Sustainable Food Technology

ROYAL SOCIETY OF CHEMISTRY

PAPER

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Cite this: *Sustainable Food Technol.*, 2025, **3**, 1556

# Drivers of Industry 5.0 technologies in dairy industry: an exploratory study

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Received 20th April 2025
Accepted 25th July 2025

DOI: 10.1039/d5fb00156k

rsc.li/susfoodtech

This paper aims to identify and analyse the key drivers affecting the adoption of Industry 5.0 (I5.0) technologies in the dairy industry. The data collected from various dairy stakeholders was analysed using Exploratory Factor Analysis (EFA) to uncover the underlying factors, and Multiple Linear Regression (MLR) was employed to evaluate the impact of the factors on the adoption level of I5.0 technologies. The EFA identified five key factors driving the adoption of I5.0 technologies: operational efficiency and productivity, animal health and product quality, sustainability and environmental impact, data-driven decision-making and compliance, and market competitiveness and collaboration. The MLR analysis revealed that these factors significantly impact the level of adoption (LOA), with operational efficiency and productivity being the most influential factors. The findings indicate that dairy stakeholders recognise the potential benefits of I5.0 technologies in enhancing efficiency, improving product quality, and enabling effective decision-making.

**Sustainability spotlight**

This research is significant for both theoretical understanding and practical applications for the stakeholders, as it presents a framework for comprehending the implementation of Industry 5.0 technologies in the dairy industry. The outcomes emphasize sustainability's importance, demonstrating how precise resource management and optimized waste treatment can help reduce environmental footprints. The identified sustainability-related factors point to employing technologies that optimize feed and water consumption, minimize environmental footprints, ensure compliance with environmental regulations, and explicitly cover SDG 3, SDG 9, SDG 11, and SDG 12.

## 1. Introduction

Industry 5.0 (I5.0) represents a radical shift in technological innovation, emphasising a transition from conventional productivity and automation to a more human-centric, sustainable, and resilient industry approach.[1] In the dairy sector, Industry 5.0 is defined by the integration of contemporary digital technologies such as advanced robotics, blockchain, the Internet of Everything (IoET), generative artificial intelligence (AI), and real-time analytics, along with human-centred and sustainable practices aimed at improving animal welfare, mitigating negative environmental effects, and fostering data-driven decision-making across the dairy value chain to enhance overall productivity.[2] Compared to the Fourth Industrial Revolution (Industry 4.0), I5.0 highlights the advantageous interaction between human creativity and enhanced machine intelligence, creating a synergistic relationship that drives innovation and efficiency.[3] The primary objective of I5.0 is to improve efficiency, adaptability, and personalisation in manufacturing processes while prioritising sustainability and ethical considerations.[4]

The food industry, including the dairy sector, has a significant opportunity to leverage the technological advances introduced by I5.0. Agriculture and the food industry have traditionally been slower than other sectors in implementing state-of-the-art technological advances, often relying on labour-intensive and traditional techniques.[5] Still, the increasing requirement for food and sustainable approaches has driven an evolution towards innovative and efficient agricultural methodologies. The shift in dairy operational activities handles bottleneck concerns associated with productivity, regulatory compliance, quality challenges, and environmental effects.[6] The rising demand for high-quality and sustainably produced dairy products indicates the necessity for a transition from labour-intensive operations to intelligent, adaptable, and data-driven

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businesses. Industry 5.0 can completely transform agricultural operations by incorporating technological interventions in all aspects of farming to maximise resource use, improve product quality, and enhance farm management.[7] Within the dairy farming sector, I5.0 has the potential to tackle significant obstacles such as a scarcity of workers, unpredictable market needs, and strict regulatory standards. This can lead to a more robust, resilient, and environmentally friendly agricultural industry.[8]

Industry 5.0 aims to improve productivity and operational effectiveness in the dairy sector. By implementing generative AI and IoET technologies, the dairy sector has achieved exemplary levels of automation and accuracy.[9–11] AI-driven analytics can utilise real-time data to forecast the most effective milking schedules, resulting in more production and improved cow well-being. IoT sensors can constantly monitor environmental variables, including humidity, temperature, and animal health indicators.[12] This continuous monitoring enables real-time adjustments and ensures optimal conditions for dairy production. These technologies enhance productivity while lowering labour costs and minimising human error, resulting in consistent, high-quality products.[13] Moreover, these technologies enable predictive maintenance, greatly diminishing equipment downtime and guaranteeing uninterrupted and effective agricultural operations. By optimising every component of the production process, Industry 5.0 can enhance efficiency and profitability for dairy farms.[14]

Decision-making based on data plays a crucial role in the present dairy industry by optimising operations and ensuring regulatory compliance. Industry 5.0 enables effortless regulation adherence through continuous surveillance and data gathering.[15] Blockchain technology, an essential element of I5.0, guarantees the capacity to track and verify every supply chain step, from the origin to the destination. This ensures compliance with regulations and promotes consumer confidence by offering verifiable data about the origin and quality of dairy products.[16] Blockchain technology enhances the security of transactions and data by minimising the possibility of fraudulent activities and ensuring transparency and accountability throughout the dairy production process.[17] In addition, real-time data analytics allows farmers to make well-informed choices on livestock management, feeding plans, and health interventions. This approach helps maximise productivity and ensure regulatory compliance.[18] Continuous monitoring systems guarantee farms' compliance with food safety and livestock welfare requirements, minimising the likelihood of breaches and the resulting fines.[19]

Industry 5.0 technologies enable the provision of customised product offerings tailored to customers' preferences, augmenting competitiveness. Advanced data analysis identifies emerging trends and consumer needs, allowing the farmers to produce goods that align with these requirements.[20] Utilising blockchain and IoT, transparent operations enhance trust and collaboration with supply chain partners, fostering stronger collaborations and stimulating innovation. By embracing I5.0 technologies, dairy farms can strengthen their competitive advantage and market position while establishing more robust and flexible supply networks.[21] Collaborations and agricultural innovation can enhance the development and implementation of advanced solutions.[2]

Despite these advantages, the full potential of I5.0 technologies still needs to be explored in the dairy sector. Therefore, the current research identifies and analyses the key factors driving the adoption of I5.0 technologies in the dairy industry. It offers a thorough understanding of integrating I5.0 technologies into the dairy industry and their resulting impacts. The objectives of the current research are to:

(1) Identify and analyse the key factors driving the adoption of Industry 5.0 technologies in the dairy industry.

(2) Investigate the influence of these drivers on the adoption level of Industry 5.0 technologies.

This research aims to explain the factors contributing to this transformation and highlight the advantages that I5.0 technologies can offer the dairy industry sector. The article is organised as follows: Section 2 reviews the related studies, Section 3 outlines the materials and methods used for the current research, Section 4 presents the results and discussion, and Section 5 concludes the research.

## 2. Literature analysis

The dairy business has gradually embraced Industry 4.0 technology, significantly enhancing efficiency and production. Notable progress has been made in developing automated milking systems, precision feeding technology, and real-time monitoring systems for the health of the herd and milk output.[6] These technologies empower dairy producers to enhance their operations, minimise labour expenses, and enhance product quality. Automated milking systems improve efficiency and offer vital information on milk production and cow well-being, enabling more effective management decisions.[22] Extensive research has provided evidence of the beneficial effects of Industry 4.0 technology in dairy farming. Precision feeding systems enhance feed utilisation, optimising animal nutrition and minimising wastage.[23] Real-time monitoring systems provide uninterrupted health surveillance, enabling early disease detection and quick interventions that enhance total herd health and production.[24]

Industry 5.0 builds upon the principles of Industry 4.0 but emphasises human-centred and ecological methods.[25] It introduces advanced technologies that combine human intelligence with sophisticated systems. Key components of I5.0 that apply to the dairy industry include advanced robotics. Robots are employed in dairy farming for milking, feeding, and cleaning.[26–28] These robots collaborate with human workers, enhancing productivity and minimising labour-intensive assignments.[29] Advanced robotics can carry out repetitive and precise operations, enabling human workers to concentrate on more intricate duties that necessitate problem-solving abilities and smart decision-making.[30] The transition from Industry 4.0 to Industry 5.0 indicates considerable breakthroughs in industrial processes and innovations, acknowledging advancements in different industries. The shift from the Internet of Things (IoT) to the Internet of Everything (IoT) is a significant advance

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that expands connections beyond devices to incorporate humans, processes, information, and everything. This leads to more interconnected and smart networks.[10] The transition from classical AI to generative AI, like ChatGPT, indicates a significant advancement in capabilities, allowing machines to produce complicated, human-like, innovative products. This expansion broadens the range of AI applications.[11] The transition of 3D printing to 4D printing for industrial use integrates the component of time, enabling printed items to alter their shape or functioning in response to outside inputs. This advancement enhances the adaptability and effectiveness of additive production.[31] The transition from 4G to 5G and beyond greatly enhances data transmission speeds, decreases latency, and augments network capacity, essential for facilitating sophisticated applications like self-driving cars and smart towns.[32] These improvements represent a significant period of change in the industry, fuelled by exceptional levels of communication, intellect, and interaction. This will lead to a more adaptable, customised, and environmentally friendly industrial system.[33]

### 2.1 Theoretical framework: technology-organization-environment (TOE)

The present research employs the TOE framework to enhance empirical credibility. The TOE framework, introduced by Tornatzky *et al.* (1990), highlights three fundamental components that affect the adoption of technical advancements.[34] TOE combines technological capabilities, organisational context, and environmental components that influence the adoption process. This research explores the adoption process and includes dairy stakeholders involved in all aspects of the dairy industry, which makes the TOE framework a more suitable perspective. Given that the current research aligns with the TOE framework, it is essential to acknowledge its relationships and differentiation from other established theories, such as the Technology Acceptance Model (TAM), which focuses on individuals' perspectives regarding acceptance of technologies, and DOI, which mainly concentrates on the innovation dissemination process. TAM includes individual acceptance, such as ease of use and perceived usefulness, while TOE highlights organisational readiness and external variables. Similarly, enablers such as sustainability impacts and operational efficiency indirectly reflect the perceived usefulness (TAM) and advantage (DOI). Thus, the current research adopted the TOE framework, providing a comprehensive perspective by integrating technological, organisational, and environmental aspects essential to a systematic transition in the dairy industry. Future studies could investigate hybrid frameworks that integrate both individual behavioural intentions and organisational capabilities, especially during complicated transformations such as Industry 5.0.

In the context of I5.0, some authors highlight the significance of personalisation. Industry 5.0 considers consumer satisfaction and organisational flexibility as key factors that confer a competitive advantage.[35] The researchers stated that I5.0 leverages Industry 4.0 technology to facilitate personalisation and collaboration within society. However, the challenge of adaptation, customisation, and technological advancement can only be effectively addressed with the help of human interaction. The contemporary difficulties have led to the emergence of I5.0, which seeks to synchronise technological progress with human empowerment.[36,37] Industry 5.0 offers customers highly tailored items and services that reflect the customisation era.[36] According to Salimova *et al.* (2019), I5.0 aims to optimise the utilisation of robots and humans simultaneously. This is done by providing a harmonious atmosphere that fosters collaboration and enables customisation, ultimately leading to greater productivity within the context of I5.0.[38]

Industry 5.0 may still need to be considered an immature and futuristic concept. Industry 4.0 establishes the basis for the smart factory, whereas I5.0 represents the era of a socially smart factory.[39] It is worth noting that I5.0 presents a significant disparity in its implications for industries. A systematic keyword search in reputed scientific databases, including Web of Science and Scopus, revealed that although existing articles discuss the relationship between I5.0 and Industry 4.0, the impact of I5.0 on supply chain management remains underexplored.[9] In addition to the limited understanding of I5.0 in the context of supply chains, there is a significant gap in the literature considering the critical role supply chains play for consumers. The adoption of I5.0 will undoubtedly impact supply chain processes and participants. Hence, comprehensively understanding the correlation between I5.0 and supply chains is crucial.

To facilitate this transformation, the dairy industry can leverage I5.0 technologies by tackling challenges and taking advantage of critical factors. The literature review discusses the transition of Industry 4.0 to I5.0 by emphasising the future applications of I5.0 in the dairy industry. Despite the numerous applications of I5.0, the literature needs a thorough investigation into key factors driving its adoption in the dairy industry. These research gaps motivated the authors to carry out this study.

## 3. Methods

The authors identified the potential applications of Industry 5.0 in the dairy industry through a literature review to make statements and investigate them empirically. EFA was used to analyse the data to identify the key factors driving the adoption of I5.0 technologies, and MLR was used to measure the impact of identified factors on the adoption level of I5.0 in the dairy industry. The authors applied EFA step by step, and the Bartlett test of sphericity indicated that the analysis is appropriate, as suggested by Hair *et al.* (2006).[40] The Kaiser–Meyer–Olkin (KMO) values suggested the suitability of the data. As per the threshold criteria of EFA, the commonality values for every considered statement should be greater than 0.5. A lower value than the threshold leads to removing the statement and re-analysing the data.[41] The ANOVA table shows that the regression model is statistically significant and that the independent variables explain a large amount of the adoption of I5.0 technologies.

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### 3.1 Sampling and data collection

The authors designed a questionnaire based on a literature analysis to highlight the key drivers of I5.0 for the dairy industry. The authors formulated 37 statements related to the major applications of I5.0 to identify the key drivers and four statements to investigate the stakeholders' perspective on the level of adoption. The data was collected through online survey forms and emails. Experts from academia and industry validated the questionnaire, including 37 statements, of which four statements were used to investigate the level of adoption of I5.0 in dairy from the stakeholders' perspective. The authors used a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). The initial number of participants was 410; the study considered the final 327 stakeholders from different dairy segments (Table 6 – Appendix).

### 3.2 Exploratory factor analysis

The authors applied the factor analysis method to analyse the key factors. The EFA can be used when the research objective is to explore the factors and examine the reliability of identified factors. IBM SPSS v23 was used for EFA. EFA process, including data cleaning after collection, coding, loading the data in SPSS (a statistical software), and performing the analysis. The authors opted for factor analysis, selecting Principal Component Analysis (PCA) and utilising the Varimax rotation method. The selection of PCA over common factor extraction methods like principal axis in EFA was due to the focus of the study being data reduction, considering the dimension of responses. PCA identifies the most significant factors statistically, highlighting five factors having an eigenvalue greater than 1 and explaining a variance of more than 70% cumulatively. Statements with commonalities less than 0.5 were generally excluded from the analysis. But the analysis did not encounter such a statement; all the required results were within acceptable thresholds.

### 3.3 Multiple linear regression

The authors applied multiple linear regression (MLR) to measure the impact of identified key drivers on the level of adoption. The identified factors were used as independent variables, and the level of adoption was used as the dependent variable. A licensed version of XLStat was used to apply MLR. The steps involved in applying MLR were data preparation, which included calculating the composite score for the dependent variable "level of adoption" by averaging the respondents' data and, similarly, for the independent variables, which identified five factors. Then, all assumptions were checked and analysed.

## 4. Analysis and findings

### 4.1 Reliability analysis

The authors used the Cronbach alpha method to check the reliability of data collected through responses. The purpose is to verify the reliability and consistency of measurement instruments. The data's overall reliability was 0.962, suggesting that measurement error influenced a slight variation in the data. This value indicates the considerably high reliability of all statements that meet the threshold values.

### 4.2 Exploratory factor analysis

The authors applied EFA step by step, and the Bartlett test of sphericity indicated that the analysis is appropriate, as suggested by Hair *et al.* (2006).[40] The Kaiser-Meyer-Olkin (KMO) values suggested the suitability of the data. Table 1 highlights the KMO value, and the Bartlett test of sphericity was computed by SPSS v23.

The analysis investigated and grouped the relevant statements into factors that are key drivers of I5.0 in the dairy industry. The results show a KMO value greater than 0.951, which is very important because it is much higher than the acceptable limit of 0.6, proving that the analysis is appropriate and reliable.[40] The Bartlett's test of sphericity was considerably significant ($P < 0.000$), which confirms the correlation among the population characteristics.

The factor analysis highlighted five factors with eigenvalues greater than 1, which include Factor 1: Operational efficiency and productivity; Factor 2: Animal health and product quality; Factor 3: Sustainability and environmental impact; Factor 4: Data-driven decision-making and compliance; and Factor 5: Market competitiveness and collaboration. The results showed that all 33 statements have commonalities of more than 0.5, which suggests that the results are acceptable.[41]

Table 2 presents the commonality values for all 33 statements, each of which is greater than 0.5, thereby validating the analysis. These statements were grouped into five factors, explaining 70.586% of the total variance. Factor 1 accounts for most of the variance, explaining 47.534% of the total variance, indicating there are no common bias method concerns.

### 4.3 Multiple regression analysis

Table 3 represents the results from MLR, including the goodness of fit statistics, where $R^2$ is 0.638 for the training dataset, indicating that the five factors explained 63.8% of the variance in the level of adoption of I5.0 technologies. The $R^2$ highlights that the model fits well for the training dataset, and these five factors contribute to the adoption levels. Despite the strong model fit, the value of $R^2$ also indicates 36.2% of the variance remained unaccounted for. It is possible because during the study design, some factors were not included in the empirical model due to some limitations associated with current research, like survey length, time, *etc.* However, the authors acknowledge the importance of these factors, which can potentially help in explaining the remaining variance. Such factors may include infrastructure cost, stakeholder resistance, organisational culture, infrastructure readiness, *etc.*, which can

Table 1 Values of KMO and Bartlett's test

| | | |
|---|---|---|
| Kaiser–Meyer–Olkin measure of sampling adequacy | | 0.951 |
| Bartlett's test of sphericity | Approx. chi-square | 8735.739 |
| | df | 561 |
| | Sig | 0.000 |

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Table 2 Identified factors[a]

| Factors & statements | Commonality | Factors loading F1 | F2 | F3 | F4 | F5 | Reliability analysis |
|---|---|---|---|---|---|---|---|
| **(F1): Operational efficiency and productivity** | | | | | | | |
| Industry 5.0 technologies significantly enhance dairy farm productivity | 0.794 | 0.812 | | | | | 0.959 |
| Automation through Industry 5.0 technologies reduces labour costs | 0.763 | 0.803 | | | | | |
| Industry 5.0 technologies optimise milking schedules, increasing yield | 0.740 | 0.785 | | | | | |
| The use of robotics in dairy farming improves operational efficiency | 0.779 | 0.785 | | | | | |
| Industry 5.0 technologies streamline dairy processing operations | 0.707 | 0.775 | | | | | |
| Predictive maintenance enabled by Industry 5.0 reduces equipment downtime | 0.692 | 0.754 | | | | | |
| The adoption of Industry 5.0 technologies improves overall farm management efficiency | 0.728 | 0.754 | | | | | |
| Real-time data analytics through Industry 5.0 improves decision-making | 0.736 | 0.750 | | | | | |
| Predictive analytics in Industry 5.0 enhances strategic planning on dairy farms | 0.723 | 0.748 | | | | | |
| Industry 5.0 technologies provide valuable insights for resource allocation | 0.680 | 0.694 | | | | | |
| The adoption of Industry 5.0 drives innovation in dairy product development | 0.620 | 0.563 | | | | | |
| **(F2): Animal welfare and product quality** | | | | | | | |
| Industry 5.0 technologies enable early detection of animal health issues | 0.713 | | 0.779 | | | | 0.922 |
| Real-time health monitoring through Industry 5.0 improves animal welfare | 0.721 | | 0.769 | | | | |
| Automated feeding systems ensure consistent and stress-free routines for animals | 0.748 | | 0.759 | | | | |
| Industry 5.0 technologies enhance the quality of milk produced | 0.685 | | 0.752 | | | | |
| Continuous monitoring through Industry 5.0 ensures high milk safety standards | 0.644 | | 0.743 | | | | |
| Industry 5.0 technologies enable better traceability of dairy products | 0.671 | | 0.735 | | | | |
| The adoption of Industry 5.0 technologies improves the nutritional quality of dairy products | 0.711 | | 0.710 | | | | |
| **(F3): Sustainability and environmental impact** | | | | | | | |
| Industry 5.0 technologies help achieve sustainability goals in dairy farming | 0.728 | | | 0.710 | | | 0.911 |
| Precise resource management through Industry 5.0 reduces water and feed consumption | 0.767 | | | 0.682 | | | |
| Industry 5.0 technologies optimise waste management on dairy farms | 0.653 | | | 0.667 | | | |
| The adoption of Industry 5.0 technologies lowers the environmental footprint of dairy operations | 0.733 | | | 0.636 | | | |
| Industry 5.0 technologies facilitate better environmental compliance in dairy farming | 0.765 | | | 0.584 | | | |
| Energy-efficient systems enabled by Industry 5.0 reduce overall farm energy consumption | 0.597 | | | 0.518 | | | |
| **(F4): Data-driven decision-making and compliance** | | | | | | | |
| The use of Industry 5.0 technologies simplifies compliance with food safety regulations | 0.725 | | | | 0.829 | | 0.856 |
| Continuous monitoring through Industry 5.0 ensures compliance with animal welfare standards | 0.740 | | | | 0.818 | | |
| Industry 5.0 technologies help meet industry certifications and standards | 0.638 | | | | 0.796 | | |
| Blockchain-enabled traceability through Industry 5.0 increases consumer trust | 0.629 | | | | 0.723 | | |
| Secure supply chain transactions enabled by Industry 5.0 reduce fraud | 0.585 | | | | 0.720 | | |
| **(F5): Market competitiveness and collaboration** | | | | | | | |
| Industry 5.0 technologies support personalised dairy product offerings to consumers | 0.733 | | | | | 0.804 | 0.859 |
| Industry 5.0 technologies foster collaboration with technology providers | 0.730 | | | | | 0.699 | |
| Transparent operations through Industry 5.0 improve partnerships in the supply chain | 0.700 | | | | | 0.585 | |
| The adoption of Industry 5.0 technologies significantly boosts our competitive advantage | 0.714 | | | | | 0.565 | |

[a] F1–F5 represent individual factors. Principal component analysis as extraction method. Varimax with Kaiser normalisation as rotation method.


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Table 3 Goodness of fit statistics

| Statistic | Training set | Validation set |
|---|---|---|
| Observations | 196 | 131 |
| Sum of weights | 196 | 131 |
| DF | 190 | 125 |
| $R^2$ | 0.638 | 0.561 |
| Adjusted $R^2$ | 0.628 | |
| MSE | 0.264 | 0.245 |
| RMSE | 0.514 | 0.495 |
| MAPE | 12.531 | 10.921 |
| DW | 2.089 | |
| Cp | 6.000 | |
| AIC | −254.852 | |
| AICC | −254.408 | |
| SBC | −235.184 | |
| PC | 0.385 | |

be considered in future studies into expanded models. The mean squared error of 0.264 indicates that the average squared difference between observed and predicted values is small. Similarly, the root mean squared error of 0.514 suggests a satisfactory fit. The model fits the data well overall, according to the MLR analysis.

The residual analysis confirmed the adherence to assumptions of independence, normality, *etc.* The Durbin–Watson statistic value of 2.089 highlights no autocorrelations among residuals. The model describes the variability in adopting I5.0 technologies, indicating that the highlighted characteristics are key drivers. The model's goodness-of-fit statistics and consistent error metrics indicate effective predictive performance on training and validation sets. Each factor positively impacts adoption, implying that operational efficiency, animal health, product quality, sustainability, environmental impact, market competitiveness, and collaboration are essential for adopting the dairy Industry 5.0. Table 4 shows the analysis of the variance.

The *p*-value suggests a highly significant model, with a low possibility of chance affecting the observed F-statistic. This shows that the independent variables (factors) explain much of the adoption variance. The model's sum of squares (88.472) explains 138.703 of the variance; the error accounts for 50.231 of the variance. The strong *F*-value (66.930) supports its capacity to explain dependent variable variance. This strongly suggests that the identified key drivers (factors) affect adoption levels. Table 5 highlights the standardised coefficients, *p*-value, and confidence intervals.

The equation below indicates the model's equation for the levels of adoption.

$$\text{LOA} = 0.344 + 0.174 \times \text{F1} + 0.046 \times \text{F2} + 0.283 \times \text{F3} + 0.114 \times \text{F4} + 0.233 \times \text{F5}$$

The coefficient of "F1: operational efficiency and productivity" highlights that the increase in productivity and operational efficiency impacts the level of adoption of I5.0 technologies. Positive coefficient values indicate operational efficiency, and productivity improvements will lead to higher adoption levels. Similarly, "F3: Sustainability and environmental impact," "F4: Data-driven decision-making and compliance," and "F5: Market competitiveness and collaboration" reflect that these factors will impact the adoption of I5.0 technologies. All factors, excluding "F2: Animal health and product quality," demonstrated significant effects statistically, whereas this factor highlights the impact of animal health and product quality, suggesting a limited perceived impact of adoption levels of I5.0, indicating it as a baseline compliance dimension instead of an influencing factor.

Table 4 Analysis of variance[a,b]

| Source | DF | Sum of squares | Mean squares | *F* | Pr > *F* | *p*-value significance codes |
|---|---|---|---|---|---|---|
| Model | 5.000 | 88.472 | 17.694 | 66.930 | **<0.0001** | *** |
| Error | 190.000 | 50.231 | 0.264 | | | |
| Corrected total | 195.000 | 138.703 | | | | |

[a] Computed against model $Y$ = mean ($Y$). [b] Significance codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < 0.0 < 0.1 < ° < 1.

Table 5 Regression coefficients and significance[a]

| Factor | Coefficient | *p*-value | Significance | 95% CI |
|---|---|---|---|---|
| (F1): Operational efficiency and productivity | 0.174 | 0.012 | * | [0.038, 0.301] |
| (F2): Animal welfare and product quality | 0.046 | 0.429 | ns (not significant) | [-0.069, 0.162] |
| (F3): Sustainability and environmental impact | 0.283 | <0.001 | *** | [0.146, 0.421] |
| (F4): Data-driven decision-making and compliance | 0.114 | 0.012 | * | [0.025, 0.203] |
| (F5): Market competitiveness and collaboration | 0.233 | <0.001 | *** | [0.113, 0.353] |

[a] Significance codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < 0.0 < 0.1 < ° < 1.

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# 5. Discussion

The current research identifies and investigates the key driving factors for adopting I5.0 technologies in the dairy sector. The statements were categorised into five key factors, presented in Table 2, with their commonalities, factor loadings, and individual reliability analysis. This section highlights a detailed discussion of the identified key factors and the role of I5.0 technologies in dairy advancements.

## 5.1 Factor 1: Operational efficiency and productivity

The first factor, "Operational efficiency and productivity," explains 47.534% of the total variance. This factor comprises eleven items with commonalities and factor loadings in highly acceptable ranges. The commonalities range from 0.620 to 0.794, and factor loadings range from 0.563 to 0.812, with a high reliability of 0.959. This factor captures the impact of I5.0 technologies on improving the productivity and efficiency of dairy operations. The high commonalities and factor loadings suggest a strong association between I5.0 technologies and operational improvements. The results highlight that technological interventions considerably enhance dairy productivity by optimising milking schedules and improving overall management efficiency.

The potential of automation, predictive maintenance, and robotics has a significant impact on effective decision-making and strategic planning, contributing to innovative dairy product development.[42] By using data analytics and real-time monitoring, farms can ensure that milking occurs at the optimal times for maximum yield, improving overall productivity.[22] Implementing robotics in tasks such as milking, feeding, and cleaning ensures consistency, reduces errors, and frees up human workers for more complex tasks.[43] Efficient processing means faster production times and less waste, leading to higher profitability and less environmental impact.[9] Predictive maintenance minimises the risk of unexpected equipment failures, ensuring that equipment is maintained before it breaks down, reducing downtime, and maintaining a steady flow of operations.[44] The comprehensive management systems based on I5.0 technologies improve the efficiency of farm operations. From resource allocation to task scheduling, these technologies help make informed decisions that enhance operational efficiency.[3] Industry 5.0 fosters innovation by leveraging advanced technologies; farms can experiment with and develop new products that meet emerging consumer demands and open new market opportunities.[45]

## 5.2 Factor 2: Animal welfare and product quality

The second factor, "Operational efficiency and productivity," explains 8.804% of the total variance. This factor comprises seven items with commonalities and factor loadings within highly acceptable ranges. The commonalities range from 0.644 to 0.748, and factor loadings range from 0.710 to 0.779, with a high reliability of 0.922. This factor highlights the role of I5.0 technologies in promoting animal welfare and improving product quality. The regression analysis highlighted that the factor is not statistically significant, but it has indirect impacts on the I5.0 adoption due to its potential in Industry 4.0 technologies. Potential applications such as real-time health monitoring, early detection of animal health issues, quality monitoring, and improving nutritional values were highlighted by many researchers.[6,46,47] This factor significantly impacted the adoption of Industry 4.0 in dairy, although it did not have a significant impact on the adoption of I5.0.

## 5.3 Factor 3: Sustainability and environmental impact

The third factor, "Sustainability and environmental impact," explains 7.030% of the total variance. This factor comprises six items with commonalities and factor loadings within highly acceptable ranges. The commonalities range from 0.597 to 0.767, and factor loadings range from 0.518 to 0.710, with a high reliability of 0.911. While Industry 4.0 highlighted the transformational role of digital technologies to achieve business goals in the dairy sector, I5.0 technologies help to achieve sustainability goals using advanced technologies that contribute to meeting sustainability targets.[48] Industry 5.0 enables precision management, minimises the use of resources, improves waste management practices and reduces the environmental impact of dairy farming operations.[49] These technologies help reduce the overall environmental impact by lowering the carbon footprint and other environmental impacts, which is critical for the long-term sustainability of dairy farming.[50]

## 5.4 Factor 4: Data-driven decision-making and compliance

The fourth factor, "Data-driven decision-making and compliance," explains 3.756% of the total variance. This factor comprises five items with commonalities and factor loadings within acceptable ranges. The commonalities range from 0.585 to 0.740, and factor loadings range from 0.720 to 0.829, with a high reliability of 0.856. This factor highlighted that I5.0 technologies make adhering to safety standards easier, ensuring that farms meet food safety regulations efficiently, reducing non-compliance risk, and enhancing consumer trust.[51] Data analytics-based decision-making ensures smooth compliance with dairy regulatory standards, facilitated by I5.0, making the process more efficient and reliable.[52] Smart decision-making ensures all transactions and processes are transparent and verifiable, making them crucial for building consumer confidence in dairy products. It indicates a reduction in fraud, which improves the integrity and authenticity of the supply chain to maintain quality and safety standards, and I5.0 technologies play a crucial role in achieving these goals.[6]

## 5.5 Factor 5: Market competitiveness and collaboration

The "Market competitiveness and collaboration" factor explains 3.462% of the total variance. This factor comprises four items with commonalities and factor loadings within acceptable ranges. The commonalities range from 0.700 to 0.733, and factor loadings range from 0.565 to 0.804, with a high reliability of 0.859. Industry 5.0 technologies enable product customisation to meet consumer needs and diverse consumer

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preferences, enhancing market competitiveness and customer satisfaction.[53] These technologies strengthen effective collaboration, which ensures that dairy farms stay at the cutting edge of technological advancements, leading to continuous improvements and innovations. Transparent operations build trust and improve collaboration with various stakeholders in the supply chain, from suppliers to retailers.[54] Implementing these technologies enhances competitiveness; dairy farms can differentiate themselves in the market, offering superior products and more efficient services, thereby gaining a competitive edge.[21]

The detailed interpretation and discussion of the EFA findings demonstrate the multifaceted benefits of I5.0 technologies in dairy farming. Each factor underscores significant areas of improvement, from operational efficiency to market competitiveness, highlighting the transformative potential of these technologies. The high-reliability scores further validate the consistency and robustness of the identified factors. Industry 4.0 adoption focused on gaining efficiency and productivity by relying on real-time monitoring, cyber-physical systems, *etc.*, but I5.0 adoption integrates sustainability, collaboration, customisation, *etc.*, as core enablers contributing towards a more resilient and sustainable dairy future.

### 5.6 Mapping the factors to TOE framework

In Section 2, the authors highlighted that the research explored the potential of I5.0 through the lens of the TOE framework. Thus, Fig. 1 presents the conceptual framework that maps the identified I5.0 enablers with the existing TOE framework. This approach connected the factors found in current research with the established TOE framework, changing the results from just analysis to a theory-based understanding.

The findings from the MLR analysis indicate that the factors can be ranked based on their coefficients from the regression equation. The ranking indicates the impact of factors on the level of adoption of I5.0 technologies. The higher coefficients show a strong influence on the adoption level. The "F3: Sustainability and environmental impact" with a coefficient of 0.283 has the highest impact, showing that improving sustainable practices and reducing environmental impact will positively affect the adoption of I5.0 technologies. The "F5: Market competitiveness and collaboration" is the second most influential key factor, with a coefficient of 0.233, indicating that increased market competitiveness and better collaboration drive adoption levels in dairy. Sustainability and environmental impact have evolved into the most significant factors because dairy stakeholders are becoming influenced by environmental impacts, regulatory aspects, and consumer requirements for sustainably produced products with minimal carbon footprints. However, operational efficiency is also relevant but highlights conventional automation objectives that are currently being redefined by I5.0 to focus on environmental impacts and human-centric approaches. F1: Operational efficiency and productivity ranks third with a factor of 0.174, highlighting that improving operational efficiency and productivity also considerably affects adopting I5.0 technologies. The "F4: Data-driven decision making and compliance," with a coefficient of 0.114, is the fourth most influential factor, indicating the importance of leveraging data and ensuring compliance in driving adoption.

The "F2: Animal health and product quality" has the lowest coefficient, indicating that while it positively affects adoption, its impact is relatively less than the other factors. The ranking indicates which factors are the most critical drivers for adopting I5.0 technologies in the dairy industry, highlighting the area of focus for the dairy stakeholders for maximum impact. Fig. 1 maps the identified enablers into TOE dimensions, which highlights the interaction among technological, organisational

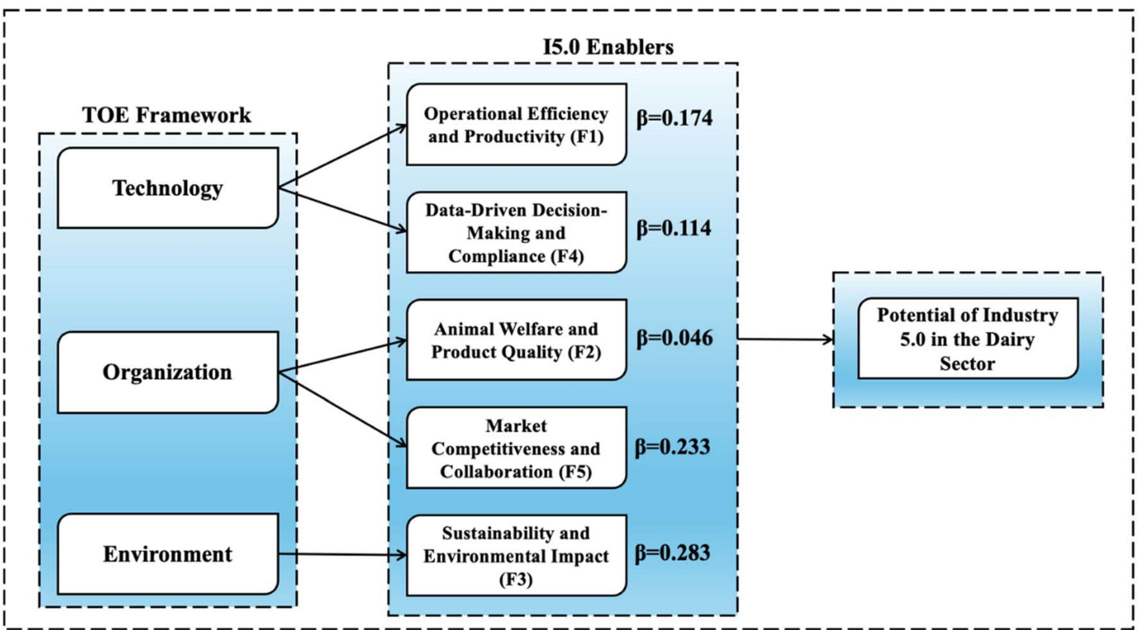


Fig. 1 Conceptual model of I5.0 enablers: TOE categorisation and standardised effects.

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and environmental dimensions to explore the potential of I5.0 towards dairy digital transformation in a sustainable and resilient way. As shown in Fig. 1, the technology dimensions bridge the operational efficiency and productivity by highlighting the technological potential, which improves the operational activities in dairy and boosts productivity. The smart decision-making based on data highlights the importance of digital technologies and regulatory compliance. The organisational dimension signifies the role of quality and animal welfare, collaborative efforts, and market competition in changing dynamics necessary for the I5.0 revolution. Finally, the environmental dimension includes ecological impacts and sustainability driven by regulatory standards related to climate, sustainable development goals and increasing consumer demands for global sustainability standards, and a rising consumer demand for ethically produced products. The extended framework can be further explored using more robust research approaches to investigate the full potential of I5.0.

## 6. Implications

The outcomes of this study are significant for both theoretical understanding and practical application and present a robust framework for comprehending the implementation of I5.0 technologies in the dairy industry. In theory, the study contributes to the current understanding by identifying and supporting essential concepts such as "Operational efficiency and productivity," "Animal welfare and product quality," "Sustainability and environmental impact," "Data-driven decision-making and compliance," and "Market competitiveness and collaboration". The constructs obtained using EFA validate that I5.0 technologies are broad and influence several aspects of dairy farming operations. This validation process assists in improving theoretical models related to technology adoption and digital transformation in conventional industries. The findings align with the I5.0 literature on other contexts, such as the dairy stakeholders, who can use these findings to strategically prioritise investments in I5.0 technologies to enhance operational efficiencies and productivity, including real-time data analytics, robotics, and predictive maintenance.[21] The emphasis on product quality and animal welfare implies that installing effective traceability systems, automated feeding mechanisms, and health monitoring systems can result in considerable gains in these areas.[2] Furthermore, the study emphasises the importance of sustainability, demonstrating how precise resource management and optimised waste treatment may reduce environmental footprints while ensuring compliance with severe ecological requirements. Managers are encouraged to implement energy-efficient technologies in line with broader environmental objectives.[9]

In addition, the analysis points out the need for proper compliance with regulations and decision-making based on data. Dairy enterprises may improve compliance with food safety and livestock welfare regulations by implementing I5.0 technologies, such as real-time monitoring and blockchain-enabled traceability, to achieve industry certifications and increase customer trust.[55] The findings also indicate that customised product offers, transparent operations, and improved relationships with technology providers can considerably raise market competitiveness by encouraging better collaborations and boosting supply chain transparency. The study also points out areas for future research, like long-term studies to see how I5.0 technologies affect things over time, comparing different regions and types of farming, and exploring how I5.0 can work with other new technologies. Further research should focus on identifying adoption constraints and analysing consumers' attitudes toward products made with these technologies. These recommendations seek to provide more comprehensive knowledge about digital transformation in agriculture and help create solutions for overcoming adoption barriers.

### 6.1. Theoretical implications

(1) Enhanced understanding of I5.0 adoption:

• This study strengthens the understanding of I5.0 adoption in the dairy industry by highlighting essential aspects such as operational efficiency, animal welfare, sustainability, data-driven decision-making, and competitiveness.

• It offers a thorough structure for defining I5.0 technologies and their influence on dairy businesses.

(2). Validation of constructs:

• The research evaluates I5.0 constructs using EFA, demonstrating their reliability and distinctness. This contributes to refining theoretical models surrounding I5.0 and its applications in many industries.

• Constructs including "Operational efficiency and productivity," "Animal welfare and product quality," "Sustainability and environmental impact," "Data-driven decision-making and compliance," and "Market competitiveness and collaboration" offer a foundation for future research.

(3). New insights on technology adoption:

• The research offers new insights into the factors driving the adoption of advanced emerging technologies, specifically for dairy. This can inform theoretical models of technology adoption, innovation diffusion, and traditional industries' digital transformation.

### 6.2 Practical implications

To assist practitioners in prioritising I5.0 adoption, the schematic given in Fig. 2 demonstrates the five key enablers based on their standardised regression weights, as well as the practical implications resulting from the findings. Each enabler highlights practical implications such as "Sustainability & environmental impact (F3)," which pointed towards a focus on net-zero goals and exploring green energy sources to meet sustainability objectives; "Market competitiveness & collaboration (F5)," which emphasised the importance of collaborative environments and strategic roadmaps for market dynamics; "Operational efficiency & productivity (F1)," which outlined the integration of technological advancements within operational activities; and "Data-driven decision-making & compliance (F4)," which suggested implementing the digital dashboard for real-time decision-making and maintaining transparency for regulatory compliances.

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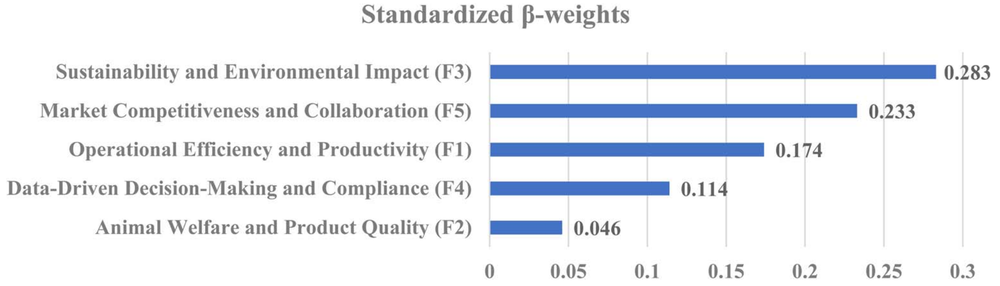


Fig. 2 Ranked Industry 5.0 enablers based on standardised β-weights.

Despite having less influence, "Animal welfare & product quality (F2)" outlined responsible production, improved quality, and enhanced animal welfare. Therefore, the stakeholders can develop effective strategies following the ranking given in Fig. 2, focusing on the influence of each enabler. Fig. 2's findings suggest the following practical implications:

(1) Strategic planning for dairy farms:

• Dairy management can use the findings to identify investment areas related to I5.0 technologies and improve productivity and operational efficiency.

• The identified factors pave the way to address issues, including animal welfare and related aspects.

(2). Sustainability initiatives:

• The identified sustainability-related factors discussed the importance of effective waste optimisation and resource management. Management should employ technologies that optimise feed and water consumption, minimise environmental footprints, and ensure compliance with environmental regulations.

• Management needs to ensure the use of energy-efficient systems to minimise energy consumption, aligning with sustainability goals.

(3). Regulatory compliance and data-driven decision-making:

• Dairy stakeholders must adopt technologies to improve the regulatory compliance processes related to food safety and animal welfare regulations. Traceability and real-time monitoring are essential for consumer trust and meeting industry standards.

• Data-driven decision-making should be a core strategy, leveraging I5.0 technologies to ensure compliance and optimise operations.

(4). Market competitiveness and collaboration:

• Dairy management should focus on customised product development, transparency in dairy operations, and collaboration with research and technology developers to improve competitive advantage. I5.0 technologies can enhance market competitiveness by fostering better partnerships and improving supply chain transparency.

## 7. Conclusion

This research explores the key factors driving the adoption of I5.0 in the dairy industry using EFA and MLR methods. The key factors were investigated using a literature review, and 33 statements were analysed. The EFA categorised these statements into five key factors. These five factors include operational efficiency and productivity, animal welfare and product quality, sustainability and environmental impact, data-driven decision-making and compliance, and market competitiveness and collaboration. The reliability analysis highlights highly significant reliability for all factors, which are 0.959, 0.922, 0.911, 0.856, and 0.859. The multifaceted advantages of integrating emerging digital technologies into dairy operations make it an interesting study. The findings can assist dairy stakeholders in utilising I5.0 technologies for animal welfare, production, management, safety, quality, sustainability, and regulatory aspects.

Considering the limitations of the current research, the empirical survey includes most of the participants from the Indian context. In the future, the inclusion of multiple developing countries will enhance the generalisation of the findings. Additionally, the findings may be influenced by some limitations related to participants, such as insufficient knowledge of digital technologies, social desirability, and inaccurate self-assessment. Inclusion of responses from other related stakeholders, such as consumers, regulators, *etc.*, can also impact the findings. The 63.8% variance explained by the five identified factors means that some important factors, which could significantly change the model, are not included. Future studies could include factors such as infrastructure cost and readiness, organisational and stakeholder resistance, *etc.* Thus, the current research outlines these limitations and recommends a thorough investigation in the future to develop a sustainable and resilient roadmap. Addressing these limitations will help extend the findings of the study to more generalised, comparative, and stakeholder-industry-oriented approaches. Moreover, the findings point to future research opportunities, such as long-term studies to look at lasting effects, comparisons with other studies, and assessing how I5.0 can work with new technologies. The most promising future research avenues are examining the key challenges related to adopting I5.0 technologies from an industrial perspective and developing effective strategies to address these barriers. By addressing these research directions, academics and industry professionals can work together to accelerate the digital transformation of the dairy sector, enabling innovation, sustainability, and competitive advantage. Overall, this study highlights the revolutionary possibilities of I5.0 technology in the dairy industry. The study adds to theoretical knowledge and offers practical

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recommendations for effectively integrating modern technologies by identifying critical aspects and offering a detailed analysis of their effects. The ongoing investigation of these issues will further promote innovation and sustainable practices in the dairy industry, ensuring its growth and resilience in an increasingly digital transformation era.

## Conflicts of interest

There are no conflicts to declare.

## Data availability

The data supporting this article have been included in the article, or no new data were generated as part of this research.

## Appendix

Table 6 Respondent demographics summary

| Categories | | Number of Participants |
|---|---|---|
| Role in Dairy | Production | 42 |
| | Processing | 103 |
| | Distribution | 35 |
| | Dairy Management | 111 |
| | Technology Provider | 29 |
| | Policy Makers | 7 |
| Experience | 0–7 | 74 |
| | 7–15 | 113 |
| | 15–20 | 121 |
| | More than 20 | 19 |
| Total | | 327 |

## Acknowledgements

The authors acknowledge their institutes. Sandeep Jagtap would like to acknowledge the FORCE (Center for Food System Resilience and Competitiveness) at Lund University.

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