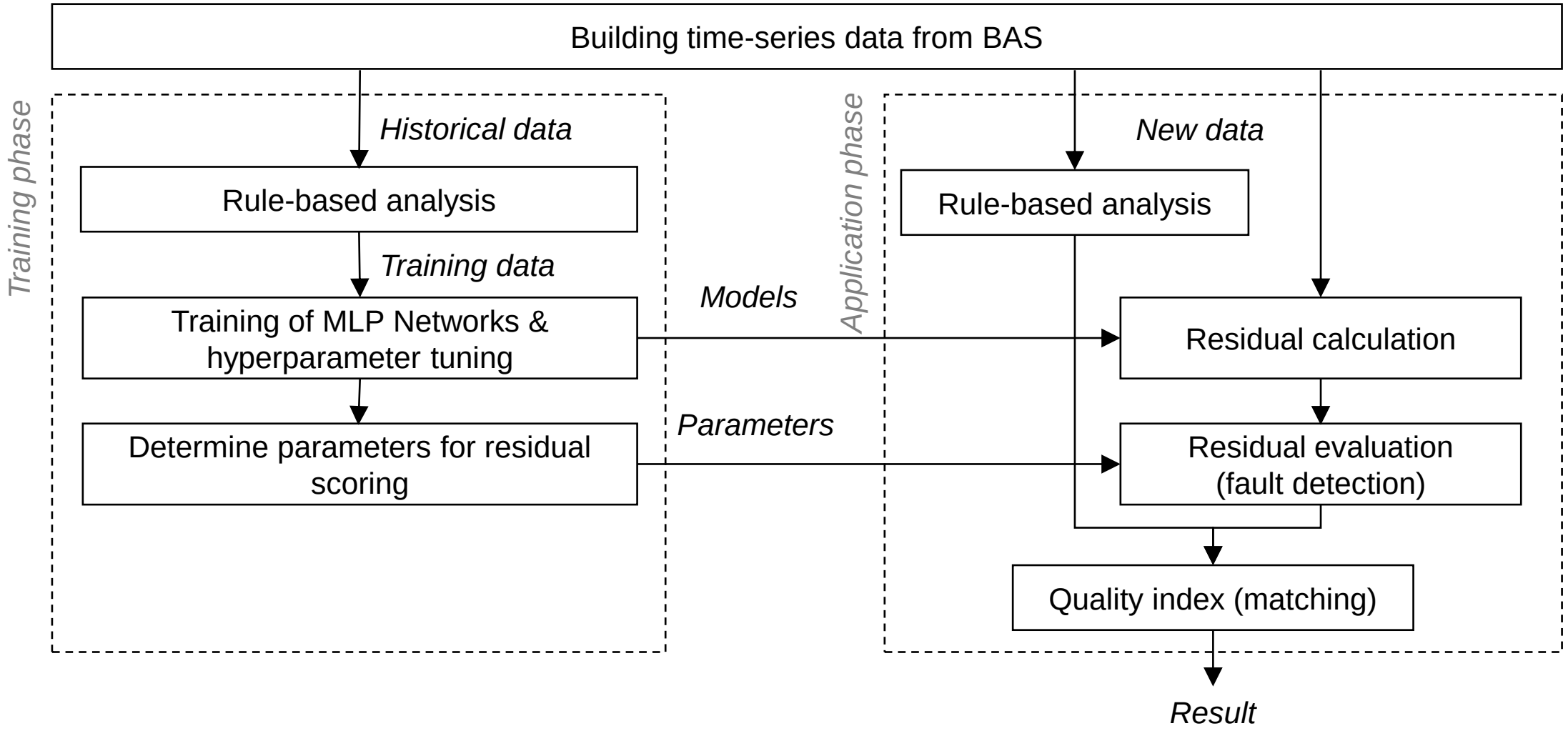
➢ Improving the transferability and quality of FDD through a hybrid AI method based on a **rule-based system** combined with a **machine-learning based residual generation**



Residual generating FDD

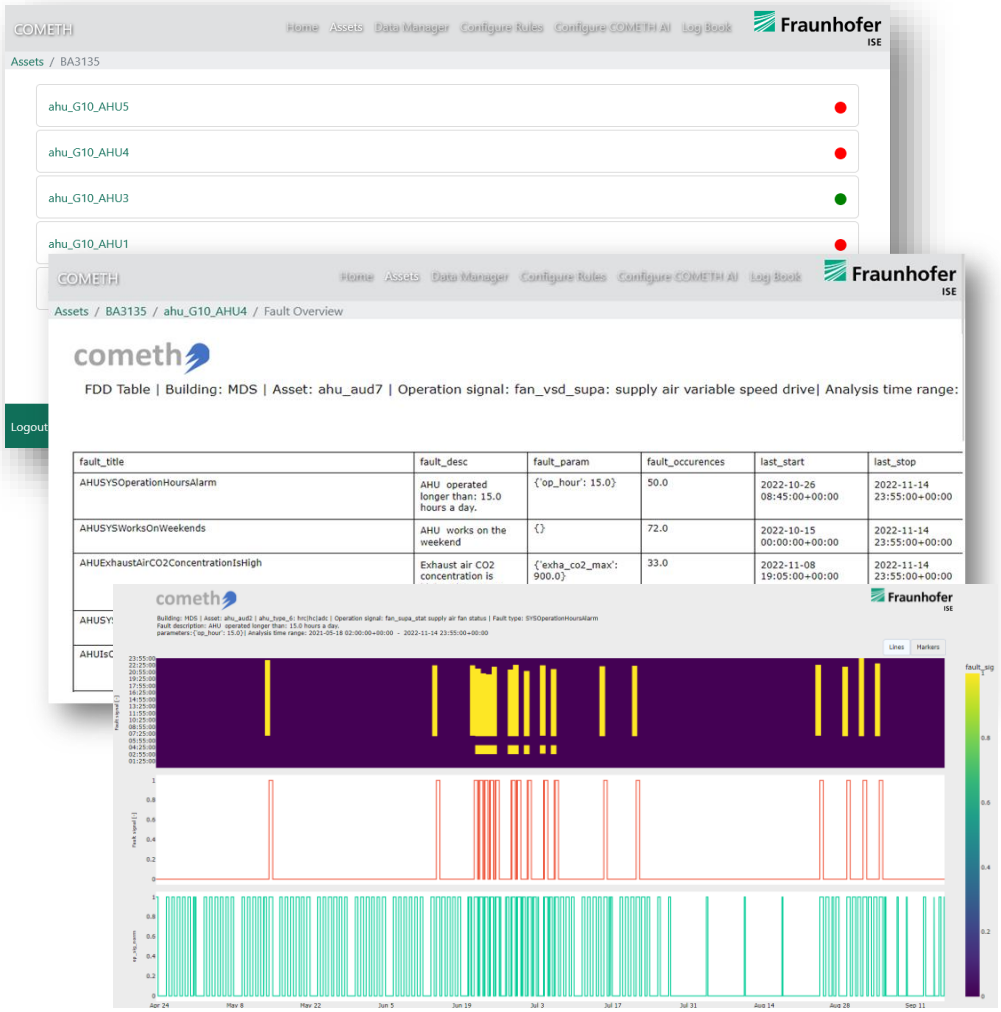


Hybrid AI methodology for FDD



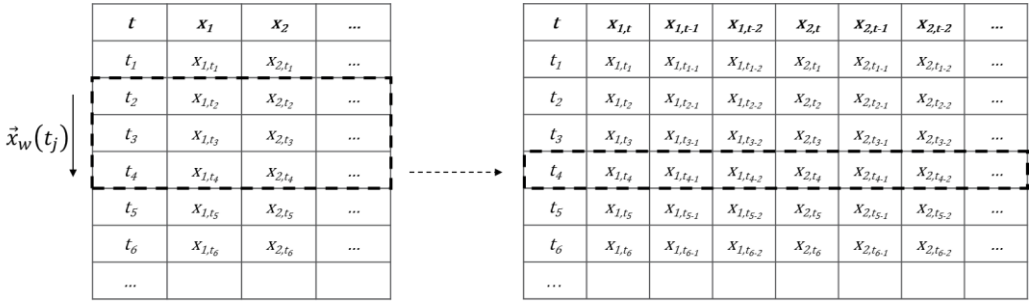
Rule-based system – COMETH Rules

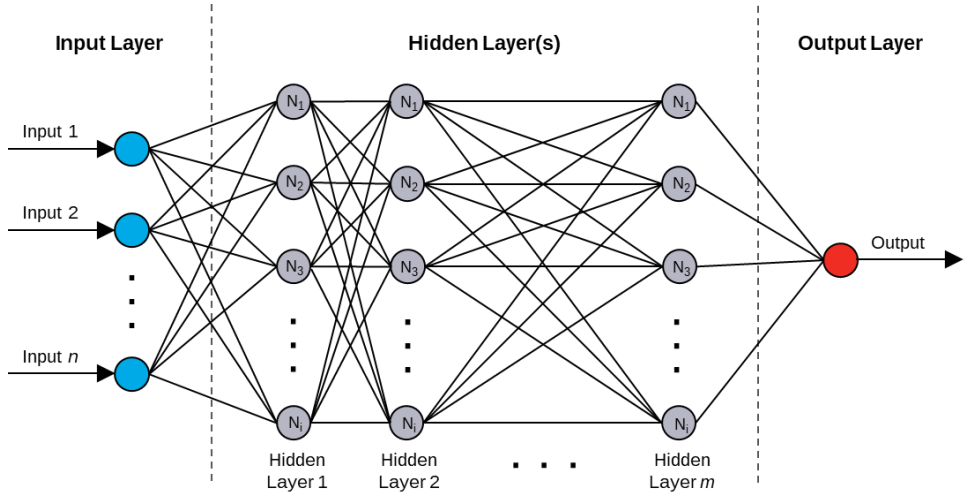
- Features
  - Extensive set of "if-then rules" for HVAC systems
  - Automated discovery of data points and plant topologies based on unified semantics
- Advantages
  - Simple and comprehensible implementation
  - Immediate diagnosis
  - High specificity if parameterized correctly
- Drawbacks
  - Rich in parameters – high parametrization efforts
  - Low sensitivity (no detection of new faults)



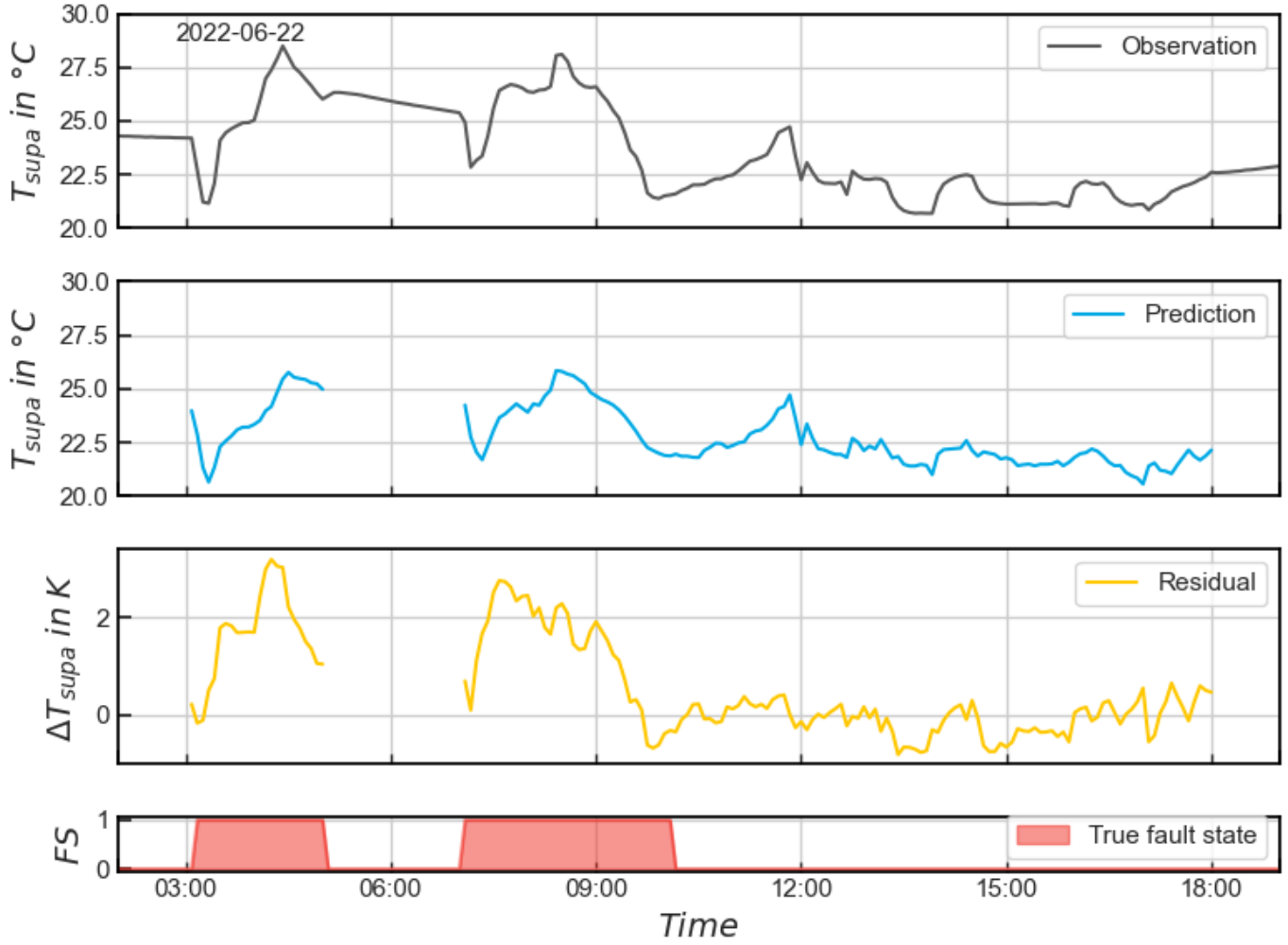
MLP Networks & hyperparameter tuning

- Transformation of the input data into a sliding time window (2h)
- Creation of separate MLP network models for each estimated variable (n inputs, 1 output)
  - Regression for continuous variables
  - Classification for discrete variables
- Bayesian hyperparameter optimization
  (e.g. hidden layers = 3-6, neurons per layer = 24-552)



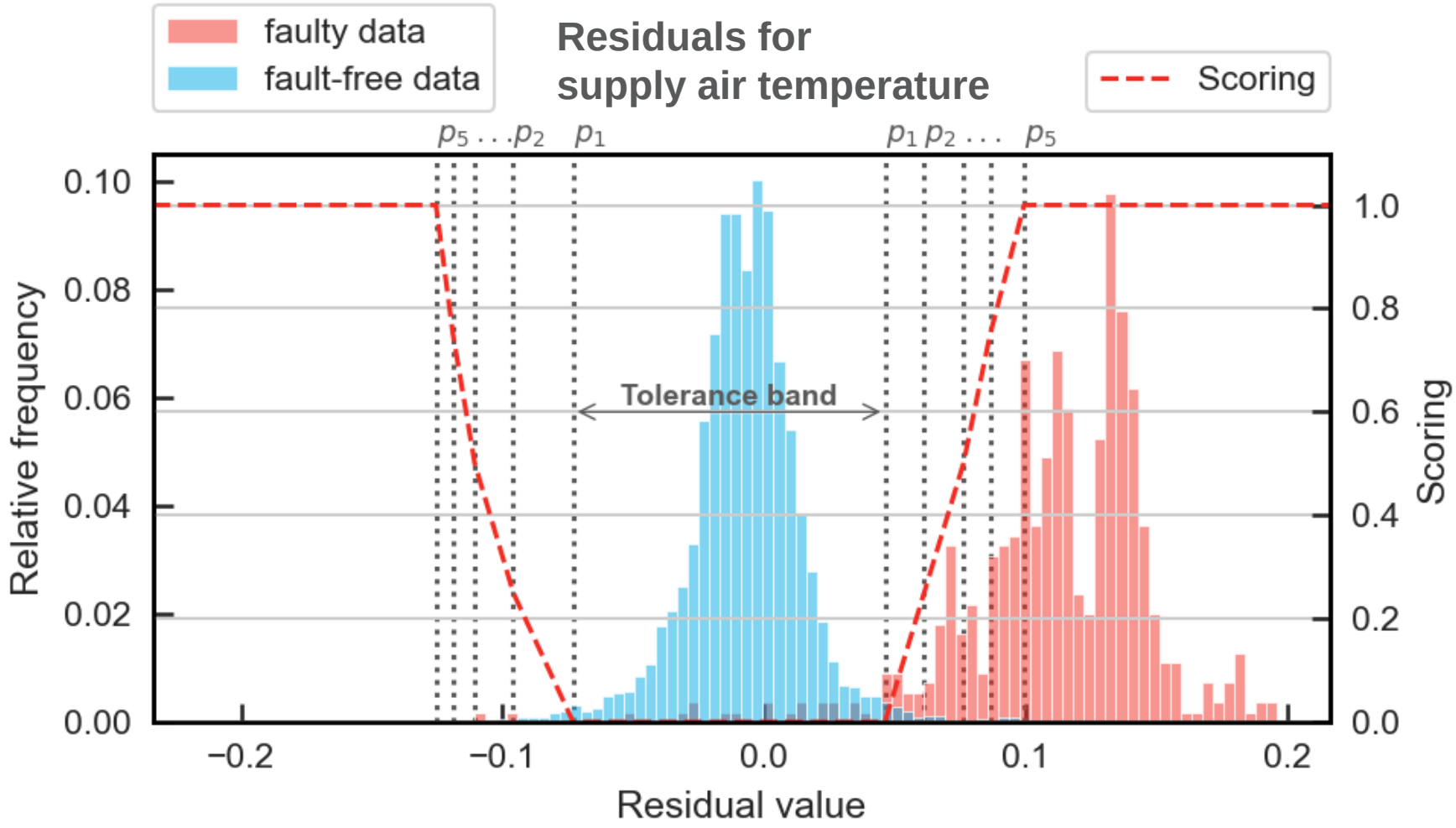


Residual evaluation



- Time series example of residual generation for supply air temperature
- Fault shown in the period: Heating without heat recovery

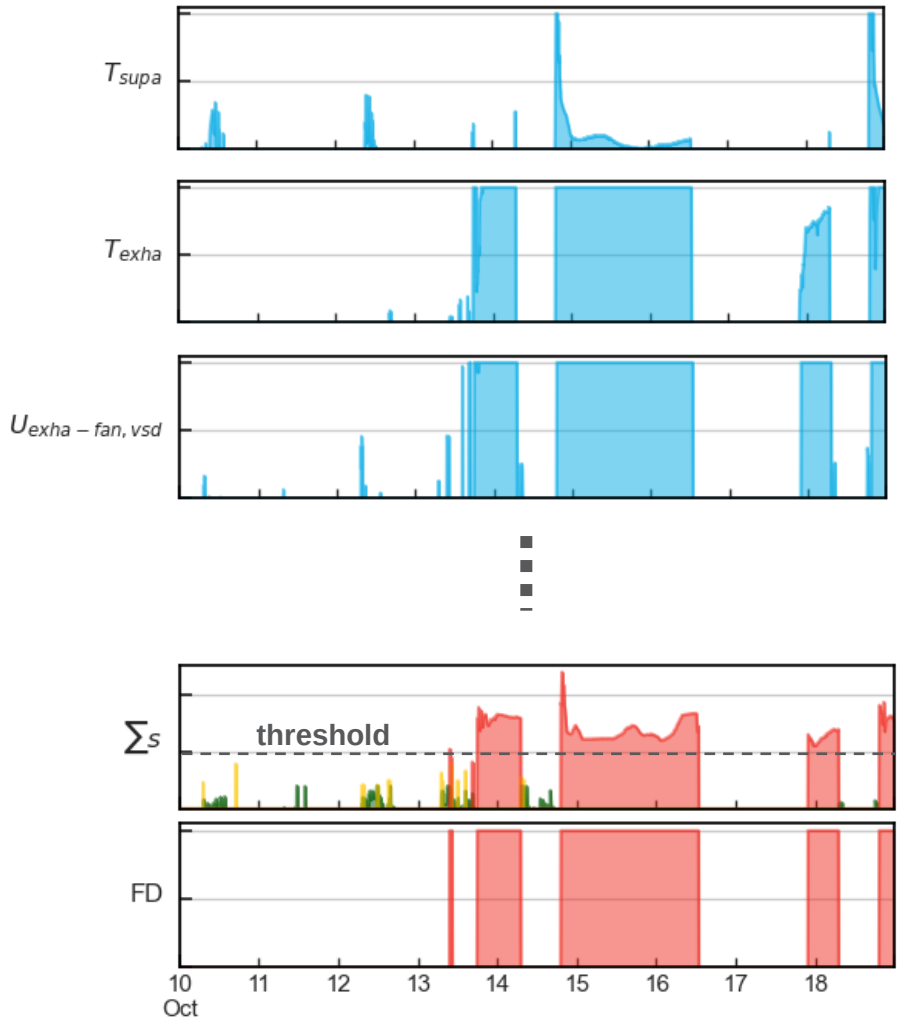
Residual evaluation



Residual evaluation

Single scores

- supply air temperature
- exhaust air temperature
- control signal of fan
- ⋮
- Sum of scores
- Fault detection result (yes / no)



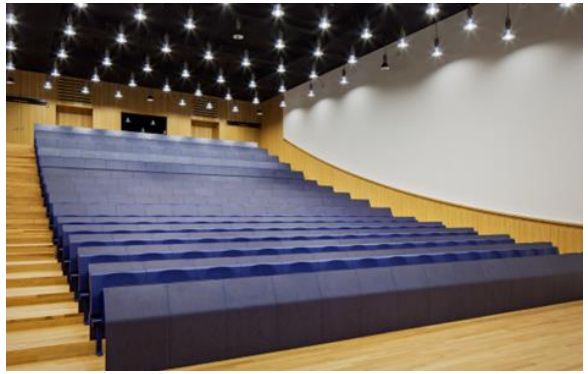
Case studies

- **9 different air handling units (AHUs) from 3 buildings** (2850 m³/h - 6000 m³/h)

Primary school Hohen Neuendorf (PSHN)

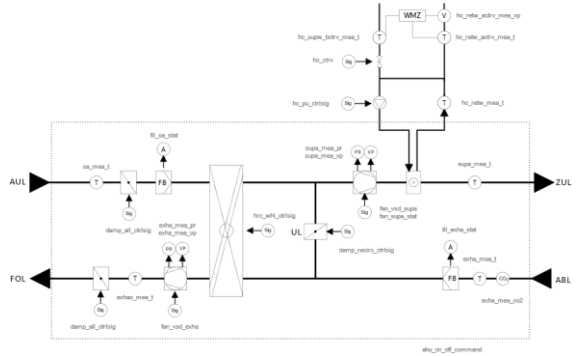
- Combined natural & mechanical ventilation
- Supplying classrooms (FLA, FLB) and a sports hall (SPO)
- Supply and exhaust air systems, plate heat exchanger & heating coil

Maison du Savoir (MSA)



- University of Luxembourg
- Supplying lecture rooms (AUD2, AUD7, AUD8)
- Supply and exhaust air systems, heat recovery wheel, heating coil and adiabatic cooling

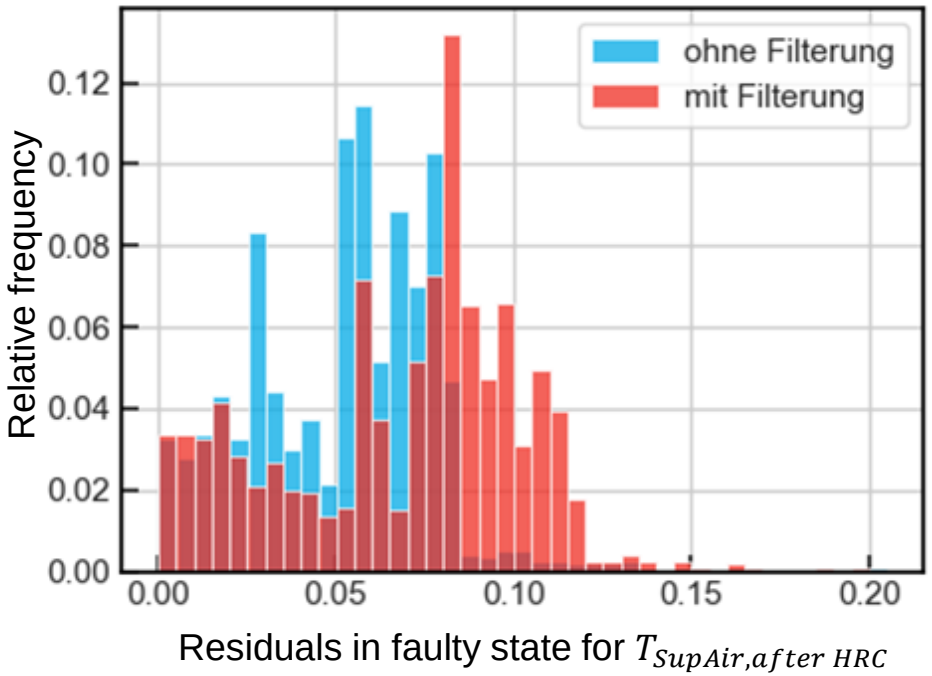
Anonymised boarding school building (ISC)



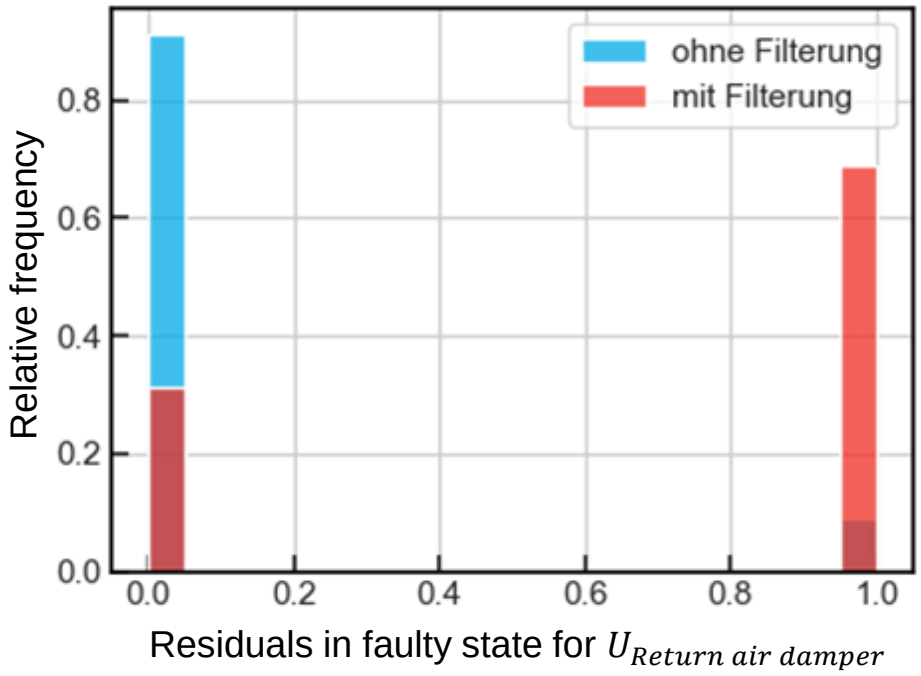
- Supplying a theater hall (AUD2) ,laboratories (AUD8) and accommodation areas (AUD17)
- Supply and exhaust air systems, heat recovery wheel, heating coil, adiabatic cooling for AUD2

Fault state filtering in training data

Residual-Modulus with and without filtering of faulty states in the training data



Residuals in faulty state for $T_{SupAir,after\ HRC}$

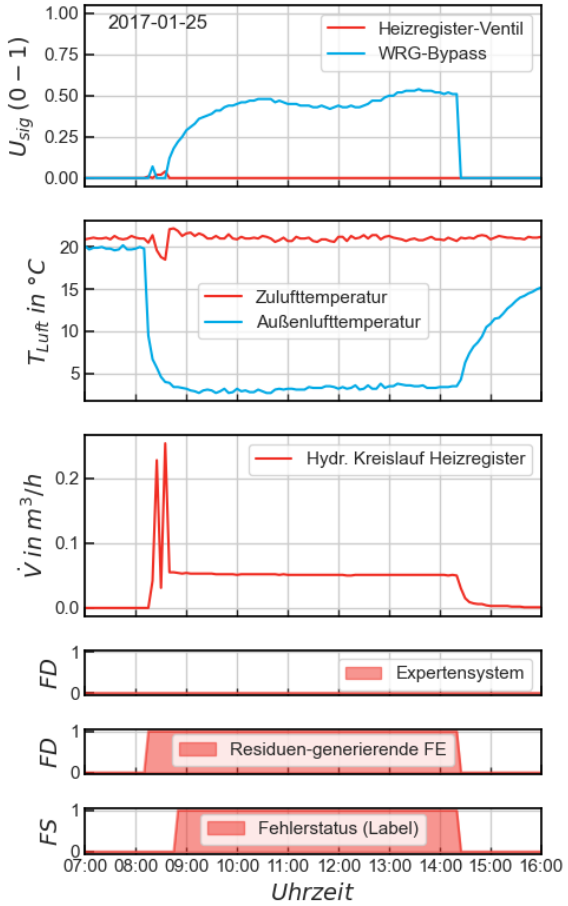


Residuals in faulty state for $U_{Return\ air\ damper}$

➢ *Rule-based pre-filtering of the training data increases the quality of the residuals in the event of a fault*

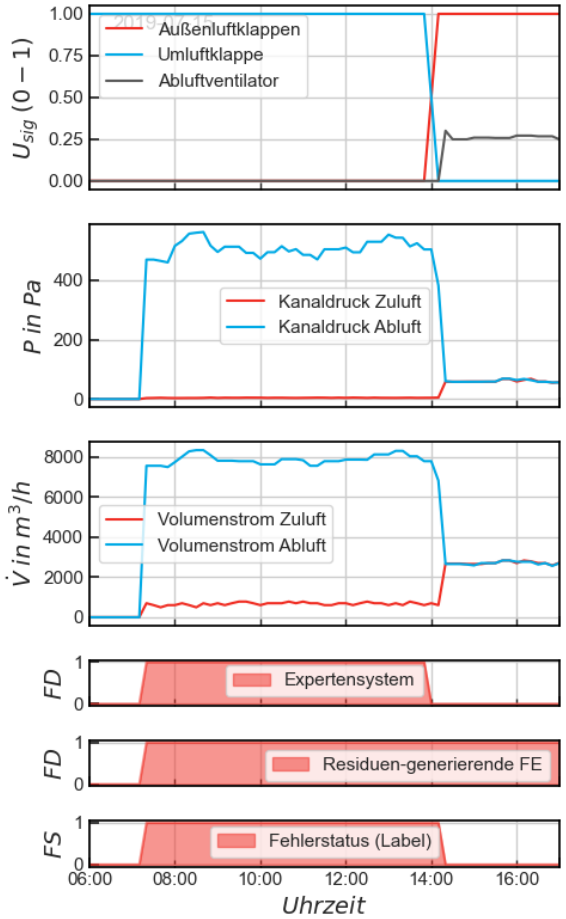
FD time series examples

HC valve leackage
(FLB, PSHN)



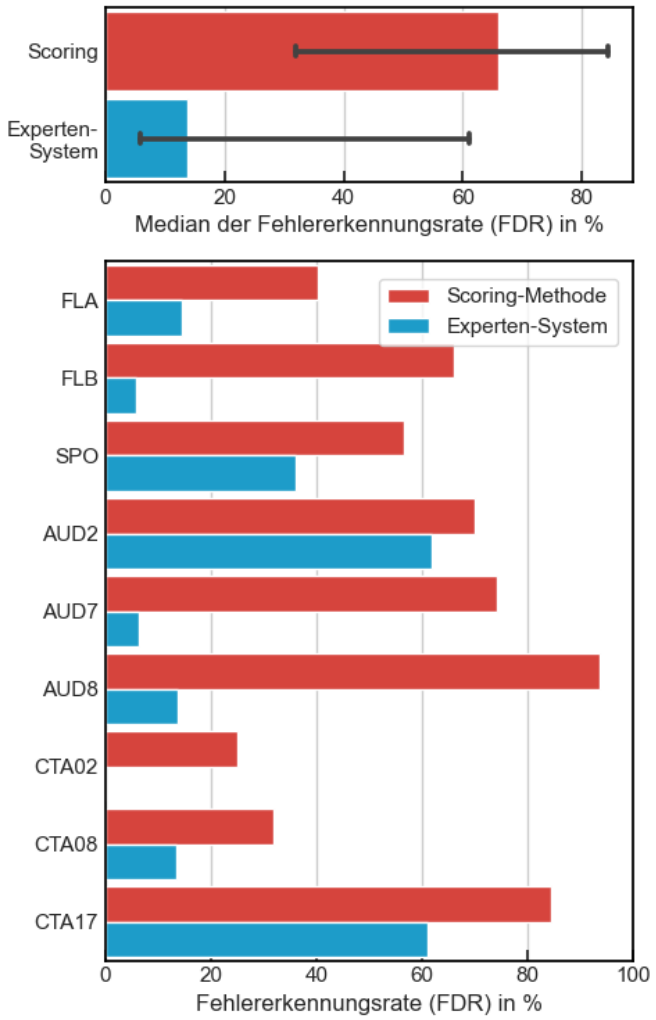
- Volume flow with closed heating coil valve signal indicates a leakage
- Limited data availability prevents the fault from being detected by the rules (supply air temperature upstream of the heating coil is missing)

Fan operation and dampers closed
(CTA17, ISC)



- High duct pressure with closed dampers indicate fan operation (although the control signal = 0)
- Consistency of both methods shows high confidence in the result

Fault detection performance



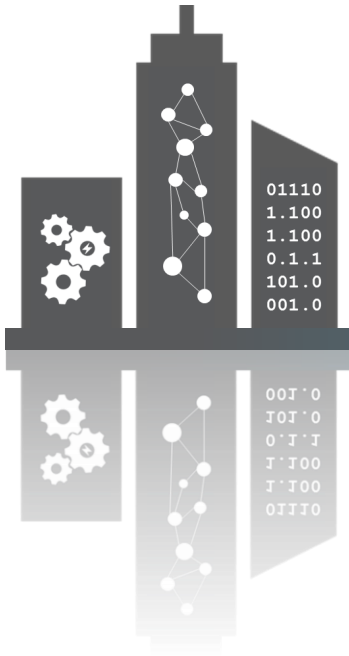
Residual generating approach versus expert system

- Higher sensitivity of the residual generating method
- In case of bad training data or changing boundary conditions, risk of high FARs exists
- Detection of novel faults for which no rules are implemented, or rules can’t be implemented due to data availability
- Combined application increases the FD performance

Achievements

A Hybrid AI methodology for FDD in buildings based on rules & ML-techniques

- Highly automated / low implementation effort
- Easily transferable to new systems
- Increased FD-Performance
- Limitation: Requires re-training if boundary conditions change (e.g. set points)



Thank you for your attention!

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