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Department of Information Engineering and Computer Science
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Graz University of Technology
Institute of Business Economics and Industrial Sociology

EPIEM

Creating Effective Research Partnerships in Central and Eastern Europe to Tackle Innovation and Sustainability Challenges in the Era of AI

Proceedings of the 17th EPIEM Conference 2024

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Editors
Marco Formentini
Nikola Suzic
Caterina Trevisan
Janpriy Sharma
Amila Omazic
Bernd M. Zunk

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Series Editor:
Em. o. Univ.-Prof. Dipl.-Ing. Dr.techn. Ulrich BAUER
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Responsible for the design and the content:
Institute of Business Economics and Industrial Sociology (BWL)
Kopernikusgasse 24/II
8010 Graz
Austria

Editors
Assoc. Prof. Dr. Marco FORMENTINI
Asst. Prof. Dr. Nikola SUZIC
Ing. Caterina TREVISAN
Dr. Janpriy SHARMA
Univ.-Ass. Amila OMAZIC, BSc MSc
Assoc. Prof. Priv.-Doz. Dipl.-Ing. Dipl.-Ing. Dr.techn. Bernd Markus ZUNK

Layout, Typesetting
Univ.-Ass. Vanessa Halwax, BSc MSc
Institute of Business Economics and Industrial Sociology (BWL)
Kopernikusgasse 24/II
8010 Graz
Austria

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* Extended Abstract

Creating effective research partnerships in Central and Eastern Europe to tackle innovation and sustainability challenges in the era of AI

The 17th EPIEM (European Professors of Industrial Engineering and Management) Conference in October 2024 was organised and hosted by the Department of Information Engineering and Computer Science, the Department of Industrial Engineering, and Department of Economics and Management at the University of Trento.

The conference aimed to bring together enthusiastic operations management, industrial engineering, and management scholars (e.g., professors, instructors, lecturers, researchers at all levels, PhD students, and postdocs) and practitioners from the CEE region. Thus, the 17th EPIEM Conference offered participants a good opportunity to present their research findings as well as their teaching and practical experience, exchange information, discuss current issues, and publish their work in the EPIEM conference proceedings (30th BWL Publication Series). The conference proceedings include two types of submissions, i.e., extended abstracts, and full papers.

Although the focus of this conference was placed on the central theme of Artificial Intelligence in Operations and Supply Chain Management, Industrial Engineering and Management, and the related challenges, for example, sustainability, circular economy, ethics, and innovation, all papers from major areas in the management, business economics, and industrial engineering fields – theoretical or empirical with a strong link to technology management/techno-economics – were highly encouraged. A specific attention was given to opportunities and challenges in CEE region.

Trento, 4/12/2024

Prof. Dr. Marco FORMENTINI

Measuring the unmeasurable: An IIoT evaluation framework

Davide Bonfio (davide.bonfio@phd.unipd.it)
Università degli Studi di Padova, Italy

Andrea Furlan (andrea.furlan@unipd.it)
Università degli Studi di Padova, Italy

Extended Abstract

Industry 4.0 is a transformative force that has pervasively impacted different organizations' functions (Schwab, 2016). In operations, it manifests through a set of technologies such as the Industrial Internet of Things (IIoT), Artificial Intelligence (AI), and Advanced Robotics (Martin et al., 2017). Due to their pervasiveness and ubiquity, traditional investment evaluation tools are no longer sufficient to fully appreciate the potential improvements and synergies these investments can bring to firms.

In this paper, we propose a flexible model that integrates each firm's strategic priorities and the impact of technology implementation expressed as cost savings. This tool starts with a qualitative assessment of a firm's strategic priority through Analytical Hierarchical Processing (AHP), then through Manufacturing Cost Deployment (MCD), waste is detected and categorized into one of the five performance objectives. Finally, the monetary value of saving after the technology implementation is monetized and actualized via Discounted Cash Flow. With its quali-quantitative approach, the tool simultaneously addresses two key questions: "How much are we saving?" and "How are these savings generated, and why are they valuable for our businesses?" (Kalip et al., 2022).

The starting point of our tools is to prioritize firms' strategic objectives via AHP of the five Manufacturing Performance Objectives (i.e., Speed, Dependability, Flexibility, Cost, and Quality). The primary purpose of the AHP in our model is to assist decision-makers in multi-objective situations. AHP is structured as a hierarchy, beginning with a vector of preferences and ending with a coherent set of preferences. To mitigate personal bias, the AHP must be compiled by different operations managers. This step is necessary to assess the magnitude of the impact and the area in which a firm wants to improve by investing in an IIoT technology. Beyond building a set of preferences, AHP can ensure coherence between those preferences. AHP allows a qualitative evaluation of which aspects of operations can be improved by investing in I4.0 technologies, providing a clear and structured process for decision-making.

The next step is to categorize each of the eleven losses identified by Yamashina and Kubo (2002) and associate them with one of the manufacturing performance objectives. This step is thought to assign a different weight to each loss. Operations in different firms have different features. Thus, implementing a technology can have different impacts on different MPOs and affect a firm's operation. For example, if two firms assign different importance to speed investing in a speed-increasing technology, the cost savings must be weighted differently.

The next step is to collect data about waste, following the Manufacturing Cost Deployment procedure and pairing it with MPOs. This is a critical step in the evaluation tool: the impact of technology implementation is given by the savings in terms of time. Over time, a correct technology implementation and operators' know-how should reduce the

non-value-adding time (i.e., waste). Each time a work center stops, the root cause of this stop can be reconducted to one of the eleven causes hypothesized by MCD. Multiplying these non-value-adding time by the hourly cost of the specific work center makes it possible to quantify each center's waste. After data collection, each waste can be normalized using a factor that can be derived from the following proportion:

$$t_{ji} : w_{ji} = T_i : X$$

Where t_{ij} is the time spent with the machine turned on the day j of the month i, w_{ji} is the time wasted on the same day, Ti is the daily average of the time spent with the machine turned on the month i. X will represent the time wasted in a certain day if the machine stayed turn on exactly for the time expressed by Ti. This normalization is necessary since there are no perfectly efficient operations. During the peak of production, there will be a higher wasting time due to higher production rather than a negative effect of the investment.

The wasted time is then monetized and weighted with the relative importance provided by the AHP. The cost savings are actualized to evaluate the Net Present value, using the WACC as a discount factor.

To verify the model's actual outcome, we applied it to a real case in which AI is used in manufacturing to fully grasp this technology's advantages and synergies. We use data from an IT company that develops AI solutions for manufacturers. We tested our model retrieving data on an Italian precision mechanic firm. As the project started, we identified a very important constraint that also affects some tool development choices: even if some technologies can satisfy all the data requirements of cost deployment, many others are in the early stages and cannot fully meet that request. For example, some machinery can automatically recognize and communicate a change in its state (i.e., from a setup to a working state). At the same time, in other cases, human intervention is required. Finally, even if all the workstations in which the technology has been implemented can automatically transmit data, the firm context (e.g., employees' openness to technologies and support in the implementation phase) may play a crucial role in fully exploiting the investments

The expectation is that over time, the implementation of technology and the building of specific know-how of operators should reduce the production process stops. By embedding a qualitative evaluation of different operational aspects that a particular investment can impact, this flexible tool can overcome some major inefficiencies of traditional investment evaluation tools.

Keywords: IIoT, AI, Smart Manufacturing, Operational Excellence, AI Valuation Tool.

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Industry 4.0 impact on sustainability performance: Evidence from the Italian mechanical and machinery sectors

Ahmed Mohamed Omar Hmouda (ahmedmohamedomar.hmouda@unibz.it)
Faculty of Engineering, Free University of Bozen-Bolzano, Italy

Margherita Molinaro (margherita.molinaro@unibz.it)
Faculty of Engineering, Free University of Bozen-Bolzano, Italy

Guido Orzes (guido.orzes@unibz.it)
Faculty of Engineering, Free University of Bozen-Bolzano, Italy

Extended Abstract

Implementing Industry 4.0 (I4.0) at different levels (i.e., plant/ process, supply chain, ecosystem) is increasingly viewed as essential for maintaining a competitive advantage (Battaglia et al., 2023). Furthermore, it potentially leads to economic, environmental, and social benefits, ultimately improving overall sustainability performance (Shri et al., 2023). However, several uncertainties regarding the negative effects of industry 4.0 have recently been highlighted (Dieste et al., 2023). Accordingly, the aim of this study is to explore the drivers of the adoption of I4.0 technologies and their impact on the environmental and social pillars of sustainability in Italian mechanical and machinery companies.

To reach the research objective, a comprehensive literature review is conducted that focuses on the I4.0 intersection with sustainability performance in the production and manufacturing domains. Following that, four semi-structured interviews with Italian companies in the mechanical and machinery sectors (i.e., Companies A, B, C, and D) were carried out. These interviews lasted around 90 minutes and are based on a research protocol that includes detailed questions about: (1) the specific I4.0 technologies applied at the process level; (2) motivations and goals for implementing these technologies; and (3) their detailed impact on environmental and social sustainability. Lastly, to derive insights from the collected data and information, within-case analysis was conducted, followed by cross-case comparisons (Yin, 2015).

Preliminary results show numerous applications of I4.0 in the Italian mechanical and machinery sector. They range from incorporating Radio Frequency Identification and the Internet of Things to Collaborative Robots, Automated Internal Logistics and Digital Twins. The cross-case analysis shows that sustainability outcomes were not the main objective driving decisions to introduce I4.0 technologies in the production process. All interviewed companies claimed indeed that the need for digitalization and/or automation came from emerging business and market needs, such as the need for increased production and logistics capacity. Sustainability impacts have been achieved only as an indirect consequence of Industry 4.0 implementation. Overall, the identified impacts are positive, but some negative aspects were also mentioned. In particular, many companies highlighted highly positive impacts on the environmental pillar of sustainability. For example, Company A implemented various I4.0 technologies, which directly reflected positive environmental impacts. More specifically, one of the main achievements by Company A was the realization of an automated warehouse, where the temperature is maintained at room tempera-

ture - neither heated nor cooled – thereby reducing energy waste and consumption, as well as the CO_2 emissions associated with manufacturing activities. A similar scenario has been noticed in Company B. This latter provided also interesting results in terms of social benefits. Many tasks have indeed been automated with robots and this consequently improved the ergonomic health of the workers, avoiding their exposure to ergonomic risks. On the negative side, few negative environmental impacts have been mentioned, but they have been encountered eventually. For example, Company A initially encountered excessive power use in one of its 4.0 solutions aimed at automatizing the internal logistics process. However, with the support of the technology provider, the company is now finalizing some changes that should solve the problem. Some negative social impacts were highlighted as well in several positions during the interviews. For example, company D noted that, during the implementation phase of I4.0 technologies, it did not take into consideration some social consequences of the digitalized process. In more details, they encountered difficulties related to the level of technological readiness of the employees due to a lack of basic interaction with digital devices. In addition, the company mentioned that the employees experienced two main issues: first, feeling more surveilled by the company; and second, dealing with an added burden, as the added value to their work output is not noticeable. However, from the managers' side, they have noticed added value to the overall performance of the company, to name just a few, transparency and accuracy of operations.

The research is still ongoing and additional case studies are planned to further strengthen and corroborate the results. In its complete form, the study aims to contribute to both theory and practice. To the best of our knowledge, it is one of the few studies to systematically analyse the I4.0 impact on environmental and social pillars of sustainability in the Italian mechanical and machinery sectors. As a result, the research generates research propositions that open several avenues for future research, as well as practical insights that could be leveraged by both policy makers and industry.

Keywords: Industry 4.0, Environmental Sustainability, Social Sustainability, Drivers of Adoption and Impact, Italian Mechanical and Machinery Sectors, Semi-structured Interviews.

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Ren-AI-ssance Pedagogy: Teaching to Question Rather Than Teaching to Answer

Ligita Zailskaitė-Jakštė (ligita.zailskaite@go.kauko.lt)
Communication Department, Faculty of Business, Kauno Kolegija, Lithuania

Robertas Damaševičius (robertas.damasevicius@vdu.lt)
Vytautas Magnus University, Department of Applied Informatics, Lithuania

Abstract

This article introduces and discusses the Ren-AI-ssance Pedagogy in a Human-Computer Interaction (HCI) design course. The Ren-AI-ssance Pedagogy, a novel educational method, integrates the humanistic principles of the Renaissance with advanced Artificial Intelligence (AI) technologies, aiming to transform the traditional learning experience. The aim of this study is a comprehensive assessment of how this pedagogy influences student performance, engagement, and retention in a practical HCI design course setting.
A mixed-methods approach was employed, combining quantitative and qualitative analysis. The survey was performed with 21 students, seeking to get feedback in such areas as academic performance, engagement with course material, and retention of knowledge, using a blend of performance, engagement, and retention questions. The results indicate positive outcomes in all three categories. Qualitative feedback further revealed that the pedagogy's feedforward strategies played a crucial role in enhancing students' understanding of assignment requirements, leading to better academic performance and a deeper engagement with the course content.

Keywords: AI-Enhanced Learning, Educational Technology, Adaptive Learning, Student-Centric Learning.

Introduction

The need for a new pedagogical approach in the 21st century is driven by the imperative to harmonize education with the rapid pace of technological and societal changes (Tapalova and Zhiyenbayeva, 2022). This new paradigm, which we term "Ren-AI-ssance Pedagogy," is motivated by the need to foster critical thinking, creativity, and adaptability among students, skills that are quintessential for navigating the complexities of the contemporary world (Jian, 2023; Hasibuan and Azizah, 2023).

The integration of Artificial Intelligence (AI) in this pedagogical approach is not merely a technological enhancement but a shift towards a more personalized, inquiry-based, and student-centric learning model. The rationale for this shift is twofold. Firstly, the exponential growth in information necessitates a focus on developing the ability to discern, analyze, and synthesize knowledge rather than merely acquiring it (Kataria, 2023). Secondly, the unpredictable nature of future career landscapes requires an educational system that not only imparts knowledge but also cultivates the intellectual agility to adapt to new scenarios (Du Boulay, 2016; de Oliveira Silva and dos Santos Janes, 2020).

Ren-AI-ssance Pedagogy approach, inspired by the humanistic ideals of the Renaissance and empowered by the capabilities of modern AI, promises a transformative impact on the educational landscape, preparing students not just for academic success but for a lifetime of learning and adaptation (Hernández-Ramos et al. 2021). It seeks to redefine the educational landscape by prioritizing the cultivation of critical thinking, creative problem-solving, and an inquisitive mind-set in learners (Lee et al. 2018). The role of AI in this paradigm is not only instrumental, functioning not as a replacement for human interaction and traditional teaching methods, but as an augmentative tool that enhances and personalizes the learning experience (Jian, 2023). AI’s ability to adapt to personalized learning styles and provide feedback in real-time transforms the educational process into a more dynamic, interactive, and learner-centric experience (Reigeluth et al. 2015).

The Ren-AI-ssance Pedagogy is designed to redefine the scope of education, expanding its boundaries beyond conventional learning methodologies. The novelty of the Ren-AI-ssance Pedagogy lies in its unique fusion of Renaissance humanism’s enduring values with the dynamic capabilities of modern AI. This approach places a strong emphasis on inquiry-based learning and the development of questioning skills, and move the focus from teaching to answer to teaching to question.

The Ren-AI-ssance Pedagogy was practically applied in a Human-Computer Interaction Design course delivered at Kaunas University of Technology (KTU) in Lithuania. The pedagogy employed AI tools to create adaptive learning experiences tailored to individual student needs, enhancing engagement and understanding.

The paper is divided into multiple sections that elaborate on the Ren-AI-ssance Pedagogy: section 2 explains the pedagogical approach; section 3 discusses a practical application in a university HCI design course, showcasing how AI tools are employed to foster collaborative learning and improve engagement and problem-solving skills; section 4 concludes the study.

The Ren-AI-ssance Pedagogy Approach

The Importance of Questioning in the Information Age. The Ren-AI-ssance approach emphasize the critical role of questioning in the Information Age. In an era where information is abundant and readily accessible, the ability to ask pertinent, insightful questions becomes more valuable than the mere accumulation of facts. This shift reflects a deeper understanding that knowledge is not static but dynamic, requiring a constant process of inquiry, evaluation, and reinterpretation (Wu et al. 2018).

The emphasis on questioning is rooted in the belief that critical inquiry is the cornerstone of intellectual growth and discovery. In the Ren-AI-ssance pedagogy, students are encouraged to be not just passive recipients of information but active participants in their learning journey. In this context, teachers play a pivotal role in modelling and nurturing effective questioning. They guide students in the art of formulating meaningful and thought-provoking questions, which leads to deeper learning and understanding.

Emphasis on Inquiry-Based Learning. The Ren-AI-ssance pedagogy places a strong emphasis on inquiry-based learning, a method where the process of exploration and discovery is central to the educational experience. This approach is characterized by student-centric learning, where learners are actively engaged in the process of investigation, experimentation, and problem-solving. Instead of being mere recipients of pre-determined knowledge, students are encouraged to explore topics of interest, formulate their hypotheses, and engage in a process of discovery to test and refine their ideas (Ruzaman, 2020; Xie, 2023).

Inquiry-based learning under this new pedagogical model is greatly enhanced by the integration of AI technologies. AI can provide a rich, adaptive environment where students can engage in simulated experiments, access a wide range of resources, and receive personalized feedback. This technology enables teachers to create more dynamic and interactive learning experiences, catering to the diverse needs and interests of students (Wang et al., 2010).

Through inquiry-based learning, students learn to approach problems not just with a desire to find the right answers, but with the curiosity to ask the right questions (Pedaste et al., 2015).

Evolving Role of Teachers. The Ren-AI-ssance approach to education calls for a transformation in the role of teachers.

1) The Role of Teacher. Traditionally, teachers have been viewed primarily as source knowledge to students. However, in the Ren-AIssance approach, this role is expanded. Teachers are now seen as facilitators of inquiry, guiding students in navigating the vast landscape of information and encouraging them to engage in critical thinking and exploration (Poekert, 2011).

In this role, teachers encourage students to ask questions, explore various sources of information, and develop their understanding through investigation and research. This approach requires teachers to adopt more of a coaching mindset, where they support and guide students in their learning process rather than simply providing answers. It involves creating learning environments that stimulate curiosity and foster a culture of inquiry, where students feel empowered to explore and discover (Walker and Shore, 2015).

2) Mentorship and Guidance in AI-Enhanced Learning. In AI education context, teachers are not only responsible for teaching subject matter but also for helping students navigate and effectively utilize AI tools for learning. This role involves teachers being knowledgeable about the capabilities and limitations of AI in education and being able to integrate these tools seamlessly into the curriculum (Arora et al., 2023). Teachers has to mentor students in using AI responsibly and effectively, ethically, and helping them develop the necessary skills.

3) Benefits for Students. AI technologies support adaptive learning, provide data analysis and feedback, and offer interactive learning experiences. Teachers play a critical role as mentors in developing critical thinking skills. Students are primary beneficiaries of this pedagogical model, who are active learners, engaged in critical thinking, and practicing lifelong learning. Educational outcomes are the desired results of implementing the Ren-AI-ssance Pedagogy, including enhanced critical thinking, improved problem-solving skills, and adaptability to change (Figure 1).

4) Innovation beyond SOTA. The Ren-AI-ssance Pedagogy introduces a genuinely novel educational approach that is innovative beyond the state-of the art (SOTA) in educational strategies as it leverages AI not just as a tool but as a core component to adapt learning processes to individual student profiles in real-time, a significant advancement over traditional one-size-fits-all educational models (Damasevicius and Sidekerskiene, 2024).

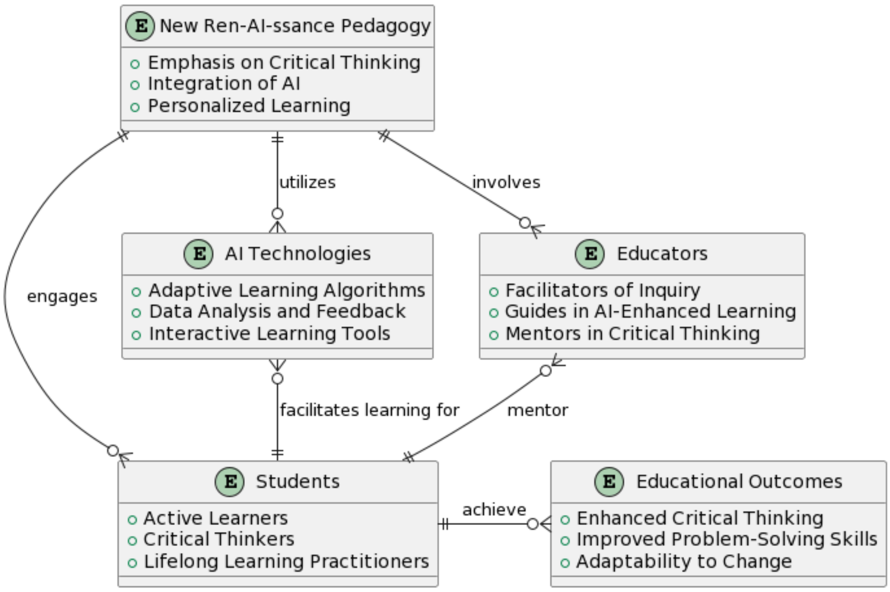

Figure 1: Concepts of Ren-AI-ssance Pedagogy

CASE STUDY. The HCI Design course at KTU is designed to equip students with skills in designing intuitive and user-friendly digital interfaces. The course combines theoretical knowledge with practical application, focusing on user experience (UX), design principles, and the integration of technology in creating effective human-computer interactions (Table 1).

Component Description	**Component Description**
Methods	Teaching methods used, such as inquiry-based learning and collaborative projects.
Pedagogy	Pedagogy Integration of critical thinking and elements of the Ren-AI-ssance
Curriculum	Course content, including AI-enhanced learning modules,
Technology	Technological tools used in the course, like AI tools for
Teachers	Faculty expertise in AI integration, facilitation of inquiry based
Students	Student engagement, development of critical thinking and
Environment	The learning environment, including a supportive atmosphere,
Resources	Resources available, such as access to latest research, industry partnerships, and funding for innovation.
Evaluation	Methods for providing continuous feedback and measuring performance.
Outcomes	Ultimate goals, like enhanced design skills and critical thinking

Table 1: Components of HCI Design Course in Ren-Ai-ssance Pedagogy

In embracing the Ren-AI-ssance Pedagogy, KTU's HCI Design course has integrated AI tools to enhance collaborative learning and research. AI-powered platforms are utilized for various purposes, including user behavior analysis, prototype testing, and data-driven design decision-making. These tools allow students to simulate and analyze user interactions, providing valuable insights that inform their design processes. During HCI Design a group of students embarked on a project to design a smartphone app game. This project exemplifies the integration of AI-enhanced learning, critical thinking, and collaborative efforts in developing a user-centric digital product.

1) **Objective** is to design a smartphone app game that is engaging, intuitive, and accessible to a wide range of users. **Game Concept**: The game, titled "EcoQuest," (inspired by a similar game Swacha et al., 2021) is an educational adventure game about environmental sustainability. Set in various global ecosystems, players complete missions to save these environments from different ecological threats. **Target Audience** – teenagers and young adults, ages 13-25, interested in environmental issues.

2) The students chose Unity, a leading game development platform, for its versatility and support for both 2D and 3D game development. Unity's robust features, including AI integration for personalized gaming experiences and extensive asset libraries, made it an ideal choice.

3) "EcoQuest" scenarios are set in diverse ecosystems such as rainforests, oceans, and urban landscapes. Each scenario presents a unique environmental challenge, such as deforestation, ocean pollution, or urban waste management. Players engage in missions like planting trees, organizing clean-up drives, or innovating sustainable solutions, earning points and rewards for their efforts.

This workflow diagram (Figure 1) represents the key stages in the development of a smartphone app game, with specific emphasis on integrating the principles of the Ren-AI-ssance Pedagogy.

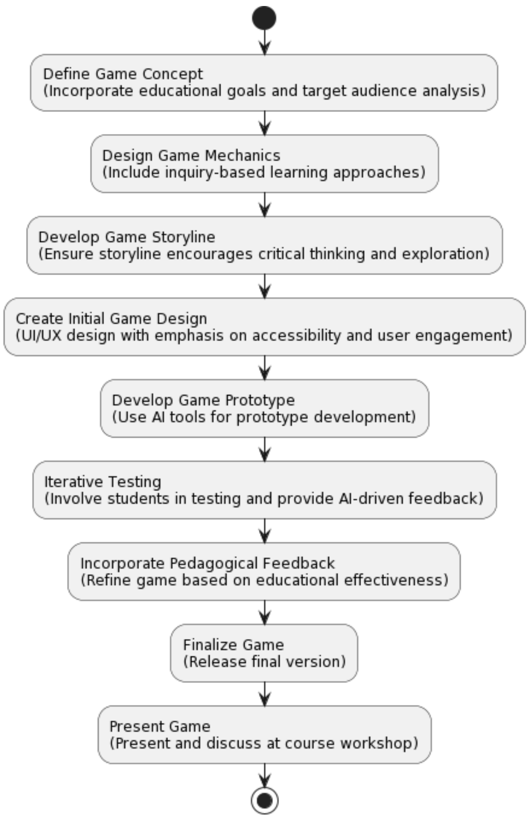

Figure 1: Game Design Workflow

UI Prototype Design using AI-powered Tools. The development of the "EcoQuest" game interface begins with the Concept Definition phase, where students utilize ChatGPT to generate and refine content ideas. This step ensures the conceptual foundation of "EcoQuest" aligns robustly with its educational goals and the anticipated demographic.

Game UI Design Challenges and Solutions. During the UI design process students had to solve such challenges: Challenge 1: Accessibility and User Engagement; Challenge 2: Adapting to Diverse User Preferences; Challenge 3: Balancing Educational Content with Entertainment

Throughout the project, students were encouraged to question every aspect of their design choices (Table 2). This process began with defining the game concept, where questions focused on how to effectively convey environmental issues through gameplay mechanics that are engaging and educational.

In the prototype development and iterative testing phases, questioning deepened with a focus on user experience and technical functionality. Students utilized ChatGPT to simulate how real users might interact with the game and then critically assessed these interactions.

No.	***Example of Quuestion***	***Question Refined by AI Tool (ChatGPT)***	***Pedagogical Outcomes of a Question***
1	How do AI algorithms improve UX in UI design?	Could you illustrate how specific AI algorithms enhance UI design, particularly in terms of user engagement and satisfaction?	Promotes understanding of practical AI applications in UI design and the impact on UX.
2	What are the best practices for usability testing?	Can you discuss the best practices for conducting effective usability testing in HCI, particularly for mobile applications?	Encourages a deeper exploration of usability testing methods and their specific relevance to mobile app development.
3	How can we integrate AI in our game design?	What are the strategies for integrating AI in game design to create a personalized and adaptive user experience?	Fosters critical thinking about the innovative use of AI to enhance gameplay and user interaction.

Table 2: Refinement and Outcomes of Student Questions in HCI course

Method

For the case study analysis a mixed-methods approach was employed, combining quantitative data from a survey of 21 students to evaluate the effectiveness of the pedagogy. The survey assessed key areas such as academic performance, engagement with course material, and retention of knowledge, using a blend of performance, engagement, and retention questions.

Qualitative method was used for evaluate the educational impact of the ”EcoQuest” game within the HCI design course utilizing Ren-AI-ssance Pedagogy, an inclusive and reflective end-of-course meeting was organized following the reflection-based course evaluation methodology (Klimova, 2014; Deggs and Weaver, 2009). This meeting involved all students who participated in the course. During the meeting, a designated note-taker (2nd author) documented key points, capturing direct quotes and general sentiments.

Results

Qualitative method. The survey results from the group of 21 students (4th study year) who participated in the HCI design course. The results are categorized into three key areas:

• Performance. 66% (14/21) of the students felt that the course positively impacted their academic performance. This is attributed to feedforward strategies that allowed students to apply useful knowledge prior to assessments, aligning their work more closely with the lecturer's expectations.

• Engagement. 76% (16/21) of the students reported enhanced engagement with the course material. The feedforward approaches provided clarity on the nature of assignments, contributing to a more engaging learning experience.

• Retention. 81% (17/21) of the students indicated better retention of the course content. The pedagogical strategies led to an increased understanding and ability to retain knowledge related to the task.

The qualitative analysis showed that many students expressed that the game significantly enhanced their engagement, making the learning process more interactive and less tedious compared to traditional methods. They appreciated the practical application of theoretical knowledge within the game's simulated environment, which not only made learning more relevant but also more dynamic. Students valued the empowerment they felt through the inquiry-based approach encouraged by the game, which shifted their role from passive recipients of information to active participants in their learning process. Additionally, the meeting revealed areas for improvement.

The students' overall comments highlighted the effectiveness of the feedforward strategies in enhancing their understanding of assignment requirements, thereby improving both their academic performance and engagement with the course material.

Discussion

The survey results disclose the positive AI in education in study process. This promises to revolutionize the way learning is conducted and experienced. The AI's potential to personalize learning, enhance student engagement, and provide insights into the learning process opens up new possibilities for educational innovation. The ability to adapt to each learner's unique pace and style, the facilitation of collaborative and interactive learning environments, and the provision of real-time feedback and support are just a few examples of how AI can enrich the educational experience and prepare students for the challenges and opportunities of an increasingly digital and interconnected world. The skills developed through the Ren-AI-ssance Pedagogy – critical thinking, adaptability, problem-solving, and effective communication – are essential for success in the 21st century.

Conclusion

The exploration of the Ren-AI-ssance Pedagogy throughout this discourse illuminates a profound paradigm shift in the field of education.

This pedagogical method shift is not merely an adaptation to the changing technological landscape but reimagining of the educational process. It acknowledges and embraces the complexity and diversity of the modern learning environment and the individual learner. In this new paradigm, education is seen as a dynamic, interactive, and lifelong process, where the emphasis is on cultivating curiosity, adaptability, and a deep-seated love for learning. The Ren-AI-ssance Pedagogy also redefines the role of teachers and learners. Teachers transform from being sole knowledge providers to facilitators and mentors, guiding students in navigating an increasingly complex information landscape. Students are encouraged to take an active role in their learning, leveraging AI tools to tailor their educational experiences to their individual needs and interests.

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Eduverse 2.0: Towards eXtended Reality Education

Robertas Damasevicius (robertas.damasevicius@vdu.lt)
Department of Applied Informatics, Vytautas Magnus University, Kaunas, Lithuania

Ligita Zailskaite-Jakste (ligita.zailskaite@go.kauko.lt)
Communication Department, Faculty of Business, Kauno Kolegija, Kaunas, Lithuania

Abstract

This paper explores the advancements and transformative impact of virtual education in the evolving landscape of the Eduverse. This paper focuses on the emergence of Eduverse 2.0, an emerging iteration of Eduverse that harnesses cutting-edge technologies to create immersive and interactive learning environments. The paper highlights the latest developments in virtual education, encompassing virtual reality (VR), augmented reality (AR) (jointly known as eXtended Reality (XR)), and the integration of artificial intelligence (AI) within Metaverse classrooms. The integration of virtual platforms, digital resources, and adaptive learning algorithms, fostering personalized and engaging educational experiences for students across diverse disciplines and age groups is presented as well.

Keywords: Virtual Education, eXtended Reality, Virtual Classrooms, Metaverse.

Introduction

The Eduverse, a combination of "education" and "universe", represents the expansive and ever-evolving digital landscape of education. It encompasses various forms of technology-enhanced learning, including online courses, virtual classrooms, digital resources, and immersive learning environments. The concept of Eduverse has its roots in the advent of the internet and digital technology, which have progressively transformed the traditional classroom-based education into a more flexible and personalized learning experience. Over the past decade, the Eduverse has witnessed significant advancements, driven by rapid technological innovations and changing pedagogical approaches (Damasevicius, 2023; Damasevicius & Sidekerskiene, 2023a). This paper aims to explore these recent advances, their implications for teaching and learning, and the future trajectory of the Eduverse.

The motivation for exploring the Eduverse stems from the significant impact digital learning has had on reshaping education. The COVID-19 pandemic, for instance, served as a catalyst for digital learning, particularly in mathematics education, as evidenced by the study conducted by (Mulenga and Marban, 2020).

The objectives of this paper are twofold. Firstly, it aims to provide an overview of the recent progress in virtual education, particularly focusing on the advancements in Eduverse 2.0. It focuses on the evolution of virtual education, explores the key components of Eduverse 2.0, and examines the emerging technologies that have revolutionized virtual classrooms. Secondly, this paper aims to highlight the implications of these recent advances for education and shed light on the future directions and possibilities in the field.

The study makes several significant contributions to the understanding and advancement of virtual education:

- The paper focuses on the emerging technologies driving the progress in virtual education, such as virtual reality (VR), augmented reality (AR), and artificial intelligence (AI). It explores their application and impact in the context of Eduverse 2.0, providing valuable insights into the transformative potential of these technologies for enhancing teaching and learning experiences.
- The paper highlights recent advancements in Eduverse, with a specific focus on virtual classrooms and adaptive learning systems. By examining these recent developments, it offers educators and researchers valuable information to enhance instructional practices and improve learning outcomes.

Eduverse 2.0: An Overview

Eduverse 2.0 represents the next generation of the Eduverse, characterized by more advanced technologies, enhanced interactivity, and a more immersive learning experience. This evolution is driven by continuous advancements in digital technologies and growing understanding of their potential in education.

Conceptualisation and Evolution of Eduverse

The concept of Eduverse has its roots in the advent of the internet and digital technology, which have progressively transformed the traditional classroom-based education into a more flexible and personalized learning experience. The evolution of the Eduverse can be traced back to the early days of computer-based learning, which gradually evolved into online learning with the advent of the internet. The introduction of Learning Management Systems (LMS) and Massive Open Online Courses (MOOCs) marked a significant milestone in this evolution, making quality education accessible to a global audience.

The concept of Eduverse has its roots in the early 2000s, with the advent of 3D virtual learning environments in education (Lo et al., 2002). These environments, such as Active World Eduverse, provided a new platform for interactive and immersive learning experiences. Over the years, the concept of Eduverse has evolved, incorporating advancements in technologies such as VR, AI, and data analytics (Okewu et al., 2021). The technical perspectives and history of VR and Eduverse have been extensively reviewed by Andembubtob et al. (2023b). They provided a comprehensive overview of the evolution of Eduverse, highlighting the key technological advancements that have shaped its development. The adoption of Eduverse platforms by learners has been studied by Teng et al. (2022), who conducted an empirical study based on an extended UTAUT model. Their findings provide valuable insights into the factors affecting learners' adoption of an educational Metaverse platform. The transformative potential of Eduverse has been explored by Hsiung (2022), who discussed the transformation of educational video into interactive, immersive, personalized, and gamified experiences. This transformation represents a significant shift in the way we approach education, offering new possibilities for teaching and learning. The implementation of VR in the classroom has been discussed by Bishop (2023), who shared lessons learned from implementing VR in the classroom. These lessons provide valuable insights for educators looking to incorporate VR into their teaching practices. The potential of Metaverse technology in education has been analyzed by Mustafa (2022), who highlighted the transformative potential of this technology in reshaping the educational landscape.

Metaverse classrooms represent the next evolution in virtual education, offering immersive and interactive learning experiences that transcend the limitations of traditional classrooms (Table 1). These classrooms use technologies such as VR, AR, and AI to create engaging and personalized learning environments such as digital escape rooms (Damaševičius & Sidekerskiene, 2023b). The concept of Metaverse classrooms and their potential for creating a new educational and inclusive paradigm have been discussed by Fabiano (2023). He provided valuable insights into the potential of Metaverse classrooms for creating more inclusive and accessible learning environments. The comparison of social virtual worlds for educational purposes has been conducted by Reis et al. (2011). They provided valuable insights into the potential of social virtual worlds for creating engaging and interactive learning experiences.

Concept/Feature	Description
Evolution in Virtual Education	Metaverse classrooms offer immersive and interactive learning experiences that go beyond the constraints of traditional classrooms.
Technologies	Utilizes technologies such as VR, augmented reality, and AI to create engaging and personalized learning environments.
Digital Escape Rooms	An example of the engaging learning environments created using Metaverse technologies.
Teaching Approach	Requires a shift from centralized control to a more pluralistic and entrepreneurial approach to learning in virtual worlds.
Student Interest	Students have expressed interest in using the Meta- verse for classroom learning, believing it can enhance knowledge, enjoyment, and motivation.
Collaborative Learning	Development of products based on self-determination, connectivism theories, and collaborative learning for postgraduate environments.
Mixed Reality Tools	Potential to increase student participation and engagement in a virtual classroom setting, shaping the future of digital classrooms in the Metaverse.

Table 1: Concept and Features of Metaverse Classrooms

The development of a framework for Metaverse in education has been discussed by Roy et al. (2023), who conducted a systematic literature review to develop a comprehensive framework for Metaverse in education. The critical success factors of Metaverse adoption in education have been explored by Andembubtob et al. (2023a). They identified the key factors that contribute to the successful adoption of Metaverse in education, providing valuable insights for educators and policymakers. The construction of an Edu-Metaverse ecosystem has been discussed by Wang et al. (2022), who proposed a new and innovative framework for constructing an Edu-metaverse ecosystem. The use of Metaverse technology in digital-virtual living spaces has been explored by Schlemmer et al. (2009), who discussed the use of Second Life Metaverse technology in creating digital-virtual living spaces. The reimagining of learning in virtual spaces has been discussed by Aleman et al. (2022), who bridged the gap between theory and practice in reimagining learning in virtual spaces. The emergence of advanced technologies such as AI, VR, and AR has led to the development of Eduverse 2.0. This new phase is characterized by immersive learning environments, intelligent tutoring systems, and personalized learning paths, offering a more engaging and effective learning experience (Wang et al., 2022). The evolution of the Eduverse is a continuous process, driven by technological advancements and pedagogical innovations. As we move forward, we can expect to see more advanced features and applications in the Eduverse, transforming the way we teach and learn.

Key Components of Eduverse 2.0

Eduverse 2.0 is characterized by several key components that contribute to its effectiveness as a learning environment. These components include advanced technologies such as AI, VR, AR, and mobile applications, as well as pedagogical strategies tailored to these technologies. AI plays a crucial role in Eduverse 2.0, enabling personalized learning paths and intelligent tutoring systems (Damaševičius & Sidekerskiene, 2024). AI can adapt to individual learners' needs, providing personalized content and feedback, and enhancing the learning experience (Wang et al., 2022). VR and AR technologies contribute to the creation of immersive learning environments in Eduverse 2.0. These technologies allow learners to interact with virtual objects and environments, enhancing their understanding of complex concepts (Bork et al., 2019). Mobile applications are another key component of Eduverse 2.0, providing access to learning materials anytime, anywhere. The key components of Eduverse 2.0 are summarized in Figure 1.

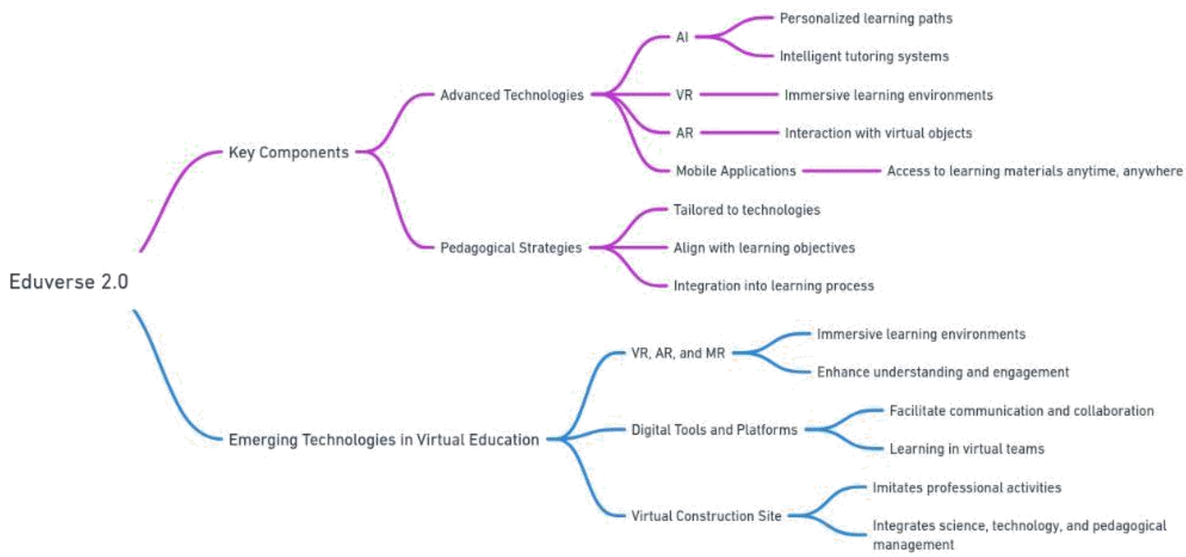

Figure 1: A Mindmap of Components in Eduverse 2.0

These applications can facilitate understanding of various subjects, as demonstrated by Alkhateeb and Al-Duwairi (2019) in the context of geometry learning. The evolution of the Eduverse also involves the development of pedagogical strategies tailored to these technologies. These strategies aim to maximize the potential of the technologies, aligning them with learning objectives and ensuring their effective integration into the learning process.

Emerging Technologies in Virtual Education

Emerging technologies are playing a pivotal role in the evolution of virtual education, offering new possibilities for teaching and learning. These technologies include VR, AR, Mixed Reality (MR), and various digital tools and platforms. VR, AR, and MR technologies are increasingly being used in education, providing immersive learning environments that enhance students' understanding and engagement.

For instance, Mallam et al. (2019) discussed the potential benefits and limitations of these technologies in maritime education and training, highlighting their potential to provide immersive, accessible, and cost-effective simulation-based experiences. Digital tools and platforms are another key aspect of emerging technologies in virtual education. These tools facilitate communication, collaboration, and learning in virtual teams, as demonstrated by Hu (2015). The study highlighted the importance of effective training, communication, and assessment measures in cultivating virtual teams for collaborative learning.

The concept of a virtual construction site has been proposed as a digital resource for pedagogical management in construction education (Pugacheva et al., 2020). This resource imitates professional activities and integrates science, technology, and pedagogical management based on common data description standards, providing a comprehensive and practical learning experience for students.

Pedagogical Innovations and Best Practices

Pedagogical innovations and best practices are crucial for maximizing the potential of Eduverse 2.0. These innovations and practices leverage the unique features of Eduverse 2.0 to create engaging and effective learning experiences (Table 2).

Innovation / Practice	**Description**
Organizational Sustainability	Best practices in organizational sustainability management can provide insights for educational practices in Eduverse 2.0 (Nawaz & Koc, 2019).
Heritage-Led Rural Regeneration	Six systemic innovation areas identified can guide the development of pedagogical innovations in Eduverse 2.0 (Egusquiza et al., 2021).
Service-Learning	Tips and strategies for implementing service-learning, connecting students with the community, can be effectively used in Eduverse 2.0 (Pawlowski, 2018).

Table 2: Pedagogical Innovations and Best Practices

A comprehensive analysis of the best practices in organizational sustainability management has been conducted by Nawaz and Koc (2019). They explored the organizational sustainability themes, functional areas, and the corresponding best practices of the most sustainable organizations, providing insights that can be applied to the field of education. In the context of heritage-led rural regeneration, Egusquiza et al. (2021) identified six systemic innovation areas that facilitate capital transference. These areas can be used as a guide for developing pedagogical innovations in Eduverse 2.0. Pawlowski (2018) provided tips and strategies for implementing service-learning in the classroom. Service-learning is a pedagogical approach that connects students with the community while focusing on course outcomes, and it can be effectively implemented in Eduverse 2.0.

Conclusion and Discussions

The advent of Eduverse 2.0 has ushered in a new era of education, characterized by immersive, interactive, and personalized learning experiences. This paradigm shift from traditional education to virtual education has been facilitated by advancements in technologies such as AI, VR, augmented reality, and data analytics. These technologies have enabled the creation of virtual classrooms, adaptive learning systems, and real-time feedback and assessment mechanisms, transforming the way we approach education. The Metaverse classrooms, with their avatar-based learning and social interactions, represent the future of education. They offer the potential to transcend the limitations of physical classrooms and create a more inclusive and accessible learning environment. The transformative potential of Eduverse 2.0 lies in its ability to transform education, making it more engaging, effective, and efficient. However, realizing this potential requires pedagogical innovations and best practices that leverage the unique features of Eduverse 2.0. Collaborative research and policy recommendations are crucial for guiding these innovations and practices. As we continue to explore and understand the possibilities of Eduverse 2.0, it is essential to keep the focus on creating learning experiences that are not only technologically advanced but also pedagogically sound.

In conclusion, Eduverse 2.0 represents a step forward in the evolution of education. While there are challenges to overcome, the potential benefits for learners are immense. As we continue to innovate and experiment with new ways of teaching and learning in this virtual universe, we are shaping the future of education.

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Challenges and opportunities in integrating human-centric artificial intelligence solutions in industry

Leila Zare (Leila.Zare@student.unibz.it)
Sustainable Manufacturing Lab, Faculty of Engineering, Institute for Industrial and Energy Engineering, Free University of Bozen-Bolzano, Italy

Marwa Ben Ali (marwa.benaliepbelarbi@unibz.it)
Sustainable Manufacturing Lab, Faculty of Engineering, Institute for Industrial and Energy Engineering, Free University of Bozen-Bolzano, Italy

Erwin Rauch (erwin.rauch@unibz.it)
Sustainable Manufacturing Lab, Faculty of Engineering, Institute for Industrial and Energy Engineering, Free University of Bozen-Bolzano, Italy

Abstract

As the industrial sector progresses toward Industry 5.0 (I5.0) Artificial Intelligence (AI) is revolutionizing manufacturing to become more human-centred in industries. Technologies that are well-designed and provide a balance between human control and computer automation can enhance human performance, resulting in more acceptance and usage. This transformation brings new opportunities for enhanced capabilities, unique features, and developing patterns for industries. However, industries have faced a new set of challenges due to the rapid progress of AI. In this vein, the present study aimed to examine the challenges and opportunities faced in various industries implementing AI, with a particular emphasis on investigating human-centred solutions. Hence, the study analysed future work opportunities and challenges, workplace inclusiveness and diversity, and technologies to empower workers in industries. The goal was to provide recommendations for future research, industry small and medium enterprises (SMEs), and policy makers.

Keywords: Artificial Intelligence, Industry 5.0, Sustainable Manufacturing, Human-centric.

Introduction

Industries are undergoing a transformation to embrace Artificial Intelligence (AI) using innovative approaches that automate data computations in a more efficient and effective manner, thereby enhancing workforce duties (Fraga et al., 2019). The European Commission has recently introduced the concept of Industry 5.0 (I5.0), with the aim of establishing a European sector that places human well-being at the centre of the manufacturing industry (Alves et al., 2023). The objective of I5.0 is to employ human intelligence to integrate with AI systems (Leng et al., 2023). Therefore, human-centred AI (HCAI) approach was recommended in the development of AI systems to work with and for people (Shneiderman, 2022). HCAI aims to place humans at the centre of AI implementation cycle (Riedl, 2019; Xu, 2019), and enhance human performance by augmentation of human capabilities, ensuring reliability, safety, and trustworthiness without replacing human beings (Shneiderman, 2020). Although HCAI technology has provided industries numerous opportunities including effective and productive workforce (Shneiderman, 2022), human wellbeing, responsible design of AI, hybrid intelligence, privacy, design framework, governance and oversight, human-AI Interaction (Ozman et al., 2023; Xu et al., 2023), it has adversely influenced industries in terms of lack of skills, ethical issues, trust, transparency, regulatory policy, machine unexpected behaviour, lack of knowledge, accountability, human replacing AI, risks, misusing AI, and abusing AI.

In general, due to the current limited knowledge regarding the HCAI opportunities and challenges, the objective of this study is to examine the opportunities and challenges faced by manufacturing industries in implementing AI. To run the analysis, the research focuses on opportunities and challenges for future work, inclusiveness and diversity in workplace and technologies for empowering worker in industries. This analysis aimes to summarize recommendations for future research for industry SMEs and policy makers. More specifically, three research questions will be addressed in the present paper:

RQ1. What is human-centric AI?
RQ2. What are the opportunities and challenges of manufacturing industries implementing HCAI?
RQ3. What are HCAI solutions and recommendations for policy makers, industries, and academics?

The paper is structured as follows: after the introductory section, the paper delves into an explanation of AI and HCAI. This is followed by a discussion of the challenges and opportunities of HCAI for industries, then solutions and recommendations are presented. Lastly, the paper concludes by providing a concise overview of the main issues.

What is AI?

Artificial intelligence (AI) is a field of study focused on creating robots that possess the ability to think and learn like humans, allowing them to perceive their own needs and make decisions accordingly. There are other sub-fields within this domain, such as machine learning, language processing, computer vision, and expert systems (Russell and Norvig, 2016). Furthermore, industrial AI is an approach that provides engineers with the necessary tools to methodically design and implement AI algorithms. Currently, there is a notable increase in dedication to intelligence, observed in various industries, research fields, government initiatives, and investment efforts. These industries are directing an extraordinary amount of financial resources towards innovative machine learning technology and their various applications (Dagnaw et al., 2020).

Human-centric AI: A Closer Look

Human-Centered AI (HCAI) is a developing field focused on designing AI systems that enhance and support human capabilities instead of replacing them. HCAI aims to maintain human authority in a manner that guarantees AI fulfils human requirements, operates with transparency, produces fair results, and upholds privacy (Schmidt, 2020). It provides opportunity to create a system that allow for both high levels in of human control and computer automation in balance to enhance human performance. As shown in figure 1, HCAI entails the following elements: (i) prioritization of people well-being; (ii) efficient manufacturing process (iii) effective human-centred production (iv) adherence to human-centred principles (Rafsanjani et al., 2023; Ozmen et al., 2023).

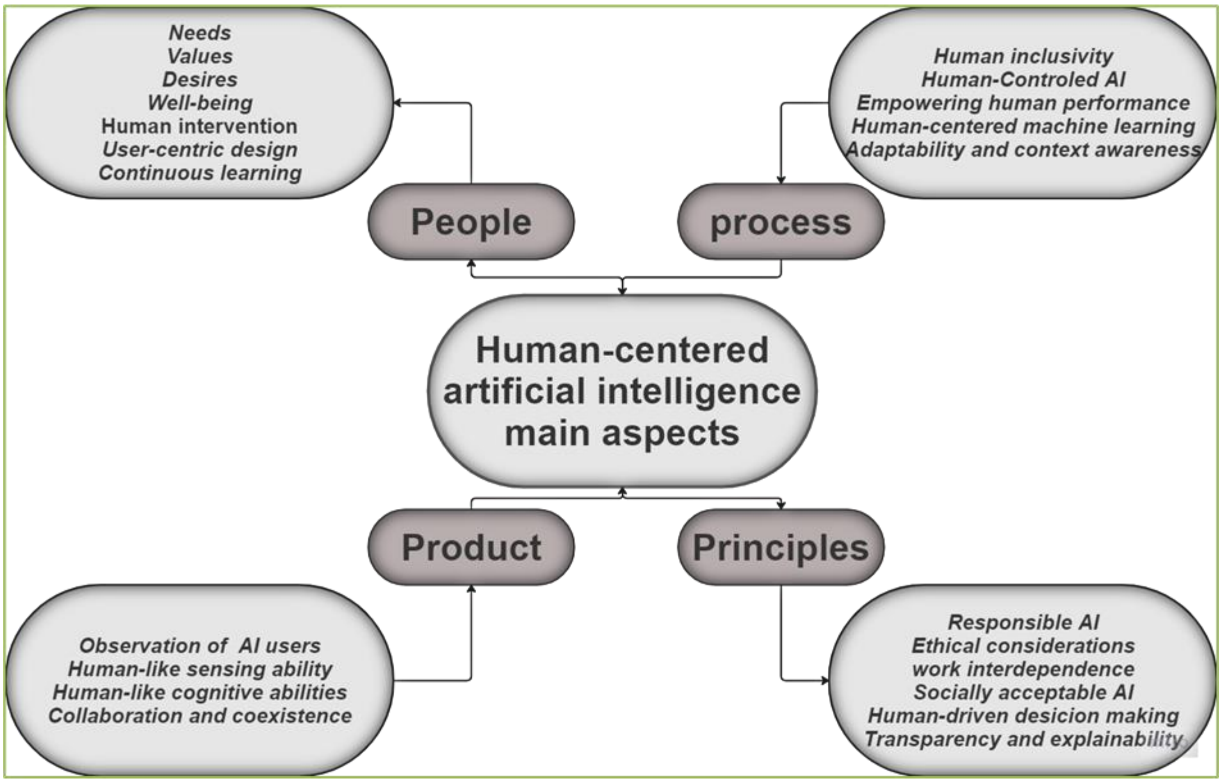

Figure 1: Human-centred artificial intelligence main aspects.

Challenges and Opportunities of HCAI for Industries

In recent years, AI has garnered considerable attention on account of its potential to revolutionize industries (Vyhmeister et al.,2024). According to (Howarth et al., 2021; Schmidt et al., 2020) in contemporary AI practices, robots primarily engage in planning, managing, controlling, and optimizing work without adequately considering human-related input and preferences. Therefore, the goal of I5.0 is to establish a cooperative environment in which robots and technologies are developed with a focus on addressing human needs. The objective is to enhance factory efficiency and worker performance by integrating collaborative robotics and industrial AI systems. (Leng et al., 2024; Vyhmeister et al., 2024). This target can be achieved by acquiring HCAI strategy in industries, because it provides novelty to existing AI methodologies by allowing machines to better comprehend and cooperate with humans.

When addressing this topic several new studies have analysed the challenges and opportunities of HCAI (He et al., 2021; Xu et al., 2023; Ozmen et al., 2023; Liu et al., 2022). Accordingly, (Shneiderman, 2020) suggested that HCAI is developing AI systems that focus on empowering humans to enhance their potential and promote self-reflection and creativity. It aims to tackle a wide range of key challenges, including privacy, security, promoting environmental sustainability, supporting justice, and safeguarding human rights. On the other hand, (He et al., 2021; Xu et al., 2023; Ozman et al., 2023) recognized several important challenges for deploying HCAI, including possible issues with human-AI collaboration, misusing AI, unpredictable machine behaviour, lack of competences, lack of trust to AI, and ethical considerations.

Therefore, the present work shed light on what are HCAI solutions, how it is understood by literature and what opportunities and barriers are coming up with implementation in manufacturing industry. Table 1 provides further details regarding the opportunities and challenges of HCAI implementation (Rafsanjani et al., 2023; Xu et al., 2023).

	Opportunities	**Challenges**
Future of work	○ Human wellbeing ○ Human-computer symbiosis ○ Clarification of human and AI's roles ○ Increasing in production ○ Enhancing efficiency ○ Decrease of human errors ○ Augmenting human skills	○ Regulatory policy ○ Data ownership ○ Lack of expert ○ Lack of knowledge ○ Lack of skills ○ Proper training ○ Costly ○ AI limited intelligence
Inclusiveness and diversity in workplaces	○ Hybrid intelligence ○ User-centric design ○ Effective interaction design ○ Human self-efficacy ○ Human mastery and creativity ○ Accessibility of AI to disabled people ○ Human-driven decision-making	○ Accountability ○ Misusing AI ○ Abusing AI ○ Ethical issues ○ Lack of privacy ○ Unpredictable operations ○ Ensuring human-controlled AI
Technologies for empowering workers	○ Managing machine behavior ○ Human-controlled hybrid intelligence ○ Augmenting human operators ○ Design for human-controlled AI ○ Adapting AI technology to human capability	○ Machine unexpected behavior ○ Design risks ○ AI effectiveness in team-working ○ Debate on human-AI teaming ○ Safety and reliability ○ Trust and transparency ○ AI unpredictable behaviors. ○ Required high level security

Table 1: Human-centred AI - Future opportunities and challenges.

Solutions and Recommendations

According to (Dagnaw et al. 2020) AI has been developing at an exponential rate in recent years. AI is being praised for its enormous transformative potential and is no longer limited to innovation labs, as humans and machines are collaborating more than ever in I5.0 HCAI approach. (Rafsanjani et al., 2023) claimed that AI has brought about numerous benefits in manufacturing industries, including intelligent and faster decision-making, a decrease in human errors, human wellbeing, improved operations and procedures, enhanced safety, increased productivity, and resource optimization. However, considering HCAI integrating challenges, (Xu et al.,2023) discussed that HCAI systems can demonstrate distinctive machine behaviours that may have inherent biases and unforeseen results. In addition, HCAI goal may be to establish cooperative human-AI connections; however, there is ongoing discussion and disagreement regarding human-AI cooperating. AI machines possess a restricted level of intelligence and are unable to replicate the superior cognitive abilities of humans. Additionally, HCAI ethical concerns, encompassing privacy, ethics, fairness, lack of expertise, and human decision-making, can also be considered. (Lee et al., 2021; Rafsanjani et al., 2023) proposed that Enhancing communication between humans and robots is crucial for establishing optimal work environments and project sites that prioritize human needs, cyber ethics, and responsibility. Therefore, the utilization of I5.0 human-centred AI facilitates the automation of sophisticated technologies such as robots, as well as the precise management of machinery and tools on a project site through the collection and analysis of person-specific information.

Based on a literature review study, Table 2 presents recommendations for various stakeholders, including policy makers, industries particularly SMEs, and academics. The recommendations offer a clear and effective solutions for each stakeholder category (Ozmen et al., 2023; Xu et al., 2023; Shneiderman et al., 2020).

Policy-Maker	Industry (SMEs)	Academia and Research
○ Ensuring financial support and accelerating HCAI research fields ○ Providing training for ethical and responsible AI ○ Consider the needs, values, and desires of different industries, users, and stakeholders ○ Providing HCAI regulations that promote well-being for humans and the planet	○ Implementing inclusiveness into every aspect of AI-enabled system including data selection, model training, software development, validation, and testing ○ Implementing privacy by design principles in AI systems ○ Using human-cantered AI throughout production ○ Updating skills and knowledge ○ Ensuring human control while employing a high level of automation	○ Studying human-AI interaction to evaluate the human AI interaction ○ Studying shared situation awareness and trust, shared control, and flexible autonomy in human-AI interaction ○ Investigating theories, concepts, and frameworks related to the teaming between humans and AI requirements, and measures ○ Providing education on HCAI approach ○ Studying the HCAI benefits and harms

Table 2: Recommendations for policy makers, industries, and academics.

Conclusion

The objective of this study was to analyse the potential advantages and barriers faced by manufacturing industries in using I5.0 HCAI and exploring industry-specific solutions that prioritize human needs. The study found that HCAI could boost the whole production process in industries and providing human wellbeing as well by human-controlled AI. However, there are potential hazards in terms of safety, AI teaming, lack of AI related skills and knowledge, and the possibility of AI replacing humans. To successfully apply HCAI, it is imperative to have a workforce that possesses a profound comprehension of AI systems. Furthermore, it is important to have ongoing training, providing workforce inclusiveness, and human supervision on AI. Adopting technology ethics is also necessary to ensure the implementation of HCAI.

When it comes to research gaps, one of the challenges is that AI can be complex and difficult for humans to use. This is because AI often provides recommendations without further explanation, leading to a conflict between the human operator and the AI tool. In such situations, people must trust the results generated by AI, which can be a challenge. Future work will involve analysing the required competences for implementing human-centric AI.

Acknowledgements

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Supply chain transparency pursuance: From antecedents and capabilities to outcomes

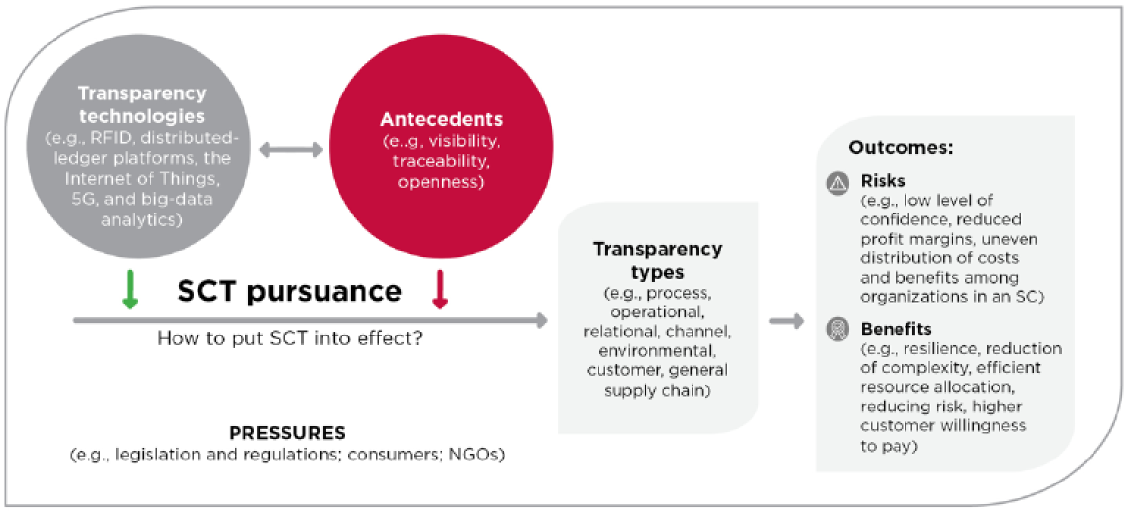
Marko Budler (marko.budler@ef.uni-lj.si)
School of Economics and Business, University of Ljubljana, Slovenia

Peter Trkman (peter.trkman@ef.uni-lj.si)
School of Economics and Business, University of Ljubljana, Slovenia

Bernie P. Quiroga (berniequirogauc@gmail.com)
West Virginia University, U.S.A.

Extended Abstract

The concept of Supply Chain Transparency (SCT) has received greater attention in recent years, becoming a widely used 'term' yet often misunderstood due to a lack of clarity and its colloquial usage. As the interchangeable use of terms such as visibility, transparency, and traceability without a clear conceptual foundation prevented scholars and practitioners from fully understanding the role of SCT and to investigate its antecedents, enabling technologies, and outcomes, we have first – as a part of a large international project – carried out a scoping review to provide a conceptual framework underlying SCT (Figure 1; *JBL*, 2024).



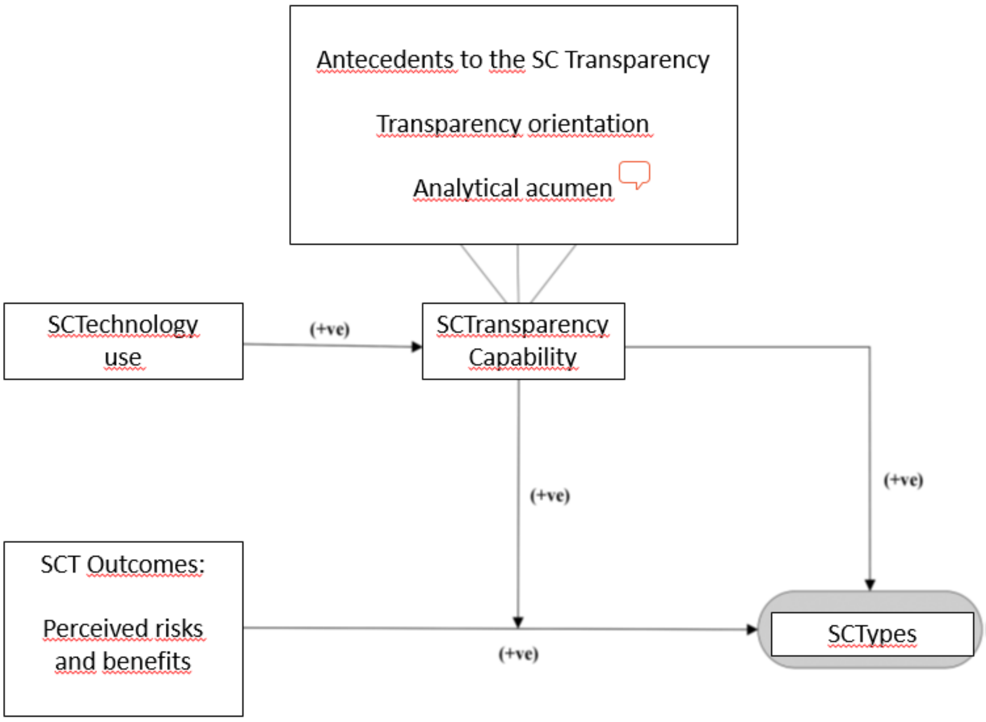
(Budler, Trkman, and Quiroga, 2024)

While our scoping review and past research altogether established a unifying and nuanced framework that distinguishes SCT from adjacent domains, and explores the contexts (i.e., pressures) in which companies pursue transparency, we need to focus on the pursuance of SCT and its outcomes in light of perceived benefits and risks (Figure 2).

The study at hand provides a basis for advancing SCT pursuance by examining key "pursuance" skills, fostering a transparency mindset, and developing the analytical acumen required for effective SCT pursuance.

Central to our study is the introduction of the SCT capability construct. We investigate the SCT, and the trade-offs between the extent of information shared and 'confidentiality' (see e.g., perceived risks and benefits). An analytical model has been crafted (Figure 2), identifying additional building blocks of SCT pursuance. The model will be finalized with the insights from the qualitive pre-study with SC and purchasing managers, agency and game theory. The relationships between the building blocks will be tested by carrying out a survey on mid- and C-level managers (the 1st author of this study will gain initial access to the respondents by capitalizing on its advisory-board position in Purchasing association of Slovenia).

This framework aids in understanding how companies can build and enhance their SCT by developing and maintaining capabilities to meet the growing demands for transparency from other SC actors and stakeholders (Bateman and Bonanni, 2019; Sorge and Boston, 2021; Sodhi and Tang, 2019; Chen, 2022). In fact, companies are increasingly voluntarily disclosing information about their processes, operations, suppliers, material flows, financial data, and products/services (Gligor et al., 2022).



Our study thus not only enhances the theoretical foundations of SCT but also offers practical guidance for companies striving to achieve greater transparency in their SCs. By providing recommendations for SC managers, we outline a 'roadmap' for more effectively pursuing SCT, navigating its associated antecedents and technology, and capitalizing on its potential outcomes – specifically, benefits.

Keywords: Transparency, Supply chain, Visibility, Information sharing, Capabilities, Model.

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From Fashion to Tech: Ethical Supply Chains

Ahmad Siar Nazeri (siarnazeri@gmail.com)
Economic Behavior and Governance, Faculty of Economics and Management, University of Kassel, Germany

Agnieszka Kabalska (kabalska@agh.edu.pl)
Faculty of Management, AGH University of Krakow, Poland
Department of Sustainable Marketing, Faculty of Economics and Management, University of Kassel, Germany

Mohammed Salem (mzsalem@ucas.edu.ps)
Department of Sustainable Marketing, Faculty of Economics and Management, University of Kassel, Germany
Department of Technology Management, University College of Applied Sciences, Gaza, Palestine

Ralf Wagner (rwagner@wirtschaft.uni-kassel.de)
Department of Sustainable Marketing, Faculty of Economics and Management, University of Kassel, Germany

Extended Abstract

This study investigates how consumer behavior in the electronics and apparel industries is affected by ethical supply chain policies. Framed in the Stakeholder Issue Salience research stream (Bundy et al., 2013; Mazutis et al., 2021), this study provides empirical evidence on the issue of salience gathered from 258 respondents. The supply chains of the two industries under consideration are well-known for environmental and social issues worldwide, and most recently, the intersection of these industries by means of digitalizing fashion has been recognized in the scholarly discussions (Wagner and Kabalska, 2023, 2024).

The research aim of this study responds to Bundy et al. (2013)'s description of the managerial challenges of coping with numerous heterogeneous stakeholder conceptualizations of sustainability and their projections on sustainable value creation.

This study evaluates the salience of *ethical sourcing of raw materials*, *labor conditions* and *fair wages, eco-friendly packing*, and *Corporate Social Responsibility* on *consumers' perceptions and purchase intentions towards sustainable products*. Complementing, the research design covers the moderating impacts of sustainable management practices in the *efficient tracking of product information, market adaptability and competitiveness on the consumers' perceptions and buying intentions*.

The conceptual model has been fitted to the empirical data using the partial least squares algorithm in the SMART PLS implementation. All common quality criteria (scale reliability, constructs' discriminant validity) are met. Notably, the four antecedents and the moderating impacts explain 62.4 percent (adjusted R^2) of variance in consumers' response.

Results indicate that the *eco-friendly packaging* is the most salient feature with approximately double the direct effect size of three other direct antecedents which do not dif-

fer substantially by means of the effect size. The moderating effect is significant for all four direct antecedents.

The main contribution of this study's result is the fact that consumers' perception and preferences are by far more sensitive to manifest visual (or even sensual) manifestations of sustainability rather than the abstract knowledge of fair labor relations throughout the supply chain, sound social corporate responsibility actions or the ethical sourcing of raw materials. This result complements the scholarly progress of managing supply chain and marketing practices in managing the (co-) creation of sustainable value in the domain of two highly critical industries. However, the indication to provide the buyers with manifest indications to increase issue salience might go beyond the boundaries of these two industries.

A limitation of this study is the lack of managers' response to the evidence on stakeholders' issue salience in contrast to the most recent waves of sustainability issues as discussed in public media.

The significance of this study arises from the fact that the salience of stakeholders' issues needs to be distinguished between "manifested" and "abstract" ones. If any supply chain capitalizes in the domains of "abstract" stakeholder issues, manifestations of progress and advantages are needed to make a difference to competing supply chains, brands, etc.

Keywords: Ethical Supply Chain, Corporate Social Responsibility, Fashion Industry, Electronic Industry, Sustainable Practices, Stakeholder Issue Salience.

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Industry 4.0 Readiness and Artificial Intelligence in Manufacturing Companies

Iztok Palčič (iztok.palcic@um.si)
Faculty of Mechanical Engineering, University of Maribor, Slovenia

Klemen Kovič (klemen.kovic@um.si)
Faculty of Mechanical Engineering, University of Maribor, Slovenia

Abstract

This study investigates the adoption of artificial intelligence (AI) software in manufacturing companies in Slovenia, Slovakia and Croatia. We examine whether Industry 4.0 readiness of manufacturing companies influences AI adoption. The Industry 4.0 readiness in measured by the use of digital technologies, typical for cyber production systems. Our research is based on the European Manufacturing Survey 2022 data, which shows that the use of AI is still relatively low. The logistic regression analysis revealed a significant positive relationship between I4.0 readiness and AI adoption, suggesting that companies with advanced digital infrastructures and integrated cyber-physical systems are more likely to adopt AI. This finding underlines the importance of digital transformation for the integration of AI software.

Keywords: Artificial Intelligence, Manufacturing Company, Industry 4.0, Industry 4.0 Readiness.

Introduction

Industry 4.0 integrates cutting-edge technologies such as the Internet of Things (IoT), cloud computing, cyber-physical systems (CPS), additive manufacturing, advanced robotics and artificial intelligence (AI) into existing manufacturing systems (Da Xu et al., 2018; Oztemel and Gursev, 2020). In the context of Industry 4.0 and manufacturing, AI is considered a crucial component for securing a competitive advantage in business (Wamba-Taguimdje et al., 2020). The increasing availability of data and the emergence of publicly accessible AI chatbots in the last year have sparked a growing interest in AI research. Current research mainly focuses on different areas of AI implementation and shows its positive impact on manufacturing processes, especially in the areas of quality control, product design, predictive maintenance, creativity and innovation (Makar, 2023; Lee et al., 2023). Given these benefits, it is important to empirically investigate the current state of AI implementation in manufacturing organizations to better understand how these research findings are applied in practice

In recent years, both academics and practitioners have faced the challenge of determining the current maturity and readiness of companies for Industry 4.0 concepts (Elibal and Özceylan, 2020). There is an ongoing search for the development and improvement of self-assessment models that can be used to determine the readiness of organizations for

Industry 4.0 (Hizam-Hanafiah et al., 2020). These models focus on different dimensions of manufacturing companies, including the technologies that are the pillars of the Industry 4.0 concept. The use of various technologies, especially digital technologies, is one of the most important factors in assessing the I4.0 readiness of the manufacturing company. AI is a complementary technology to other digital technologies as it focuses on data analysis. Therefore, it can be assumed that the use of various digital technologies also fosters the use of AI solutions.

This study aims to assess the diffusion of AI tools in specific production areas in European manufacturing companies. We consider that there is a gap in the literature regarding the relationship between I4.0 readiness and AI adoption, i.e. whether I4.0 readiness affects AI adoption. To address this research question, this study uses a subset of data from the 2022 European Manufacturing Survey (EMS), focusing specifically on responses from Slovenia, Slovakia and Croatia.

Industry 4.0 and AI in manufacturing

Industry 4.0 (I4.0) is a significant and complex concept for modern and future manufacturing. It integrates various advanced technologies transforming production processes, including fully autonomous smart factories, cyber-physical systems (CPS), self-organizing manufacturing systems, new distribution and procurement systems, individualized product and service frameworks, human-centric manufacturing approaches, and sustainability initiatives. Despite the clarity of these components, a universally accepted definition of I4.0 is still lacking. This ambiguity arises because research often focuses on specific technologies and domain-specific applications, overlooking broader management roles and challenges.

Many companies struggle with understanding and implementing I4.0 concepts due to high investment costs, complexity, and requisite knowledge. Existing IT infrastructures, including hardware, software, networks, and traditional business processes, further hinder seamless integration of advanced technologies. To address these challenges, various readiness and maturity models have been developed to aid companies in their transition to I4.0 (Schumacher and Sihn, 2024).

These models are crucial for several reasons. Firstly, they assess current capabilities, helping companies identify gaps between their present state and desired I4.0 integration. Secondly, they provide a structured implementation guide, outlining clear steps for improving systems, processes, and capabilities. This facilitates strategic planning and prioritization of technology and innovation investments, ensuring efficient resource allocation for digital transformation. Thirdly, these models enable benchmarking against industry standards, offering insights into competitive positioning and areas needing improvement to enhance operational efficiency and innovation capabilities. While these models vary in scope, focus, and complexity, technology remains a central component. Regardless of focus, technology underpins each model, enabling detailed assessments and facilitating adaptation to evolving industry trends. Methods behind these models, whether from academia, industry, or consulting firms, range from rigorous empirical research to expert consensus (Zamora Iribarren et al., 2024; Angreani et al., 2020; Mittal et al., 2018).

The fact is that the new industrial paradigm is driven by digitalization and the increasing connectivity of devices and machines, with data being a critical resource for value creation (Klingenberg et al., 2019). Despite extensive literature on I4.0, there is a noticeable gap in examining the direct relationship between I4.0 readiness and AI implementation. Given the importance of data for AI and AI's role within I4.0, we propose the following hypothesis: “A higher readiness for Industry 4.0 has a positive impact on the adoption of AI in manufacturing companies”.

Research methodology

European Manufacturing Survey

The research data was collected via the European Manufacturing Survey (EMS), coordinated by the Fraunhofer Institute for Systems and Innovation Research – ISI, the largest European survey of manufacturing activities. The survey addresses manufacturing strategies, innovative organizational and technological concepts, cooperation issues, production offshoring and backshoring, servitisation, and personnel deployment and qualification. It also gathers data on performance indicators such as productivity, flexibility, quality, and returns. In our latest EMS round, we included questions on digital product elements, new business models, artificial intelligence, and the circular economy. Conducted every three years, the EMS is primarily a paper-based survey at the company level, with the core questionnaire spanning six pages. Production managers or CEOs of manufacturing companies are the main respondents. The survey captures a cross-section of key manufacturing industries, including producers of rubber and plastics, metal works, mechanical engineering, electrical engineering, textiles, and more. It targets manufacturing companies (NACE Revision 2 codes 13 to 32) with at least 20 employees. The main objectives of the EMS project are to explore the use of production and information technologies, new organizational approaches in manufacturing, and the implementation of best management practices.

There were 384 companies in our sample: 138 from Croatia, 101 from Slovakia and 145 from Slovenia. In total, there were 112 small companies, 195 medium companies and 77 large companies. Overall, suppliers account for 30%, OEM producers for 64% and companies that are both suppliers and OEM producers for 5% of the companies in our sample.

Industry 4.0 Readiness model

We have used the Industry 4.0 readiness index developed by Fraunhofer ISI (Lerch et al., 2016) to analyse data collected within our research. The Fraunhofer Industry 4.0 readiness index is based on the selected Industry 4.0 enabling digital technologies. Since the different technologies are highly process and operation-dependent and come from different technology fields, a simple counting of the technologies used is not sufficient for an Industry 4.0 readiness index. The index is using 7 technologies, divided into three technology fields: Digital management systems, Wireless human-machine communication and Cyber-physical system (CPS)-related processes.

Field 1: Digital management systems

- Enterprise resource planning - ERP and
- Product Lifecycle Management – PLM.

Field 2: Wireless human-machine communication

- Digital visualization technologies and
- Mobile devices.

Field 3: Cyber-physical system (CPS)-related processes

- Near-real-time production control systems,
- Technologies for automation and management of internal logistics,
- Technologies for digital data exchange.

Companies were categorized from into the appropriate level of Industry 4.0 readiness according to the following rules:

- Level 0 – Company does not use any of the seven technologies.
- Level 1 – Company uses one technology in either of the three technology fields.
- Level 2 – Company uses two technologies in two of the three technology fields.

- Level 3 – Company uses at least one technology in the first two fields and at least one technology in field Cyber-physical system (CPS)-related processes.
- Level 4 – Company uses at least one technology in the first two fields and at least two technologies in field Cyber-physical system (CPS)-related processes.
- Level 5 – Company uses at least one technology in the first two fields and all three technologies in field Cyber-physical system (CPS)-related processes.

While the first two technology fields cover IT-related processes (Industry 4.0 basic technologies) and still have a clear distance from Industry 4.0, technology field CPS already contains the first approaches to networked/digital production and can therefore be classified as Industry 4.0 closer than the other two technology fields (Lerch et al., 2016).

Results and discussion

We begin by presenting the share of users of specialized software (SW) with AI in each production area (Table 1). The six production areas indicated were:

- Management of production processes (e.g., process monitoring).
- Quality control (e.g., defect detection).
- Maintenance of machinery and equipment (e.g., condition monitoring).
- Management of internal logistics (e.g., warehouse, transport, etc.).
- Energy management.
- Improvement or innovation of production processes.

Production area	Share of AI users [%]
Process management	8.0
Quality control	8.8
Maintenance	7.5
Internal logistics	5.4
Energy management	4.1
Improvement or innovation	4.4

Table 1: Breakdown of SW and AI users across individual production areas

In the overall sample, only 8% of all companies in our sample use AI for the management of production processes. In the area of quality control, this area has the largest share of AI users in the entire sample at 8.8%. The areas of maintenance of machinery and equipment has 7,5% share, and the other three are around 4 to 5%.

Next, we present the distribution of companies according to their I4.0 readiness level. The majority of companies fall into the lower levels of I4.0 readiness. 17.4% of companies have not implemented any of the seven basic technologies and are therefore not ready for I4.0. Companies that have implemented at least one I4.0 technology account for 19.9%. Almost a third, i.e. 29.5% of companies fall into level 2 of I4.0 readiness. Companies that have at least one enabling technology in the CPS group and one in one of the first two groups fall into the level 3 category of I4.0 readiness and account for 14.8% of the companies in this sample. The last two readiness levels represent the lowest share of companies in this sample. Companies that fall into readiness level 4 account for 9.6% and companies that fall into the highest readiness category account for 8.8%. Table 6 shows the distribution of companies for every readiness level.

Readiness level	Share [%]
Level 0	17.4
Level 1	19.9
Level 2	29.5
Level 3	14.8
Level 4	9.6
Level 5	8.8

Table 2: Breakdown of SW and AI users across individual production areas

We have examined the relationship between readiness for Industry 4.0 and the use of AI. For the purposes of our study, an I4.0 readiness model was used that was developed based on previous EMS studies. This model is based only on technologies that are seen as enablers of I4.0. Since AI is part of a broader concept of I4.0, we were interested in whether there is a relationship between a higher level of readiness (and thus more enabling technologies) and the use of AI.

In connection with the readiness for Industry 4.0 and the probability of using AI, the results of the logistic regression show that this variable is statistically significant in predicting the use of AI in manufacturing companies.

Variable	β	S.E.	Sig.	Exp(β)	LB	UB
I4.0 readiness	0.19	0.087	**0.029***	1.21	1.02	1.43

Table 3: Results for logistic regression

This model is statistically significant and indicates that readiness for I4.0 has a positive effect on the use of AI, i.e. it increases the likelihood of using AI. For this reason, we can also analyze the probability of AI usage at different levels of readiness. Figure 1 shows that the higher the readiness level for I4.0, the higher the probability of AI use in manufacturing companies. However, even if a company falls into the highest level, the probability of it using AI is still below 30%.

Our analysis, therefore, confirms a positive relationship and shows that the higher the level of readiness, the greater the likelihood of using AI in at least one production area. Therefore, we can accept the hypothesis that the level of I4.0 readiness influences the use of AI. This means that the use of AI solutions in manufacturing companies is closely related to the readiness for Industry 4.0 (I4.0), especially with the use of other (enabling) digital technologies used in the company. In other words, manufacturing companies that were better prepared for I4.0 were more likely to adopt AI solutions that can increase their efficiency, productivity and competitiveness. Our findings clearly show that manufacturing companies characterized by advanced digital infrastructures, integrated cyber-physical systems and a strong emphasis on data analytics and IoT tend to adopt AI technologies faster and more extensively. Manufacturing companies with a low readiness for Industry 4.0 are at an early stage of digital transformation and typically have limited integration of digital technologies. These companies focus on basic AI applications such as quality control. For companies with low Industry 4.0 readiness, the introduction of AI can serve as a catalyst for digital transformation in the future. By gradually integrating AI technologies, these companies can increase operational efficiency, improve quality control and prepare for the future integration of Industry 4.0.

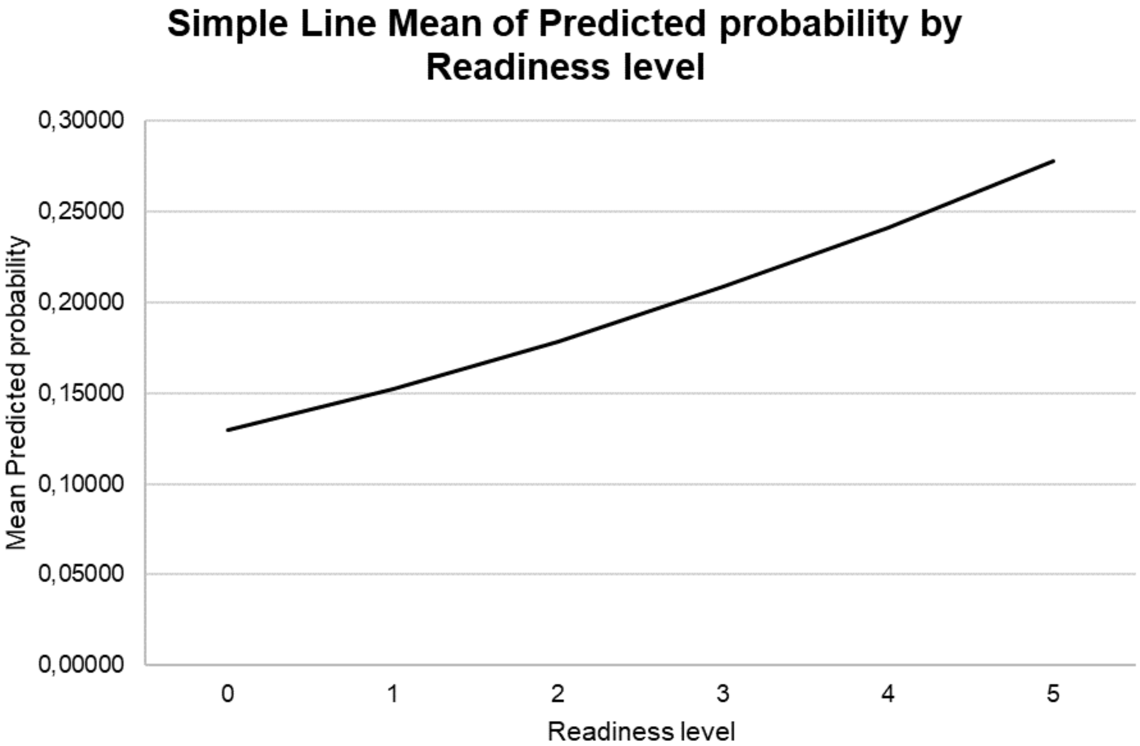

Figure 1: Probability of AI usage for every I4.0 readiness level.

Conclusions

The aim of our study was to investigate the diffusion of AI tools in manufacturing companies in the three selected countries and the potential influence of I4.0 readiness on the likelihood of AI implementation. A positive relationship between I4.0 and the likelihood of AI adoption was un-covered.

Our study has two contributions. First, it contributes to the current state of knowledge about the use of AI in manufacturing. It shows that the share of manufacturing companies using AI is quite low. The second contribution of this study looks at the relationship between the readiness of companies for I4.0 and the likelihood of AI adoption. It confirms that companies that have reached a higher level of I4.0 readiness (in our case, they use more I4.0 enabling technologies) are more likely to use AI.

This study offers some limited managerial implications. The positive relationship between AI use and the selected I4.0 readiness model shows that a higher level leads to a higher likelihood of AI use. Since the selected I4.0 model consists only of technologies that are believed to be enablers of I4.0, our results imply that certain technologies have a greater impact on the likelihood of AI use. This is an important managerial implication since it motivates managers to analyze their current processes and identify missing technologies that would enable easier implementation of AI. However, for a more detailed overview of AI-enabling technologies and factors, further studies need to be conducted.

The main limitation of this study is the sample of manufacturing companies. As only companies from Eastern and Southern Europe were analyzed, this could influence the results regarding AI usage. Another limitation concerns the sample size. Although a total of 384 companies were surveyed, this sample size may not be able to provide adequate statistical power. Therefore, further studies need to include companies from Western Europe, which in turn would lead to a larger sample size and more robust results regarding AI use. Further studies are needed to identify the key drivers of AI adoption in manufacturing.

While the use of AI has been shown to be influenced by Industry 4.0 enabling technologies, a detailed investigation into the exact technologies influencing the adoption of AI has yet to be conducted.

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Evaluation of companies' operational performance and sustainability: A case study

M. Florentina Abreu (florentinaabreu@netcabo.pt)
ALGORITMI/LASI Research Centre, School of Engineering, University of Minho, Portugal

Anabela Carvalho Alves (anabela@dps.uminho.pt)
ALGORITMI/LASI Research Centre, School of Engineering, University of Minho, Portugal

Abstract
This paper presents a global indicator for evaluation of companies' operational performance and sustainability. This was termed Business Overall Performance and Sustainability Effectiveness (BOPSE). Its primary goal is to evaluate business effectiveness by considering operational performance and sustainability compliance. The sustainability aspect is adapted and simplified from the Global Reporting Initiative (GRI) within a lean-green framework. This approach emphasises continuous efforts to reduce lean waste and focuses on cleaner production, environmental compliance, and social responsibility, which are essential for the factories of the future. The BOPSE has been applied in automotive case studies and this paper presents an application on a chemical company. The main findings indicated that the BOPSE is practical and feasible, regardless of the sector.

Keywords: Lean thinking, Lean-Green, Key Performance Indicators, Sustainability, Overall Equipment Effectiveness.

Introduction
Contemporary businesses face numerous challenges, including environmental and sustainability concerns, social responsibility, and the evolving paradigms of Society 5.0 (S5.0) (Keidanren, 2018) and Industry 5.0 (I5.0) (Breque et al., 2021). To address these challenges and ensure business sustainability, companies must focus on human-centric approaches, adopt and adapt technologies for higher business effectiveness and production systems eco-efficiency, and ensure future resilience. Therefore, companies depend on technological, design, and social innovation (European Union, 2020) to shift mind-sets towards this new paradigm. The organizations responding most effectively to these challenges will certainly achieve better performance in Environmental, Social and Governance (ESG) (UN Environment Programme – Finance Initiative, 2004) criteria.

The primary objective of this paper is to present a global indicator that evaluate companies' operational performance and sustainability using the Business Overall Performance and Sustainability Effectiveness (BOPSE) model (Abreu et al., 2024). This model integrates Lean principles and tools, eco-efficiency, and sustainable development pillars. BOPSE assesses economic, social, and environmental dimensions, providing a comprehensive indicator for companies to gauge their performance over time and relative to peers. It combines Overall Equipment Effectiveness (OEE) for operational performance and Global Reporting Initiative (GRI) based indicators for sustainability.

The BOPSE indicator offers insights into a company's standing and improvement areas in both performance and sustainability, aligning with Sustainable Development Goal (SDG)12 for responsible production and consumption. The model was validated in six case studies from the automotive sector in Northern Portugal (Abreu, 2020), four from the electric, electronic and energy sector, one from commercial and industrial scales, one from boat building, another from metallurgical parts, other from furniture manufacturing and other from exotic rock transformation (Abreu, 2020; Alves & Abreu, 2021). The BOPSE had not yet been applied to the chemical sector, and the authors aimed to identify the challenges related to its implementation.

This motivates the study presented in this paper, which aims to present a case study implementing the BOPSE indicator in a chemical company.

This paper is structured in six main sections. After this introduction, it is presented a background about the main topics of the paper. The third section presents the BOPSE model, followed by the methods section. Then, some results about the BOPSE implementation in a chemical company are presented in the fifth section named Case Study. Finally, the sixth section presents the main conclusions and future work.

Theoretical Background

Global consumption and production are exerting significant pressure on the environment, disrupting its delicate balance (IPCC, 2019; UNCC, 2019). The rise in extreme climatic events and other environmental issues appears to be the result of prolonged, excessive use of natural resources. Societies, companies, and individuals play crucial roles in addressing these challenges. The Synthesis Report (SYR) of the IPCC Sixth Assessment Report (IPCC, 2023) highlights the interconnections between climate change adaptation, mitigation, ecosystem health, human well-being, and sustainable development (SD).

This context requires a paradigm shift, where "business as usual" is no longer enough for companies. Businesses must adopt a comprehensive approach that integrates sustainability into core strategies, embraces innovation, and adheres to responsible corporate governance. Successfully navigating these challenges allows companies to mitigate risks and seize growth opportunities for long-term viability. To ensure this, companies must adopt the I5.0 concept, aligning operations with ESG criteria and the European Union's taxonomy. This alignment is crucial as it encompasses factors impacting financial performance, risk management, and stakeholder relationships (Arvidsson & Dumay, 2022; Li et al., 2021). Embracing ESG prepares companies for sustainable growth and success in the evolving business landscape (BCSD, 1993).

Companies' production processes impact the environment daily, affecting national economies. Therefore, it is imperative to implement processes that mitigate this impact. Sanidas and Shin (2017) advocate for the global adoption of lean production, which improves inventory management and enhances production efficiency. Nations that reduce inventory ratios tend to experience higher economic growth. Donofrio and Whitefoot (2015) also noted that lean practices have been key in reshoring manufacturing operations to the US, boosting competitiveness.

Lean Thinking (Womack & Jones, 1996) guides companies on a transformative journey, serving as a mind-set or way of life (Alves et al., 2012; Amaro et al., 2021; Bittencourt et al., 2021; Cusumano et al., 2021; Dorval et al., 2019; Hopp & Spearman, 2021). Its principles can be applied across various industries, including the service sector and even personal life (Amaro et al., 2019). Womack and Jones (Womack & Jones, 2005) introduced the concept of lean consumption, acknowledging a disconnect between consumers and producers. Companies must ensure every decision impacts the entire value chain, addressing performance and environmental concerns in a coordinated manner. The integration of lean and green practices has been recognized for a long time (Florida, 1996; Maxwell et al., 1993), enhancing operational and sustainability efficiency and producing unparalleled outcomes (Alves et al., 2019).

Lean aims to deliver more value to customers by reducing waste (Ng et al., 2015), while green practices focus on minimizing environmental footprints and health risks throughout a product's lifecycle (Dües et al., 2013). The intersection of lean and green embodies the principles of "doing more with less" (Womack et al., 1990) and "creating more with less" (BCSD, 1993), enabling companies to grow while reducing environmental impacts, conserving resources, and ensuring the safety of employees, communities, and consumers. This approach advances companies towards I5.0 (Alves, 2022; Breque et al., 2021).

The US-Environmental Protection Agency (US-EPA) recognises this link, defining environmental waste as "any unnecessary use of resources or the release of substances into the air, water, or land that could harm human health or the environment" (US-EPA, 2007). Reducing the seven wastes of lean directly or indirectly diminishes environmental waste, as resource-efficient production reduces the overall impact on the planet (Alves et al., 2019; Moreira et al., 2010).

Despite advancements, the connection between lean and green practices is not universally recognised (Abreu & Alves, 2015; Alves et al., 2016). Although the literature contains many lean-green models for eco-efficient production (Abreu et al., 2017, 2020; Alves et al., 2016), these models are often criticised for their complexity. Internationally, several frameworks exist for assessing sustainability efforts, such as the GRI (GRI, 2018). However, these frameworks are often complex and challenging for many businesses. To overcome this complexity, the authors propose the BOPSE model.

BOPSE model

To address the gap referred, the BOPSE model was developed (Abreu, 2020; Abreu et al., 2019; Alves & Abreu, 2021), aimed at evaluating a company's operational performance and sustainability, aligned with ESG objectives and the European Union's taxonomy.

The BOPSE model emerged from research conducted as part of a Ph.D. thesis in Industrial and Systems Engineering at the University of Minho, Portugal, from one of these authors' paper (Abreu, 2020). The BOPSE model hinges on an indicator that aggregates company performance from both sustainability and operational standpoints. The BOPSE indicator (Abreu et al., 2024) is derived from the arithmetic mean of two primary strands: sustainability and OEE. Both strands are given equal weight, highlighting their shared priority and significance in evaluating an organization's performance. OEE is considered a stringent Key Performance Indicator (KPI) because it is a product of its constituent components. Similarly, the sustainability strand is treated as a product of its dimensions. Values range from zero to one, but percentages were used for a clearer understanding of the results. The overall structure of the BOPSE indicator is depicted in Figure 1.

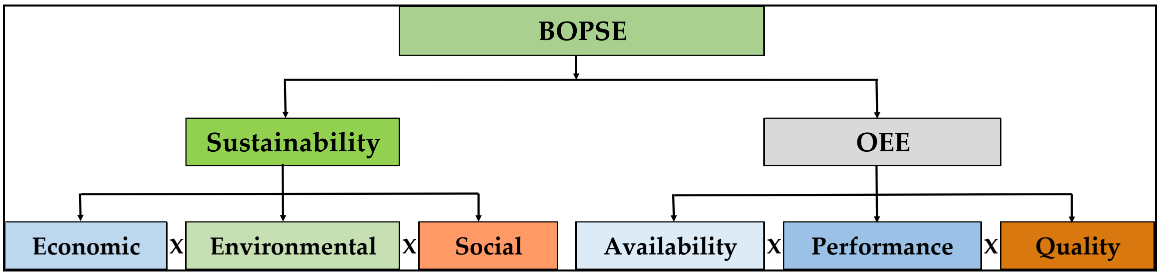

Figure 1: The BOPSE indicator structure

Within the sustainability strand, Key indicators had been identified to characterize each dimension. The calculation for each dimension involved computing the simple arithmetic mean derived from the results of these key indicators. For each identified key indicator, a set of descriptive indicators had been carefully chosen as the most relevant and representative. Thus, each key indicator was calculated either as the simple arithmetic mean of its constituent descriptive indicators or, in some cases, from a single descriptive indicator. Due to industry-specific distinctions and the need for normalization, rankings were assigned to 27 descriptive indicators, where direct calculation was not feasible. These rankings established performance intervals to standardize the descriptive indicator values between low (set at 60%), medium (set at 80%), and high performance (set at 100%). The BOPSE final version, comprises: 18 key indicators, 15 related with sustainability and three related with OEE; 32 descriptive indicators within the sustainability strand; three sustainability dimensions; product of sustainability three dimensions; product of OEE three components and the arithmetic mean of two primary strands for BOPSE calculus.

The BOPSE was applied to three case studies in the automotive sector (Abreu, 2020). These case studies allowed the validation of the BOPSE and the collection of results, acknowledging the unique nature of each company as an individual case. Furthermore, in 2021, the BOPSE was applied in twelve companies, to reinforce its validation (Alves & Abreu, 2021).

Method

The cooperation and support of the participating company was crucial for providing all the necessary information and data for the advancement of this research. The aim was to evaluate BOPSE effectiveness and functionality. The case study – a chemical company – demonstrated its interest in applying BOPSE, showing the willingness to participate, openness, and support in providing the necessary data. The protocol employed adhered to the guidelines outlined by (Yin, (2003).

The deployment of case study followed the following four-stage process: (1) designing the case study; (2) executing the case study; (3) analysing evidence gathered from the case study; and (4) formulating conclusions, recommendations, and implications. The first stage involved outlining protocols, setting procedures, and establishing general rules for the case study design. The second stage encompassed company visits, meetings, interviews, and data collection. The third stage involved detailed analysis, while the final stage encompassed drawing conclusions based on evidence derived from the collected data.

Case study

This section describes the implementation of the BOPSE in a chemical company, as well as the development of a corresponding dashboard. This implementation was made by a master's student, under the supervision of these paper's authors (Vilas Boas, 2024).

BOPSE indicator implementation

The BOPSE was implemented in a chemical company which mission underscored its commitment to sustainability, continually seeking ways to minimize the environmental impact and ecological footprint of its activities, and actively promoting a circular economy.

At the core of its values was the prioritisation of sustainability through sustainable management, efficient resource utilisation, production processes, and the promotion of an ecological policy. The company maintained a strong commitment to social and environmental responsibility throughout its value chain. Driven by a desire to consistently improve operations in a sustainable manner, this chemical company was interested in the BOPSE indicator. There was a visit to the company to share knowledge about the BOPSE indicator.

The procedure used to obtain the necessary data for the indicators that constitute the BOPSE was carried out through: data collection from various departments and analysis to understand which indicators existed within the company, and inputting the collected data into an Excel file. These data were sourced from sustainability reports, management review reports, and monthly KPIs. The sustainability and OEE strands were calculated, followed by BOPSE calculation (Vilas Boas, 2024), as illustrated in Figure 2.

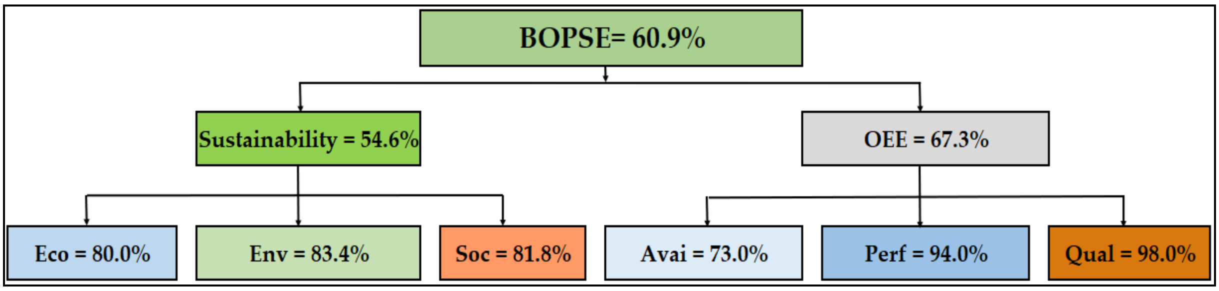

Figure 2: BOPSE results in the chemical company (adapted from Vilas Boas (2024))

It should be noted that the sustainability values reflected the company's recent investments in this area, including the preparation of the sustainability report since 2019, participation in environmental associations such as the United Nations Global Compact, Supplier Ethical Data Exchange (SEDEX), and the Sustainability Club. These initiatives ensured that the company was always aligned with the latest information on sustainability and the environment.

However, the company's production processes still had a considerable electricity consumption despite the transition to green energy. This negatively impacted the indicator's score. Additionally, the high-water consumption of the company also represented a significant challenge, especially given the increasing scarcity of this resource.

In the financial sphere, the low investment in Research, Development, and Innovation (RD&I) affected the indicator's calculation, as did the lack of disclosure of the average entry-level salary.

On the social dimension, the company showed a commitment to the well-being of employees and constant engagement with the local community. Nevertheless, the score was negatively impacted by the investment lack in volunteer activities and in continuous employee training. Gender inequality also persisted in some departments, such as production, where there were no female operators. This was an aspect the company needed to address to improve its social performance.

BOPSE dashboard development

For the company visualise and interpret in a more straightforward and effective way the results of the indicators included in the BOPSE, a dashboard was created using *Microsoft Power BI*. This tool aimed to provide a detailed analysis of a data set through a dashboard, thereby enabling better interpretation of the data. The conception of this dashboard not only simplified the detailed analysis of the BOPSE indicators but also supported the company in future presentations to potential clients and all its stakeholders (Vilas Boas, 2024).

This approach allowed a fluid integration of data, simplifying preparation for the analyses that followed. The *Power BI* tool was used to provide an efficient environment for using and visualizing data, thus solidifying the basis for in-depth interpretations that unfolded into the strands and associated key indicators. After standardizing data from the several transferred tables, the dashboard layout was built, as shown in Figure 3.

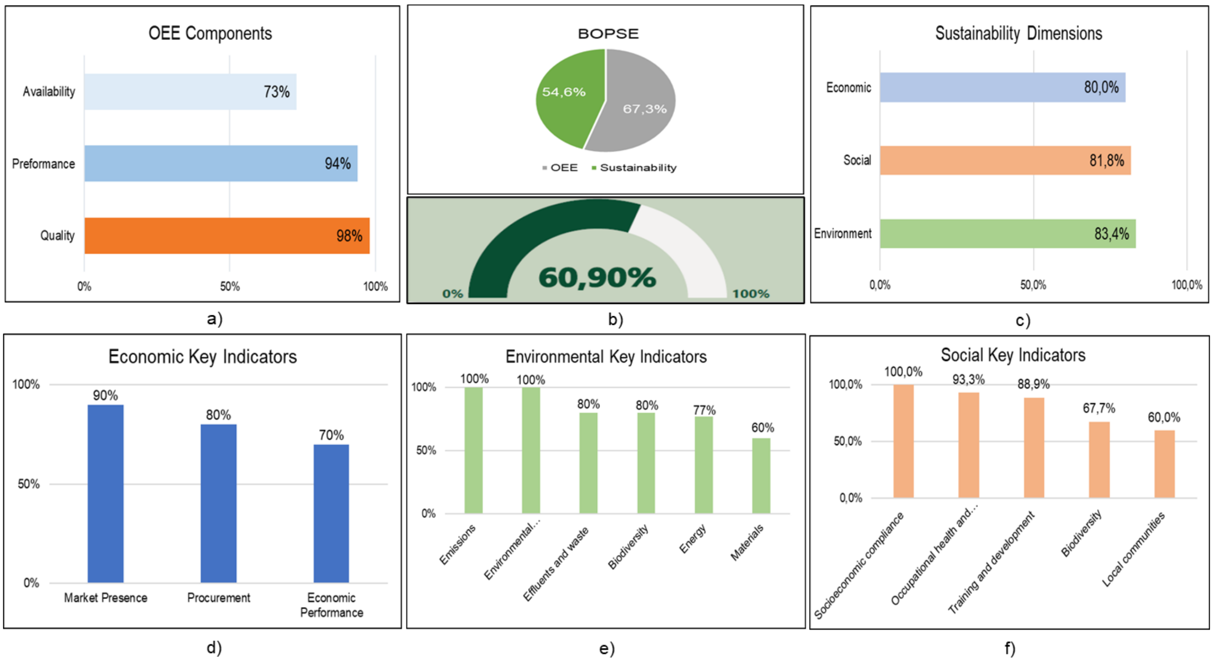

Figure 3: BOPSE Indicator Dashboard – Power BI: a) OEE components b) BOPSE and BOPSE strands c) Sustainability dimensions d) Economic key indicators e) Environmental key indicators f) Social key indicators (adapted from Vilas Boas (2024))

As seen in Figure 3, the visualization of BOPSE through a dashboard simplified its interpretation and allowed discussion on indicators requiring improvement. Breaking down the information represented in Figure 3, and analyzing them, it can be observed, in Figure 3b) that the OEE percentage was slightly higher than Sustainability, suggesting that the sustainability strand should be analyzed in detail to understand which indicators were affecting its results. The OEE components are displayed in Figure 3a).

Concerning the sustainability strand, the Figure 3c) showed that its dimensions' results were close to each other, so it was important to understand within them, which indicators performed worst. Analyzing the three dimensions, it was possible to understand which key indicators obtained a less positive result. For instance, for the environment dimension in Figure 3e), the key indicators performing worst were: "materials" which evaluated the company's investment in recyclable raw materials used in the production process and "energy" which measured the amount of non-renewable energy that the company consumed during the year 2022. These two indicators required improvement actions designed to increase their results, the consequent negative impact in BOPSE and in the company's production process. The same was carried out for the economic and social dimensions (Figure 3d) and f) respectively) to investigate which key indicators required improvement.

Discussion

The implementation of the BOPSE indicator in another sector allowed to reinforce what was found in the others cases studies: the companies' current state awareness and the visual management of this state, offering a comprehensive view of key metrics and performance indicators, helping users to promptly assess and comprehend all relevant information. The BOPSE allowed a substantial emphasis on the capacity to make informed decisions regarding the future. This indicator had the potential to identify weaknesses within companies concerning performance and sustainability, thereby presenting opportunities for enhancing overall competitiveness.

The BOPSE is straightforward for large and medium and small-sized organizations use and it is cost-effective. Also, it integrates familiar concepts and indicators (i.e., OEE and GRI), which should help understanding and implementing, especially if already existing in the company.

As the case studies showed, BOPSE is a robust indicator. Interpreting case studies findings, a pattern in sustainability performance was attained. A company displaying good sustainability practices attains a score above 50%. Moreover, for a good BOPSE value, a company would characteristically score above 65%. This means that in this particular case study, the company had a good operational performance (OEE scored around 67%) and a good performance in sustainability (sustainability scored around 55%). However, some improvement opportunities became noticeable. These were: training investments and workshops in lean-green, improve internal communication, defining measures in each department, improve water reutilization process, energy consumption identification in each production line and department, and promotion of biodiversity.

This case study evidenced what others already revealed: a need for improved data collection for the indicators composing the BOPSE, predominantly concerning environmental metrics, emphasizing the necessity of systematization of all available information. Difficulties reported were related to the time, resources needed and commitment level. As the current manual data entry process for BOPSE calculation was time-consuming and error-prone, and some machines lacked real-time data measurement devices, is paramount to automate the collection data using portable devices and sensor fusion concepts. The purpose is to reduce repetitive tasks, enhance human potential for digitalization, and improve robotic process automation.

Given the large volume of data generated by machines and equipment, data analytics methods should be carefully selected to efficiently extract necessary information from industrial systems databases. Consequently, companies need to be more technological, more digital on their way to I5.0 and S5.0. That is focusing on human-centric approaches that prioritize core human needs and safeguard workers' rights and fostering sustainable practices (such as developing circular processes, reducing energy and water consumption, and minimizing greenhouse gas (GHG) emissions) to protect natural resources for future generations. Simultaneously companies should create adaptable production capacities and flexible business processes to withstand disruptions in order to be resilient.

Conclusion

This paper presented the BOPSE model that support organizations on the capacity to make informed decisions regarding the future. It has the potential to identify weaknesses within companies concerning performance and sustainability, thereby presenting opportunities for enhancing overall competitiveness. In this particular company the opportunities brought by BOPSE indicators visibility were for instance: training investments and workshops in lean-green, improve internal communication, among others.

In future, an IT application will be developed to enable companies to input shop-floor data. Once the BOPSE result is obtained, the application will offer various scenarios for improving operational and sustainability performance. Using data from company databases, it will automatically generate system status reports displayed on customizable dashboards. These dashboards will visually present key operational indicators for dynamic assessment, aiding decision-making based on indicator values and predefined objectives. This approach will help users understand the impact of different indicators on the production system and identify areas for improvement, ultimately benefiting society and the planet by enhancing companies' understanding of their improvement potential.

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Characterising Industrial value chains from a circular economy perspective: Indicators

Jabier Reteg (jretegi@mondragon.edu)
Mechanical and Industrial Production Department, Mondragon University, Spain

Juan Ignacio Igartua (jigartua@mondragon.edu)
Mechanical and Industrial Production Department, Mondragon University, Spain

Dorleta Ibarra (dibarra@mondragon.edu)
Mechanical and Industrial Production Department, Mondragon University, Spain

Abstract

A clear and intuitive representation of the steps of value chains, their connections and their corresponding emissions is crucial to understand where greenhouse emissions are produced. Based on a linear representation of value chains obtained from environmentally extended input–output tables, this article proposes and calculates a set of seven indicators to characterise how industrial value chains emit greenhouse gases and their associated employment: complexity, length, total emissions, proximity to final demand, dispersion, social impact, and intensity. The indicators allow comprehensive evaluation of the weight of total emissions per value chain, the complexity of value chains in terms of links and the sectors involved, the hypothetical impact on employment when reducing polluting activities and the possibility of reducing emissions by applying circular economy loops at different levels. The indicators provide relevant information for decisions at the corporate or policy-maker level.

Keywords: Value Chains, Circular Economy, Input-Output, Mapping.

Introduction and research questions

Policymakers have emphasised the need to transition from a linear to a circular economy to limit the impact of climate change. Together with industrial strategies, a new circular economy action plan will help modernise the EU's economy and lead to both domestic and global benefits from the opportunities provided by a circular economy (European Commission, 2019).

Climate change and supply chains influence each other through natural disasters and greenhouse gas (GHG) emissions, respectively (Ghadge et al., 2020). Thus, research on climate change has concentrated on calculating carbon footprints and ways to reduce GHG emissions in supply chain management (McKinnon et al., 2015).

The impact that emission reduction measures will have on a given territory depends on the distribution of emissions across value chains and on the overall industrial fabric of the region (Retegi et al., 2023). Even if many industrial sectors take part in global value chains, the effects of global production fragmentation must be analysed together with the changing structure of domestic production to obtain the whole picture, one that might provide important information for policymaking and industrial policy (Knez et al., 2021).

Understanding the structure of value chains by empirically measuring all paths of each country-sector is already an end in itself (Knez et al., 2021). For instance, integrated modelling of emissions and economies using input–output tables has been used to assess the trade-offs between economic activity and GHG emissions (Mi et al., 2017). This can help stakeholders (corporate managers, supply chain managers, policymakers, etc.) understand the strengths and weaknesses of the industrial fabric, as well as the opportunities and threats that systems based on one or another value chain face. Binet et al. (2021) conclude that models using mathematical frameworks that can track both material flows and related environmental impacts can also be used to assess the mitigation potential of individual or combined circular economy strategies.

Although, in the corporate context, life cycle assessment (LCA) is usually applied, input–output analysis is suitable for assessing the impact of final demand on GHG emissions on a macro scale and for considering the total environmental effect of an industrial activity (Peters et al., 2011). Environmentally extended input–output tables (EEIOTs) are quite often used to assess the impact of economic activities on the environment (Kitzes, 2013) at regional or international levels (Alcántara & Padilla, 2020; Davidescu et al., 2022) even if input–output analysis is considered less accurate (though more comprehensive) than process analysis (Rauf, 2022). Material input and output (MIO) or its variants can be a way to measure and assess the sustainability of value chain business models (Brändström & Eriksson, 2022).

To assess environmental impact at different levels of the value chain, input–output tables and structural decomposition analysis have also been used to identify the drivers of energy consumption and carbon emissions (Peters et al., 2007).

Issues concerning the use of input–output tables arise when attempting to understand how emissions are produced by a country's economic activities. The average nature of value added to output ratios in the tables, the emergence of production cycles in the process of aggregating several value chains into a single table, and the characteristic of the so-called inverse Leontief matrix to even out the value-added distribution result in the distortions observed in static decompositions of value chains (Nomaler & Verspagen B., 2014).

Even considering these limitations, faced with the challenge of gathering the information needed to map value chains with precise information using LCA methods, Farris (2010) proposes using input–output analysis to initiate mapping at the macro industry level as a key starting point.

Authors have proposed methods to characterise value chains from a domestic-global (Knez et al., 2021) or upstreamness (Antràs et al., 2012; Lalanne, 2023) perspective. With the literature highlighting the need to map and characterise value chains from a sustainability perspective (Gereffi & Fernández-Stark, 2011; Williams et al., 2013), more research is needed to understand the interdependencies of sectors inside value chains and to assess opportunities for fostering sustainability.

Considering the state of the art that has been described, this paper proposes the following research questions:

- RQ1. Is it possible to define a set of variables to characterise the GHG emission structure in value chains in an intuitive way in a country/region based on input–output tables?
- RQ2. Are these variables meaningful to describe the sustainability of value chains and to afford insights for corporate and policymaker decision-making?

Methodology

To answer the research questions, this study uses secondary data from the latest available version of the input–output economic tables for Spain obtained from the Organisation for Economic Co-operation and Development (OECD, 2021), as well as data on GHG emissions (INE, 2020) and Spanish firms and employment (INE, 2023). The methodology is based on a previous article by the authors (Retegi et al., 2024) in which, based on environmentally extended input–output tables, they studied GHG emissions (CO2-eq) along industrial value chains and represented their dependency links linearly as the first step in assessing the GHG-reducing potential of circular economy strategies. In this context, 'value chain' is defined as a series of stages in the production of a product or a service for the end user, where each stage adds value and the total value of the end product is the sum of the value added at each stage (Knez et al., 2021).

The methodology entails the construction of environmentally extended input–output tables, a trimming process of links to reduce complexity while keeping a high degree of representativity, a triangulation process to achieve a linear model and the final representation of linear links and the calculation of emissions and jobs related to each of them.

The result of this previous research was a set of intersectoral relations (links) arranged based on their belonging to value chains and their position within them. Each link is assigned a quantity of GHG emissions obtained by the average values of each sector. The sectors included in this research correspond to the statistical classification of economic activity (NACE) codes from 10 to 43 at a two-digit level of detail, with some groupings of NACE branches of activities due to the availability of data on GHG emissions.

The outcome of applying this methodology is an independent linear model for each of 20 industrial sectors, representing 94.5% of total industrial emissions. Figure 1, as an example, presents the model representing emissions related to sector NACE 29 (*Motor vehicles*) as a final demand supplier. It shows the backward tree of relationships with other sectors and the related emissions of the economic exchanges at every step. The links are presented hierarchically (Link-x), depending on their proximity to final demand, and total emissions at each level are calculated. A similar tree structure can be obtained with jobs associated with each of the links.

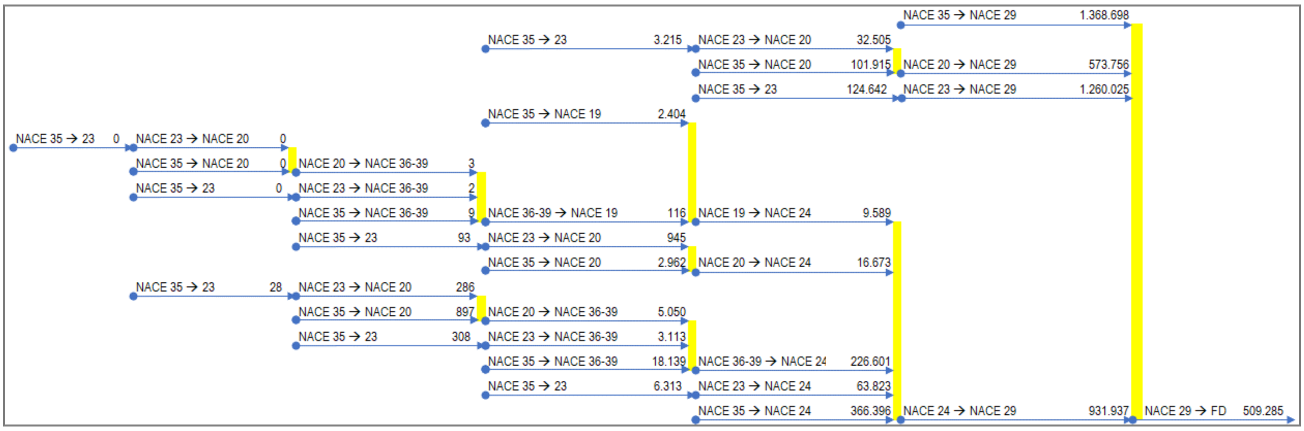

Figure 1: Distribution of GHG emissions in automotive value chain

Finally, the information is structured as a database gathering all the information needed to describe the emissions which occurred in the 20 value chains to meet the final demand. The fields in which this database is structured are presented in Table 1 (380 rows in total):

Value Chain	Branch #	Emitting NACE	Emissions	Associated Jobs
VC 35	1	NACE 35	34 612 812	23 314
VC 23	1	NACE 23	9 436 127	43 615
VC 23	1.1	NACE 35	933 424	628
VC 17-18	1	NACE 17-18	2 883 360	79 681
…….	…….	…….	……	……

Table 1: Description of value chains and emissions in database format

where “Value Chain” refers to the final industrial sector serving final demand, “Branch #” signifies the position within the value chain where GHG emissions occur, “Emitting NACE” identifies the specific industrial sector responsible for producing these emissions, the term “Emissions” represents the actual greenhouse gas emissions themselves in TCO2-eq and “Associated Jobs” is the number of jobs corresponding to the economic activity of the link. The allocation of employment associated with each link is proportionally determined, considering the amount of economic exchange that this link represents in relation to the totality of the exchanges of each sector.

The term ‘value chain’ is designated by incorporating the letters ‘VC’ along with the NACE code of the sectors that directly supply the final demand. By using this method, the issue of the emergence of production cycles in aggregating several value chains is solved with high representativeness (94.5%) of total industrial emissions.

The database has been explored to calculate the indicators proposed in this article for characterising value chains.

Results and discussion

As mentioned, one of the objectives of this study is to establish and measure indicators which allow for the characterisation of value chains from a GHG emissions perspective.

Based on the methodology presented earlier, seven indicators have been identified with the aim of characterising value chains in terms of how they create and provide value, as well as the resources used. The proposed indicators are as follows:

- Complexity (number of links): Represents the number of ‘links’ (intersectoral economic relationships) that make up the value chain.
- Length (number of sequential links). Expresses the length of the longest sequential chain of links in a value chain to serve the final demand and the number of sectors with significant emissions involved in the value chain.
- Total emissions (TCO2-eq): Represents the GHG emissions generated to produce what is necessary to meet the final annual demand of the value chain.
- Proximity to final demand (links): Indicates the average proximity or distance of emissions with respect to the final demand. Its value varies between 1 and 7. The closer the value is to 1, the closer the emissions will be to the final demand. A value of 1 means that all emissions generated in that value chain occur in the industrial sector that directly supplies the final demand.
- Dispersion (standard deviation): Reflects the dispersion of emissions within the value chain. The smaller the figure, the more concentrated the emissions are in certain phases within the value chain indicated by the proximity to final demand indicator.
- Social impact (jobs): Indicates the jobs generated by the value chain. This is an important aspect of the social value of value chains.

- Intensity (emissions per job): Indicates the emissions generated by each value chain per job and allows identifying those value chains where a potential reduction in activity and emissions has a greater impact on employment.

Considering the described variables, Table 2 presents the indicators associated with each of the value chains:

Value chain	Complexity	Length	Total Emissions	Proximity to Final Demand	Dispersion	Social Impact	Intensity
VC 10-12	40	6	12 628 454	1.54	1.37	519 154	24.33
VC 13-15	6	4	997 383	1.60	1.21	120 821	8.26
VC 16	2	2	406 373	1.66	0.67	52 473	7.74
VC 17-18	14	5	4 176 088	1.32	1.00	83 208	50.19
VC 19	10	5	17 801 755	1.21	0.77	13 314	1 337.09
VC 20	4	3	12 106 511	1.20	0.81	72 521	166.94
VC 21	6	4	1 710 931	1.58	1.32	58 585	29.20
VC 22	26	6	2 649 728	2.02	1.63	104 860	25.27
VC 23	2	2	10 369 551	1.09	0.55	44 244	234.37
VC 24	26	6	8 250 940	1.46	1.22	43 805	188.35
VC 25	42	7	7 060 815	2.31	1.98	274 825	25.69
VC 26	1	1	27 494	1.00	0.00	25 476	1.08
VC 27	30	7	2 108 837	2.17	1.90	75 456	27.95
VC 28	30	7	2 476 256	1.93	1.78	112 680	21.98
VC 29	34	7	5 629 730	2.09	1.86	143 099	39.34
VC 30	2	2	377 918	1.60	0.72	43 187	8.75
VC 31-33	44	7	1 245 066	2.04	1.85	207 869	5.99
VC 35	1	1	34 612 812	1.00	0.00	23 314	1 484.63
VC 36-39	8	4	9 448 896	1.12	0.66	98 504	95.92
VC 41-43	52	7	17 434 680	1.93	1.53	1 109 637	15.71
TOTAL	**380**	**4.65**	**151 520 216**	**1.41**	**1.1**	**3 227 033**	**46.95**

Table 2: Characterisation of industrial value chains

The codes of the value chains analysed in this study and reflected in the table correspond to the two-digit code of NACE 2009.

From an initial analysis, we observe variety among the value chains in each of the variables. As regards value chain complexity, this varies from a value of 1 for VC 26 (*Computer, electronic and optical products*) and VC 35 (*Electricity, gas, steam and air conditioning*) to a value of 52 for VC 41-43 (*Construction*). Both value chains (VC 26 and VC 35) show a length of 1 link. Other sectors, such as VC 27 (*Electrical equipment)*, VC 28 (*Machinery and equipment*), VC 29 (*Motor vehicles*), VC 31-33 (*Repairing and installation of machinery and equipment*) and VC 41-43 (*Construction*) need to sequentially coordinate seven sectors to provide the final demand. Emissions occur in a distributed way in all the links.

Considering total emissions, the figures range from 27 494 TCO2-eq for VC 26 (*Computer, electronic and optical products*) to 34 612 812 TCO2-eq for VC 35 (*Electricity, gas, steam and air conditioning*). In general, emissions occur in the final steps of the value chain. For most of the value chains, proximity to final demand is lower than 2. This means that most of the emissions are generated in the two links preceding final demand. In all the cases, the standard deviation of the position of the emissions is lower than 2. There is a clear correlation between the variables ‘proximity to final demand’ and ‘dispersion’.

Social impact is an indicator of the number of jobs induced by final demand in the value chain. It varies from 13 314 jobs for VC 19 (*Coke and refined petroleum products*) to 1 109 637 jobs for VC 41-43 (*Construction)*. VC 19 (*Coke and refined petroleum products*) and VC 35 (*Electricity, gas, steam and air conditioning*) are value chains related to energy and have a high ‘intensity’, with 1 337 TCO2-eq/job and 1 484 TCO2-eq/job respectively.

Conclusions

This study contributes to circular economy by proposing metrics which allow characterising value chains from a sustainability perspective. The authors test the possibility of obtaining, from the information available in regional input–output matrices, a set of variables which characterise GHG emissions in industrial value chains (RQ1) and verify whether they can contribute to evaluation of their sustainability and thus assist decision-making (RQ2).

After applying a method for extracting value chains from input–output matrices, seven variables related to the configuration of emissions and weight in terms of employment are proposed and calculated: Complexity, Length, Total emissions, Proximity to final demand, Dispersion, Social impact and Intensity. A comprehensive table has been constructed to calculate the aforementioned indicators for each of the 20 industrial value chains, yielding insightful conclusions for decision-making by corporate managers and policymakers.

Recognising the limitations of the use of the input–output matrices mentioned in this article, the defined set of variables has various utilities related to sustainability, the application of circular economy concepts and the impact of circular economy on industrial employment in regions.

Firstly, the method allows for a graphical and intuitive view of the emissions of each value chain and the supply chains that feed them. In addition, it allows evaluating the weight of each value chain in total emissions. It should be noted that data relating to emissions corresponding to sectors (such as productive sectors) is usually available, but not the emissions of their complete value chains. On the other hand, the description based on the proposed indicators allows evaluation of the complexity of a value chain in terms of length and the sectors involved. This gives an idea of the diversity of stakeholders that make up a value chain with a significant level of emissions.

The analysis also makes it possible to evaluate the impact on employment of a hypothetical reduction in emissions due to a reduction in the activity of the most polluting activities, facilitating its consideration when pursuing emissions reduction policies. This evaluation is carried out in terms of both absolute employment values and intensity (emissions/job).

Furthermore, the position of emissions in terms of their concentration and proximity to or distance from final demand allows evaluating the possibility of reducing emissions through the application of circular economy loops at different levels.

Finally, the characterisation, based on the defined variables of the chains in different states or regions of Europe, allows a comparative analysis of the configuration of industrial emissions in different countries and therefore learning from the different contexts. A comparative analysis of different countries based on the indicators is part of future research plans. Future research could also incorporate other types of indicators and extend the input–output tables.

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A Qualitative Study on Sustainability and Industry 5.0 in SMEs 2024

*Julieta Gutnisk (*julieta.gutnisky@usal.edu.ar*)*
Science and Technology Research Institute (USAL), Argentina

Sofía Maid
Science and Technology Research Institute (USAL), Argentina

Brian Benedini
Science and Technology Research Institute (USAL), Argentina

Leila Zare (leila.zare@student.unibz.it)
Sustainable Manufacturing Lab, Faculty of Engineering, Institute for Industrial and Energy Engineering, Free University of Bozen-Bolzano, Italy

Sergio Salimbeni (sergio.salimbeni@usal.edu.ar)
Science and Technology Research Institute (USAL), Argentina

Abstract

A few years after the term Industry 4.0 was coined at Hannover Messe in 2013, the United Nations' 2030 Agenda and its 17 Sustainable Development Goals prompted a rethinking of the Industry 4.0 concept. That event triggered the Industry 5.0 concept, which no longer focuses on technology, but rather considers sustainability, resilience and the human factor. The objective of this study is to analyse the impact of new technologies on sustainability and the environment. To this aim two focus groups were held in Argentina, the first one in the city of Pilar, and the second one in the city of Buenos Aires, totalling 36 people from 24 different companies. This work focused on the second pillar of Industry 5.0, Sustainability. From this it follows that the main benefits of the use of new technologies in relation to sustainability are waste control and management, more efficient use of resources, cost saving and economic benefits from recycling, reusing and reducing. The main challenges are incorporation of new processes, initial costs and financing and return of investment. This new advancement in Industry 4.0, known as Industry 5.0, places humans at the centre, benefiting not only individuals but also enhancing the sustainability and resilience of companies in extreme situations.

Keywords: Industry 4.0, Industry 5.0, Sustainability, Focus group, SMEs, Challenges.

Introduction

While the 4th Industrial Revolution (4IR) and its application to manufacturing, known as Industry 4.0, focus on technology, this new phase, Industry 5.0, emphasises a sustainable industry centered on human well-being and enterprise resilience. Industry 5.0 seeks to prioritise the well-being of individuals by making technology available to workers. All industries, especially small and medium-sized enterprises (SMEs), which are the backbone of the economy in many countries, including Argentina, must adapt to enter Industry 5.0. Although implementing Industry 5.0 offers SMEs advantages in sustainability, resilience, human-centricity, and innovation, it can also introduce new barriers and challenges.

The lack of awareness in Argentina about the challenges and potential benefits of Industry 5.0 from the perspectives of managers and workers within companies motivated this study. The goal was to identify the barriers and opportunities that SMEs face regarding society and sustainability. Consequently, the following research questions were formulated:

RQ-1: What are the opportunities and challenges that SMEs in the Argentine manufacturing industry face when making the transition to I5.0?

RQ-2: What are the requirements that must be met to adopt a sustainable I5.0 approach?

To conduct the analysis, two focus group workshops were held in Argentina to gather data on the advantages and challenges of implementing Industry 5.0 in SMEs. The first workshop took place in Pilar, Buenos Aires Province, while the second was held in the city of Buenos Aires. The study focused on middle and senior management of SMEs, who identified several advantages of Industry 5.0, including waste control and management, more efficient use of resources, cost saving and economic benefits from recycling, reusing and reducing. However, they also mentioned barriers such as the incorporation of new processes, initial costs and financing and return of investment.

Following the introduction, the next section describes the methodology used for the focus groups and presents the results from the workshops. This is followed by a literature review comparing Industry 4.0 and Industry 5.0. The article concludes with a summary of the main points.

Literature review

A few years after the term Industry 4.0 (I4.0) was coined, during the Hannover Messe in 2011 (Salimbeni et al., 2023), the United Nations (UN) adopted a 2030 Agenda for Sustainable Development Goals (SDG) in 2015, which sought to guide the global economy towards social equality and respect for ecology. That generated a rethinking of the I4.0 concept, advancing to the I5.0 one, which no longer focuses on technology but adds sustainability, resilience and the human factor as focal one (Mabkhot et al., 2021). The idea of I5.0 emerged as an extension of Industry 4.0 with a social and environmental dimension (Zizic et al., 2022). I5.0 also seeks to encourage essential aspects for the future, such as human well-being, sustainability and resilience (Bigerna et al., 2023).

According to the European Commission, I5.0 is a necessary evolutionary step of I4.0 because I5.0 is not a technological leap forward, but rather a way of seeing the I4.0 approach in a broader context, providing regenerative purpose and directionality to the technological transformation of industrial production for people, planet and prosperity (Zizic et al., 2022).

According to Ghobakhloo et al. (2022) the concept of I5.0 has emerged as the vision of an industry of the future that values the protection of the environment and society. This is why I5.0 is considered the evolution of I4.0. While the focus of I4.0 was automation, I5.0 focuses on cooperation between humans and machines, putting workers at the centre of the business process and making production respectful of humans and the environment planet, seeking to achieve social objectives beyond employment and economic growth, thus achieving sustainable development (Leng et al., 2022). Thus, while I4.0 is an approach focused on technological digitalization, I5.0 is a human-centered approach through three main pillars: resilience, sustainability and human centrality (Alves et al., 2023).

I5.0 is also considered the vision of an industry of the future, that values the protection of the environment and society. It is a concept that seeks to make the industry more sustainable, people-centered and resilient, where humans and robots work as collaborators instead of competitors and their objectives are sustainability, environmental management, human-centeredness and social benefit (Akundi et al., 2022).

According to Zengin et al. (2021), there was already a direct relationship between I4.0 and some of the SDG, however, I5.0 embodies all of them.

On the other hand, it is known that the new exponential technologies that defined I4.0 are having a strong impact on companies, but it is noteworthy that the manufacturing industry is undergoing a rapid transformation due to the emergence of solutions based on Artificial Intelligence (AI) (Akundi et al., 2022).

In summary, according to the researchers, I5.0 represents a new stage of the industrial revolution, which is characterised by being an industry: (1) sustainable, (2) human-centered and (3) resilient (Stroud et al., 2024).

The concept of sustainability was initially introduced in the context of sustainable forestry, which is essential for ecological balance, climate change mitigation, and biodiversity conservation. Today, particularly in the realm of corporate sustainability, it is commonly understood as a three-dimensional approach encompassing economic, environmental, and social dimensions (Mies & Gold, 2021).

Focusing on the pillar of sustainability, Industry 5.0 may be the first human-driven approach based on the principle of industrial recycling, known as the 6R policy: Recognize, Reconsider, Realize, Reduce, Reuse, and Recycle. To promote individual well-being and sustainable economic growth, Industry 5.0 aims to make production human-centered, prioritizing worker well-being within intelligent industrial production processes (Alves et al., 2023).

The author (Bataleblu et al., 2024) argued that the sustainability declaration that companies must disclose should be the European Sustainability Reporting Standard (ESRS) which covers three main categories: (1) Eco-economic (climate change, pollution, water and marine resources, biodiversity and ecosystems, use of resources and circular economy); (2) Social (own labour, value chain workers, affected communities, consumers and end users); and (3) Governance (business conduct).

For his part, author Bigerna et al. (2023) added that in the context of I5.0, a sustainable industry characterised by energy efficiency and prudent resource consumption could help reduce carbon emissions in several ways. Sustainable industry can help maintain the capacity of carbon sinks by preserving their capacities by reducing their concentration and thus reducing the greenhouse effect.

The environmental impact of manufacturing companies has led to stricter regulations aimed at reducing or eliminating harmful manufacturing processes and other business hazards. Circular Economy (CE) techniques are essential for addressing both environmental and market-driven challenges. For sustainable industrial development, it is also crucial to consider employment equity, gender equity, job security, employee well-being, and growth and quality of life. The sustainability dimension encompasses economic, social, and environmental issues that affect SMEs and sustainability in general (Raihan, 2024).

Regarding the social dimension, it must ensure the well-being of individuals, with a focus on quality of life both within and outside the company (Bigerna et al., 2023). However, looking beyond the company's immediate boundaries is as important as considering its internal social conditions and practices because resilience starts with the employee (De Marchi et al., 2023). This author also noted that the VUCA (Volatility, Uncertainty, Complexity, and Ambiguity) environment is of great interest to companies aiming to become more resilient and sustainable; both aspects are essential for creating value and achieving long-term profitability.

The analysed authors during the bibliographic review agreed on most of the factors of Benefits, Challenges, and entry barriers of Industry 5.0. A summary of this is shown in Table 1.

Author	Benefits	Barriers and challenges
Akundi	Human-Centric Approach. Advanced Technologies. Sustainability. Innovation and Digitization.	demands a workforce with new skills and competencies. The initial investment required for adopting Industry 5.0 technologies can be substantial. Small and medium-sized enterprises (SMEs) may find it difficult to allocate the necessary resources. lack of unified standards and regulations. Addressing ethical concerns, such as job displacement due to automation
Alves	Human-Centricity. Enhanced Collaboration. Sustainability and Resilience. Skill Development	Technological Integration. Cybersecurity Concerns. Economic Constraints. Regulatory and Standardization Issues. Cultural Resistance
Al-Banna	Enhanced Resilience. Efficiency and Cost Savings. Customization and Flexibility. Sustainability	High Initial Investment. Technological Integration. Cybersecurity Concerns. Skill Gaps.
Aruväli	Enhanced Resilience. Human-Centric Approach. Real-time monitoring and predictive maintenance.	Complex Integration. High Costs. Skill Requirements. Data Management and Security.
Bataleblu	Enhanced Sustainability. Efficiency and Speed. Management of Complexity. Scalability and Flexibility	Technical Challenges. Integration Issues. High Initial Costs. Resistance to Change.
Bigerna	Human-Centric Approach. Customization and Flexibility. Sustainability. Resilience. Improved Work Conditions.	High Initial Investment. Complexity and Integration Issues. Cybersecurity Risks. Skill Gap. Resistance to Change
Cubric	Economic (Innovation, Productivity and Cost). Social (Customer Satisfaction, Time, Decision Making, Predictability, Sustainability, Well-Being).	Economic (cost); Technical (support infrastructure, data). Social (model problem selection, lack of knowledge, stakeholders' perspective, safety, trust in technology, dependence on non-humans, losing jobs)
De-Marchi	Enhanced Resilience. Comprehensive Approach. Long-term Competitive Advantage.	Complexity of Implementation. Investment and Resource Allocation. Dynamic and Unpredictable Risks
Donati	Transdisciplinary Efforts. Improved Monitoring and Coordination. Sustainability. Enhanced Analytical Capabilities.	Technological Integration. Infrastructure and Governance. digital divide is essential to ensure that all stakeholders have equal access to the benefits. Resistance to Change
Ghobakhloo	Sustainable Development. Enhanced Human-Machine Interaction. Circular Economy. Resilience and Adaptability. Innovation and Employee Support:	Technological Integration. Human-Centric Design Challenges. Regulatory and Governance Issues. Skills and Training. Initial Investment Costs.
Jamwal	Resource Efficiency. Sustainable Value Creation. Flexibility and Customization.	High Initial Investment. Skill Gaps. Data Security and Privacy Concerns. Integration Challenges
Quiddi		Size, Financial resources, optional nature of approach, A concern for compliance, Resistance to change and need for assistance

Table 1: Benefits, challenges and barriers in the introduction of I5.0

Methodology

The data collection process was conducted through two focus groups, one in Pilar and the other in Buenos Aires, both located in Argentina.

It was crucial to understand how Argentine SME workers viewed I5.0's three main pillars: intelligent processes, sustainability, and the human factor. This topic is difficult to study using quantitative social research methods because business owners' opinions are hard to get through surveys or forms. Reason: Overuse of these instruments in modern times (Ríos et al., 2004).

In this context, the idea of holding workshops with the focus group format arises. This technique is used because it allows participants to generate a conversational activity and recover their opinions without interviewing them. This conversational dynamic lets participants discursively argue and counter argue. Peer-to-peer participation gives researchers more and better data. Since arguing and counterarguing are more complicated than stating one's opinion (Chitarroni et al.,2022).

The focus had to be organized after the data collection technique was chosen. It was decided to start with an expository phase because the object of study required certain lexical conventions and theories. The three main I5.0 components were discussed. After setting the groundwork, the discussion began by dividing the subject into thematic axes (Table 2). As shown, the focus group had three main thematic axes with two sub-axes, totaling six discussion blocks.

Intelligence		Sustainability		Human-centered	
Oppourtunities	Barriers	Oppourtunities	Barriers	Oppourtunities	Barriers

Table 2: Thematic axes of inquiry for Industry 5.0.

In turn, each of these discussion blocks was composed of two activities. For the first, participants wrote their main ideas about the topic on sticky notes. After 2 minutes, the moderators removed all the sticky notes and posted them on the board with the same thematic classification as Table 2. The moderator then read the sticky notes again and discussed each phrase or word from that session. This exercise often involves the group changing the sticky note from one block to another with the help of the facilitator.

After the presentation of the speakers, the Buenos Aires and Pilar focus groups took a 10-minute break. After the restart, the moderator started the first thematic axis, Intelligent Processes. First, people were asked to write down the main incentives for implementing smart processes in their industries, emphasizing that the task was to write words or phrases. After a reasonable amount of writing time, all the notes were grouped on the board in the incentives and benefits column within the axis of the intelligent process. Their thematic affinity was carefully demonstrated by pasting the post-it notes.

After organising this work, each board note was debated as a “trigger”. Those “triggers” caused the units of analysis to talk, allowing them to gather two pieces of information simultaneously. A detailed explanation of what the author of each note thought when writing it and the opinions of the other participants on the same topic were available. It should be noted that many notes had to be moved to other columns because they related to barriers to intelligent process incorporation, sustainability, or human factor.

The task in the previous paragraph only covered the first block; it had to be repeated five times to cover all six. We often had to intervene on attendees' notes and write new ideas by moderating conversational dynamics. The workshops lasted 3 hours each and were organized as shown in Fig.1.

To form the two groups for each workshop, a “snowball” strategy was carried out since there is no appropriate sampling frame for the preparation of a probabilistic sample. This strategy was based on contacting SME staff belonging to the network of contacts of the USAL asking them to contact other analysis units that they know.

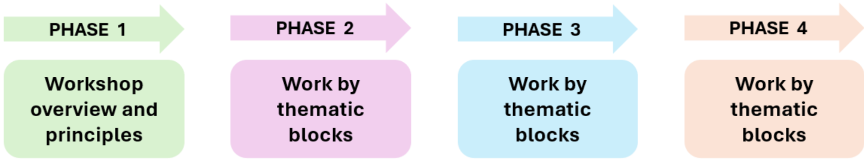

Figure 1: Workshops ‘process.

The samples (SME staff) were completed with 21 analysis units at the USAL Pilar campus and 15 at USAL Buenos Aires headquarters. All those attendees were SME people with employees under their supervision since that was a necessary condition to be able to think about social aspects, sustainability and the human factor. The results of the workshops are presented in Table 3.

	Qty. of SME	Qty. of people	Number of inputs (repeated non counted)						
			Intelligence		Sustainability		Human-Centered		
			Opportuniti-es	Barriers	Opportuniti-es	Barriers	Opportunities	Barriers	
Pilar City	14	21	18	15	11	7	18	15	119
Buenos Aires City	10	15	9	7	5	6	8	7	67
Total of both	24	36	27	22	16	13	26	22	186

Table 3: Main Results

Results Analysis

To begin to interpret the results from the focus groups carried out with SME entrepreneurs in Argentina, first, it is necessary to understand what concepts they associate with sustainable processes. In their words, sustainable processes involve “energy savings”, “reuse of materials”, “resource control”, “waste management”, “reduction”, “reprocessing” and “emissions regulation”. We find terms that are generally strongly associated with the idea of sustainability but when working with a sample, concepts associated with economy quickly begin to appear, such as “savings in energy costs”, “economic benefits of recycling” or “greater efficiency in the use of ‘economic resources’”. With this, the participants give signs that they see a possible cost reduction resulting from incorporating sustainable processes. This is in line with the results obtained by (Al-Banna et al., 2023). The participants were also aware that this process is largely used for the purpose of “avoiding sanctions”, giving rise to “investor lawsuits” or rethinking the “brand image”. All these processes can imply a competitive advantage over other companies, as pointed out by De Marchi et al. (2023). Despite the aforementioned competitive advantages, there was some agreement among the participants that the incorporation of these sustainable processes ends up producing “greater efficiency.” Although the problem seems to be that to achieve this greater efficiency it is necessary to incorporate “new processes” which the participants see as a barrier to the establishment of sustainable processes. Along these lines, the participants pointed out that the “costs” and “financing” of the initial investment for the incorporation of sustainable methods can be a great barrier to its realisation. This is largely in line with what is expressed by various authors such as (Al-Banna et al., 2023), (Quiddi & Habba, 2023), (Bataleblu et al., 2024), (Bigerna et al., 2023) (Ghobakhloo et al., 2022). Argentine SME staff especially point out the “return on investment” as a possible barrier since they sense that the initial costs of sustainability can be very high. This is the reason why when re-asked about it, they denote the importance of carrying out a “socio-economic analysis” that allows them to know if their “market is enough”. This is of utmost importance since in an economy in crisis, like Argentina's, consumer preferences may not tend towards sustainability.

Among the possible results indicated for the market study are a possible increase in "customer costs" and a possible "lack of knowledge of sustainability in the local market" as barriers. Precisely these points are those that could put the return on investment in sustainable processes at risk. It is also important to note that other participants pointed out that the incorporation of sustainable processes can improve "customer references" which could also improve the brand image.

The results obtained from the focus groups with SME staff in Argentina denote great similarities with studies on the topic at a global level, which increases the concurrent validity of the results.

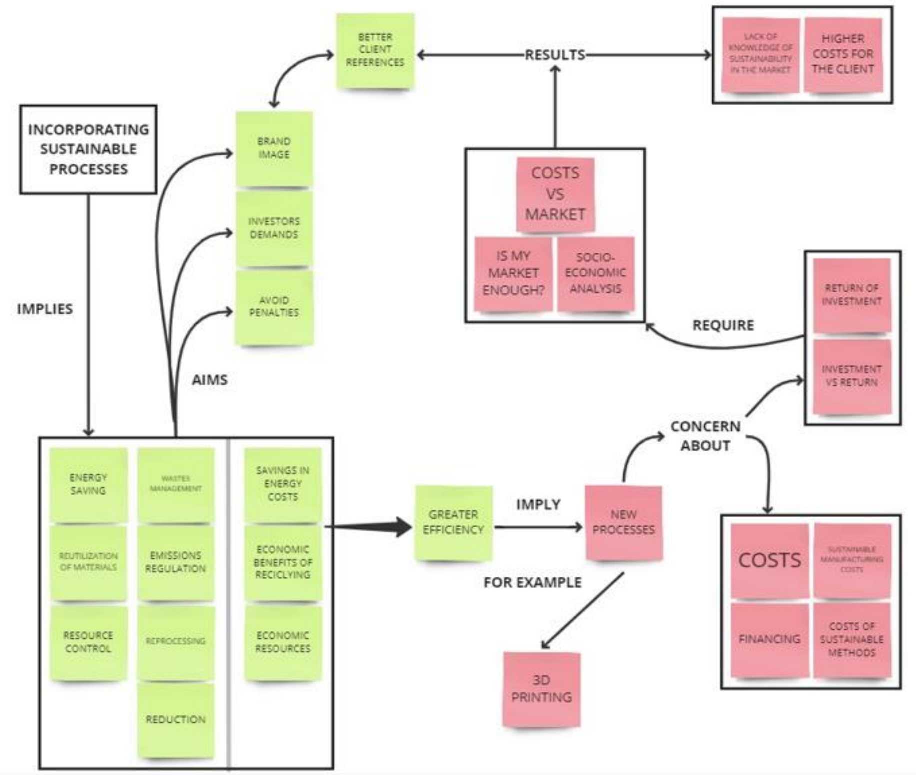

Figure 2: Results´ Mind Map

Advantages	Barriers and challenges
Waste control and management.	Incorporation of new processes (e.g. 3D printing).
More efficient use of resources and resource saving.	Initial costs and financing for the incorporation of sustainable methods.
Cost saving and economic benefits from recycling, reusing and reducing.	Return of investment, which requires socio-economic analysis to determine if the market is enough.
Avoid penalties.	Lack of knowledge of sustainability in the market.
Investors demands.	
Brand image.	

Table 4: Benefits, challenges and barriers in the introduction of sustainable processes

Conclusions

This study aimed to analyse the impact of recent technological advancements on sustainability and the environment. Our research focused on identifying both opportunities and barriers to implementing the sustainability approach in I5.0. To achieve this goal, two focus groups were held in Argentina. The results of these workshops revealed a consensus on the primary benefits and obstacles of integrating Industry 5.0 into sustainability efforts. The main advantages of employing new technologies for sustainability include resource-saving and economic benefits from recycling, reusing, and reducing. However, significant obstacles such as the implementation of new procedures, the initial costs and financing required for sustainable methods, and the lack of market knowledge about sustainability were also identified. In summary, it can be concluding that I5.0 sustainability approach provides more opportunities rather than barriers for SMEs. Future research will focus on the intelligent strategies employed in Industry 5.0.

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Austrian Association of Industrial Engineering and Management (WING)

WING
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*„Industrial engineers are **engineers educated and trained in economic sciences** with an **academic degree** who **integrate their technical and economic expertise** in their professional activities.“*

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2024 WING has approx. 1.100 members

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► Implementation of WING Purpose and Activities

WING **actively supports** its members in **scientific** and **professional** matters e. g. by providing insights on **professional issues** as well as on **questions** about **educational matters**. WING promotes the **exchange of ideas** and the **social integration** of the members through **various activities**. There are **many activities** including, but not limited to

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- transfer of knowledge,
- supporting universities in design of the WING curriculum,
- targeted career development measures,
- representation of interests of the members and nourishing association´s image
- strengthening the link between economy and science.

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WING - Österreichischer Verband der Wirtschaftsingenieure
Münzgrabenstraße 11 I A - 8010 Graz
Tel.: +43 316 873 7795
E-Mail: office@wing-online.at I Web: www.wing-online.at