applied sciences

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Empowering Industry 5.0: A Multicriteria Framework for Energy Sustainability in Industrial Companies

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Abstract

Industry 5.0 introduces a transformative vision for manufacturing by emphasizing human-centricity, sustainability, and resilience in tandem with advanced technologies. While Industry 4.0 focused on automation and connectivity, Industry 5.0 shifts the paradigm toward enhancing human involvement, environmental responsibility, and adaptive capacity. Despite growing interest, there remains a lack of standardized metrics for evaluating Industry 5.0 implementation within companies. This paper proposes a comprehensive multicriteria evaluation framework to assess a company's alignment with Industry 5.0 principles across ten key criteria from the human-centricity, sustainability and resilience sectors. A structured scoring system—ranging from A (full alignment) to E (no alignment)—was developed to quantify implementation maturity. The framework was applied to a medium-sized Lithuanian manufacturing company specializing in furniture components, providing a real-world case study to validate the method. The company received a low Industry 5.0 score, indicating poor alignment; however, targeted recommendations were proposed that could improve the score by nearly 70%, moving the company toward a well-aligned status. This study offers a practical tool for evaluating and guiding Industry 5.0 transitions in manufacturing contexts.

Keywords: Industry 5.0; multicriteria evaluation; energy sustainability; human-centricity; resilience; industrial companies

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Academic Editor: Mirco Peron

Received: 23 July 2025
Revised: 15 August 2025
Accepted: 18 August 2025
Published: 20 August 2025

Citation: Skėrė, S.; Bastida-Molina, P.; Skėrys, P.; Molina-Palomares, P. Empowering Industry 5.0: A Multicriteria Framework for Energy Sustainability in Industrial Companies. *Appl. Sci.* **2025**, *15*, 9170. https://doi.org/10.3390/app15169170

1. Introduction

The Industrial Revolutions have continually reshaped manufacturing and society, with Industry 4.0 and Industry 5.0 representing the latest phases. On the one hand, Industry 4.0 focuses on integrating automation, data exchange, and advanced manufacturing technologies. Key components include cyber-physical systems, the Internet of Things (IoT), big data, and cloud computing. The primary goal is to enhance efficiency, flexibility, and productivity by enabling machines to communicate and make decisions autonomously. This revolution emphasizes smart factories where interconnected machines optimize production processes, leading to significant improvements in manufacturing performance and responsiveness to market demands [1]. On the other hand, Industry 5.0 represents a shift towards the synergy between humans and machines. It emphasizes the role of human intelligence, creativity, and decision-making, alongside advanced robotics and artificial intelligence [2].

Unlike Industry 4.0′s focus on automation and efficiency, Industry 5.0 aims to create more personalized and human-centered production environments. It strives for sustainability, adaptability, and the well-being of workers. This approach highlights the importance of collaborative robots (cobots) that assist human workers rather than replace them, fostering an environment where human creativity can thrive [2].

One of the significant challenges with Industry 5.0 is the lack of established metrics to evaluate a company's level of implementation. While Industry 4.0′s progress can be quantified through technological adoption and data integration metrics, Industry 5.0 involves qualitative aspects that are harder to measure [3]. Factors such as the level of human–machine collaboration, the degree of personalization in production, and the impact on worker satisfaction and well-being are more subjective and complex to quantify.

Various studies have attempted to define and evaluate the emerging principles of Industry 5.0 with varying degrees of success. Rajkumar et al. [3] explored human-centric manufacturing and proposed a conceptual framework for sustainability and well-being but stopped short of offering practical evaluation metrics. Romero et al. [4] introduced the "Operator 4.0" typology as a way to frame the evolving human role in industrial systems; however, their work remains largely theoretical. Ghislieri et al. [5] addressed the psychosocial dimensions of Industry 4.0 and 5.0, proposing that worker well-being and organizational adaptation are critical but difficult to quantify using conventional performance metrics. Oztemel and Gursev [6], in a comprehensive review of Industry 4.0 technologies, emphasized the technological baseline needed for a transition to Industry 5.0, but acknowledged that existing frameworks rarely account for human factors. Gorecky et al. [7] examined human–machine interaction in smart factories, presenting qualitative findings without translating them into standardized assessment tools. Nahavandi et al. [8] proposed a human-centric design approach, involving sensory systems and artificial intelligence (AI), but focused more on system architecture than measurable implementation criteria. Javaid and Haleem [9] discussed readiness frameworks for Industry 5.0 and their application in crisis contexts like COVID-19, though their indicators primarily reflect technological—not social—dimensions.

Beyond high-level positioning, prior approaches show three recurrent limitations. First, typologies such as Operator 4.0 and readiness indices prioritize technological adoption and seldom operationalize human-centric constructs (e.g., ergonomics, personalization) into auditable indicators with explicit scoring rules [4]. Second, studies that foreground worker well-being or psychosocial factors typically stop at narrative guidance and do not provide comparable, rubric-based assessment procedures [5,7]. Third, validation in SME contexts is limited; most frameworks do not report transparent evidence-to-score mapping or sensitivity to weighting choices, which reduces transferability. The current literature often proposes conceptual models or sector-specific tools that lack generalizability and practical utility in industry-wide benchmarking. For instance, as described, Rajkumar et al. [3] and Ghislieri et al. [5] focused on conceptual and psychosocial aspects without translating them into measurable indicators. Romero et al. [4] proposed typologies but lacked scoring mechanisms or structured rubrics. In contrast, this study introduces a weighted multicriteria framework with ten defined criteria, a standardized scoring system (A–E), and an overall alignment index, enabling practical and repeatable evaluation across industries. Our framework fully addresses these mentioned gaps by: (i) defining ten auditable criteria spanning human-centricity, sustainability, and resilience; (ii) supplying an A–E rubric with observable descriptors for each criterion; and (iii) demonstrating application in an SME with full score traceability and scenario weighting.

The main idea of this study is to address this research gap and propose a multicriteria methodology to evaluate the achievement of an Industry 5.0 implementation level. Thus, specific criteria for the Industry 5.0 implementation level are presented, together with recommendations on how this level could be improved. This paper was applied to the case study of a real company in Lithuania to test and validate the proposed criteria in a practical, industrial setting. The selected company operates in the manufacturing sector and is actively pursuing Industry 5.0 integration, which allows for meaningful evaluation of human-centered metrics and collaborative processes.

The rest of the paper is organized as follows: Section 2 includes the literature review, Section 3 presents the methodology, Section 4 describes the case study, while Section 5 provides the results and discussion of this application. Finally, the paper conclusions are outlined in Section 6.

2. Literature Review

Industry 5.0 represents the next evolutionary stage of industrial development, characterized by the integration of human creativity and advanced technological systems. While Industry 4.0 emphasized automation, digitalization, and the interconnectivity of cyber-physical systems, Industry 5.0 shifts focus towards a human-centric paradigm [3]. This new phase of industrialization does not seek to displace human labor, but to empower it through synergistic collaboration with technologies such as AI, robotics, and the Internet of Things (IoT) [10,11]. Through this symbiosis, Industry 5.0 enables increased flexibility, mass personalization, and a stronger alignment with societal and environmental values, addressing contemporary demands for bespoke products and sustainable development [12,13]. By reintroducing the human element as central to industrial innovation, this paradigm aims to create production systems that are not only more efficient but also more ethically and socially responsible [14].

The conceptual foundation of Industry 5.0 rests on three interdependent pillars: human-centricity, sustainability, and resilience. These principles are not independent silos but intersecting dimensions that together define the strategic vision of future manufacturing systems.

At the core of Industry 5.0 lies human-centricity, which repositions the worker from a passive participant to an active, creative agent within the production environment. This principle entails designing socio-technical systems that prioritize ergonomics, inclusivity, and user empowerment. Technologies such as collaborative robots (cobots), wearable sensors, and adaptive interfaces are deployed not to substitute labor but to augment human skill, decision-making, and safety. Human-centricity also requires that the work environment be responsive to individual needs, fostering employee engagement, motivation, and long-term well-being [15,16]. Importantly, this shift requires a reconsideration of value creation, moving beyond productivity metrics to include factors such as psychological safety, job satisfaction, and knowledge transfer.

The second fundamental principle is sustainability, which extends beyond environmental stewardship to encompass circular resource flows, energy efficiency, and social equity. Industry 5.0 advocates the transition from linear "take-make-dispose" models toward regenerative industrial ecosystems that emphasize renewable energy integration, closed-loop supply chains, and eco-design. This transition is not only ethical but strategic, as it mitigates risks related to regulatory pressure, supply scarcity, and climate volatility [17,18]. Moreover, sustainable production processes are increasingly seen as competitive differentiators, with consumers and stakeholders demanding greater transparency and accountability in corporate practices. The alignment of digital innovation with green technologies is thus a core enabler of both environmental resilience and economic viability in the Industry 5.0 context [19].

The third foundational principle is resilience, which is understood as the capacity of industrial systems to anticipate, absorb, and adapt to disruptions—whether economic, environmental, or technological in nature. The COVID-19 pandemic, geopolitical tensions, and cyber-threats have underscored the vulnerability of global supply chains and the need for structural robustness. Industry 5.0 responds to this challenge through the deployment of smart and modular production systems, predictive analytics, and digital twins that simulate contingencies in real time. Resilience also entails organizational agility: fostering a culture of continuous learning, innovation, and redundancy to navigate uncertainty and ensure continuity of operations [20,21]. By embedding resilience into the fabric of industrial planning and execution, organizations can safeguard long-term sustainability and stakeholder trust.

Each of these three principles is operationalized through a set of measurable factors, as detailed in Table 1. These factors represent the key enablers that companies must adopt to successfully transition toward Industry 5.0 maturity.

Table 1. Factors of Industry 5.0 in companies.

Dim.	Criteria	Metrics	Ref.
Human-Centricity	User Experience	Prioritizing the needs, behaviors, and limitations of users to ensure products, services, or systems are intuitive and user-friendly.	[22]
	Inclusivity	Ensuring that design, functionality, and accessibility are tailored to cater to a diverse range of users, including those with disabilities or special needs.	[23]
	Safety and Well-being	Designing with a focus on minimizing risks, promoting health, and ensuring the physical and psychological well-being of individuals interacting with the system or product.	[24]
	Enhanced User Interfaces	Advanced interfaces such as augmented reality and virtual reality improve human–machine interaction, making complex processes more intuitive and accessible.	[25]
	Skill Development and Training	Continuous education and upskilling programs ensure that workers are adept at using new technologies, fostering a culture of lifelong learning.	[26]
	Ergonomic Design	Designing workplaces and tools that reduce physical strain and improve comfort, contributing to overall worker well-being.	[27]
	Personalized Workflows	Tailoring work processes to individual preferences and strengths, increasing job satisfaction and efficiency.	[28]
Sustainability	Sustainable Energy Integration	Utilizing solar photovoltaic, wind, and other renewable energy sources to power industrial operations, reducing reliance on fossil fuels.	[29]
	Resource Efficiency	Implementing techniques such as lean manufacturing and circular economy principles to minimize waste and optimize resource use.	[30]
	Eco-Friendly Materials	Developing and using sustainable materials that have a lower environmental impact throughout their lifecycle.	[31]
	Energy Management Systems	Advanced systems to monitor and manage energy consumption, improving efficiency and reducing carbon footprints.	[32]
	Sustainable Supply Chains	Ensuring that every step in the supply chain, from raw materials to finished products, adheres to sustainability standards.	[33]
Resilience	Redundancy	Building in additional capacity or backup systems to ensure continuous operation even if certain components fail or are compromised.	[34]
	Flexible Manufacturing Systems	Deploying modular and adaptable manufacturing setups that can quickly respond to changes in demand or disruptions.	[35]
	Predictive Maintenance	Using IoT and AI to predict equipment failures before they occur, minimizing downtime and extending machinery life.	[36]
	Digital Twins	Creating virtual models of physical assets to simulate and optimize performance, allowing for proactive management and quick problem resolution.	[37]
	Robust Supply Chain Management	Diversifying suppliers and utilizing advanced logistics technologies to ensure supply chain continuity during disruptions.	[38]
	Crisis Management Strategies	Developing comprehensive plans for various potential crises, including pandemics, natural disasters, and cyber-attacks, to ensure rapid and effective responses.	[39]

While ESG reporting frameworks such as GRI or ISO 26000 [40] address sustainability and social responsibility, they often lack specific guidance for operationalizing human–machine collaboration or ergonomic workflow design. Our model complements such frameworks by offering a structured scoring system tailored to industrial contexts, enabling better alignment between strategic ESG goals and day-to-day manufacturing practices.

3. Methodology

To assess a company's alignment with Industry 5.0 principles, this study employed a mixed methods approach, combining the literature review and the multicriteria-weighted evaluation. The methodology consists of two core phases: (1) extraction of key evaluation factors from academic literature and policy reports, and (2) development of a structured evaluation model based on multicriteria scoring, considering 3 weighted dimensions (human-centricity, sustainability and resilience). Ten distinct criteria were grouped under the dimensions of human-centricity, sustainability and resilience. Each criterion was assigned qualitative performance descriptors. The final Industry 5.0 alignment score was calculated as a weighted sum of all criteria, offering a comprehensive snapshot of the company's current positioning and improvement potential. The overall methodology can be seen in Figure 1.

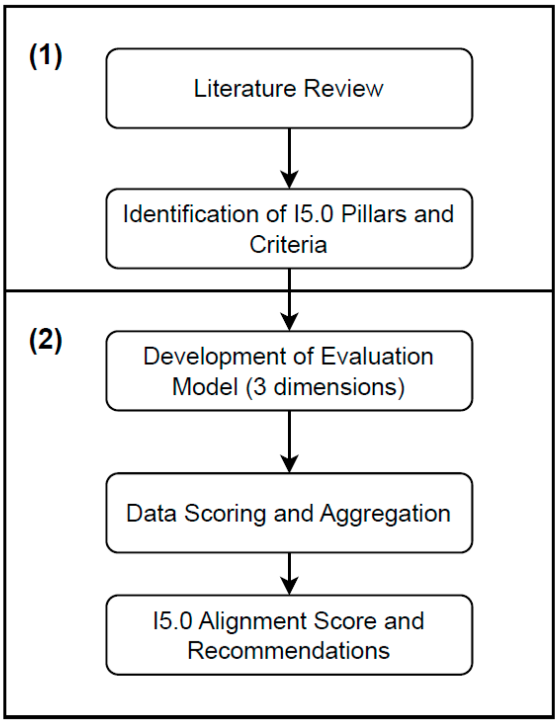

Figure 1. Methodology workflow.

3.1. Selection of Industry 5.0 Criteria

This subsection briefly refines the Industry 5.0 evaluation model and selected criteria. After a deep literature review, the authors realized that the main criteria to evaluate the dimensions of Industry 5.0 inclusion in companies do not exactly match those initially presented in Table 1. These initial criteria were filtered according to their relevance for evaluating each dimension (human-centricity, sustainability and resilience) and their significance appearance in previous studies. Thus, criteria with a low range of appearance were discarded.

Table 2 aligns directly with the core pillars outlined in the literature review: human-centricity, sustainability, and resilience. Each factor is associated with measurable indicators. This structure enables a standardized, objective assessment of a company's alignment with Industry 5.0, ensuring consistency across the model and empirical application.

Table 2. Evaluation of company regarding Industry 5.0.

Dimensions	Criteria	Abbreviation
Human-Centricity	Safety and Well-being Skill Development and Training Personalized Workflows and Ergonomic Design	SW SDT PWED
Sustainability	Sustainable Energy Integration Sustainable Supply Chains Resource Efficiency and Energy Management Systems	SEI SSC REEMS
Resilience	Crisis Management Strategies Robust Supply Chain Management Flexible Manufacturing Systems Predictive Maintenance and Digital Twins	CMS RSCM FMS PMDT

3.2. Multicriteria Evaluation

To objectively assess a company's alignment with Industry 5.0 principles, a structured multicriteria evaluation framework was developed. This framework provides a quantitative and reproducible method for translating qualitative organizational characteristics into standardized performance metrics.

The evaluation is built upon the three core criteria of Industry 5.0—human-centricity, sustainability, and resilience—as previously outlined. Each of these pillars comprises several factors, each measurable through practical indicators. To facilitate consistent interpretation across different companies and contexts, each factor is evaluated using a five-level rubric that converts qualitative judgments into percentage scores. The five levels are labeled as A, B, C, D, and E, corresponding, respectively, to scores of 100%, 75%, 50%, 25%, and 0%. This approach ensures flexibility while preserving comparability across industries.

Table 3 summarizes the rubric design proposed for the assessment. Each performance level is described in terms of observable criteria, allowing evaluators to assign a score that accurately reflects the maturity of implementation for each factor. These scores are then aggregated within each dimension (human-centricity, sustainability, resilience), providing both individual criterion scores and a global Industry 5.0 alignment score.

Table 3. Industry 5.0 Scoring Framework: A–E Evaluation Rubric.

Dim.	Criteria	Level of Achievement				
		A (100%)	B (75%)	C (50%)	D (25%)	E (0%)
Hu-man-Centricity	Safety and Well-being	Comprehensive well-being program, verified through employee feedback surveys and third-party safety audits; zero-incident safety culture.	Well-being initiatives in place with partial implementation; some feedback gathered, safety reporting culture present.	Basic safety policies exist but implementation is inconsistent; no formal feedback or follow-up mechanisms.	Minimal compliance with basic safety rules; no well-being metrics or monitoring processes in place.	Unsafe environment with repeated incidents; no programs, no feedback, no corrective action protocols.
	Skill Development and Training	Comprehensive upskilling programs with documented learning outcomes; regular assessments and tracked employee certifications.	Structured training plans with partial coverage across departments; training logs and participation records maintained.	Occasional training sessions; minimal record-keeping or alignment with company goals.	Basic onboarding only; no ongoing learning initiatives or structured content.	No formal training, development plans, or resources available to staff.
	Personalized Workflows and Ergonomic Design	Highly adaptive workstations with real-time adjustments to individual ergonomics and task preferences; supported by data.	Adjustable equipment and workflow customization available for some roles; employee input partially integrated.	Basic ergonomic practices in place; some flexibility, but not personalized or monitored regularly.	Standardized workflows dominate; few ergonomic considerations; some discomfort or inefficiencies reported.	Rigid, non-adjustable workflows and workstations; no ergonomics applied or measured.

Table 3. *Cont.*

Dim.	Criteria	Level of Achievement				
		A (100%)	B (75%)	C (50%)	D (25%)	E (0%)
Sustainability	Sustainable Energy Integration	Over 75% of energy from renewables with strong CO_2 emissions reduction; includes energy storage or grid feedback.	50–75% renewable usage and moderate emission reduction; backed by energy tracking data.	25–50% renewable contribution and limited emissions improvements; tracking systems partially implemented.	10–25% renewable usage; reliance on grid remains high; monitoring is manual or inconsistent.	No renewable energy usage or emissions monitoring in place.
	Sustainable Supply Chains	Full supply chain mapped and verified for sustainability; circular economy principles and closed-loop logistics applied.	Major suppliers comply with sustainability standards; monitoring and supplier audits are ongoing.	Some sustainability clauses in contracts; supplier assessments not fully implemented.	Minimal sustainability screening in procurement; no follow-up or data collection.	No sustainability criteria applied in supplier selection or supply chain management.
	Resource Efficiency and Energy Management Systems	Fully implemented lean and circular economy practices; real-time energy monitoring and zero-waste goals tracked.	Lean manufacturing adopted; advanced energy tracking used in key areas; partial waste reduction targets.	Basic lean techniques applied; energy data collected manually or irregularly.	Limited application of efficient methods; energy use is inefficient and untracked.	No resource efficiency strategies or energy monitoring in place.
Resilience	Crisis Management Strategies	Tested, multi-scenario crisis response plans including cybersecurity, supply, and health events; employee drills performed.	Response plans exist and are updated periodically; limited simulations performed.	Plans are written but outdated or untested; staff unaware of procedures.	Risk awareness exists, but plans are incomplete, and response is improvised.	No documented crisis plans or response capabilities.
	Robust Supply Chain Management	Digitally monitored, diversified, and redundant supplier network; real-time logistics visibility and contingency plans in place.	Supplier diversification present; some use of digital tracking; performance metrics reviewed.	Basic monitoring tools used; no redundancy or resilience-focused strategy.	Single-source dependencies common; issues resolved only reactively.	No resilience measures in supply chain; high risk of disruption.
	Flexible Manufacturing Systems	Fully modular and rapidly reconfigurable production lines; machine settings and sequences adapted on-demand.	Partial reconfigurability in core systems; upgrades possible with short downtime.	Minor flexibility; most changes require manual adjustments and scheduling.	Production is rigid with only basic batch variability.	Fixed setup; no adaptation possible without full retooling.
	Predictive Maintenance and Digital Twins	Integrated DT system with predictive analytics; downtime virtually eliminated through AI-driven interventions.	Predictive tools cover key equipment; real-time alerts in place; manual interventions still needed.	Early-stage predictive analytics applied; data collected but not fully leveraged.	Only preventive maintenance plans used; limited predictive capabilities.	Maintenance is reactive only; no digital tools or predictive planning.

This multicriteria method offers a holistic yet actionable lens for companies to understand their Industry 5.0 readiness. It supports organizations not only in measuring their current standing but also in tracking progress over time as they implement improvements aligned with human-centric, sustainable, and resilient manufacturing practices.

Data for each criterion was collected through a combination of (i) direct observation of operations, (ii) structured interviews with responsible department managers, (iii) analysis of internal energy consumption and procurement records, and (iv) employee questionnaires assessing safety, ergonomics, and training availability. Each criterion score was determined by each author applying the A–E rubric in Table 3, with discrepancies resolved through consensus. Quantitative measures were directly mapped to rubric levels where possible, while qualitative aspects were scored based on documented evidence and staff feedback.

After analyzing these criteria, sustainable energy integration arises as a combined criterion of the Renewable Generation degree (ReG) and CO_2 emissions reduction due to energy (EmR) [41].

On the one hand, EmR determines the reduction in CO_2 emissions when incorporating renewable sources in the generation system of the company, as Equation (1) describes:

$$EmR = \frac{\left[E_{grid} \cdot g_{grid}\right] - \left[E_{ren+grid} \cdot g_{ren+grid}\right]}{E_{grid} \cdot g_{grid}}. \quad (1)$$

where E_{grid} and g_{grid} represent the electricity generated exclusively from the grid and its emissivity. On the other hand, $E_{ren+grid}$ and $g_{ren+grid}$ represent the electricity generated from a renewable system supported by the grid and its emissivity. This last parameter, $g_{ren+grid}$, is in turn obtained as Equation (2) indicates:

$$g_{ren+grid} = \frac{E_{grid}}{E_{ren+grid}} \cdot g_{grid} + \frac{E_{ren}}{E_{ren+grid}} \cdot g_{ren}. \quad (2)$$

Moreover, ReG indicates the contribution of renewable resources to the total electricity consumption. It considers not only the direct contribution of renewable systems, but also the renewable percentage of the electricity consumed from the grid, as Equation (3) represents:

$$ReG = \frac{E_{ren} + x_r \cdot E_{grid}}{E_{PV+grid}}. \quad (3)$$

being x_r the renewable contribution of the electricity taken from the grid.

Sustainable Energy Integration criteria (SE) are finally obtained as a weighted combination of the previous factors, as Equation (4) indicates:

$$\text{SE} = \beta_{EmR} \cdot EmR + \beta_{ReG} \cdot ReG. \quad (4)$$

being β_{EmR} and β_{ReG} the weighting factors for EmR and ReG, respectively.

3.3. Industry 5.0 Alignment

Finally, a weighted multicriteria evaluation is proposed, to assess the global alignment of the company in question with Industry 5.0.

$$I_{5.0} = \alpha_{SW} \cdot SW + \alpha_{SDT} \cdot SDT + \alpha_{PWED} \cdot PWED + \alpha_{SEI} \cdot SEI + \alpha_{SSC} \cdot SSC + \alpha_{REEMS} \cdot REEMS + \alpha_{CMS} \cdot CMS + \alpha_{RSCM} \cdot RSCM + \alpha_{FMS} \cdot FMS + \alpha_{PMDT} \cdot PMDT \quad (5)$$

being the different weighting coefficients presented in Table 4.

Table 4. Weighting coefficients.

Dimensions	Coefficient	Description
Human-Centricity	α_{SW}	Weighting coefficient for Safety and Well-being
	α_{SDT}	Weighting coefficient for Skill Development and Training
	α_{PWED}	Weighting coefficient for Personalized Workflows and Ergonomic Design
Sustainability	α_{SEI}	Weighting coefficient for Sustainable Energy Integration
	α_{SSC}	Weighting coefficient for Sustainable Supply Chains
	α_{REEMS}	Weighting coefficient for Resource Efficiency and Energy Management Systems
Resilience	α_{CMS}	Weighting coefficient for Crisis Management Strategies
	α_{RSCM}	Weighting coefficient for Robust Supply Chain Management
	α_{FMS}	Weighting coefficient for Flexible Manufacturing Systems
	α_{PMDT}	Weighting coefficient for Predictive Maintenance and Digital Twins

The summation of all alpha weighs should be 100% at the most. With these alpha factors we can give different weights to the different criteria, and dimensions consequently.

The resulting scores provide a quantitative basis for evaluating the extent to which an organization conforms to Industry 5.0 standards. Table 5 defines five distinct levels of implementation, ranging from minimal to full alignment.

Table 5. Scoring Framework for Assessing Industry 5.0 Implementation.

$I_{5.0}$ Score	Alignment
100–80%	Completely aligned
80–60%	Well aligned
60–40%	Aligned
40–20%	Poorly aligned
20–0%	Not aligned

Unlike the Operator 4.0 typology, which categorizes future human roles without offering an evaluative structure, and the Industry 4.0 Readiness Index [15], which emphasizes technological adoption, our proposed model combines human-centric, sustainable, and resilient dimensions within a unified scoring system. This allows companies to measure qualitative and social aspects—such as well-being or ergonomic design—alongside technological maturity, which most previous frameworks overlook.

4. Case Study

To prove the feasibility of the proposed methodology, it has been applied to a medium-sized Lithuanian manufacturing company employing 64 staff members. The company specializes in the production of furniture components, including metal tube legs, brackets, and structural frames for shelves and tables, maintaining a portfolio of over 500 active product articles tailored to diverse customer specifications. In addition to standard production, the company offers small-batch and individual sample orders, as well as general metal processing services. Given the highly variable and fluctuating nature of its daily production demands, operational flexibility, rapid response, and adaptability are considered critical to its business model. Currently, all equipment maintenance is performed manually by in-house personnel, and the company does not operate any robotic or automated production lines. Thus, the company can be characterized as employee-centered, as it does not utilize automated production lines, robots, or conveyor systems. At present, there are no concrete plans to integrate advanced manufacturing technologies into its operations. It operates in two shifts, five days a week. Observation was performed from March of 2023 to April of 2024.

The company has recently rented Solar PV panels from a group company. This arrangement allows the company to utilize a specified number of solar PV panels to meet a portion of its energy requirements. Although the electricity generated by 6000 kWh of solar PV panels does not completely satisfy the company's total energy consumption, it provides a significant contribution toward offsetting its overall usage. The company has a significant dependence on weather conditions for its energy supply, since it is situated in the northern region of Lithuania. Lithuania has a significantly lower number of sunny days compared to Central European countries, resulting in lower solar power benefits (Figure 2).

The usage of electricity from the grid along the period under study (from May 2023 to April 2024) is given in Figure 3. Figure 4 represents the quantity of consumed electricity that was produced from solar PV panels.

The company sourced the majority of its electricity from the grid, with approximately only 18.4% of its annual electricity derived from solar PV panels. This is because the company has a limited number of solar PV panels installed, due to the available space in the rooftop, and high dependency between sunny hours and generated solar power is a crucial relationship which causes less efficiency in such countries as Lithuania. Figure 5 presents the percentage of generated solar electricity compared with the most efficient month—June—when it was the highest number of generated kWh from solar PV panels

(4850 kWh). In January, only 1016 kWh was generated, and this is a significant difference, showing the turbulence of such power generation in the investigated company.

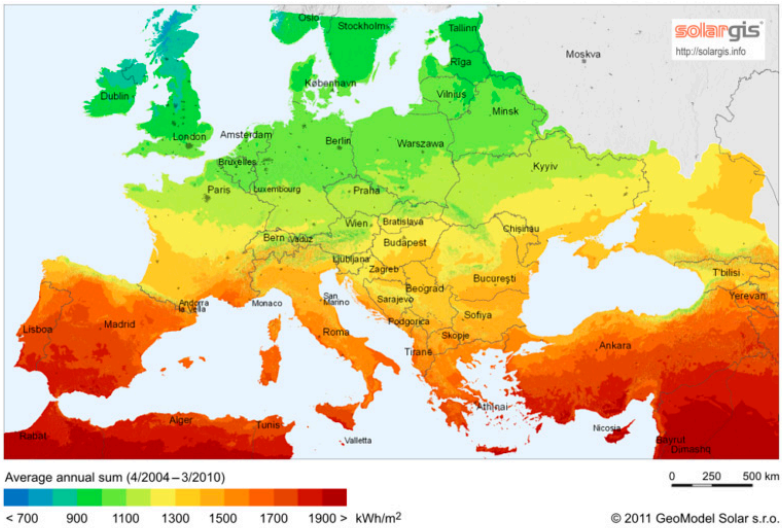

Figure 2. Average annual global horizontal irradiation (kWh/m^2) for Europe; darker shades indicate higher solar resource [42].

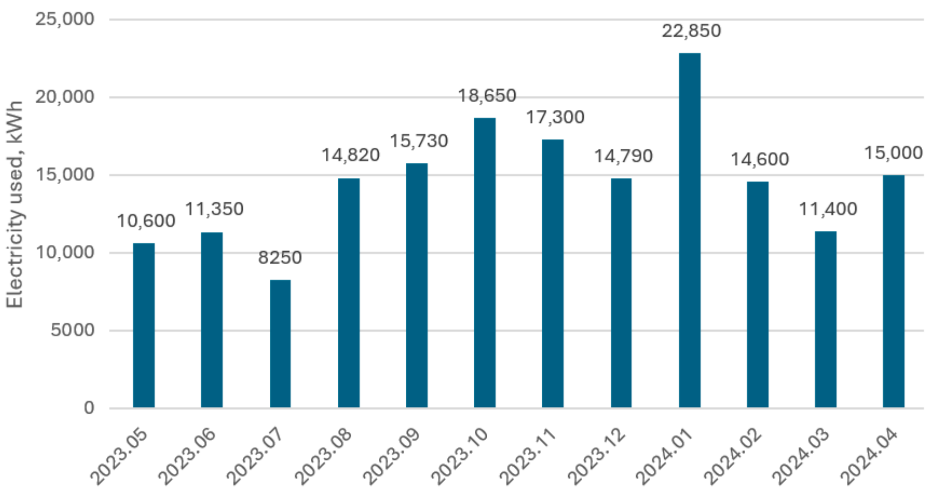

Figure 3. Monthly electricity drawn from the grid (kWh), May 2023–April 2024, case company.

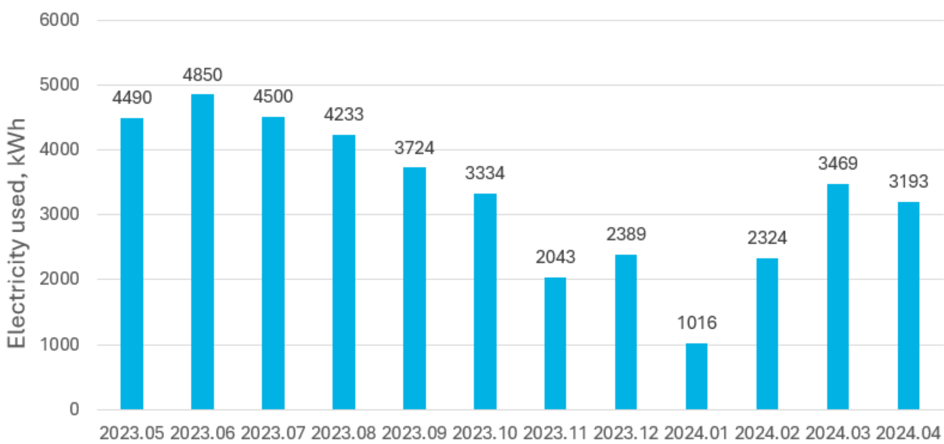

Figure 4. Monthly electricity supplied by PV panels (kWh), May 2023–April 2024, case company.

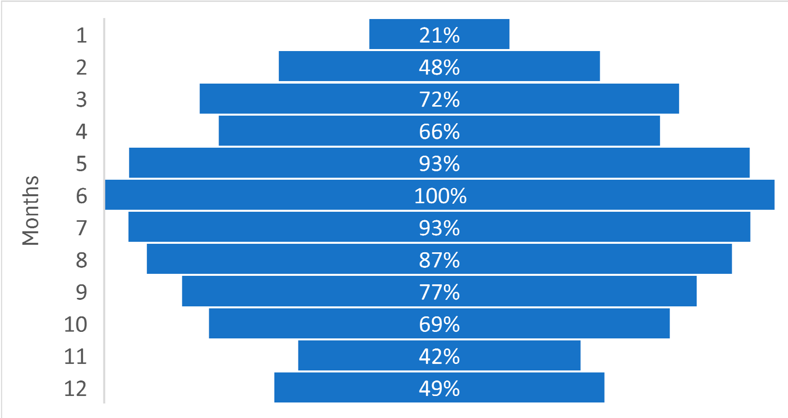

Figure 5. Monthly PV generation as a percentage relative to the peak month (June).

Overall, the data show that solar energy generation is highly seasonal, with summer months—particularly June—reaching peak output (4850 kWh), while winter months like January show minimal contribution (1016 kWh). This variation directly impacts the company's ability to rely on renewable energy consistently.

This unequal distribution can be caused by several factors. Solar power generation depends on the amount of solar irradiance (sunlight intensity) hitting the solar PV panels. Also, the power output of a solar PV panel is directly proportional to the amount of sunlight it receives. With more sunny hours, the panels receive more sunlight, thus generating more electricity. The capacity factor of a solar power system is the ratio of its actual output over a period of time to its potential output if it operated at full capacity all the time. The capacity factor can be improved with a higher number of sunny hours. Lithuania has a significant difference in a day length over the year, so longer days and clearer skies in summer lead to higher power generation compared to shorter, cloudier days in winter. Regions closer to the equator generally receive more consistent and intense sunlight throughout the year. Also, weather conditions such as cloud cover, rain, and snow reduce the number of effective sunny hours, thereby decreasing the amount of generated solar power.

Regarding the Lithuanian electricity grid, in 2024 its emissivity was 139 g CO_2eq/kWh being composed by renewable resources in 77% out of the total [43]. Figure 6 indicates the composition of this electricity grid in 2024.

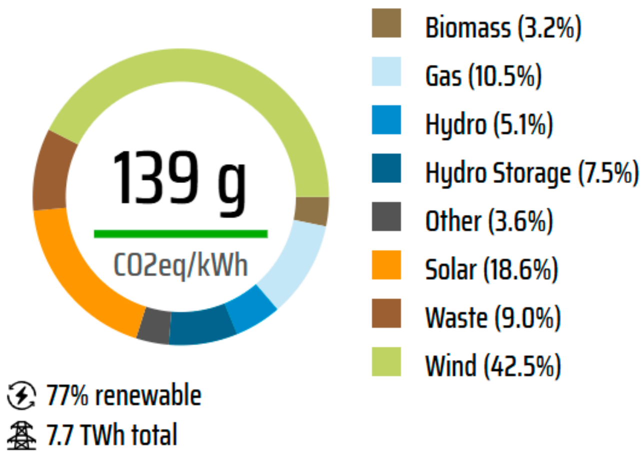

Figure 6. Lithuania 2024 electricity mix and aggregated emissions intensity (gCO_2eq/kWh) [43].

In the case study section, we should also include the weights for the multicriteria assessment coefficients. In this research, authors consider that all parameters have a homogeneous importance over the total. Thus, all coefficients acquire the same value of 10% (Table 6).

Table 6. Value of coefficients.

Dimensions	Coefficient	Value
Human-Centricity	α_{SW}	10%
	α_{SDT}	10%
	α_{PWED}	10%
Sustainability	α_{SEI}	10%
	α_{SSC}	10%
	α_{REEMS}	10%
Resilience	α_{CMS}	10%
	α_{RSCM}	10%
	α_{FMS}	10%
	α_{PMDT}	10%

Moreover, the Sustainable Energy Integration (SEI) criteria are composed of the Emissions Reduction factor (EmR) and the Renewable Energy Generation factor (ReG). Both factors have the same influence on SEI criteria, so their corresponding coefficients acquire a value of 50%, as Table 7 represents.

Table 7. Sustainability—Sustainable Energy Integration value.

Dimension—Criteria	Coefficients	Value
Sustainability—Sustainable Energy Integration	β_{EmR}	50%
	β_{ReG}	50%

5. Results and Discussion

This section presents the outcomes of applying the Industry 5.0 multicriteria evaluation framework to the selected manufacturing company, followed by a critical interpretation of the findings. The results are categorized by the three core pillars—human-centricity, sustainability, and resilience—and highlight the company's current alignment with each dimension. Special emphasis is placed on sustainability due to its central role in this study. Both the quantitative scores and qualitative observations are analyzed to identify strengths, gaps, and areas for improvement. This analysis ultimately informs targeted recommendations for enhancing the company's Industry 5.0 maturity.

5.1. Sustainable Energy Integration Evaluation

As described, the Sustainable Energy Integration criteria were evaluated deeper, taking into account the CO_2 emissions reduction (EmR) and Renewable Generation degree (ReG).

Table 8 represents the EmR results, and Table 9 represents the ReG calculations after including the solar PV system on case study company.

Table 8. EmR calculations by month after including the solar PV system in the case study company.

Date	EmR(%)
05.2023	29.75
06.2023	29.94
07.2023	35.29

Table 8. *Cont.*

Date	*EmR*(%)
08.2023	22.22
09.2023	19.14
10.2023	15.17
11.2023	10.56
12.2023	13.91
01.2024	4.26
02.2024	13.73
03.2024	23.33
04.2024	17.55
Average	**19.57**

Table 9. *ReG* calculations by month after including the solar PV system in the case study company.

Date	*ReG*(%)
05.2023	85.25
06.2023	85.29
07.2023	86.41
08.2023	83.67
09.2023	83.02
10.2023	82.18
11.2023	81.22
12.2023	81.92
01.2024	79.89
02.2024	81.88
03.2024	83.90
04.2024	82.69
Average	**83.11**

Overall, the value of SEI is the average value of the averaged *ReG* and *EmR*. In this case, the SEI results in 51.34% which is rounded down to 50% for later calculations.

5.2. Industry 5.0 Alignment in Case Study Company

The results obtained from the case study offer valuable insights into the current level of Industry 5.0 implementation within the selected company. This subsection interprets the numerical evaluations presented earlier, linking them to the three core dimensions—human-centricity, sustainability, and resilience. The discussion highlights the areas where the company demonstrates strong alignment with Industry 5.0 principles, as well as those requiring further development. Particular attention is given to systemic gaps, organizational limitations, and contextual factors influencing implementation. By reflecting on the company's existing practices and strategic outlook, this section also identifies potential pathways for enhancing readiness and maturity in line with Industry 5.0 objectives. The results are presented below.

5.2.1. Human-Centricity Dimensions of Investigated Company

1. Safety and Well-being score (Score: 50%): Investigated company places moderate emphasis on employee well-being through basic health and wellness programs. The company organizes occasional wellness workshops and has policies that allow flexible working hours. Surveys show employees appreciate the work–life balance but desire more comprehensive benefits, such as mental health support and enhanced parental leave.

2. Skill Development and Training score (Score: 25%): Training hours per employee are low, with an average of 10 h focused on basic skills annually. Certification rates are below industry averages, as the company offers limited programs for advanced skill enhancement, relying on informal mentoring and on-the-job training instead of structured educational initiatives.
3. Personalized Workflows and Ergonomic Design score (Score: 25%): The company relies heavily on manual labor with no use of robots or automated systems. The absence of cobots means tasks are labor-intensive, potentially leading to repetitive strain injuries. Safety incident reports highlight frequent minor accidents, which could be mitigated by introducing semi-automated safety systems and enhancing worker safety training.

5.2.2. Sustainability Dimensions of Investigated Company

4. Sustainable Energy Integration score (Score: 50%): The environmental impact of the company acquires an acceptable level, although it can be improved, as presented later in discussion. Both EmR and ReG have a homogeneous weight over the total SEI criteria (50% each). However, EmR presents a low score (19.57%) compared to ReG (83.11%). The main reason for this lies in the high presence of renewable sources in the Lithuanian electricity system (79%), that for the whole ReG represent 64.5% of the value. Thus, the solar PV currently consumed from the self-consumption installation of the company matches the other 18.6% of the whole ReG. Regarding emissions, only 19.57% of the emissions are reduced when comparing the real supply (grid + solar PV) with a totally grid dependent system, since just 80% of the electricity still comes from the grid.
5. Sustainable Supply Chains score (Score: 75%): The company excels in producing sustainable furniture components, with over 60% of its products made from recycled metals. The company has achieved ISO 14001 [44] certification for its environmental management system and uses lifecycle assessment tools to further reduce its carbon footprint, such as optimizing energy use in its manufacturing processes with sensor lightning and electrical forklifts.
6. Resource Efficiency and Energy Management Systems score (Score: 0%): The company currently has no AI-driven processes. Attempts to explore AI have been limited to preliminary discussions on predictive maintenance for its machinery, with no concrete projects or investment as yet. Consequently, there is no AI-driven revenue or demonstrable success in AI projects.

5.2.3. Resilience Dimensions of Investigated Company

7. Crisis Management Strategies score (Score: 25%): The company's adoption of new technologies is limited, with a market response lag of approximately 6–12 months behind leading competitors. While business continuity plans exist, they are basic and do not fully account for technological disruptions. The company is in the early stages of experimenting with 3D printing for prototyping but lacks a structured innovation pipeline.
8. Robust Supply Chain Management score (Score: 75%): Despite limited technological use, the company effectively manages inventory, experiencing a high turnover rate due to strong demand forecasting. The company has robust relationships with multiple local suppliers, allowing it to quickly recover from supply chain disruptions, which were exemplified during recent raw material shortages, in which it maintained production with minimal delays.

9. Flexible Manufacturing Systems score (Score: 25%): R&D spending is modest and primarily dedicated to improving existing product lines rather than groundbreaking innovations. The company holds a few patents related to metal processing techniques and periodically launches improved variants of existing components rather than entirely new product offerings.
10. Predictive Maintenance and Digital Twins score (Score: 25%): Utilization of IoT technology is minimal, with only a few IoT-enabled sensors used to monitor the machinery temperature. While this provides basic equipment status updates, it falls short of comprehensive data analysis capabilities that could significantly enhance operational efficiency and predictive maintenance strategies.

All the scores mentioned are presented in Table 10.

Table 10. Evaluation of case study company regarding Industry 5.0.

Abbreviation	Score (%)
SW	50
SDT	25
PWED	25
SEI	50
SSC	75
REEMS	0
CMS	25
RSCM	75
FMS	25
PMDT	25

In this study, all criteria were assigned equal weighting to avoid bias in the absence of stakeholder-defined priorities. While this ensures neutrality, it does not necessarily reflect the real-world relative importance of each factor. Thus, the final score of the case study company regarding its alignment with Industry 5.0 is 37.5% of the possible 100%. This result, according to Table 5, is described as a poorly aligned company. Based on the identified gaps in this section, targeted improvement actions are proposed for each criterion to enhance the company's Industry 5.0 alignment score.

5.3. Recommendations for Improvement

The previous low score of the company regarding Industry 5.0 requirements (37.5%) indicates the necessity of proposing improvement actions to achieve I5.0 alignment. Therefore, recommendations for how the company could improve its scores across each of the evaluated criteria are given by the authors. Implementing the proposed strategies could lead to significant improvements in the scores. All the proposed actions seek a progressive enhancement, so improvements are proposed to increase I5.0 alignment for each criterion in just one step (individual improvement of 25% for each criterion).

Below is a potential improvement forecast after the recommended actions are taken.

5.3.1. Human-Centricity Dimension

1 Safety and Well-being score: improvement from 50% to 75%

New Wellness Initiatives: Implement programs such as on-site yoga or mindfulness sessions and offer free counseling services. For instance, introduce an annual "Health and Wellness Week" featuring various workshops and activities.

Flexible Work Arrangements: Allow remote work options for eligible roles and implement compressed workweek schedules, enabling employees to have three-day weekends occasionally.

2. Skill Development and Training score: improvement from 25% to 50%

Skill Development Programs: Introduce an online learning platform with courses in advanced machining techniques and digital tools, providing 40+ hours of training annually per employee.

Certification Opportunities: Partner with local technical institutes to offer certifications in areas such as welding technology and CNC machining, aiming to increase certification rates by 60%.

3. Personalized Workflows and Ergonomic Design score: from 25% to 50%

Introduction of Cobots: Add cobots to assist with repetitive tasks such as welding or assembly processes, reducing physical strain on workers and increasing efficiency.

Enhanced Safety Protocols: Implement automated safety monitoring systems, such as RFID-enabled PPE equipment that can alert workers and supervisors to safety violations.

5.3.2. Sustainability Dimension

4. Sustainable Energy Integration score: from 50% to 75%

EmR and ReG, which directly affect the SEI criteria, match the electricity supply origin of the company: electricity mix and its current solar PV installation. On the one hand, the company cannot modify the electricity mix of the country. However, it can decrease its dependency from the electricity grid, increasing the renewable self-consumption generation, mainly solar PV. Thus, EmR and ReG will improve. For instance, increasing solar self-consumption from 18.4% to 40% could raise EmR from 19.57% to approximately 40%, and ReG from 83.11% to over 86%, improving the SEI score to nearly 63%.

The current ratio of solar PV self-consumption of the company is low (20% on average). It should be increased by avoiding excessive energy surpluses throughout the year and considering rooftop restrictions. Concerning the latter point, the rooftop of the company presents suitable areas for including solar PV (with no obstacles and shadows). Thus, these spaces should be optimized to include the necessary installation to maximize solar PV production limiting excessive surpluses.

5. Sustainable Supply Chains score: from 75% to 100%

Sustainable Material Sourcing: Shift to using 80% recycled materials in production. Establish a partnership with a local recycling firm to secure a steady supply of these materials.

Achieve Additional Certifications: Attain certifications such as Fair Trade or Cradle to Cradle for product lines, ensuring transparency and sustainability throughout the supply chain.

6. Resource Efficiency and Energy Management Systems score: from 0% to 25%

Pilot AI in Quality Control: Deploy visual AI systems for detecting defects in products, leading to a reduction in waste due to improved accuracy in quality assessments.

AI Training Programs: Conduct workshops for staff to understand AI applications in manufacturing, thus fostering an environment in which employees can contribute ideas for AI projects.

5.3.3. Resilience Dimension

7. Crisis Management Strategies score: from 25% to 50%

Creation of an Innovation Lab: Set up a dedicated space where small teams can work on projects, such as experimenting with lightweight metal alloys for furniture components that reduce material usage without compromising strength.

Faster Market Response: Reduce product development cycles by implementing agile methodologies, which could decrease the time-to-market for new products.

8. Robust Supply Chain Management score: from 75% to 100%

Advanced Inventory Management: Implement AI-driven demand forecasting to optimize inventory levels and reduce excess stock, leading to an increase in inventory turnover rate.

Supplier Diversification: Form strategic alliances with secondary suppliers for key materials, ensuring the continuity of supply even amid disruptions such as during unforeseen global supply chain crises.

9. Flexible Manufacturing Systems score: from 25% to 50%

Increased R&D Spending: Allocate an additional 5% of revenue towards R&D, focusing on developing new products that incorporate advanced features like smart furniture components with built-in charging stations or connectivity options.

Patent Development: Initiate a company-wide challenge to encourage innovation, leading to an increase in patent filings of 50% within two years.

10. Predictive Maintenance and Digital Twins score: from 25% to 50%

Expanded IoT Integration: Install IoT sensors throughout the facility to monitor equipment health and predict maintenance needs, resulting in a reduction in unexpected machine downtime.

Data Analytics Utilization: Use the collected data to enhance decision-making processes, such as optimizing energy use and reducing utility costs.

The overall score now would be 62.5%, which considers the company well aligned to I5.0. This is about 67% more than during the investigated period.

This study employed equal weighting across all criteria to maintain neutrality in the absence of stakeholder input. However, future applications of this framework could adopt alternative weighting methods such as the Analytic Hierarchy Process (AHP), which uses structured expert judgments; the Delphi method, which builds consensus through multiple survey rounds; or entropy weighting, which derives weights objectively from data variability. Additionally, multi-stakeholder consultations could be conducted to align weighting with the values of diverse interest groups. Sensitivity analysis is recommended to evaluate how different weighting configurations affect the overall Industry 5.0 score, thereby improving the robustness and credibility of the assessment. These strategic initiatives are designed to drive the company towards a more competitive and technologically advanced position, consistent with Industry 5.0 principles. The application of the framework to a single company limits generalization. Future studies should include cross-sectoral comparisons and integration of international benchmarks to strengthen the reliability of the scoring method. Expert reviews and applications across multiple SMEs in Europe could help refine the model and support broader validation.

6. Conclusions

This study contributes to the emerging field of Industry 5.0 by proposing a structured and measurable framework for evaluating a company's alignment with its core principles—human-centricity, sustainability, and resilience—and giving valuable recommendations to enhance Industry 5.0 alignment. By developing a ten-criterion rubric and applying it to a real-world Lithuanian manufacturing company, the research demonstrates how qualitative aspects of Industry 5.0 can be translated into a standardized evaluation system. The results revealed that while the company shows strong adaptability and operational flexibility, significant gaps remain in areas such as sustainability practices, digital integration, and workforce upskilling. The developed methodology provides a practical tool for industry practitioners and researchers to assess Industry 5.0 maturity and identify targeted areas for improvement. Future research may expand the framework to different sectors and refine the criteria weighting, thus enhancing its generalizability and decision-support capability. The case study provided the result that the investigated company has a poor level according to I 5.0 scoring. Recommendations were provided to achieve an almost 70% better score, which could be described as a well-aligned company. The presented framework provides a foundation for future cross-sectoral applications and benchmarking studies. Expanding the sample size to include companies from different industrial sectors would help assess the model's robustness and general applicability across varying operational environments.

Author Contributions: Conceptualization, S.S. and P.B.-M.; methodology, S.S. and P.B.-M.; validation, S.S. and P.B.-M.; formal analysis, P.B.-M.; investigation, S.S. and P.S.; resources, S.S.; data curation, P.B.-M.; writing—original draft preparation, S.S.; writing—review and editing, P.B.-M. and P.M.-P.; visualization, S.S. and P.S.; supervision, P.B.-M.; project administration, P.M.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: We really appreciate the help of the company that presented details for the case study. Without them, we could not have carried out the research. The authors gratefully acknowledge the support received through the Erasmus+ program, which provided funding for a research stay that contributed significantly to the development of this work.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
CMS	Crisis Management Strategies
DT	Digital Twin
EmR	Emissions Reduction
FMS	Flexible Manufacturing Systems
IoT	Internet of Things
PMDT	Predictive Maintenance and Digital Twins
PV	Photovoltaic
PWED	Personalized Workflows and Ergonomic Design
REEMS	Resource Efficiency and Energy Management Systems
ReG	Renewable Generation
RSCM	Robust Supply Chain Management
SDT	Skill Development and Training
SEI	Sustainable Energy Integration
SSC	Sustainable Supply Chains
SW	Safety and Well-being

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