IETI Transactions on Engineering Research and Practice
http://ieti.net/TERP/

2025, Volume 9, Issue 1, 1-10, DOI 10.6723/TERP.202511_9(1).0001

CONTRIBUTION OF THE HUMAN-CENTRIC APPROACH TO ENVIRONMENTAL, SOCIAL AND ECONOMIC SUSTAINABILITY

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Abstract Industry 5.0 is based on three main pillars: the human-centric approach, sustainability and resilience. While the need to develop all three concepts is confirmed, the specific role of the human-centric approach in the development of sustainability is not explored enough. This research fills that gap by systematically investigating whether and how human needs and capabilities that are put at the center of industrial processes contribute to environmental, economic, and social sustainability. The contribution of this paper is to give a detailed analysis of the synergistic relationship between human-centricity and sustainable development. The findings show that human-machine collaboration, focused on human well-being, directly optimizes resource consumption and energy management (environmental sustainability); productivity and innovation through creativity (economic sustainability); and inclusive, safe, and ethical workplaces (social sustainability). For decision-makers, especially as regards the European Commission, the findings provide empirical arguments for the "Green deal" and Industry 5.0 agenda. The research implies that sustainability targets cannot be achieved by technological upgrades alone but require a workforce that is enabled by human-centric design. Furthermore, for the Community of Practice on Industry 5.0 (CoP I5.0), this study provides a validated framework for best practices showing that the "human" pillar is the vital driver for the "sustainability" pillar, changing the paradigm from trade-off to mutual reinforcement.

Keywords: Human-centric approach; sustainability; Industry 5.0; community of practice CoP I5.0; environmental sustainability; social sustainability; economic sustainability.

1. INTRODUCTION

Industry 5.0 is supported by three core conceptual pillars, by human-centric approach, sustainability, and resilience. For the development of Industry 5.0, it is necessary to advance all three concepts. However, it is not yet clear whether the development of one of the main pillars, the human-centric approach, contributes to the advancement of another important pillar, sustainability. This research is focused on uncovering that impact. In this regard, it will examine whether and how the human-centric approach influences the development of environmental, social, and economic sustainability.

The human-centric approach, according to Industry 5.0 is a methodology that puts the human capabilities, needs, and well-being at the center of the design, development, and implementation of technologies and industrial processes. This orientation makes intuitive interaction between people,

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machines, intelligent systems, and the working environment possible, aiming at maximum efficiency and safety - and at the same time in line with ethical principles and social values.

Globally observed, sustainability in the concept of Industry 5.0 is the integration of ecological, economic and social aspects into the development of technologies and industrial processes. The aim is to achieve long-term preservation of resources, reduction of negative environmental impacts and support for communities, whilst at the same time balancing production and innovation with responsible management of the planet.

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

Environmental sustainability is the responsible and long-term management of natural resources, reduction of ecological footprint, minimization of pollution by industrial and social practices so as to achieve the ecological balance, preservation of biodiversity, and the reduction of harmful emissions to meet the needs of present and future generations without degradation of the ecosystems.

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

The human-centric approach enables an active role of people in the optimization and implementation of environmentally responsible processes, thereby ensuring interaction between humans and technology that results in the reduction of the negative impact of industry on the environment. The following are key indicators illustrating in which segments and how the human-centric approach contributes to environmental sustainability (Figure 1).

2.1.1. Optimization of Resource Consumption Through Human–Machine Interaction

The human-centric approach facilitates improved resource control within smart production systems through the ability of humans and machines to make decisions jointly in real time, and based on sensor and other context information. To illustrate, a worker is the key element of the human-centric cyber-physical production system (CPPS), and it provides a reliable channel of managing the consumption of raw materials and minimization of waste [1].

2.1.2. Precise Energy Management Through Adaptive Systems

When adaptive systems are developed to consider the user behavior and their needs, then there is an improved energy efficiency. The human-centric design of buildings allows controlling lighting, heating, and ventilation to the real user habits, which minimizes the unnecessary use of energy [2].

2.1.3. Intelligent Logistics and Reduction of CO_2 Emissions Through Human Decision-Making

Human intuition combined with artificial intelligence in logistics decision-making allows optimizing the routes in transport, minimizing empty trips, and decreasing carbon dioxide emissions. Decision-making based on human-centric approaches is more efficient and, at the same time, environmentally responsible [3].

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2.1.4. Circular Economy and Recycling Through Human–Machine Collaboration

Engaging people in the design and oversight of the recycling operations in the industry, in conjunction with the automated systems, allows conducting more efficient separation and processing of materials. This kind of flexible collaboration is possible with the help of human-centric CPPS models that help to bridge the production cycle [1].

2.1.5. Improvement of Air Quality Through Active Worker Monitoring

In intelligent industrial systems that engage the workers actively in the process of monitoring and reporting on air pollution-related problems, one can act in a timely manner and minimize exposures to dangerous gases. Such human-centric surveillance helps to maintain the health and environmental levels [4].

2.1.6. Design of Ecological Products Through Collaboration Between Engineers and AI Systems

Human ingenuity and compassion combined with the computing abilities of the AI systems allow creating products that are both practical and attractive and eco-friendly. A design approach that includes end users and craftsmen, makes products of a lower ecological footprint [5].

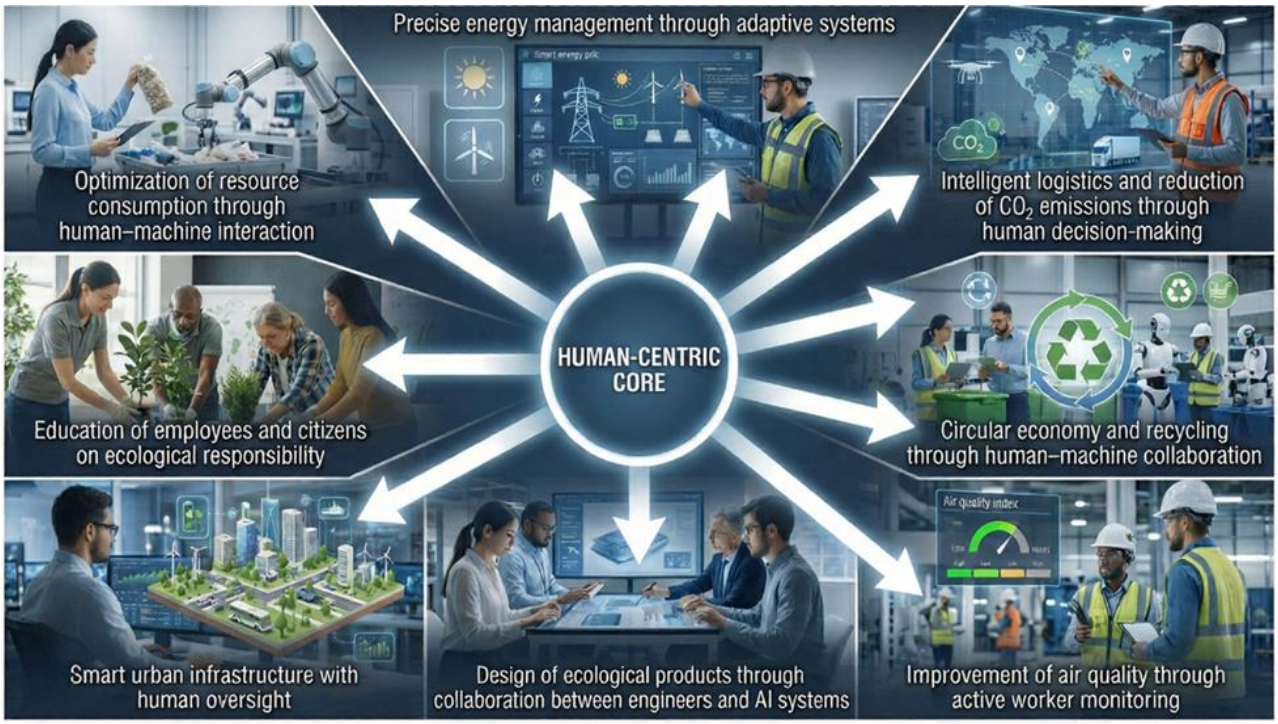

Figure 1. Main segments in which the human‑centric approach contributes to environmental sustainability (figure created using a digital graphic tool to illustrate conceptual relationships).

2.1.7. Smart Urban Infrastructure With Human Oversight

Smart cities with human-focused design consider spacing patterns, movement, and needs of citizens, thus finding sustainable solutions to their issues (irrigation system, light, and traffic management)

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more easily. The infrastructure is adjusted to live conditions and minimizes ecological footprint with the assistance of human perception and feedback [6].

2.1.8. Education of Employees and Citizens on Ecological Responsibility

The most important conditions with regard to environmental preservation are human consciousness and human behavior. The changes in behavior of citizens and employees can be facilitated by education via human-centric means, i.e. by concentrating on the understanding, motivation, and emotional closeness to nature [7].

3. CONTRIBUTION OF THE HUMAN-CENTRIC APPROACH TO ECONOMIC SUSTAINABILITY

Economic sustainability can be explained as the establishment of long-term, stable and equitable economic systems that can be extended into their growth, innovation and profitability without compromising equitable access and allocation of resources as well as social security, and environmental responsibility - without harming the natural or human resources.

3.1. Segments in Which the Human-Centric Approach Contributes to Economic Sustainability

The human-centric approach allows optimizing the models of economic processes as human and technology are directly interacting, thus enhancing efficiency, innovation, and profitability, and at the same time, maintaining market stability and equitable distribution of economic benefits. The following are key indicators illustrating in which segments and how the human-centric approach contributes to economic sustainability (Figure 2).

3.1.1. Increasing Productivity Through Human–Machine Collaboration

Human-centered Industry 5.0 focuses on the interaction between human beings and machines, where human beings are focused on creativity and critical thinking, and machines are focused on routine and analytical duties. Such partnership results in increased productivity and more robust production courses [3].

3.1.2. Cost Optimization Through AI Analytics

Human-centric principles incorporated in data management allow the AI analytics to be human-oriented in their application to human needs and decision making. This saves the needless expenses and enhances the business performance since systems are more transparent and accessible to the workforce [8].

3.1.3. Sustainable Employment and Human Capital Development

Human-centric approach implies the creation of individual training courses and ongoing training of employees to reinforce the human capital and guarantee the stable pool of qualified employees to be used in the long-term prospective [9].

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3.1.4. Supply Chain Stability Through Transparency and Digitalization

Digitalization and the utilization of digital tools to collect data in real-time, analyze it and exchange information make a stable and transparent supply chain possible. Digitalization of the supply chain in terms of sustainability is also empirically proven - companies that systematize digital solutions not only have better environmental and social sustainability outcomes but also better risk management, therefore, having a direct impact on providing the economy with the sustainable background of its work [10]. Through the integration of digital technologies with a human approach, they will have more transparency in the supply chain, whereby crisis incidence and response can be faster, thereby minimizing the business crippling.

3.1.5. Increasing Innovation Through Human-Centric Product Design

Through the human-centric design that engages users and employees during the product development process, the companies promote innovations that are more responsive to the needs of the market and thus create economic benefits over the long-term [5].

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

3.1.6. Increasing Energy Efficiency and Reducing Operational Costs

Having the human factor as a part of energy management by human-centric solutions, organizations use energy more efficiently and spend less, which will directly ensure economic sustainability [2].

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3.1.7. Smart Economy Through Flexible Work Models

The flexibility of work models [11], including remote work and hybrid systems allow taking a human-centric approach, finding a balance between productivity and employee satisfaction, increasing economic resilience and decreasing turnover rates.

3.1.8. Expanding Market Access Through Digitalization and E-Commerce

Human-centric digital economy opens up access of digital platforms to a highly diverse user base, which creates new markets and opportunities to small and medium enterprises [12].

3.1.9. Reducing Economic Inequality Through Fair Wages and Benefits

The human-centric economy implies the re-definition of priorities in terms of equal distribution of incomes and social protection, which reduces the level of economic inequality and enhances the stability of society [13].

4. CONTRIBUTION OF THE HUMAN-CENTRIC APPROACH TO SOCIAL SUSTAINABILITY

4.1. Definition of Social Sustainability

Social sustainability involves the production of just, open and secure social and working conditions, where everyone is given equal chances, able to access education and even safety of working conditions, and where industrial and social systems allow communities to prosper economically, culturally and health-wise over a long period of time.

4.2. Segments in Which the Human-Centric Approach Contributes to Social Sustainability

The human-centred approach allows people to become active participants in the development of socially responsible industrial and economic mechanisms and will, therefore, ensure a fairer and more cohesive society concerning the dialogue between people and technology. These are the major indicators that show how and in which segments the human-centric approach leads to social sustainability (Figure 3).

4.2.1. Creating Inclusive Workplaces Through Ergonomic and Technological Support

The human-centric production models have made the worker central to the production process and this has allowed the design of the factories to consider both age, disability or experience constraints. These will help to promote inclusivity and the improvement of the working capacities of employees, which directly enhances social sustainability [14].

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4.2.2. Improving Worker Safety Through Interactive Monitoring Systems

With the help of human-oriented cyber-physical production systems (CPPS), the interaction technologies of working conditions monitoring can be integrated, which increases the safety of workers and minimizes the risk of injuries [1].

4.2.3. Enhancing Mental Health Through Humanized Work Processes

The industrialization of factories as human-centric working conditions decreases the burden of the historically mechanical and task-oriented work models, which leads to a decrease in stress and a rise in the welfare of the employees [15].

4.2.4. Transparency in Decision-Making and Ethical Working Conditions

Human-centric governance in AI and digital systems implies openness and involvement of employees in decision-making, compliance with ethical principles, and reinforcement in the levels of trust in organizations [8].

4.2.5. Improving Quality of Life Through Flexible Work Models

Future workplaces in the human-focused factories are gradually moving towards the models that give the workers the autonomy and flexibility to enhance the work-life balance [15].

4.2.6. Encouraging Employee Education and Professional Development

Human-oriented, human capital development through life-long learning and professional development is identified as one of the important factors towards the long-term social sustainability and prosperity of the society [16].

4.2.7. Economic Security Through Fair Wages and Stable Working Conditions

The idea of human-centric economy [13] means that human-centric aspects, including fair wages and consistent working environments, are the key determinants of sustainability since they guarantee long-term sustainability and equality within society.

4.2.8. Creating Ethical and Responsible Business Practices Through Social Dialogue

The social values and economic goals are integrated in human-centric business models allowing the companies to do both good and well at the same time [17], which supports the social sustainability and the trust of the community.

4.2.9. Empowering Women and Minority Groups in Industry

The process of empowering women and minority groups in labor market and industry is needed to create an inclusive dynamic and sustainable society [18]. The human-centric approach involves

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formulation of equality policies, equal access to employment, professional growth, advancement, and professional positions and affirmative action to reduce the impact of multiple discrimination.

4.2.10. Employee Engagement in Socially Responsible Projects

Agile thought, human-centric mindset, and corporate social responsibility stimulate the employee involvement in the projects that create social value, thus strengthening the social sustainability in the long term [19].

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

5. CONCLUSION

The transition to Industry 5.0 requires a holistic combination of the three main pillars of the concept, i.e. the human-centric approach, sustainability and resilience. This study concentrated on the key crossroads of the first two pillars, and it was found that the human-centric approach is not only a parallel aim but an important driver to attaining sustainability.

In terms of environmental sustainability, the research finds that the active use of human intuition and active monitoring in cyber-physical systems is an effective way of optimizing resource use and minimizing the ecological footprint. Responsive systems that respond to the user behaviour lead to correct energy management, which proves that ecological responsibility is inherently linked to the human-system interaction.

Regarding economic sustainability, the analysis supports the fact that the focus on human abilities, including creativity and critical thinking, instead of mechanical work, leads to higher productivity and innovativeness. The human-centric approach ensures the long-term economic stability and

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cost-efficiency through stable supply chains, transparency and the development of flexible working models.

Lastly, the contribution to social sustainability is, perhaps, the most direct. The human-centric model is transforming the industrial world into an inclusive and safe world, with the introduction of ergonomic support and ethical governance. Industry 5.0 ensures the welfare of the community and the stability of society by empowering the workforce through education, fair wages, and minimized inequality.

To sum up, the progress of sustainability is preconditioned by the development of the human-centric approach. To make Industry 5.0 successful, the technology should be human-centered, which further inherently puts the industrial processes in line with the larger objectives of planetary conservation and social justice.

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