The 4th International Symposium on Industrial Engineering and Automation (ISIEA 2025)

Manufacturing 2030: A Perspective to Future Challenges in Industrial Production

June 18-20, 2025, Bozen-Bolzano, Italy

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How can *smart* lead to *green* production?

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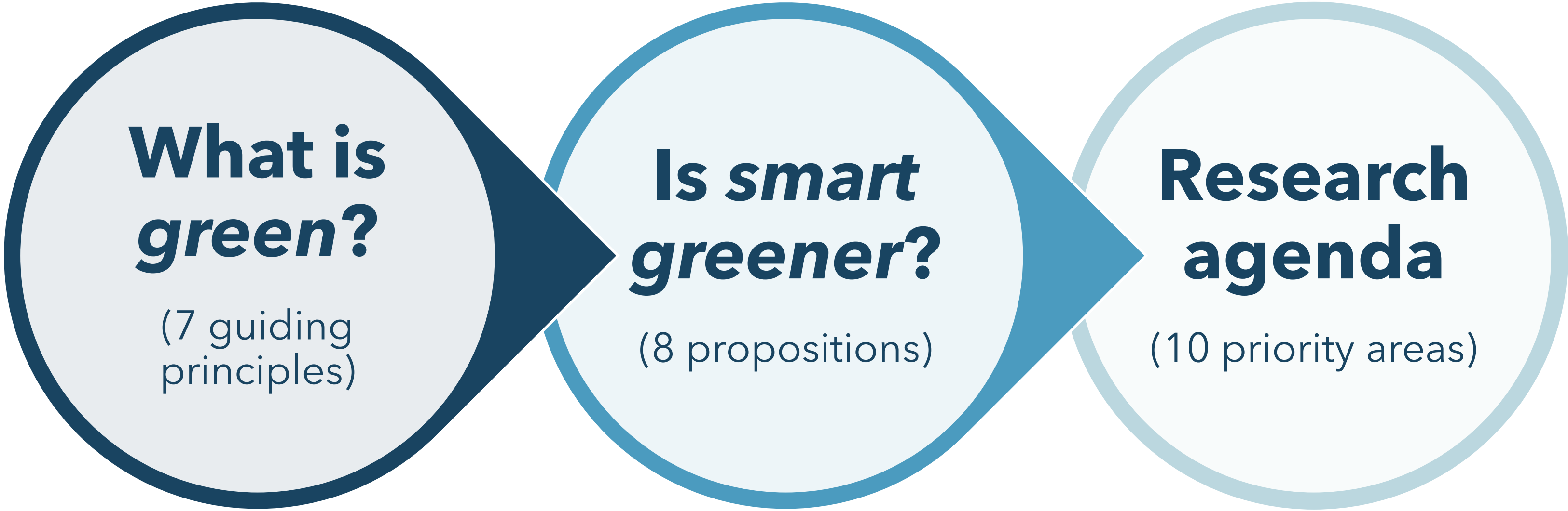
How can *smart* lead to *green* production?



ECO-EFFICIENT MANUFACTURING

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1. Reduce the **material intensity** of goods and services
2. Reduce the **energy intensity** of goods and services
3. Reduce **toxic** dispersion (pollution & climate impact)
4. Enhance material **recyclability**
5. Maximize sustainable use of **renewable** resources
6. Extend product **durability** (reuse, repair, reman, etc.)
7. Increase the **service intensity** of goods and services

Source: World Business Council for Sustainable Development (WBCSD, 1996)

1 Reduce the **material intensity**

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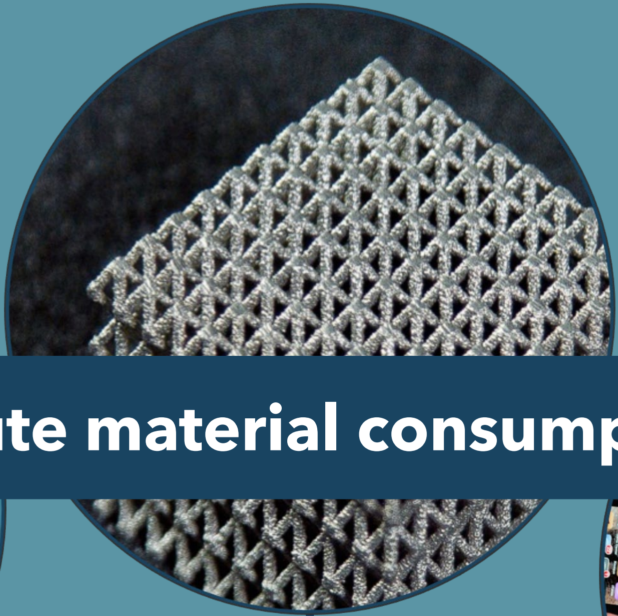
Process efficiency



Dematerialisation

Multifunctionality

Absolute material consumption

2 Reduce the **energy intensity**

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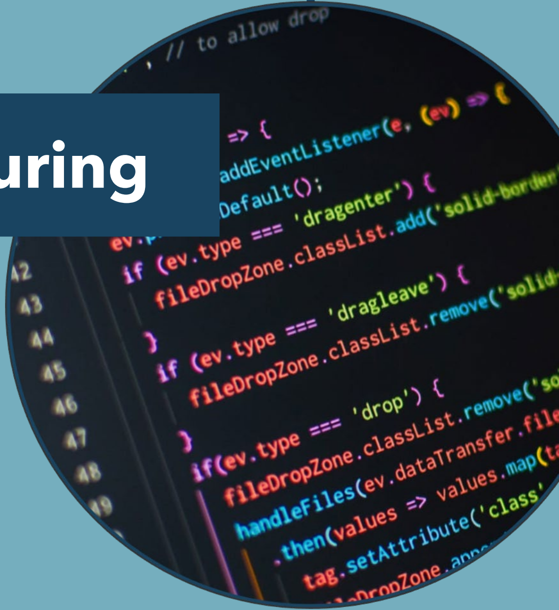
Process efficiency

Free energy

Green IT/OT



Frugal and sufficient manufacturing

3 Reduce **toxic** dispersion

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Natural processes

Avoidance & reduction

It’s all about concentrations.
“The dose makes the poison”

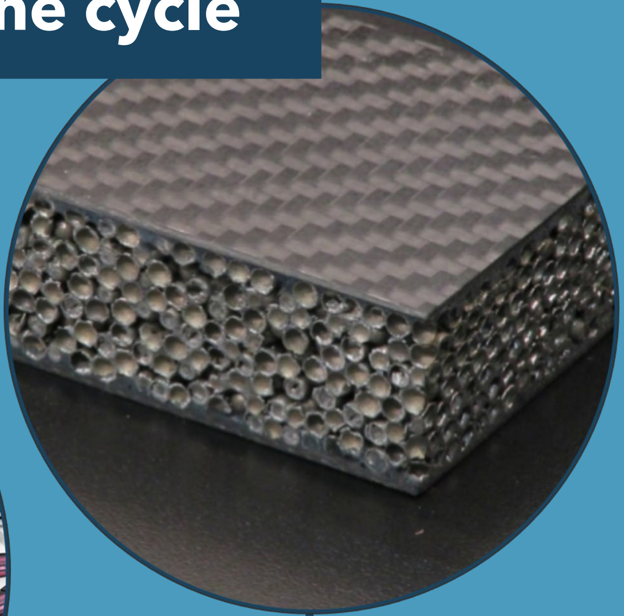
Treatment

4 Enhance material **recyclability**

Keeping materials in the cycle

Upstream

Separation



Downstream

5 Maximize sustainable use of **renewables**

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Energy

Material

Renewal capacity

Balancing resource use and regeneration

6 Extend product **durability**

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Production quality

Keeping parts and products in use

R-strategies

7 Increase the **service intensity**

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Digital services

Sharing economy

Focus on value and performance

Service-based business models

DOES RESEARCH SUPPORT ECO-EFFICIENT MANUFACTURING?

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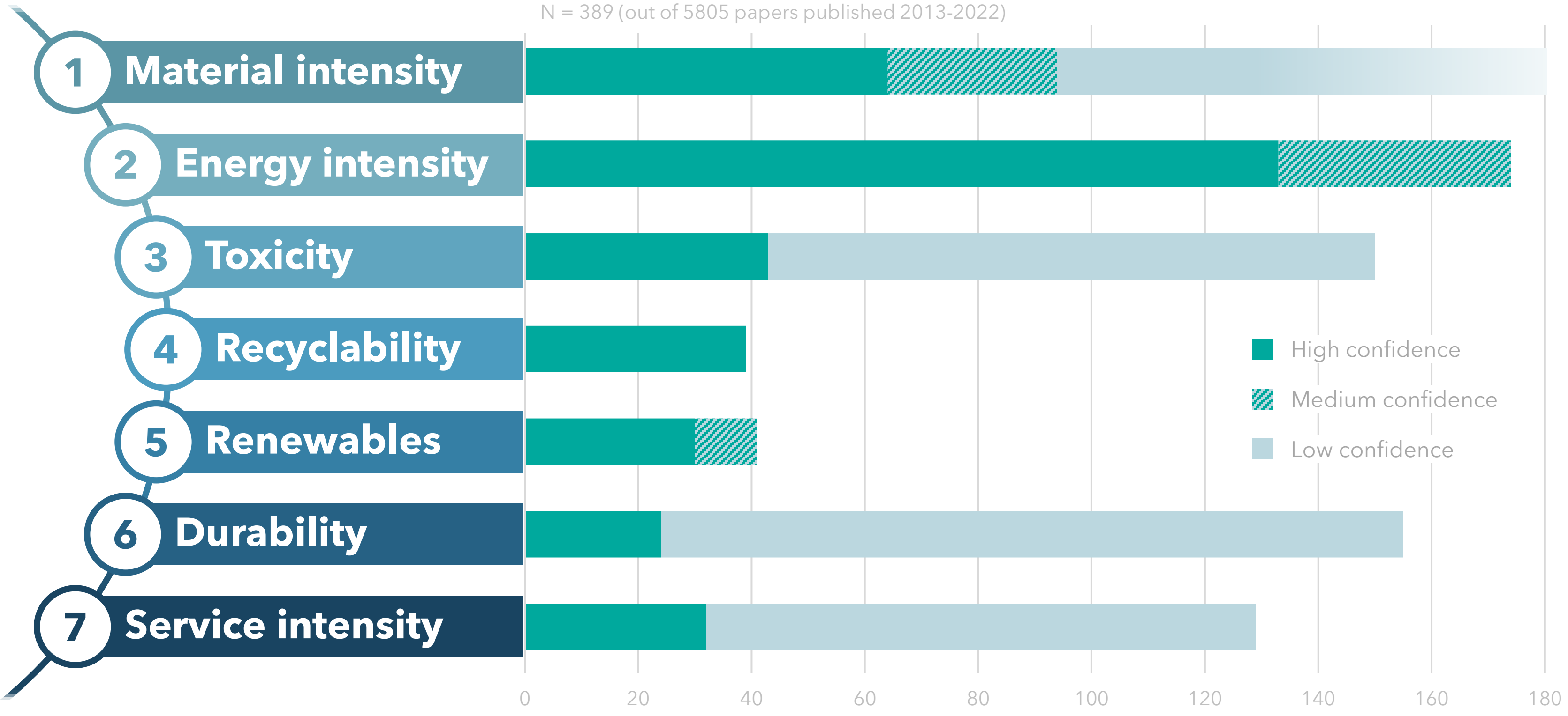

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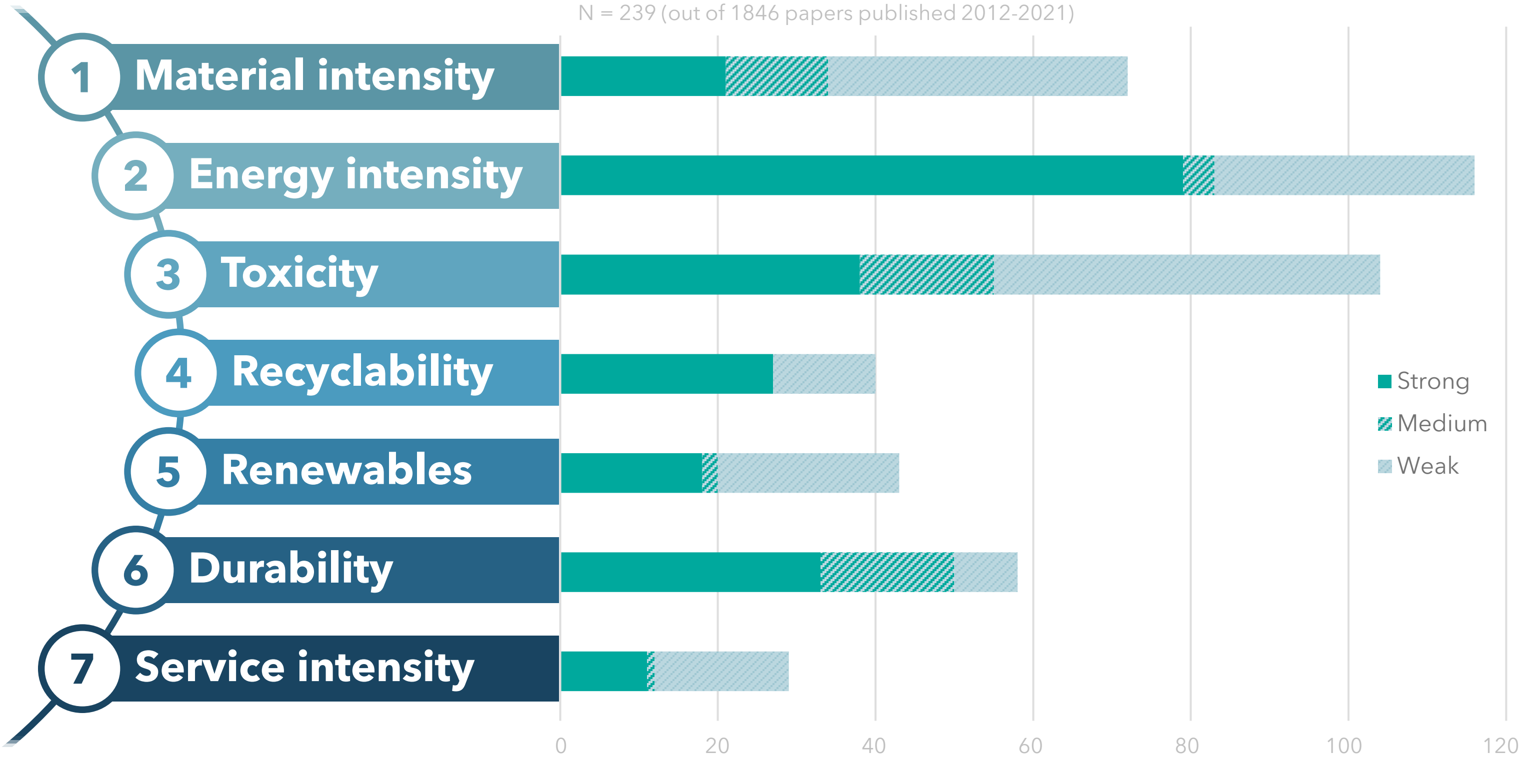

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DOES RESEARCH SUPPORT ECO-EFFICIENT MANUFACTURING?

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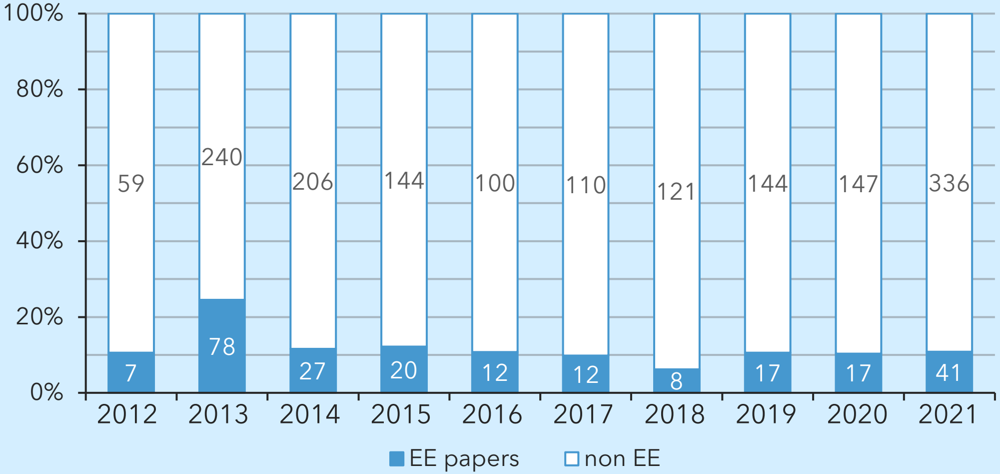
1. Material intensity
2. Energy intensity
3. Toxicity
4. Recyclability
5. Renewables
6. Durability
7. Service intensity

How have these trends evolved over time?



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DOES RESEARCH SUPPORT ECO-EFFICIENT MANUFACTURING?

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BETTER.
FASTER.
STRONGER.

SMART = GREEN?

Industrial digitalization can support eco-efficient manufacturing

Technological development ≠ greener production

Environmental impacts still rarely considered in *'smart'* research

Sustainability must be considered more explicitly as a core objective

Need guiding frameworks to align industrial and sustainable development systematically

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CHALLENGES OF GOING GREEN

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Strong focus on efficient **linear** production systems and reduced **direct** environmental impacts

Few studies on production waste recovery and **closed-loop** material flows in production

Need to quantify long-term impacts, including **uncertainties**, potential **rebound effects** and **trade-offs**

Productivity tools (Lean, six sigma) and EMS are **imperatives** for sustainable digitalization

LCA as a dominant tool, often **gate-to-gate** in scope due to uncertainty in other life cycle stages

Few studies on how manufacturing fits with **service-based** business models

Easy-to-use and reliable quantitative methods needed to **reduce subjectivity** in decision making

Lean is synergistic with green but not automatically, **dedicated sustainability metrics** needed

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PROPOSITIONS FOR GOING GREEN

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Digitalization should more systematically support…

…resource efficiency and environmental impact reduction

…a life cycle perspective of manufacturing systems to avoid rebound effects

…hybrid methods for optimisation and multi-criteria decision analysis

…manufacturers in a more circular, service-based economy

…the proactive integration of sustainability as a driver of performance

…the identification of trade-offs between the different dimensions of sustainability

…sustainability assessments for data-informed and fact-based business decisions

…the integration of sustainability considerations into established management systems

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RESEARCH AGENDA

Systematic review to create the **thematic framework**

+

Workshops to identify **priority areas**

=

Consolidated thematic research framework with RQs

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RESEARCH AGENDA

- Redefine success
- Highlight trade-offs
- Empower people
- Data-driven solutions
- Experiment and learn from failure
- Disruptive or radical change
- Continuous improvement
- Technology for sustainability
- Co-create value
- Doing good

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RESEARCH AGENDA

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Redefine success

- Environmental sustainability implications at different levels
- Definition of industrial performance and success

RESEARCH AGENDA

Highlight trade-offs

- Lifecycle perspective for holistic decision making
- Key variables and acceptable simplifications

RESEARCH AGENDA

Empower people

- Barriers to sustainable practices and behaviours
- Incentives for sustainable practices and behaviours
- Effective engagement mechanisms for employers and employees

RESEARCH AGENDA

Continuous improvement

- Performance assessment
- Practices and improvements

RESEARCH AGENDA

Disruptive or radical change

- Sustainability as a core value, not an add-on

RESEARCH AGENDA

Experiment and learn from failure

- Ease implementation to encourage experiments
- Share pitfalls/failures to help others overcome challenges
- Learn from failure, failure is not a taboo

RESEARCH AGENDA

Data-driven solutions

- Type of data/information
- Internal integration
- External integration

RESEARCH AGENDA

Technology for sustainability

- Environmental implications of advanced technologies
- Sustainability guidelines for technology management

RESEARCH AGENDA

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Co-create value

- Co-design in product/service beginning-of-life phase
- Co-creation in middle- and end-of-life phases
- Green product/service typology and design standards

RESEARCH AGENDA

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Doing good

- Understand the planetary boundaries at a local level
- Translate regenerative concepts into actionable practices

RESEARCH AGENDA

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- Redefine success
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Thematic Research Framework (**2022**)
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Research Challenges for Eco-Efficient and Circular Industrial Systems (**2024**)
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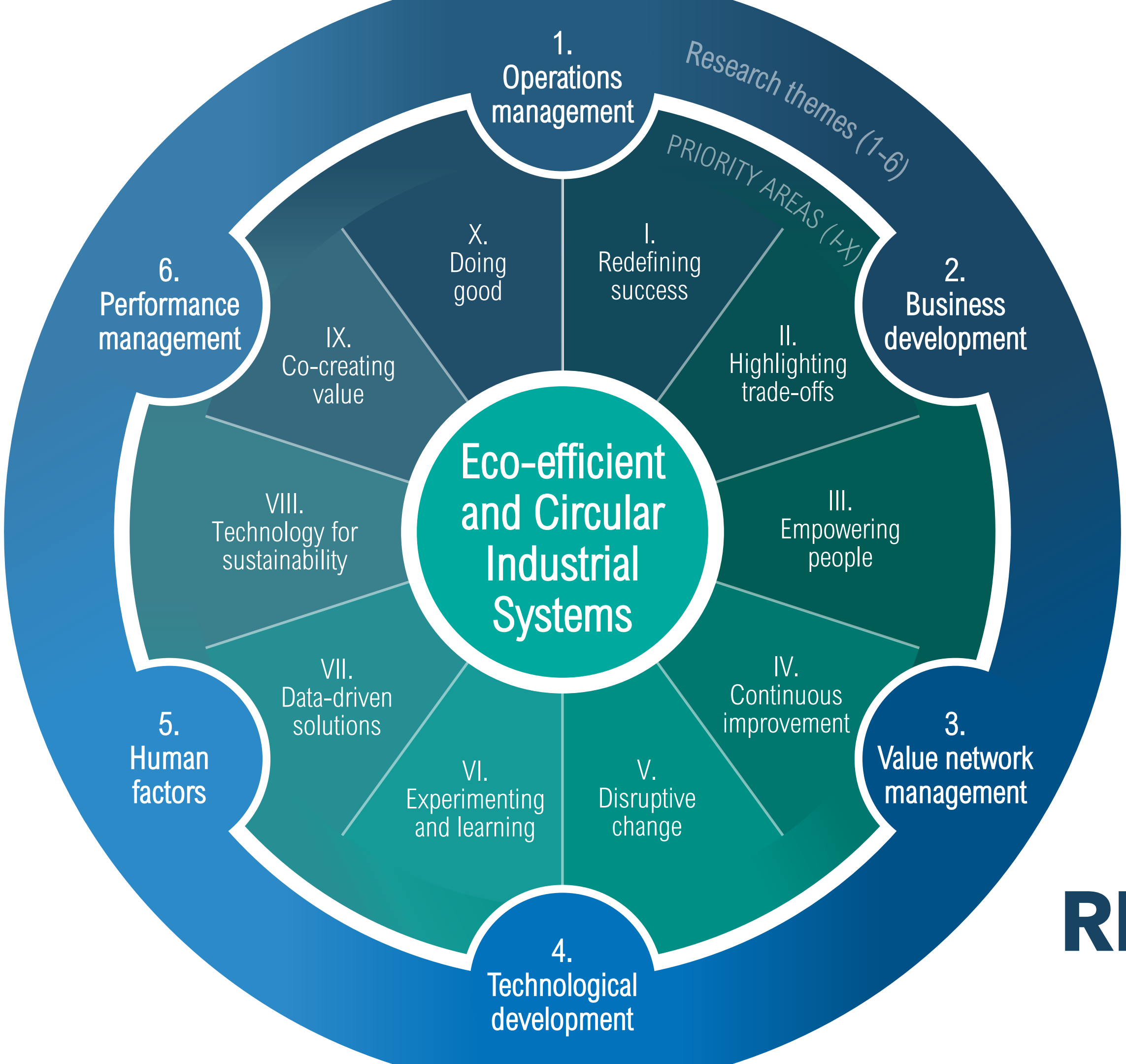

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LIVING RESEARCH AGENDA

Let's make *smart greener*

Eco-efficiency

(7 guiding principles)

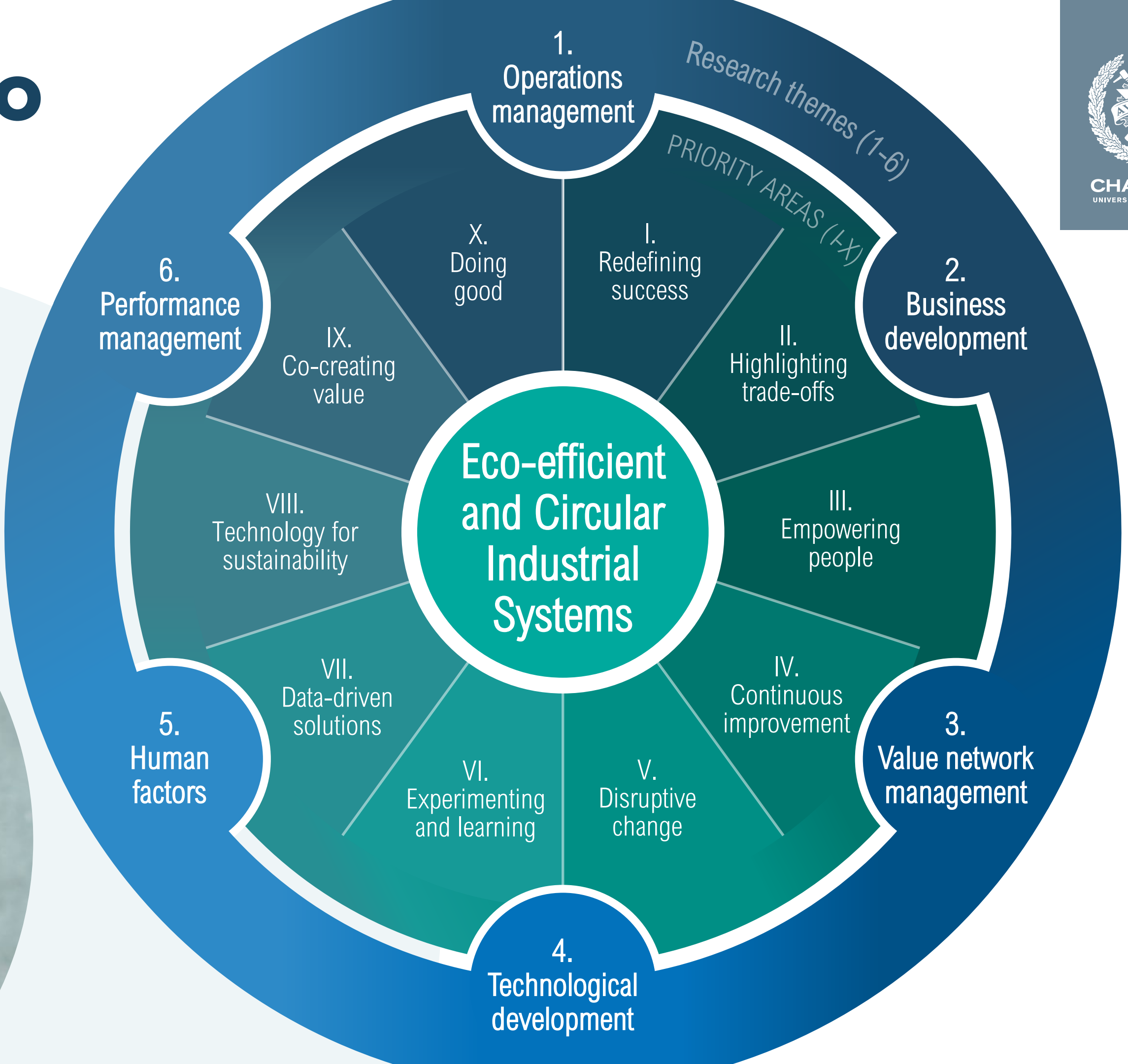
Better Smarter Greener

(8 propositions)

Living research agenda

(10 priority areas)

With thanks to my team and collaborators



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With thanks to my team, colleagues, project partners and students for advancing the field of industrial sustainability! Yes, we can! ☺

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AVANCEZ

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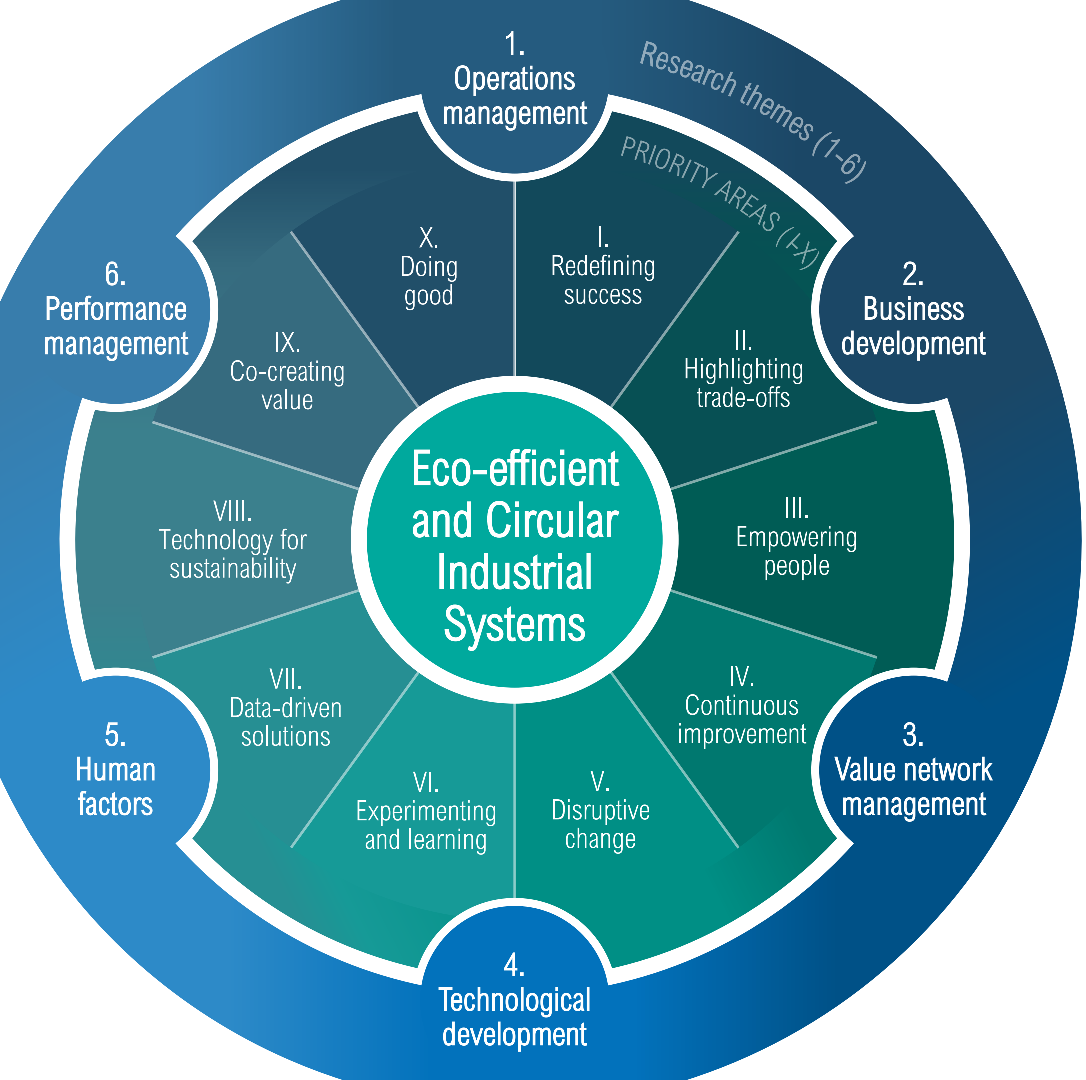

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PRIORITY AREAS

- **I. Redefining success**
  - Environmental sustainability implications at different levels
  - Definition of industrial performance and success
- **II. Highlight trade-offs**
  - Lifecycle perspective for holistic decision making
  - Key variables and acceptable simplifications
- **III. Empowering people**
  - Barriers to sustainable practices and behaviours
  - Incentives for sustainable practices and behaviours
  - Effective engagement mechanisms for employers and employees
- **IV. Continuous improvement**
  - Performance assessment
  - Practices and improvements
- **V. Disruptive change**
  - Sustainability as a core value, not an add-on
- **VI. Dare to fail and share**
  - Ease implementation to encourage experiments
  - Share pitfalls/failures to help others overcome challenges
  - Learn from failure, failure is not a taboo
- **VII. Data-driven solutions**
  - Type of data/information
  - Internal integration
  - External integration
- **VIII. Technology for sustainability**
  - Environmental implications of advanced technologies
  - Sustainability guidelines for technology management
- **IX. Customer-oriented value**
  - Co-design in product/service beginning-of-life phase
  - Co-creation in middle- and end-of-life phases
  - Green product/service typology and design standards
- **X. Doing good**
  - Understand the planetary boundaries at a local level
  - Translate regenerative concepts into actionable practices

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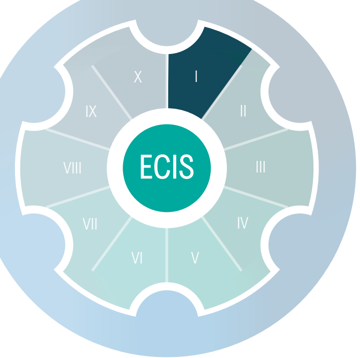

I. Redefining success

RQ1.1. Environmental implications at different levels (time and scale)
What are the environmental sustainability implications of manufacturing, service, and logistics operations improvements in the short and long term for individual organisations and industry as a whole?

RQ1.2. Definition of industrial performance and success
How can these environmental implications be measured and integrated into the definition of sustainable industrial performance and therefore success?

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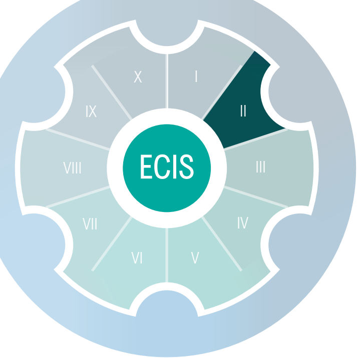

II. Highlighting trade-offs

RQ2.1. Lifecycle perspective for holistic decision making

What needs to be considered to enable holistic decision making from a lifecycle perspective for environmental sustainability?

RQ2.2. Key variables and acceptable simplifications

What are key variables to consider and appropriate simplifications to reduce complexity in decision-making processes for environmental sustainability?

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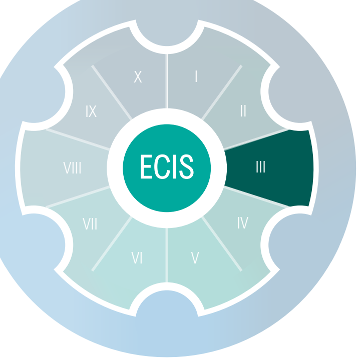

III. Empowering people

RQ3.1. Barriers to sustainable practices and behaviours
What are the barriers preventing people from engaging directly and indirectly in sustainable practices and behaviours?

RQ3.2. Incentives for sustainable practices and behaviours
What are appropriate incentives to empower different stakeholders to transition towards environmentally sustainable practices and behaviours?

RQ3.3. Effective engagement mechanisms for employers and employees
How can employers and employees be actively involved in the transition towards environmentally sustainable operations?

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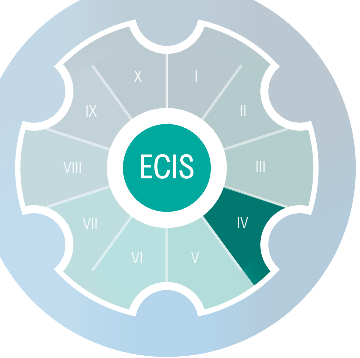

IV. Continuous improvement

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RQ4.1. Performance assessment

How can manufacturing companies assess their current performance and identify potential for improvements towards environmental sustainability?

RQ4.2. Practices and improvements

What are the practices already in place to support environmentally sustainable activities? What improvements can be made to these practices/activities?

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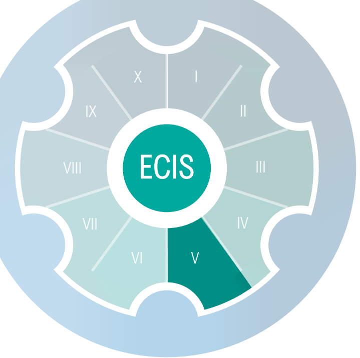

V. Disruptive change

RQ5.1. Sustainability as a core value, not an add-on

How can sustainability be integrated and elevated as a core design principle for all products, services, and systems from their conception (and not as an add-on)?

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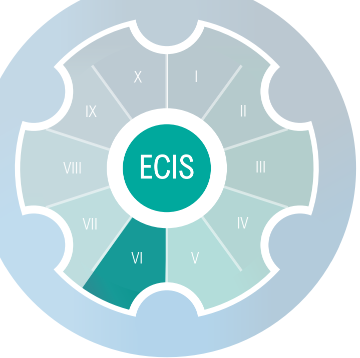

VI. Experimenting and learning

RQ6.1. Ease implementation of green solutions to encourage experiments
What are the best practices, tools, methods, and frameworks that ease the implementation of environmental solutions towards sustainable operations?

RQ6.2. Share pitfalls and failures to help others overcome challenges
What are the pitfalls that hinder the implementation of environmental solutions towards sustainable operations?

RQ6.3. Learn from failure as a powerful method, not a taboo
How can falsification speed up the development of more effective, robust, and feasible environmental solutions, lowering barriers to implementation and success in achieving sustainable operations?

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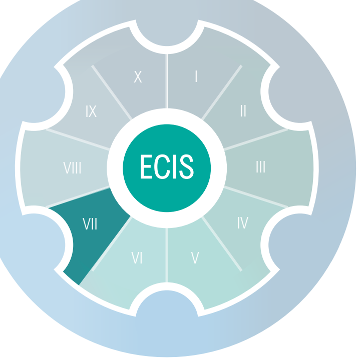

VII. Data-driven solutions

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RQ7.1. Type of data/information
What data/information needs to be shared, at which level of granularity, and amongst which stakeholder(s) to facilitate efficient, sustainable operations?

RQ7.2. Internal integration
How to ensure information systems interoperability and avoid misinterpretation of data/information using standards for improved decision making? Internal integration of info flow

RQ7.3. External integration
How to facilitate communication and information exchange beyond organisational boundaries for more efficient, sustainable value chain operations? External integration of info flow

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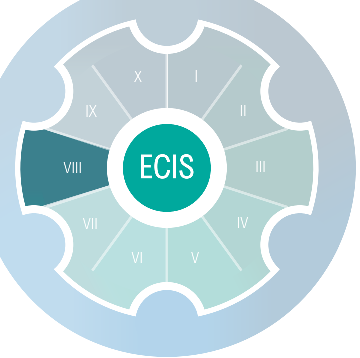

VIII. Technology for sustainability

RQ8.1. Environmental implications of advanced technologies

What are the environmental sustainability implications (positive and negative) when developing, selecting, and implementing advanced technologies?

RQ8.2. Sustainability principles and guidelines for technology management

How can these implications be measured and integrated into technology development, selection, and implementation to ensure positive outcomes?

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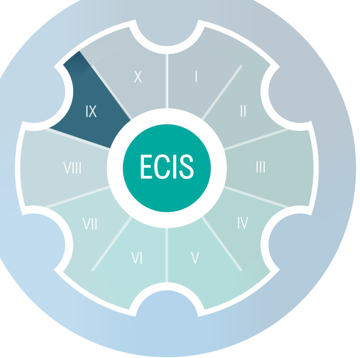

IX. Co-creating value

RQ9.1. Co-design in product/service beginning-of-life phase

How to involve customers in the co-design of products and services to meet their needs in a more eco-efficient way?

RQ9.2. Co-creation in middle- and end-of-life phases

How to involve customers in extending the life of their products and increasing value co-creation during their usage phase?

RQ9.3. Green product/service typology and design standards

What type of product and service design standards facilitate the transition towards environmentally sustainable and circular business operations?

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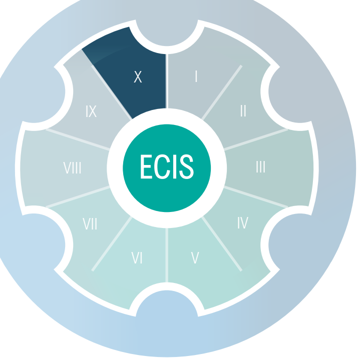

X. Doing good

RQ10.1. Understand the planetary boundaries at a local level
How can companies operate within natural ecosystems' limits, accounting for their renewal and assimilation ability (eco-efficient and circular practices)?

RQ10.2. Translate regenerative/restorative concepts into actionable practices
What are the mechanisms through which companies can contribute positively to ecosystems' health (regenerative and restorative practices)?

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