

CONTRIBUTION OF THE HUMAN-CENTRIC APPROACH TO TECHNOLOGICAL, RESOURCE AND INNOVATION SUSTAINABILITY

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Abstract The specific role of the human-centric approach in the development of sustainability has not been sufficiently explored. In this paper, the overall contribution of the human-centric approach to the reinforcement of the three dimensions of sustainability established in Industry 5.0, technological, resource, and innovation sustainability, is considered. The analysis shows that human-centricity has a systematic impact on every dimension with all the relevant segments that are found in the literature and practice, ranging from the design of the adaptable, energy-efficient and ethically aligned technologies, responsible resource use with the help of human-machine decision-making, circularity, digitalization in accordance with human needs, and inclusive innovation processes based on user feedback, co-creation, and ethical principles. Combined, these segments bring into sight the fact that the human-centric approach is not an individual pillar of Industry 5.0, but it is an integration mechanism that operationalizes sustainability in the whole industrial ecosystem. The main value of this research is the construction of a comprehensive framework to link human-centric design with all the important technological, resource-related and innovation-oriented sustainability processes. This framework describes the channels that result in human-centricity to deliver long-term environmental, economic and social returns. The results can be used as practical evidence in the development of European Commission policies and the activities of the CoP I5.0 as they prove that an investment in human-centric strategies contributes directly to the priorities of the EU in terms of sustainable competitiveness.

Keywords: Human-centric approach; sustainability; Industry 5.0; community of practice CoP I5.0; technological sustainability; resource sustainability; innovation sustainability.

1. INTRODUCTION

Three core conceptual pillars - the human-centric approach, sustainability and resilience - are the supporting structure of Industry 5.0. To ensure the development of Industry 5.0, it is necessary to develop all three of these concepts simultaneously. However, it is not clear yet, whether the evolution of one of the main pillars, the human-centric, directly leads to the evolution of another important pillar, sustainability. This research is therefore focused on trying to uncover this specific impact. In

this respect, it would explore how and to what extent the human-centric approach influences the development of technological, resource, and innovation sustainability.

Industry 5.0 describes the human-centric approach as a design, development, and implementation approach that focuses on human capabilities, needs, and well-being as the central focus of the design, development, and implementation of technologies and industrial processes. This orientation makes the intuitive interaction between individuals, machines, intelligent systems and working environment possible with the aim at optimal efficiency and safety - and at the same time in accordance with ethical principles and social values. This ultimately ensures that technology is used in empowering the workforce to ensure that the production process is adjusted to human requirements, and not forcing the workers to adjust to the technology.

Sustainability in the meaning of Industry 5.0 as it is seen globally, is the combination of ecological, economic and social factors into technology creation and industrial process. It is a long-range goal to sustain the resources, minimize adverse environmental effects and community welfare, and ensure that production and innovation are coupled with responsible planet management. In this way, the industrial sector becomes not a passive recipient of the resources but an active regenerator and the factor of beneficial social change.

2. CONTRIBUTION OF THE HUMAN-CENTRIC APPROACH TO TECHNOLOGICAL SUSTAINABILITY

Technological sustainability can be described as the creation and use of technologies that are long-lasting, versatile, energy efficient and can be used in future innovation and at the same time reduce the ecological and social negative effects. It aims at facilitating long-term technological transformation without exhausting resources and becoming out of date.

2.1. Segments in Which the Human-Centric Approach Contributes to Technological Sustainability

The human-centric approach creates an opportunity to treat technologies in a manner that will guarantee their durability, flexibility, and effectiveness and avoid quick obsolescence of technologies, minimize waste, and allow continual technological development. The following are some of the main indicators that explain the segments where the human-centric approach can play a role in technological sustainability (Figure 1).

2.1.1. Development of Modular and Adaptable Technologies

The human-centric approach has the effect of being modular and flexible in technologies as it prioritizes the user requirements in the design of the technology and allows the flexibility of the system to adapt to the needs as they arise. Modular design helps in improving sustainability through the prolongation of the life of the products, the easiness of upgrades, and the minimization of waste generation. As an example, architectural modular strategies enable the production of buildings that can easily be modified to match the constantly changing needs of users, which leads to a lower environmental footprint and a higher value of infrastructure in the long run [1].

2.1.2. Maintenance and Extension of Technology Lifespan Through Predictive Analytics

The human-centric model of technology maintenance is founded on predictive analytics and human experience, allowing reduction of operational failures and increasing the system life cycle. This methodology incorporates user and employee feedback in the decision-making process, which allows more sustainable utilization of resources and reduces the environmental impact [2-3].

2.1.3. Interoperability and Integration of New Technologies

The focus in case of introducing new technologies is on intuitive interfaces and human-machine interaction when these technologies are introduced in a human-centric approach. This allows interoperability between various systems and allows the changeover to new technological paradigms with minimal losses and obsolescence of the current solutions [4].

2.1.4. Development of Energy-Efficient Technologies

The human-centric approach is a strategy that helps in designing energy-efficient technologies by matching the human requirements with the technological abilities hence minimizing unreasonable use of energy. The emphasis is placed on the real energy needs and how to adjust the new technologies to the human needs according to the user behavior and habits. In smart cities, human-centric design is in place to make sure that digital infrastructures are exploited to maximize resource usage and minimize environmental effects [5].

2.1.5. Implementation of Ethically Aligned Technologies Adapted to Humans

The human-centric practice is essential to the creation of ethically aligned technologies that take into consideration human rights, privacy, and inclusion. This will make the technologies not only practical but also socially sustainable because it will help them gain the trust of users and minimise social risks in their adoption [6].

2.1.6. Use of Circular Technological Processes

The human-centric approach to the circular processes is the creation of technologies that will allow reusing, recycling, and reducing waste, and also actively involve users and workers in the process of sustainability. This is to ensure that technologies are compatible to human values and needs in societies and hence reduce environmental harm [7-8].

2.1.7. Digital Transformation Through Worker Education and Training

The human-centric approach to digital transformation promotes the value of employee education and development that would allow adapting to new technologies. This will create a symbiotic relationship between the human and machine where the workers are not marginalized, and they become prime participants in sustainable technological development [9].

2.1.8. Development of Open Innovation Platforms

In a human-centric approach, open innovation platforms allow widespread inclusion of communities, academic institutions and industry, and can form inclusive sustainable innovation ecosystems. The strategy links digital technologies to social demand, which will guarantee the long-term growth and socially responsible innovation [10-11].

2.1.9. Ensuring Technological Resilience Through Decentralized Systems

The human-centric approach favours the development of decentralized systems where the technological resilience against disruptions in the environment, social, and technical sphere is increased. Adaptive and modular decentralized systems, as is the case of water supply, allow a higher degree of flexibility and just allocation of resources enhancing sustainability [12].

2.1.10. Human Creativity as a Key to Sustainable Technological Development

Human-centric approach puts human creativity and innovation as the core in development of technology. By such means, technology is not created with efficiency in mind alone, but it will also create socially useful solutions that can help sustain digital economy in the long-term [13].

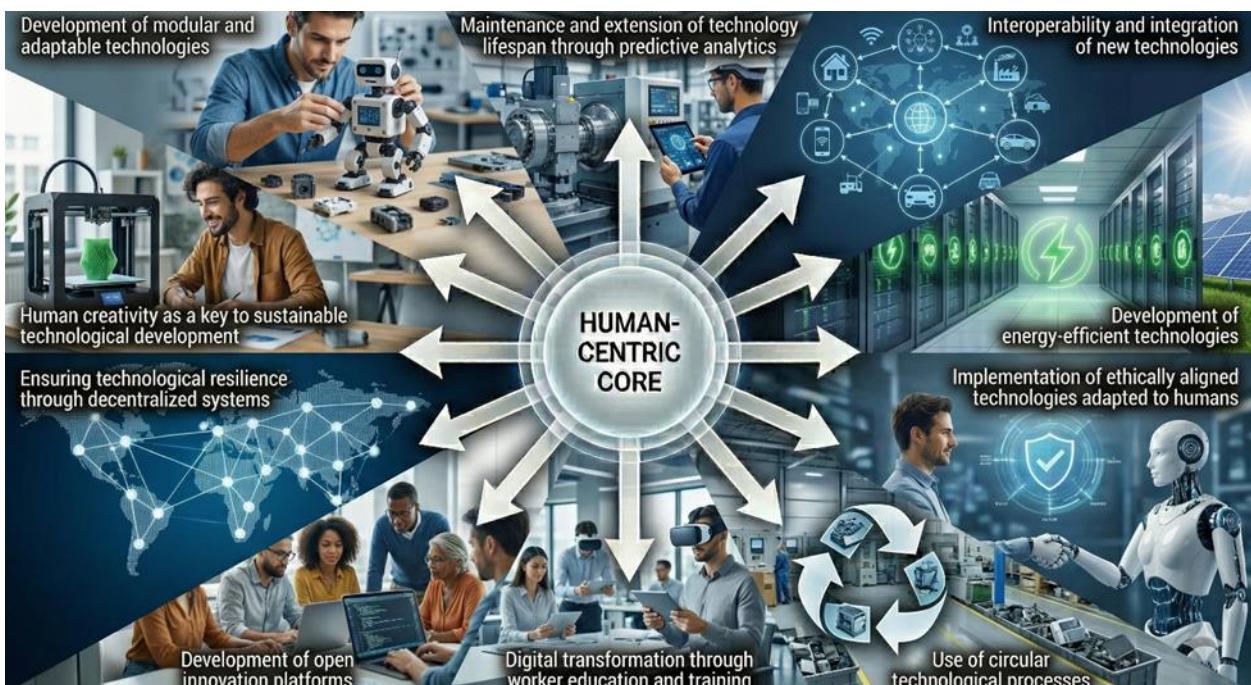


Figure 1. Main segments in which the human-centric approach contributes to technological sustainability (figure created using a digital graphic tool to illustrate conceptual relationships).

3. CONTRIBUTION OF HUMAN-CENTRIC APPROACH TO RESOURCE SUSTAINABILITY

Sustainable resource management involves the effective use of the available natural and industrial resources efficiently and responsibly in a manner that avoids depletion, wastefulness and maximizes

the availability of raw materials in future by recycling, reusing and putting in place new alternative methods in production and consumption of the natural resources.

3.1. Segments in which the human-centric approach contributes to resource sustainability

Human-centric approach facilitates people-technologies or resource management systems interaction, hence maximizing or minimizing material consumption, waste minimization and strategizing on long-term resources availability. The following are the key pointers that depict the segments and how the human-centric approach can help in resource sustainability (Figure 2).

3.1.1. Optimization of Raw Material Usage Through Intelligent Decision-Making

The human-centric approach facilitates effective utilization of the raw materials as it connects data to the humanity and decision-making. Connecting human visions and digital technologies, e.g. IoT and analytics, will allow decreasing the waste of resources and optimizing production [14].

3.1.2. Circular Economy and Material Reuse

Human-centric approach focuses on the participation of individuals and communities in bridging the resource loops by recycling, reusing and repairing products. The presence of human actors in the circular economy can improve the efficiency of processes and allow the materials to be returned to the production cycles [15].

3.1.3. Reduction of Industrial Waste Through Personalized Production

Human-centric approach to manufacturing allows making of products that are perfectly suited to the needs of a user and this will lead to less overproduction and industrial waste. This strategy follows the concepts of the circular economy, where resources are utilized in the scope of the need [16-17].

3.1.4. Precise Resource Monitoring Through IoT and Human Oversight

Accurate resource management with a human-centric IoT solution would imply the integration of sensor measurements with human professional knowledge to be able to make decisions based on social values and requirements. Having human control on the IoT systems will mean that technology will be largely user-driven, which will make it more trusted and the data gathered more relevant. This method allows optimising the utilisation of resources and minimising wastage through the connection of digital technologies and human judgment [18].

3.1.5. Efficient Energy Use in Production Processes

The human-centric approach to efficient energy consumption in production processes entails the combination of human knowledge and the optimisation algorithms to minimise energy use and CO₂ emissions. Integrating operators in the decision-making process facilitates dynamism in the production parameters; hence, energy efficiency and sustainability are enhanced. An approach to long-term sustainable manufacturing hub is established by connecting optimization and indicators of the environment, including waste minimization and reduced energy consumption [14].

3.1.6. Digitalization and Elimination of Paper Waste

Employing the human-centric approach in digitalizing processes will allow technology to be responsive to user requirements and raise the level of acceptance of the digital solutions and minimization of the use of paper-based documentation. The combination of electronic tools and the feedback provided by the workers and users helps to establish the efficient document management system, eliminating the paper waste directly. With the help of IoT, cloud services, and analytics in all their correspondence to human values and working habits, organizations are able to streamline information flows and attain sustainable goals [19].

3.1.7. Smart Irrigation Methods in Agriculture

The human-centric approach when applied to smart irrigation techniques presupposes the involvement of end users in creating AI systems, so that the technology could address the real needs of farmers. Human-machine collaboration works based on AI allows adapting the systems to the conditions of a particular farm and maximizing the use of water. The intuitive and understandable way of presenting the data promotes the decision-making process and enables the farmers to use their experience in the irrigation process [20].

3.1.8. Sustainable Mining and Natural Resource Exploitation

The integration of the human-centric approach within sustainable mining entails coming up with measures that will not only result in the balancing of the economic growth, the environment, and the prosperity of the surrounding communities. Engagement of all stakeholders including the local communities and industrial collaborators allows the establishment of a conceptual framework that is consistent with the needs of society at large and the principles of global sustainability. This is a method that helps to implement a fair shift to a low-carbon economy, and adhere to the values of the circular economy and sustainable use of resources [21].

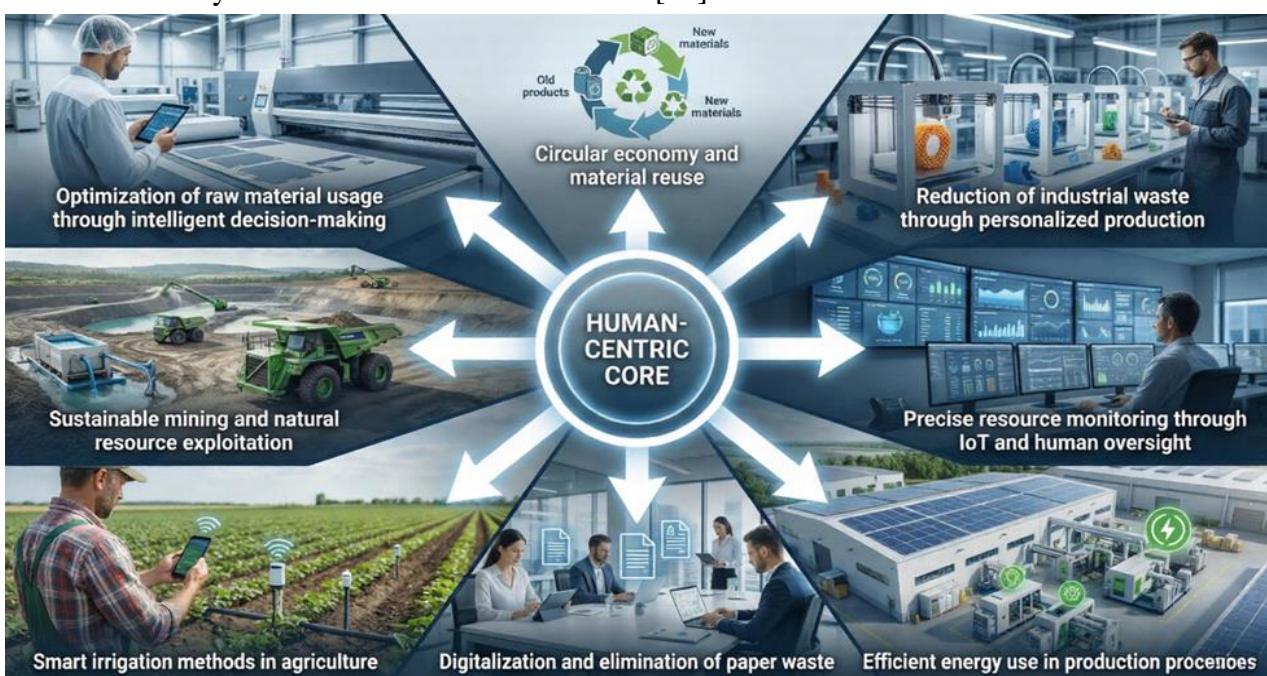


Figure 2. Main segments in which the human-centric approach contributes to resource sustainability (figure created using a digital graphic tool to illustrate conceptual relationships).

4. CONTRIBUTION OF HUMAN-CENTRIC APPROACH TO INNOVATION SUSTAINABILITY

Innovation sustainability is the process of continuous development and implementation of new ideas that will generate long term value to the organization and society, and at the same time reduce the negative environmental impacts.

4.1. Segments in Which the Human-Centric Approach Contributes to Innovation Sustainability

The human-centred vision contributes to the sustainability of the innovation process by making sure that the new solutions are the ones that are directly relevant to the real human needs, values, and well-being and are therefore likely to be accepted more, remain relevant over time and add beneficial influence to the society and the environment. The following are some of the indicators that depict the segments in which and how the human-centric approach provides sustainability on innovations (Figure 3).

4.1.1. Open Innovation Platforms for Collaboration

The human-centric approach promotes open product innovation platforms where various actors (users, researchers, companies) take part in the co-creation of knowledge and solution. Knowledge circulation, intersystem dialogue, and sustainable innovations that are socially relevant can be promoted with such a solution [22].

4.1.2. User Feedback-Driven Innovations

Within the frame of innovation, the human-centred approach allows design issues to be framed based on the needs of the users making sure that the solution is relevant and that the implementation of the process is faster. The necessity of dynamic changes in the needs and feedback of users demands a co-evolutionary approach when the user and the designer solve the problems together in the real-time [23]. This practice provides gradual convergence of solutions and increases the efficiency of innovation by relying on the knowledge, its assessment and feedback cycle.

4.1.3. Development of Flexible and Adaptable Technologies

Human-centred technology design focuses on flexibility and human - machine cooperation. Systems in such a way become more resilient and sustainable as they can react to different user needs and market changes [24].

4.1.4. Personalized Production as a Driver of Sustainable Innovation

Personalized production based on humans allows for the production of specific products based on the needs of individual users and minimizing waste and improving long-term sustainability of discoveries. It is an important aspect of Industry 5.0: human values have not been displaced in the middle of innovation procedure [25].

4.1.5. Enhancing Creativity Through Human–Machine Synergy

The human-centered approach reaches new co-creations and innovation by uniting human creativity and AI algorithms. Technology instead of supplanting human beings, is applied to complement human performance bringing about sustainable and topical solutions [26].

4.1.6. Smart Ecosystems for Accelerated Innovation Development

Human-centric approach deals with technology and entrepreneurial approaches, adapting to the ecosystem environment they are in, and the users are the major stakeholders in smart ecosystems [27]. Human-centric innovation ecosystems combine technologies, community, and societal needs, and speed up the development of inclusive and sustainable solutions. This is because the synergy of the various subsystems will guarantee that innovations will produce long-term value [28].

4.1.7. Sustainable Innovations Through the Use of Renewable Resources

The human-centric approach to sustainable innovations is essential since it ensures that technologies that are grounded on renewable resources are socially useful, applied in a responsible manner, and with the least impact on the environment. Innovations in sustainable mobility that are based on human-vehicle interaction to improve energy efficiency are one example [29].

4.1.8. Preservation of Intellectual Capital Through Educational Innovation

Human-centric concept in educational innovation allows building intellectual resources in institutes of higher learning amid innovations of strategy and amplifying process capacities to offer the quality of knowledge and expertise [30]. Innovations support knowledge transfer and maintaining the intellectual capital of the future generation, because education innovations with the human-centric approach will make it possible. By humanizing with educational frameworks, digital technologies will provide inclusiveness and sustainability of knowledge [31].

4.1.9. Integration of Ethical Principles Into Innovative Technologies

The human-centric approach is focused on incorporation of ethical considerations, including privacy, transparency, and fairness, into the processes of the innovation. This generates confidence and creates sustainability of the new technologies [32].

4.1.10. Development of Innovation Resilience to Market Changes

Human-centric approach in an innovation ecosystem allows involving a wider spectrum of stakeholders and enhances the ability of innovations to respond to the needs of the market and crisis scenarios [33]. This strategy makes innovation resilient by incorporating human values and flexibility in development strategies. This makes innovations especially applicable in cases of fast paced market changes, and organizations more flexible [34].



Figure 3. Main segments in which the human-centric approach contributes to innovation sustainability (figure created using a digital graphic tool to illustrate conceptual relationships).

5. CONCLUSION

This paper shows that the human-centric approach plays an important role in achieving technological, resource and innovation sustainability in the context of Industry 5.0. In all the fields under analysis, human engagement, whether it is the intuitive engagement with intelligent systems or the active engagement in open innovation ecosystems, proves to be a very important aspect that ensures the efficiency, flexibility, ethicality, and environmental friendliness of industrial solutions in the long term.

The conclusions emphasize that sustainability cannot be realized by technological progress alone, but is made possible by the synergy of human and technology. Human creativity, judgment, experience, and social values affect the technology development in a manner that reduces wastage, prolongs the life cycle of technology, maximizes resource utilization, maintains ethical governance, and makes innovation pertinent. The human-centric approach thus becomes the key integrative force between ecological, economic and social sustainability in Industry 5.0.

To policymakers - especially those in the European Commission and CoP I5.0 - the results indicate that human-centricity needs to be viewed as a strategic driver to sustainable industrial change. Education, digital skills, inclusive innovation, ethical design principles, and co-creative ecosystems policies will increase the capacity of the EU to attain sustainable competitiveness and guarantee long-term well-being. The human-centric approach, in this sense, is not only an ethical necessity, but a strategic direction towards the realization of the entire vision of Industry 5.0.

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