DOI: https://doi.org/10.18778/0867-5856.2026.13 e-ISSN 2080-6922, ISSN 0867-5856

COPE Member since 2019 JM14487

Turyzm/Tourism
2026, *36*(1)

Energy reduction technologies as catalysts for digital transformation and sustainable operations: Evidence from the hotel industry

Neeta Israni[a, *], James Hanrahan[b]

[a] Atlantic Technological University (Sligo, Ireland), Department of Marketing, Tourism and Sport, School of Business and Social Science; https://orcid.org/0009-0004-7761-1050; e-mail: neeta.israni@research.atu.ie
[b] Atlantic Technological University (Sligo, Ireland), Department of Marketing, Tourism and Sport, School of Business and Social Science; https://orcid.org/0000-0002-6907-0395; e-mail: james.hanrahan@atu.ie
[*] Corresponding author.

How to cite (APA style): Israni, N., & Hanrahan, J. (2026). Energy reduction technologies as catalysts for digital transformation and sustainable operations: Evidence from the hotel industry. *Turyzm/Tourism, 36*(1), 169–186. https://doi.org/10.18778/0867-5856.2026.13

ABSTRACT

The hospitality sector is facing growing scrutiny over its energy consumption and carbon emissions, placing hotels under pressure to pursue net-zero greenhouse gas (GHG) targets while maintaining high service quality. This study investigates the adoption of energy reduction technologies in the Irish hotel industry and their link to sustainable hotel operations through digital transformation, specifically via the adoption of robotics, AI and service automation (RAISA). Survey responses were collected from various star category hotels within Ireland. Valid survey responses were included in the data analysis which involved linear regression and bootstrapping. The theoretical underpinning of the study was diffusion of innovations theory. Results indicated an uneven adoption, with energy software and automation systems being more prevalent among innovators and early adopters, while technologies such as smart thermostats are more common among the late majority. Energy software strongly correlates with overall RAISA adoption, highlighting its role as a digital enabler. The study indicates that the adoption of sustainability-driven energy reduction technologies can bolster broader digital adoption. By demonstrating how sustainability-driven energy reduction technologies can catalyse broader digital transformation, the study provides actionable insights for hotel managers seeking to enhance operational efficiency and sustainability, as well as for policy-makers aiming to design targeted interventions that accelerate technology adoption across the sector. The research also contributes theoretically by linking energy management to RAISA adoption within the framework of the diffusion of innovations, offering a model for understanding technology adoption pathways in the hospitality sector.

KEYWORDS

energy reduction technologies, RAISA, diffusion of innovations, digital transformation, sustainability

ARTICLE INFORMATION DETAILS

Received:
16 October 2025
Accepted:
23 February 2026
Published:
11 June 2026

Funding information: Atlantic Technological University, Ireland, through the Postgraduate Research Training Programme in Operations and Supply Chain Research (OSCAR). **Conflicts of interests:** None. **Ethical considerations:** The Authors assure of no violations of publication ethics and take full responsibility for the content of the publication. **The percentage share of the Author in the preparation of the work is:** N.I. 70%, J.H. 30%. **Declaration regarding the use of GAI tools:** No AI tools were used to create the content of this paper. However, Grammarly was used to improve the grammar and the English language dialect in the paper.

1. Introduction

Globally, the hotel industry is facing a multitude of challenges, including rising operational costs, increasing energy consumption, stringent environmental regulations, and heightened customer expectations. Hotels are highly resource-intensive, and sustainable operations have become a pressing concern, requiring the sector to reduce greenhouse gas (GHG) emissions while maintaining high levels of service and profitability. Achieving this balance is critical not only for environmental responsibility but also for long-term competitiveness and financial performance.

Linking sustainability and digitalisation, the European Commission (2021) highlights that sustainability transitions can benefit from digital technologies which in turn can drive innovation, creating new opportunities for competitiveness. Digital sustainability refers to the deployment of smart technologies that support sustainable economic growth while integrating the United Nations Sustainable Development Goals (Mondejar et al., 2021). Organisations seeking to elevate their digital maturity need to undergo a comprehensive digital transformation across every facet of their operations (Aslanova & Kulichkina, 2020). With advancements in technology, hotels have increasingly adopted robotics, artificial intelligence and service automation (RAISA) solutions such as in-room smart technologies which may enable hotels not only to reduce costs, waste and energy consumption but also to enhance operational efficiency, design innovative service experiences, boost revenue while transforming business models and the nature of work (Webster & Ivanov, 2019).

This study was carried out in Ireland. The Irish government is committed to reducing GHG emissions by 30% by 2030 (Conefrey & Hanrahan, 2022). However, the Environmental Protection Agency (2025) projects that, under current trends, Ireland is likely to achieve only a 23% reduction, requiring comprehensive policy implementation across all sectors, including hospitality. Hotels are facing steep increases in energy costs, with reports of an 88% year-on-year rise ("Irish Hotels Federation [IHF] members report escalating business costs", 2022). To address this, many Irish hotels have begun adopting RAISA technologies and innovative energy-reduction solutions. For example, Sligo Park Hotel has upgraded boilers, implemented LED lighting, and actively monitors energy use to reduce its carbon footprint (Sustainable Energy Authority of Ireland, n.d.).

This exploratory study investigates the adoption of energy-reduction technologies in the Irish hotel industry and examines their relationship with the broader uptake of RAISA technologies. The study is guided by the following research question: To what extent and through what mechanisms does the adoption of energy technologies predict the uptake of RAISA in Irish hotels?

The study has the following four objectives, to:

1. Measure the adoption rate of RAISA technologies across Irish hotels.
2. Explore the distribution of RAISA adoption rates by hotel star category within the four provinces of Ireland (Ulster, Munster, Connacht, Leinster).
3. Classify hotels into the five adopter categories based on the diffusion of innovations.
4. Investigate the impact of energy monitoring and conservation technologies on overall RAISA adoption, identifying which energy technologies most strongly influence digital transformation in the sector.

The study limits its scope to examining patterns of association between the adoption of energy reduction technologies and RAISA adoption, identifying which energy technologies are most strongly linked with broader digitalisation. Due to the cross-sectional survey design, these analyses measure association rather than causal impact. The primary data is visualised through the theoretical lens of diffusion of innovations theory (Rogers et al., 2014).

2. Literature review

This section is divided into four sub-sections. It begins with a review of energy technologies and sustainability, followed by a review of digitalisation and RAISA. The third sub-section examines the integration of these domains, and the final section presents the grand theory of diffusion of innovations that guides this study.

2.1. Energy technologies and sustainability

Climate has changed significantly due to the change in the proportionality and concentration of GHGs in the atmosphere, and the global average temperature has gradually increased (Mikhaylov et al., 2020), leading to climate change. The United Nations' COP27 summit emphasised the urgent need for climate action (Frangoul, 2022). Climate change is a significant crisis facing humanity (Conefrey & Hanrahan, 2022). The primary sources of GHG emissions in the hospitality sector come from lighting, heating, cooling and cooking (Dube & Nhamo, 2021).

The new technological revolution (Industry 4.0) could help to combat climate change (Ben Youssef & Zeqiri, 2022). For instance, adopting smart Industry 4.0 technologies, such as internet of things (IoT) enabled systems and smart heating, ventilation and air conditioning (HVAC) controls, present significant opportunities for improving energy efficiency in hotels (Karvounidi et al., 2024) and reducing their carbon footprint. Specifically, energy management systems (EMSs) are integrated platforms that monitor, control, and optimise the energy consumption of buildings in real time by collecting data from subsystems such as HVAC, lighting and other loads. Modern EMSs incorporate IoT sensors, advanced analytics and AI to support fault detection and automated control of energy use, thereby enhancing operational efficiency and sustainability (Akbulut et al., 2025; Kozlovska et al., 2023).

With the development of technology, the advantages of innovative solutions are recognised, which lead to savings in resources and energy sources in hotels, and they become the subject of research, innovation, and implementation in the hotel industry (Floričić, 2020). For instance, Kong et al. (2022) asserted that under experimental and field conditions, occupancy-based HVAC control systems, which include smart thermostats or occupancy sensing, can reduce HVAC energy consumption by approximately 17% and 24% compared to traditional constant-setpoint control. Predictive maintenance, enabled by IoT sensors and AI analytics, can contribute significantly to energy savings in hotels by ensuring that equipment such as HVAC, refrigeration and other building systems operate at optimal efficiency and by preventing energy-intensive malfunctions (Anubala, 2023). Arfiansyah and Arifin (2021) observed that the room control automation system in the Grand Hyatt Hotel Jakarta, in 62 days, led to 29.06% electricity savings. Yousef and Chaer (2025) underscored the potential of IoT-driven smart metering systems to optimise energy efficiency by analysing energy consumption patterns of 11 hotels in London and then conducting a detailed investigation in one selected hotel where IoT-enabled smart metering was implemented. Guercio et al. (2023) studied a 5-star hotel located in southern Italy, characterised by high energy consumption. They used TRNSYS software to simulate replacing the existing air conditioning system with one powered by renewable energy.

The adoption of these energy monitoring and conservation technologies may facilitate greater digitalisation and RAISA adoption among hotels.

2.2. Digitalisation and robotics, artificial intelligence and service automation (RAISA)

Digital transformation involves leveraging new technologies to revolutionise business processes, enhance customer experiences and develop innovative business models (Aras & Büyüközkan, 2023).

The Fourth Industrial Revolution or Industry 4.0 (IR 4.0) revolution, characterised by emerging technologies such as automation, robotics, artificial intelligence, cloud computing, IoT, big data, 3D printing and blockchain (Falwadiya & Dhingra, 2022), significantly influences the hospitality and tourism sectors (Osei et al., 2020).

Substantial advancements have been observed globally within the domains of RAISA (Sharma & Aggarwal, 2024; Yan et al., 2025). RAISA has facilitated numerous service innovations, such as mobile check-in and check-out, keyless room access, in-room AI assistants, robotic services and AI-driven chatbots (Yan et al., 2025). Although these technologies have the potential to boost operational efficiency, lessen staff workloads and elevate guest experiences, their broader implementation in the hospitality sector is still constrained by factors such as uncertain return on investment (ROI), data privacy concerns, early-stage technological development, and the sector's continued reliance on human-centred service (Ozdemir et al., 2023). Accordingly, the extent and pace of RAISA adoption may differ between different countries. For example, Fu et al. (2026) observed that hotels in China have implemented more sophisticated AI and robot-enabled services, facilitated by rapid national digitalisation, lower technology-acquisition costs, and strong partnerships with domestic technology providers. By contrast, hotels in Australia have largely concentrated on more established mobile-based technologies. Australian hotel managers associated the slower uptake of RAISA with several contextual constraints, including narrower profit margins resulting from higher operating costs, a more risk-averse business culture, stringent data privacy regulations, geographic distance from global innovation hubs and cost-effective suppliers, and a less technologically competitive domestic market. Together, these institutional and market-specific factors help account for differences in RAISA adoption between the two countries and provide important context for understanding cross-national variation. Furthermore, different hotels within the same country can have different speeds of digitalisation, as was underscored by García-López et al. (2025), who concluded that digitisation in Andalusian (Spain) hotels flows at different speeds. Yang et al. (2024) used diffusion of innovations theory to suggest that in the Chinese hospitality market, budget hotels may focus on specific digital tools for operational efficiency while high-star hotels engage in more intensive and comprehensive digital transformation. The different rates of RAISA adoption by different hotels may be influenced by several factors. For instance, Nikopoulou et al. (2023), based on the 502 responses of an online questionnaire sent to managers of hotels in Greece, concluded that the intention to adopt digital technology is influenced by the digital maturity of organisations, financial resource availability and government regulations.

These studies underscore that the diffusion of innovative technologies is influenced by different factors, and different countries or different provinces within the same country can be at different stages of diffusion and thus may fall under different categories of adopters, as discussed under the theoretical framework of the study.

2.3. Energy technologies and RAISA for sustainable operations

Contemporary sustainability discourse increasingly recognises that sustainability extends beyond environmental protection to include social and economic dimensions, often conceptualised as the triple bottom line of planet, people and profit (Dube & Nhamo, 2021; Elkington, 2020). Within the hotel sector, sustainability initiatives are no longer driven solely by environmental compliance but also by operational efficiency, workforce challenges and long-term competitiveness. Recent studies indicate that hotels that adopt sustainability-oriented technologies often achieve improved financial performance, enhanced employee productivity and stronger brand positioning (Jones et al., 2016).

Across Europe, the hospitality sector is currently facing significant challenges, including labour shortages linked to declining birth rates. Ireland's total fertility rate (TFR) has been declining, reaching 1.5 births per woman in 2023, well below the 2.1 replacement level (United Nations – Department of Economic and Social Affairs Population Division, 2022). RAISA technologies, including AI-enabled service systems, robotics and automated customer interaction platforms, have been increasingly recognised as potential solutions to mitigate workforce constraints while enhancing guest experience, cost savings and operational efficiency (Ivanov & Webster, 2021; Kim et al., 2022).

Simultaneously, rising energy costs pose a major operational challenge for hotels, particularly in Europe, where energy price volatility and climate policy targets are reshaping industry priorities (Karvounidi et al., 2024; Thomas, 2022). The adoption of energy monitoring and conservation technologies, such as IoT-enabled EMS, predictive maintenance systems and smart HVAC controls, has demonstrated substantial potential to reduce operational costs while supporting environmental sustainability goals (Akbulut et al., 2025; Bekele et al., 2024; Kozlovska et al., 2023; Pastor, 2025). However, the adoption of environmental technologies, which may lead to greater digital maturity, may be constrained by several barriers, such as high purchase and implementation costs (Chan et al., 2020; García-López et al., 2025). To offset the high cost of expensive technologies, government grants and subsidies can exert a statistically significant effect on a hotel's willingness to adopt such technologies (Ezzaouia & Bulchand-Gidumal, 2020; Oloso, 2025).

A few researchers (Ka et al., 2023; Nikopoulou et al., 2023; Zaragoza-Sáez et al., 2024) suggest that the adoption of one class of technology can serve as a stepping stone toward broader digital transformation, particularly among sustainability and efficiency-focused operators. For instance, the introduction of property management systems (PMSs) may reshape hotels' daily operations and enhance their digital maturity (Ka et al., 2023). Despite increasing recognition of the potential complementarities between sustainability-driven energy technologies and digital transformation initiatives, there remains limited empirical evidence examining the extent to which the adoption of energy technologies predicts RAISA uptake for sustainable operations, particularly within the Irish hotel sector. Addressing this gap, the present study investigates how the adoption of energy monitoring and conservation technologies may catalyse RAISA adoption in Irish hotels, thereby contributing to the broader discourse on sustainable and digitally enabled hospitality operations.

2.4. Theoretical framework: Diffusion of innovations theory

To investigate how RAISA and, particularly, energy management technologies are being adopted within the Irish hotel sector, this study employs Everett Rogers' diffusion of innovations theory as a foundational theoretical framework. Rogers (2014) asserts that the characteristics of an innovation determine its rate of adoption and the five attributes of innovations are (a) relative advantage, (b) compatibility, (c) complexity, (d) trialability and (e) observability.

The diffusion of innovations theory is particularly effective for examining the rate and pattern of adoption of innovation among various user groups. The diffusion of innovations theory segments adopters into five categories based on their behaviour and timing of adoption. This segmentation provides valuable insights into how innovations permeate the sector:

1. Innovators (2.5% of the total sample): These are the pioneers who adopt the technology first. These may be forward-thinking hotel groups or luxury brands that lead experimentation, often piloting cutting-edge technologies such as advanced EMS that leverage real-time data, AI-driven analysis and building automation to optimise energy use.
2. Early adopters (13.5% of the total sample): This group consists of strategic leaders who are acutely aware of the need for change. Typically, boutique or upscale hotels that view innovation as a strategic differentiator may fall under this category. Their endorsement helps shape industry benchmarks and accelerates broader uptake.
3. Early majority (34% of the total sample): While not being leaders themselves, these individuals or organisations tend to embrace innovation after they are presented with clear evidence of the benefits

of adopting the innovative product or idea. Mid-range or business-focused hotels that implement proven solutions, having observed benefits such as cost reduction and improved service efficiency among early adopters, may fall under this category.

4. Late majority (34% of the total sample): More risk-averse operators who adopt only after clear evidence of industry-wide success, regulatory support and peer endorsement. Typically, smaller, independently owned hotels with limited resources may fall under this category.
5. Laggards (16% of the total sample): They are the traditionalists, resistant to change and the most difficult to convince. They may not necessarily be low on resources, but may believe, "Why fix it if it's not broken?". Satisfied with their legacy systems, they may be reluctant to replace them with innovative technologies.

Figure 1 demonstrates the classic adoption curve, with time depicted on the horizontal axis and the cumulative percentage of adopters implementing an innovation on the vertical axis.

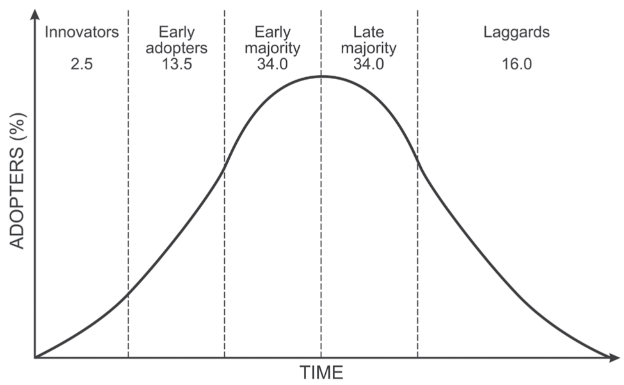

Figure 1. Diffusion of innovations theory
Source: authors, based on Rogers (1984)

By proposing a metric for RAISA adoption and examining its distribution across hotel star categories and provinces, the study applies the diffusion of innovations framework to segments of the Irish hotel sector accordingly. Furthermore, the theory supports the investigation of how specific technologies, such as energy monitoring and conservation systems, influence the overall RAISA adoption rate, thereby helping to identify which innovations act as potential catalysts for wider digital transformation in the sector.

3. Methodology

This study was the first baseline study on the rate of adoption of innovative RAISA-backed technologies by the Irish hotel sector. There are four provinces in Ireland: Ulster, Connacht, Leinster, and Munster. At the time of the study, 833 hotels were registered with Failte Ireland, the Irish tourism board. The distribution of hotel star ratings in the Irish hotel sector indicates a strong concentration in the mid-to-upper categories. Specifically, there are 365 four-star hotels and 283 three-star hotels, together forming the majority of the sector. At the higher end, there are 36 five-star hotels, representing a smaller but significant premium segment. In the lower tiers, the sector includes 77 two-star hotels and 72 one-star hotels. This distribution highlights a sector dominated by mid-range to upscale properties, with relatively fewer establishments at both the luxury and budget ends of the spectrum (Fáilte Ireland, 2024).

A survey questionnaire was designed with a list of innovative RAISA-backed technologies for both front-end and back-end hotel operations, for online circulation among the entire population of 833 listed hotels in Ireland. The questionnaire was developed particularly to capture emerging energy-reduction technologies in the hotel sector, for which, to the best of our knowledge, no previously validated unified measurement scale exists. Survey items were generated through an extensive review of academic literature, industry reports and online sources documenting technologies currently implemented or under consideration in hotel operations. To strengthen content validity and enhance clarity, the draft questionnaire was reviewed by experts. Feedback from this review was incorporated to refine item wording, improve relevance and enhance the overall quality of the questionnaire.

While the initial population of interest included 833 hotels, at the time of data collection between May 2024 and 2025, many hotels were being used as asylum centres mainly for Ukrainian war refugees and were therefore not operating as conventional hotels. This significantly reduced the response to the survey. Furthermore, it is speculated that the lack of any incentive for the respondents, whether in cash or in kind, may have contributed to the limited number of responses. Only 91 responses were obtained, which, after data cleaning, were reduced to 79. This low response rate was mitigated by bootstrapping.

3.1. Bootstrapping

Given the limited availability of hotel-level data in Ireland, particularly regarding the adoption of innovative technologies, the sample size was very small, comprising only 79 valid responses. A traditional statistical analysis based on large sample assumptions would not have yielded reliable or robust insights. To address this constraint and enhance the validity of the analysis, a bootstrapping approach was employed. From the original dataset of 79 responses, 1,000 bootstrap samples were generated. Each sample was constructed by randomly selecting observations with replacement, maintaining the same sample size as the original. For each bootstrap sample, key summary statistics and model estimates, such as adoption rates by hotel star rating and province, were recalculated. Bias-corrected confidence intervals were derived from the resulting distributions, offering more accurate and stable measures of uncertainty. The bootstrapping approach provided several benefits in this context: it improved generalisability, required no assumptions about the underlying data distribution, enhanced model robustness by mitigating the influence of outlier observations, and enabled better estimation of variability in the results. A 0.632 version of the same methodology was applied to confirm the results of a normal bootstrap.

3.2. Construction of the adoption rate variable

To quantify the extent of innovative technologies adoption across Irish hotels, a composite "adoption rate" score was developed based on responses to three key survey questions. This score serves as a numeric proxy for the intensity of technology adoption at both the individual hotel and broader sectoral level, or sector-wide levels. At individual hotel level, the first component was a binary indicator capturing actual usage, derived from responses to the question: "Do you use innovative technologies like robotics, artificial intelligence and service automation in your hotel operations?" responses were coded as 1 for *yes* and 0 for *no* resulting in the variable "use of technology", representing the presence or absence of such technologies in the respondent's hotel. The second component measured perceived hotel-level adoption through the question: "In your opinion, the current level of adoption of innovative technologies in your hotel operations is: … ", with responses ordinally coded as 1 (*low*), 2 (*moderate*) and 3 (*high*), creating the variable "hotel technology level". The third component captured perceptions of sector-wide adoption via the question: "As per your knowledge, the current level of adoption of innovative technologies in the hotel sector of Ireland is:", with identical ordinal coding to form the variable "sector technology level". These three variables were combined into a simple additive index: "adoption rate = use of technology + hotel technology level + sector technology level". This resulted in a continuous measure ranging from 2 to 7, where a score of 2 reflects limited usage and uniformly low perceptions of adoption, while a score of 7 indicates active usage and high levels of perceived adoption both within the hotel and across the sector. The internal consistency of the three-item scale was assessed using both standard Cronbach's alpha and ordinal alpha. The standard alpha, based on numeric coding of the items, was 0.60. Although classical guidelines often cite 0.70 as a typical threshold for acceptable reliability, values between 0.60 and 0.70 may be acceptable or tolerable for early or exploratory research, especially with short scales (George & Mallery, 2024; Nunnally, 1978). Ordinal alpha based on polychoric correlations, which more appropriately accounts for ordinal and dichotomous response formats, yielded a higher estimate of 0.73, consistent with recommendations that reliability coefficients above 0.70 indicate satisfactory internal consistency in social science measurement (DeVellis & Thorpe, 2021; Gadermann et al., 2012). The average inter-item correlations (0.34 for standard and 0.47 for ordinal) further suggest moderate coherence among the items, supporting the overall internal consistency of the scale.

For this exploratory study, a composite index (unweighted) was used. Weighted indices or factor-analytic models were considered, but due to the modest sample size and the heterogeneous nature of the indicators (dichotomous, ordinal and perceptual), which violates key assumptions underlying latent variable modelling, a parsimonious additive index was selected as a transparent and theoretically defensible approach consistent with the study's exploratory objectives. So, a composite index (unweighted), which integrated actual behaviour (usage), organisational self-assessment (internal perceptions), and broader market awareness (external perceptions), capturing both tangible and attitudinal dimensions of innovation uptake, was used. This multidimensional structure aligns with the diffusion of innovations theory (Rogers et al., 2014), which emphasises the role of both individual and contextual factors in innovation diffusion.

3.3. Linear regression modelling

To examine the relationship between the adoption of innovative technologies (RAISA) and the implementation of energy reduction systems within the Irish hotel industry, a multiple linear regression model was employed. This analytical approach enables the quantification of the extent to which variations in energy-related innovations can predict or explain the adoption of broader innovative technologies (RAISA). Linear regression is a commonly used statistical method that models the relationship between a dependent variable and one or more independent (predictor) variables. In this study, we applied a multiple linear regression framework because there are several predictors involved.

The general form of the multiple linear regression model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \epsilon$$

Where:
1. Y is the dependent variable (e.g. innovative technology adoption rate);
2. $X_1, X_2, \ldots, X_n$ are independent variables (e.g. use of energy-saving systems, smart thermostats, lighting automation, etc.);
3. β_0 is the intercept;
4. $\beta_1, \ldots, \beta_n$ are the coefficients representing the influence of each predictor;
5. ϵ is the error term capturing unexplained variation.

In this study, the dependent variable Y represents a log-transformed version of the adoption rate of innovative technologies in hotels. The independent variables included key indicators of energy-efficiency efforts, such as the adoption of smart energy management systems and motion-based lighting systems.

This regression model estimates the degree to which the adoption of each energy-related technology influences the likelihood or intensity of adopting broader RAISA-driven innovative systems. The underlying assumption is that hotels that invest in energy-reduction technologies are more likely to adopt other innovative technologies for eco-efficient operations. This association may reflect a broader strategic commitment to sustainability and a higher level of digital readiness.

Model estimation was conducted using the ordinary least squares (OLS) method. Given the small sample size ($n = 79$), bootstrapping was applied to generate robust confidence intervals for the regression coefficients, thereby improving the reliability of statistical inference.

4. Results and discussions

This section presents the outputs and findings from the demographic, regression and bootstrapping analyses.

4.1. Province and star-based patterns of innovation adoption in the Irish hotel sector

Table 1 and 2 present a detailed distribution of innovation adopter categories (laggards, late majority, early majority, early adopters and innovators) within the Irish hotel industry. The tables are organised into several sub-panels to reveal both regional and star-based dimensions of technology adoption.

Table 1 (left) displays the overall distribution of adopter categories across the four provinces: Connacht, Leinster, Munster and Ulster. Here, Leinster emerges as the most innovation-forward region, with 14% of hotels categorised as early adopters and 24% as early majority. In contrast, Connacht and Ulster have a higher concentration of laggards and late majority adopters, indicating a more cautious approach to technological innovation. Munster shows a relatively even spread, but with very few innovators (1%). This finding substantiates the study by García-López et al. (2025) that concluded that digitisation in Andalusian (Spain) hotels flows at different speeds.

Table 1. Distribution of innovation adopter categories across Irish provinces and hotel star ratings (% of hotels)

Adopter category	Province (% of hotels)				Hotel star rating (% of hotels)			
	Connacht	Leinster	Munster	Ulster	2 star	3 star	4 star	5 star
Laggards	6	13	5	4	0	6	19	3
Late majority	6	15	0	3	1	10	11	1
Early majority	3	24	0	0	3	9	13	3
Early adopters	0	14	1	0	0	4	9	3
Innovators	0	5	1	0	3	0	3	1

Source: authors.

Table 1 (right) focuses on the relationship between hotel star ratings and adopter categories. A clear trend emerges that the higher star ratings correlate with earlier adoption. Four-star hotels are notably progressive, with 13% representing the early majority and 9% representing the early adopters. Five-star hotels, though smaller in number, have a good presence of innovators (1%) and early adopters (3%). On the other hand, two-star and three-star hotels are predominantly laggards or part of the late majority, highlighting the lag in adoption among lower-tier establishments. This pattern is consistent with findings by Yang et al. (2024) that higher-category hotels exhibit earlier and more intensive adoption of digital technologies.

Table 2. Cross-tabulation of innovation adopter categories by Irish province and hotel star ratings (% of hotels)

Province	Adopter category	Hotel star rating (% of hotels)			
		2 star	3 star	4 star	5 star
Connacht	Laggards	0	8	33	0
	Late majority	0	25	17	0
	Early majority	0	0	17	0
	Early adopters	0	0	0	0
	Innovators	0	0	0	0

Table 2 (cont.)

Province	Adopter category	Hotel star rating (% of hotels)			
		2 star	3 star	4 star	5 star
Munster	Laggards	0	17	50	0
	Late majority	0	0	0	0
	Early majority	0	0	0	0
	Early adopters	0	17	0	0
	Innovators	17	0	0	0
Leinster	Laggards	0	5	9	4
	Late majority	0	7	13	2
	Early majority	4	13	14	4
	Early adopters	0	4	13	4
	Innovators	2	0	4	2
Ulster	Laggards	0	0	60	0
	Late majority	20	20	0	0
	Early majority	0	0	0	0
	Early adopters	0	0	0	0
	Innovators	0	0	0	0

Source: authors.

Table 2 provides a more granular view by cross-tabulating adopter categories by star rating within each province. These provincial breakdowns reveal nuanced regional disparities. For instance, in Leinster, five-star hotels include early adopters (4%) and innovators (2%), reinforcing Leinster's advanced technological posture. Conversely, Ulster exhibits a concentration of laggards (60%) in four-star hotels, with no hotels in the early adopter or innovator categories, suggesting significant barriers to innovation in that region. Connacht is characterised by a dominance of late majority and laggards across three- and four-star hotels, with no presence of early adopters or innovators. Munster exhibits some variation, with 17% innovators in the two-star hotel category, which is likely an outlier due to a small sample size.

Taken together, Tables 1 and 2 underscore the uneven diffusion of innovative technologies across Ireland's hotel sector. Both geographic location and hotel star rating appear to be influential factors, with higher-star hotels in more urbanised or economically active regions, such as Leinster, being more receptive to innovation. These results support the earlier studies (e.g. Akbulut et al., 2025; Bekele et al., 2024; Fu et al., 2026; Kozlovska et al., 2023; Nikopoulou et al., 2023; Pastor, 2025; Yang et al., 2024) that commitment to sustainability, resource availability and digital transformation readiness play crucial roles in shaping adoption behaviour. For policymakers and industry leaders, these insights underscore the need for targeted strategies to promote innovation adoption in lagging regions and among lower-rated establishments.

4.1.1. Non-response bias assessment

Although the response rate was modest (79 usable responses from a population of 833 hotels), an assessment of non-response bias was undertaken by comparing the distribution of responding hotels with that of the population across observable characteristics, namely star rating and geographic region. Descriptive comparisons are presented in Table 3 (star rating distribution) and Table 4 (region distribution).

Table 3. Star rating comparison

Star rating	Population (%)	Sample (%)
1	9	0
2	9	6
3	34	29
4	44	54
5	4	10

Source: authors.

Table 4. Regional distribution comparison

Region	Population (%)	Sample (%)
Ulster	9	6
Connacht	19	15
Munster	33	8
Leinster	39	71

Source: authors.

Chi-square goodness-of-fit tests indicate statistically significant differences between the sample and population distributions for both star rating ($p < 0.05$) and regional location ($p < 0.05$). Specifically, the sample over-represents higher-category hotels and properties located in urban regions, while lower-category and rural hotels are comparatively under-represented.

This pattern is consistent with non-response marked in previous studies. For instance, in a study carried out by Nikopoulou et al. (2023), the final sample consisted of 502 hotels in Greece out of 5800 in total. The response rate was around 10%. While the results of this study suggest the presence of non-response bias on observable characteristics, they do not invalidate the study's findings. Rather, they may imply that the results are most reflective of hotels that are comparatively more engaged with or receptive to the adoption of RAISA. Nevertheless, the implications of sample composition are carefully considered in the interpretation of results, and caution is exercised when generalising the findings to smaller, lower-category, or more rurally located hotels.

4.1.2. Distribution of technology use by hotel star category

Table 5 presents the adoption rates of selected energy management and smart building technologies across hotel categories. Overall, the results indicate a differentiated pattern of technology uptake, with higher-category hotels demonstrating greater engagement with advanced energy and automation solutions. Energy management systems (EMS) show relatively consistent adoption across categories, ranging from 45% in three-star hotels to 57% in five-star hotels, suggesting that basic energy monitoring has become a widely accepted practice irrespective of hotel classification. Smart HVAC systems are more prevalent in higher-category hotels, with adoption rates increasing from 27% in three-star hotels to 71% in five-star hotels, reflecting the higher capital capacity and infrastructural sophistication of upscale properties. In contrast, more advanced or data-driven technologies such as predictive maintenance systems and intelligent defrost systems exhibit notably low adoption across all categories, highlighting the nascent stage of advanced digital transformation in the sector. Motion sensor lighting and room automation systems display adoption across all categories of hotels, showing uniform adoption across the range. In contrast, predictive maintenance applications show moderate uptake across categories, possibly due to their high costs of purchase and implementation, reported as a barrier to adoption of environmental technologies (Chan et al., 2020; García-López et al., 2025).

Table 5. Adoption of energy use reduction technologies by hotel star rating

Technology	Hotel star rating (% of hotels adopting the technology)			
	2 star	3 star	4 star	5 star
Energy management system (EMS)	50	45	58	57
Motion sensor lighting (MSL)	50	91	78	29
Intelligent defrost system (IDS)	0	18	11	14
Room automation system (RAS)	25	18	19	29
Predictive maintenance (PM)	0	0	17	14
Mobile applications (MA)/ computer software (CS), such as Dexma, Energy Intelligence, Inavitas, Energis.Cloud etc.	25	0	31	29
Building automation (BA)	25	0	14	29
Smart thermostats (ST)	25	18	42	14
Smart heating, ventilation and air conditioning (HVAC)	50	27	50	71

Source: authors.

Taken together, these findings suggest that while energy efficiency technologies, for example motion sensor lighting (MSL), with clear operational or cost-saving benefits, are increasingly adopted across hotel categories, the implementation of more sophisticated RAISA-enabled systems, for example, HVAC, remains uneven and largely concentrated in higher-category hotels. This pattern suggests that digital transformation in the hotel sector maybe driven less by a comprehensive sustainability strategy and more by pragmatic considerations such as cost, ease of implementation and perceived return on investment.

4.1.3. Unified analysis

Figure 2 compares the uptake of different technologies by location and the average adoption rate for each technology.

Figure 2 illustrates the regional distribution of energy management technology adoption across hotel categories in Ireland. The results reveal clear regional disparities and category-specific adoption patterns, suggesting that digital transformation and RAISA-related implementation remain uneven across the sector.

In the Munster region, adoption appears relatively balanced across several foundational technologies, particularly EMS and MSL, which show moderate uptake across hotel categories. However, more advanced technologies, such as predictive maintenance and intelligent defrost systems, exhibit minimal adoption, indicating that technology integration in this region is primarily focused on basic energy-efficiency measures rather than advanced automation or predictive digital solutions.

The Ulster region demonstrates a strong concentration of adoption in motion sensor lighting and smart thermostats, particularly among higher-category hotels, while adoption of predictive maintenance, room automation and intelligent defrost technologies remains limited. This pattern suggests selective technology uptake driven by cost efficiency and operational convenience rather than comprehensive digital transformation strategies.

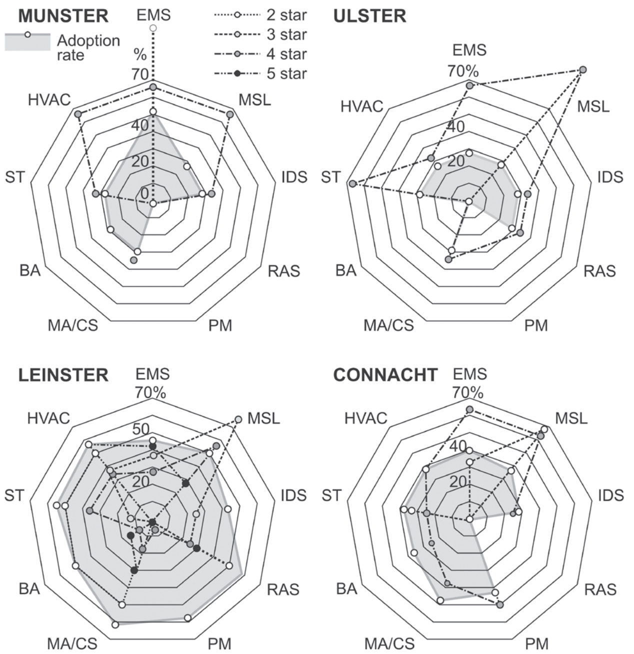

Figure 2. Comparing the distribution of technology uptake and the average adoption rate across location and hotel star rating

Note: EMS – energy management system, MSL – motion sensor lighting, IDS – intelligent defrost system, RAS – room automation system, PM – predictive maintenance, MA/CS – mobile applications/ computer software (such as Dexma, Energy Intelligence, Inavitas, Energis.Cloud etc.), BA – building automation, ST – smart thermostats, HVAC – smart heating, ventilation and air conditioning

Source: authors

Leinster displays the most diverse and advanced adoption profile among the regions. Several technologies, including room automation systems, predictive maintenance, and mobile or software-based energy management applications, exhibit relatively higher adoption rates across multiple hotel categories. This may reflect stronger digital readiness, greater access to technological resources, and higher levels of competitive or urban market pressure, encouraging broader implementation of RAISA-enabled solutions.

In contrast, Connacht demonstrates a more selective and uneven adoption pattern. While certain technologies, particularly motion sensor lighting and predictive maintenance, show moderate uptake, other automation and smart building systems remain comparatively underutilised. This may reflect structural and resource constraints typically associated with smaller or regionally dispersed hospitality markets.

Across all regions, a consistent trend emerges whereby foundational energy-saving technologies such as EMS, MSL and HVAC systems demonstrate wider adoption, while advanced automation and predictive technologies remain at an early stage of implementation. Furthermore, higher-category hotels generally display greater adoption across most technologies, suggesting the influence of financial capacity, technological infrastructure and strategic orientation toward innovation.

Collectively, these regional and categorical variations suggest that RAISA adoption within the Irish hotel sector remains nascent and context dependent. Adoption appears to be driven primarily by immediate operational and energy efficiency benefits rather than by fully integrated digital transformation or sustainability strategies.

4.2. Distribution of innovative technology adoption scores

To explore the overall level of innovative technology adoption among Irish hotels, a kernel density plot was constructed based on the composite adoption rate derived from survey responses (recall the calculation of the adoption rate given in the methodology section). As shown in Figure 3, the distribution is right-skewed, indicating that a majority of hotels have relatively low to moderate adoption rate, while a smaller subset demonstrates significantly higher engagement with innovative technologies.

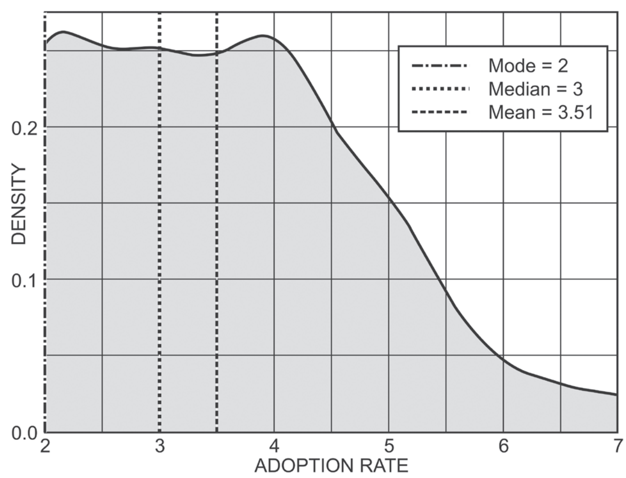

Figure 3. Density plot of innovative technology adoption scores in Irish hotels, showing a right-skewed distribution

Source: authors

The mode of the distribution is 2, meaning that the most frequently occurring adoption rate among respondents was the minimum possible on the adoption rate scale (the scale goes from 2 to 7). The median is 3, suggesting that 50% of hotels scored at or below this level. However, the mean is higher at 3.51, which reflects the influence of a tail of hotels with relatively high adoption levels. This asymmetry in the distribution implies that while adoption is still in its early to intermediate phases for many hotels, there is a growing segment of the sector that is investing more heavily in advanced systems and innovative technologies.

Notably, the distribution of the "adoption rate" variable was found to be positively skewed, suggesting that while a minority of hotels report high adoption, a substantial proportion remain at early or non-adopter stages. This skewness was considered in the selection and transformation of variables for subsequent regression modelling.

4.3. Distribution of innovative technologies: Adoption across adopter categories

To better understand the diffusion of RAISA technologies within the Irish hotel industry, the distribution of adoption rates was examined and categorised using Rogers' diffusion of innovations theory. As shown in Figure 4, the density plot represents the full spectrum of RAISA adoption levels across surveyed hotels, divided into five adopter categories: innovators, early adopters, early majority, late majority and laggards. These categories were assigned based on percentile segmentation of the adoption index, a continuous measure constructed from multiple technology implementation indicators.

The shape of the distribution suggests a slightly right-skewed pattern, with the bulk of hotels falling within the early majority and late majority categories. This suggests that while RAISA technologies are becoming increasingly common, many hotels are still in the process of fully utilising them. A smaller proportion of hotels appear at the far right of the distribution, classified as innovators, reflecting early experimentation and leadership in advanced automation. Conversely, a similar proportion of "laggards" exists on the lower end, comprising hotels with minimal or limited adoption of RAISA systems.

The relative thickness of the early majority and late majority regions, characterised by lower adoption scores, highlights the potential need for policy and investment focus, particularly in supporting hotels that are on the cusp of broader technological integration but may lack the necessary resources or strategic guidance to proceed. As stated in Section 4, the government can exert a statistically significant effect on a hotel's willingness to adopt high-cost technologies by offering subsidies and grants (Ezzaouia & Bulchand-Gidumal, 2020; Oloso, 2025).

Overall, Figure 4 reinforces the conclusion that the Irish hotel industry is progressing through the intermediate stages of innovation adoption. Encouragingly, the presence of innovators and early adopters suggests a growing receptiveness to RAISA, which may gradually influence peers and contribute to a more technology-forward hotel sector, because, according to the diffusion of innovations by Rogers (2014), observability is one of the five key attributes of an innovation that determines its rate of adoption.

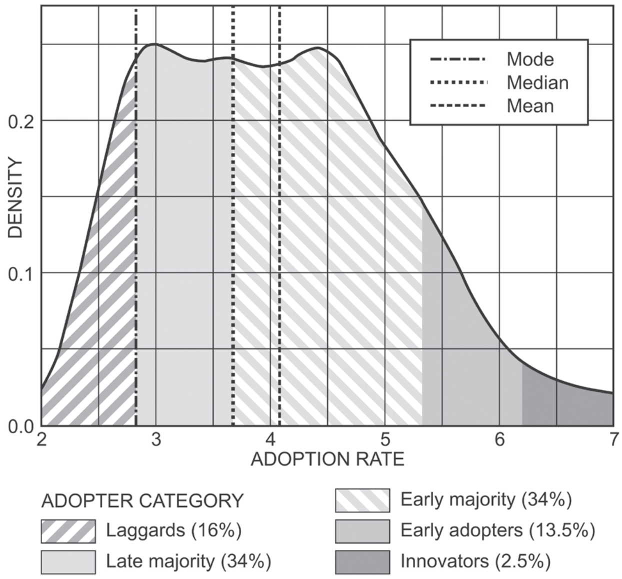

Figure 4. Density distribution of technology adoption scores in Irish hotels, segmented into adopter categories based on percentile thresholds (indicated inside brackets in the legend)
Source: authors

4.4. Energy waste reduction technology

Table 6 and Figure 5 illustrate the mean adoption rates and variability (standard deviation) for a range of energy reduction technologies implemented in hotel operations. The users of these technologies are categorised using Rogers' diffusion of innovations theory, highlighting where each innovative technology adopter lies along the adoption continuum from innovators to late majority.

Table 6. Adoption of energy reduction technologies across adoption categories in Irish hotels, with means and standard deviations of adoption rates reported for each technology

Energy reduction technology	Mean adoption rate	Standard deviation adoption rate	Adoption category
All of the above	6.0	1.4	Innovators
Room automation system	4.0	1.3	Early majority
Building automation	3.8	1.4	Early majority
Energy software	3.7	1.0	Early majority
Predictive maintenance	3.7	0.5	Early majority
Smart heating, ventilation and air conditioning (HVAC)	3.6	1.3	Early majority

Table 6 (cont.)

Energy reduction technology	Mean adoption rate	Standard deviation adoption rate	Adoption category
Motion sensor lighting	3.3	1.1	Late majority
Energy management system (EMS)	3.3	1.2	Late majority
Smart thermostats	3.2	1.2	Late majority
None of the above	2.9	0.8	Late majority
Intelligent defrost system	2.6	1.0	Late majority

Source: authors.

As shown in both the table and the chart, the most comprehensively adopted solution, indicated by the highest mean score (6.0), is "all of the above", which represents hotels actively integrating multiple technologies and aligns with the innovators category. Technologies such as room automation systems, building automation, energy software, predictive maintenance and smart heating/AC exhibit mean scores between 3.6 and 4.0, positioning their users within the early majority category. These results suggest that a significant segment of the hotel industry is proactively engaging with automation and predictive control systems, likely due to their tangible impact on operational efficiency and cost savings (Kim et al., 2022; Ivanov & Webster, 2021). Conversely, hotels using technologies such as motion sensor lighting, EMS, smart thermostats and intelligent defrost systems exhibit lower mean adoption scores (between 2.6 and 3.3), falling within the late majority. This suggests that these technologies are either more basic and commonly used, placing them at the lower end of the RAISA adoption spectrum, or that the hotels using them have not yet adopted more advanced technologies, and therefore consider themselves lower in RAISA maturity.

The standard deviations captured in Figure 5 emphasise the variation in adoption patterns across hotels, with technologies such as smart heating/air conditioning and room automation systems showing wider variability. This indicates that while some hotels have advanced significantly in their adoption journey, others remain in the early stages or have not yet implemented these innovations. Together, these findings underscore a stratified pattern of technology diffusion, where full integration remains limited to a smaller group of forward-thinking hotels, while broader adoption is still emerging across the sector.

The spread of the data also reflects a range of digital maturity levels across the sample, reinforcing the importance of understanding contextual factors, such as size, location and star rating, that may influence adoption behaviours. These findings provided a basis for further regression analysis, in which the relationship between adoption rate and specific predictors (e.g. energy-saving technologies) was examined to identify key enablers of digital transformation in the sector.

4.5. Linear regression modelling output

To further investigate the impact of specific energy reduction technologies on the overall RAISA adoption rate, a linear regression analysis was conducted, with the adoption rate serving as the dependent variable. Table 7 presents the estimated coefficients, standard errors and p-values for each predictor. The intercept value of 3.71 ($p < 0.001$) represents the baseline adoption rate in the absence of specific technology adoption. While several predictors exhibited positive or negative coefficients, none of the technologies reached conventional levels of statistical significance ($p < 0.05$). Among the variables, intelligent defrost showed the largest negative association with adoption

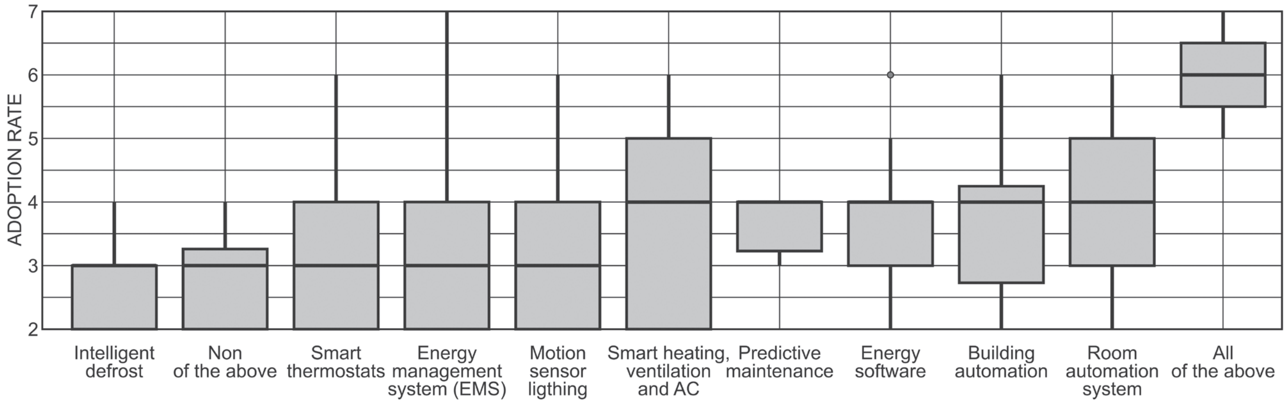

Figure 5. Distribution of adoption rates by energy reduction technologies
Source: authors

rate (estimate = –0.91; $p = 0.08$), indicating a potential inverse relationship, though it falls short of statistical significance. Conversely, energy software (estimate = 0.71; $p = 0.13$) and room automation system (estimate = 0.51; $p = 0.25$) demonstrated positive effects, suggesting that their presence may be associated with higher adoption levels, although not significantly so.

Table 7. Linear regression results illustrating the impact of individual energy technologies on the adoption rate. Coefficients for each technology indicate the estimated change in adoption rate that can be achieved by implementing the technology

Term	Estimate	Standard error	*p*-value
(Intercept)	3.71	0.25	0.00
Motion sensor lighting	–0.20	0.32	0.53
Energy management system (EMS)	–0.32	0.36	0.38
Smart heating, ventilation and air conditioning (HVAC)	0.05	0.33	0.87
Energy software	0.71	0.46	0.13
Building automation	0.23	0.55	0.68
Predictive maintenance	–0.01	0.62	0.99
Room automation system	0.51	0.44	0.25
Smart thermostats	–0.63	0.40	0.12
Intelligent defrost	–0.91	0.52	0.08

Source: authors.

This study was limited to examining patterns of association between the adoption of energy-reduction technologies and overall RAISA adoption, rather than identifying causal mechanisms underlying these relationships. Some technologies, including motion sensor lighting, energy management systems, smart thermostats, and smart defrost systems, show negative associations with overall RAISA adoption. This may reflect that these more common or specialised systems are often implemented by hotels with lower digital maturity or by hotels with very specific operational requirements, which tend to adopt only a limited set of technology solutions. In contrast, more advanced or strategically focused systems, such as predictive maintenance, room automation, and energy software, are typically adopted by hotels with greater digital ambition and broader technology portfolios, which explains the observed positive associations. While these explanations remain speculative, they provide a plausible context for the observed trends and highlight the need for future research to explore the underlying factors influencing these adoption patterns in greater depth.

These findings suggest that while individual technologies may influence overall adoption tendencies, the variations are not strong enough to be isolated as significant predictors in this model. This could indicate either a cumulative or context-dependent effect of these technologies, warranting further investigation with a larger sample or additional covariates.

4.6. Bootstrapping output

To improve the robustness of inference given the limited sample size ($n = 79$), a bootstrapping approach was applied to both descriptive adoption rates and regression modelling.

Table 8 presents the bootstrapped mean adoption rates for each energy-reduction technology, along with their corresponding standard deviations. Notably, the bootstrapped means closely align with the original sample means, demonstrating internal consistency. Technologies such as room automation systems, building automation and energy software continued to show relatively high adoption rates across resampled datasets. In contrast, intelligent defrost systems and smart thermostats exhibited lower adoption rates, suggesting a more cautious approach among hotel operators.

Table 8. Comparison of original and 0.632 bootstrapped mean adoption rates for energy reduction technologies, indicating comparable adoption rates across technologies

Technology	Mean original	Mean bootstrap	Mean bootstrap 0.632	Standard deviation bootstrap
All of the above	6.00	6.01	6.01	0.71
Room automation system	4.00	4.02	4.01	0.36
Building automation	3.75	3.74	3.74	0.45
Energy software	3.73	3.74	3.74	0.26
Predictive maintenance	3.67	3.65	3.66	0.19
Smart heating, ventilation and air conditioning (HVAC)	3.61	3.61	3.61	0.22
Motion sensor lighting	3.31	3.31	3.31	0.17
Energy management system (EMS)	3.28	3.29	3.28	0.22
Smart thermostats	3.21	3.21	3.21	0.26
None of the above	2.88	2.85	2.86	0.27
Intelligent defrost	2.57	2.58	2.58	0.34

Source: authors.

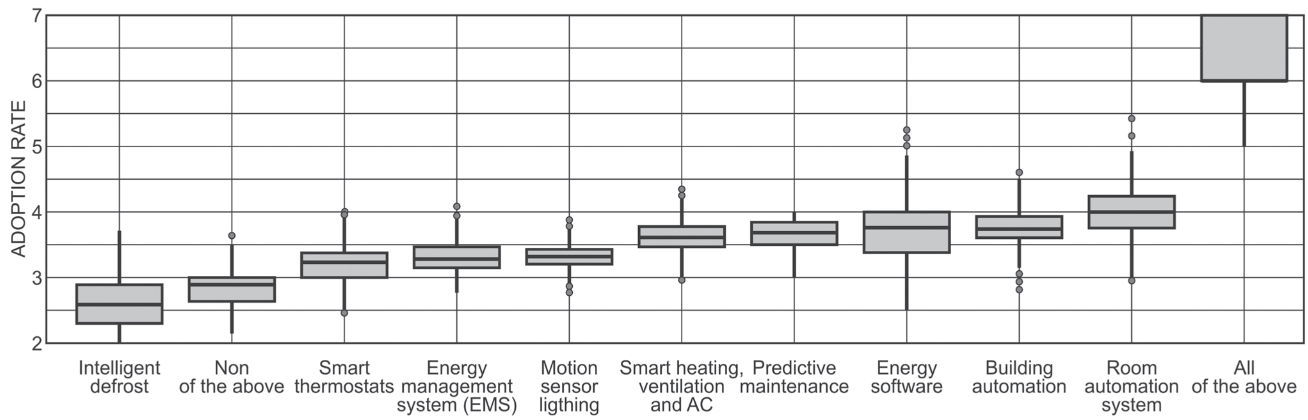

Figure 6. Bootstrapped mean adoption rate distribution of the various energy reduction technologies
Source: authors

Figure 6 visually reinforces these findings, highlighting variation in adoption rates across the range of technologies. The technologies positioned toward the right of the figure (e.g. "all of the above", "room automation system") correspond to higher bootstrapped adoption means, consistent with the innovators and early majority adopter categories described earlier. Meanwhile, technologies with lower mean values (e.g. "intelligent defrost") align with the late majority or laggards, indicating slower diffusion across the industry.

Table 9. Bootstrapped linear regression coefficients with 95% confidence intervals. Estimates reflect the effects of individual energy reduction technologies on the adoption rate of innovative technologies, based on 1,000 bootstrap samples

Technology	Mean coefficients [CI]
Intercept	3.71 [3.18, 4.29]
Motion sensor lighting	–0.26 [–0.95, 0.37]
Energy management system (EMS)	–0.25 [–0.97, 0.65]
Smart heating, ventilation air conditioning (HVAC)	0.08 [–0.56, 0.67]
Energy software	0.71 [–0.04, 1.37]
Building automation	0.17 [–1.10, 1.39]
Predictive maintenance	–0.07 [–1.26, 1.02]
Room automation system	0.49 [–0.38, 1.50]
Smart thermostats	–0.60 [–1.20, 0.07]
Intelligent defrost	–1.00 [–1.75, –0.19]

Source: authors.

Building on this, Table 9 displays bootstrapped linear regression coefficients with 95% confidence intervals, modelling the effect of individual technologies on the overall adoption rate of innovative systems. Most coefficient intervals include zero, suggesting weak or non-significant individual effects. However, the "energy software" variable shows a positive association (mean coefficient = 0.71; 95% CI: [–0.04, 1.37]), indicating a potential role in predicting broader adoption, albeit with marginal statistical confidence. In contrast, "intelligent defrost" demonstrates a significant negative effect (mean coefficient = –1.00; 95% CI: [–1.75, –0.19]), suggesting that its adoption is inversely associated with the broader implementation of innovative technologies, possibly due to perceived higher cost, complexity, or perceived lack of necessity of more advanced technology by hotels that use "intelligent defrost" technology.

In summary, the bootstrapped findings support the descriptive trends observed in the raw data and underscore the variation in adoption across technologies. They also emphasise the importance of considering the individual impact of each technology on overall innovation readiness. While some technologies may signal early adoption behaviour, others may indicate slower digital transformation trajectories within the Irish hotel industry.

5. Conclusion and implications

Using a combination of descriptive statistics, linear regression modelling and bootstrapping techniques, the research aimed to identify patterns of adoption, categorise adopter behaviour, and explore the adoption of energy-reduction technologies within the Irish hotel sector and their relationship to the broader uptake of intelligent RAISA technologies for sustainable operations. Within the scope of this exploratory study, we conclude that implementing energy software may positively affect RAISA adoption.

The data suggests that RAISA adoption within the Irish hotel sector is uneven. Furthermore, energy-related technologies are not adopted uniformly across the sector. A trend is observed, with certain technologies aligning with early adopters (innovators and early majority) while others remain within the late majority category. Technologies such as room automation systems, building automation and energy software exhibited higher average adoption rates, indicating that these technologies may be more associated with cost saving and operational efficiency. Conversely, the data suggests that hotels that use tools like intelligent defrost systems, smart thermostats and EMS tend to lag behind, possibly due to cost, complexity or unclear return on investment (ROI).

The regression analysis further illuminated these patterns. While many predictors failed to show statistically significant individual effects, energy software exhibited a moderately strong positive relationship with the RAISA adoption rate. This aligns with its role as a digital interface that may facilitate further integration of intelligent systems. In contrast, for the intelligent defrost systems negative association trend is observed, possibly indicating resistance to niche or low-perceived-value technologies among adopters. The variance in coefficient stability across technologies suggests that not all energy innovations contribute equally to the digital transformation journey.

In alignment with previous studies (Ka et al., 2023; Nikopoulou et al., 2023; Zaragoza-Sáez et al., 2024), these results indicate that implementing specific technological solutions such as energy-efficiency systems may act as a catalyst for more extensive digital transformation, especially for businesses prioritising sustainable operations. Higher adoption rates of technologies like energy software and room automation systems may act as gateways to more advanced intelligent automation.

Bootstrapped regression analysis suggests that some technologies have directional influence, even when statistical significance is marginal. Innovator behaviour is associated with bundled or integrative approaches to technology adoption ("all of the above"), suggesting that comprehensive sustainability strategies may predict readiness for digital transformation. This supports the previous research (e.g. Akbulut et al., 2025; Kozlovska et al., 2023) that organisations desiring sustainable operations are more likely to invest in innovative technologies.

While this research highlights a nuanced landscape of technological adoption within Ireland's hotel sector, the study overall contributes to the growing body of literature on sustainable innovation and digital adoption in the hospitality sector. The findings of this study carry implications for sustainability policy, hotel management strategy, and the digital transformation agenda within the Irish hospitality sector.

First, the identification of energy software and automation systems as potential enablers of broader RAISA adoption highlights the value of leveraging existing energy-management tools as strategic entry points for digital innovation. For instance, energy software designed to help hotels monitor, analyse and optimise energy use may enable managers to observe tangible financial and operational improvements through energy monitoring, thereby increasing their confidence in digital systems. As per the diffusion of innovations theory by Rogers (2014), observability, or the degree to which the results or benefits of an innovation are visible, leads to greater levels of adoption. Furthermore, the growing observability may build the organisational readiness, legitimacy and positive expectations necessary to support the diffusion of RAISA technologies across properties and departments. This suggests that investments in sustainability-friendly energy management tools can be environmental choices and can also serve as catalysts for technological competitiveness.

Second, as observed from the data, the uneven adoption landscape underscores the need for differentiated engagement strategies, potentially recognising that hotels at different stages of innovation readiness may respond to distinct drivers and barriers. For policymakers and tourism authorities, this may hint towards the necessity of more targeted interventions, particularly for hotels that stagnate in the late majority phase, through financial incentives, sector-specific training and industry benchmarking. Additionally, for technology providers, the study tries to highlight the importance of demonstrating tangible ROI and ease of integration, especially for niche or underutilised systems. Finally, by showing a trend that early-stage sustainability technologies can act as springboards to more advanced RAISA adoption, the study supports a phased approach to digital transformation, one that aligns with hotels' operational realities and resource constraints while still advancing long-term goals for smart and sustainable hospitality. Overall, the results try to provide a roadmap for evidence-based decision-making that balances operational efficiency, technological innovation and sustainability goals.

6. Limitations and future research

While this study provides valuable insights into the nexus between energy-reduction technologies and RAISA adoption in the Irish hotel industry, several limitations must be acknowledged. These constraints offer a roadmap for future scholarly inquiry.

The primary limitation of this study is the relatively small sample size, which may have constrained the statistical power necessary to detect small-to-moderate effects. While bootstrapping techniques were employed to enhance the robustness of estimates, the current dataset limits the generalisability of the findings beyond the surveyed group. Subsequent studies should aim for a larger and more diverse sample to improve statistical power and allow for a more definitive generalisation of results to the broader global hospitality sector.

The study relied on self-reported survey data, which may be subject to a social desirability bias. Respondents might have overestimated the extent of RAISA adoption or technology use to align with perceived industry norms or sustainability expectations. Although anonymity was assured to reduce such bias, the influence of self-reporting cannot be entirely ruled out. Future research could mitigate this limitation by triangulating survey responses with objective data sources, such as system usage logs or operational records, to obtain a more accurate assessment of technology adoption.

The cross-sectional nature of the data restricts the ability to infer causality. The results indicate a positive association between energy software adoption and RAISA uptake, suggesting that energy management technologies may facilitate digital transformation. However, causal interpretation was not warranted given the study design. Future longitudinal studies would be especially beneficial, enabling researchers to explore changes in adoption behaviour over time and more confidently infer causality.

A limitation of this study is that the regression model does not incorporate potentially influential covariates such as hotel category, location, capacity and chain affiliation, all of which may affect the rate of technology adoption. The exclusion of these variables may limit the analytical depth and explanatory power of the findings. However, the study was limited to examining patterns of association between the adoption of energy reduction technologies and RAISA adoption. Despite this limitation, the current analysis provides valuable preliminary evidence on the role of energy-reduction technologies in shaping the adoption of RAISA within the sector. Future research could incorporate additional hotel-specific covariates, such as chain affiliation, to examine more nuanced patterns of adoption.

The regression analysis examining the influence of energy use reduction technology implementation on RAISA adoption did not yield statistically significant coefficients. This lack of significance warrants careful consideration rather than dismissal. First, the sample size, while adequate for exploratory analysis, may have limited the statistical power required to detect small or moderate effects, particularly given the early stage of RAISA adoption across the Irish hotel sector. Second, several technology implementation variables exhibited conceptual overlap, raising the possibility of multicollinearity, which can inflate standard errors and reduce the likelihood of statistically significant estimates despite meaningful underlying relationships. Third, the measurement of technology implementation relied on relatively coarse indicators reflecting presence or absence rather than depth or maturity of use, which may have constrained variance in the predictors. Beyond methodological explanations, the findings may also reflect that RAISA adoption in Irish hotels appears to be nascent and may be often driven by pragmatic operational concerns such as staff shortages, cost containment and regulatory pressures, rather than by the level of technology implementation alone. Consequently, the relationship between technology implementation and RAISA adoption may be indirect, mediated by organisational readiness or strategic orientation, or may manifest over time rather than in cross-sectional data. To mitigate this, future models should refine measurement approaches, examine mediating organisational mechanisms, and integrate external contextual influences such as digitalisation subsidies or regulatory pressures to better capture the complexity of RAISA adoption pathways.

This study was exclusively quantitative, prioritising broad patterns over experiential narratives. Consequently, the findings do not capture the underlying "sense-making" processes or the specific organisational motivations and barriers that influence a manager's decision to adopt RAISA. Future studies can incorporate qualitative methods, such as in-depth interviews or case studies, which would enrich the literature by exploring the human and strategic priorities behind technology adoption.

References

Akbulut, L., Taşdelen, K., Atılgan, A., Malinowski, M., Coşgun, A., Şenol, R., Akbulut, A., & Petryk, A. (2025). A systematic review of building energy management systems (BEMSs): Sensors, IoT, and AI integration. *Energies*, *18*(24), Article 6522. https://doi.org/10.3390/en18246522

Anubala, R. (2023). The future of hospitality: Predictive analytics in hotel management. *Candigarh Philosophies: International Journal for Multidimensional Research Perspectives (IJMRP)*, *1*(3), 38–58. https://www.chandigarhphilosophers.com/index.php/ijmrp/article/view/86

Aras, A., & Büyüközkan, G. (2023). Digital transformation journey guidance: A holistic digital maturity model based on a systematic literature review. *Systems*, *11*(4), Article 213. https://doi.org/10.3390/systems11040213

Arfiansyah, T., & Arifin, A.S. (2021). Feasibility study on the implementation of room control automation to realize smart green buildings. *Journal of Physics: Conference Series*, *1844*(1), Article 012011. https://doi.org/10.1088/1742-6596/1844/1/012011

Aslanova, I.V., & Kulichkina, A.I. (2020). Digital maturity: Definition and model. In A.D. Nazarov (Ed.), *Proceedings of the 2nd International Scientific and Practical Conference "Modern management trends and the digital economy: From regional development to global economic growth"(MTDE 2020)* (pp. 443–449). Atlantis Press. https://doi.org/10.2991/aebmr.k.200502.073

Bekele, H., Raj, S., Singh, A., Joshi, M., & Kajla, T. (2024). Digital transformation and environmental sustainability in the hospitality industry: A three-wave time-lagged examination.

Journal of Cleaner Production, *484*, Article 144263. https://doi.org/10.1016/j.jclepro.2024.144263

Ben Youssef, A., & Zeqiri, A. (2022). Hospitality Industry 4.0 and climate change. *Circular Economy and Sustainability*, *2*(3), 1043–1063. https://doi.org/10.1007/s43615-021-00141-x

Chan, E.S.W., Okumus, F., & Chan, W. (2020). What hinders hotels' adoption of environmental technologies: A quantitative study. *International Journal of Hospitality Management*, *84*, Article 102324. https://doi.org/10.1016/j.ijhm.2019.102324

Conefrey, A., & Hanrahan, J. (2022). Comparative analysis of national tourism decarbonisation plans. *European Journal of Tourism Research*, *31*, Article 3105. https://doi.org/10.54055/ejtr.v31i.1979

DeVellis, R.F., & Thorpe, C.T. (2021). *Scale development: Theory and applications*. Sage Publications.

Dube, K., & Nhamo, G. (2021). Greenhouse gas emissions and sustainability in Victoria Falls: Focus on hotels, tour operators and related attractions. *African Geographical Review*, *40*(2), 125–140. https://doi.org/10.1080/19376812.2020.1777437

Elkington, J. (2020). *Green swans: The coming boom in regenerative capitalism*. Greenleaf Book Group.

Environmental Protection Agency. (2025, May). *Ireland's greenhouse gas emissions projections 2024–2055*. https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/07875-EPA-GHG-Projections-Report-FINAL.pdf

European Commission. (2021, March 19). *Declaration of the European Green Digital Coalition Members "In support of the Green and Digital Transformation of the EU"*. https://ec.europa.eu/information_society/newsroom/image/document/2021-12/european_green_digital_coaliton_declaration_-_final_-digital_day_2021_E592503B-D1CC-A599-5EF97E6891B038DF_74943.pdf

Ezzaouia, I., & Bulchand-Gidumal, J. (2020). Factors influencing the adoption of information technology in the hotel industry: An analysis in a developing country. *Tourism Management Perspectives*, *34*, Article 100675. https://doi.org/10.1016/j.tmp.2020.100675

Fáilte Ireland. (2024, April 16). *Accommodation supply dashboard*. https://www.failteireland.ie/Research-Insights/Papers-Reports/accommodation-supply-dashboard.aspx

Falwadiya, H., & Dhingra, S. (2022). Blockchain technology adoption in government organizations: A systematic literature review. *Journal of Global Operations and Strategic Sourcing*, *15*(3), 473–501. https://doi.org/10.1108/JGOSS-09-2021-0079

Floričić, T. (2020). Sustainable solutions in the hospitality industry and competitiveness context of "green hotels". *Civil Engineering Journal*, *6*(6), 1104–1113. https://doi.org/10.28991/cej-2020-03091532

Frangoul, A. (2022, November 7). We're on a 'highway to climate hell', UN chief Guterres says, calling for a global phase-out of coal. *CNBC*. https://www.cnbc.com/2022/11/07/were-on-a-highway-to-climate-hell-un-chief-guterres-says.html

Fu, M., Arcodia, C., & Fraser, B. (2026). Is human-RAISA collaboration the future of hospitality service? Examining Gen Z's preferences and industry insights from China and Australia. *International Journal of Hospitality Management*, *134*, Article 104565. https://doi.org/10.1016/j.ijhm.2026.104565

Gadermann, A.M., Guhn, M., & Zumbo, B.D. (2012). Estimating ordinal reliability for Likert-type and ordinal item response data: A conceptual, empirical, and practical guide. *Practical Assessment, Research, and Evaluation (PARE)*, *17*(1), Article 3. https://doi.org/10.7275/n560-j767

García-López, A.M., Galindo-Pérez-de-Azpillaga, L., & Foronda-Robles, C. (2025). The flow of digital transition: The challenges of technological solutions for hotels. *Social Indicators Research*, *178*, 1323–1346. https://doi.org/10.1007/s11205-024-03487-5

George, D., & Mallery, P. (2024). *IBM SPSS statistics 29 step by step: A simple guide and reference* (18th ed.). Routledge.

Guercio, A., Curto, D., Franzitta, V., Frascati, M., Milone, D., Martorana, P., & Mantegna, M. (2023). Energy analyses and optimization proposals for hotels in Sicily: A case study. *Sustainability*, *16*(1), Article 146. https://doi.org/10.3390/su16010146

Irish Hotels Federation (IHF) members report escalating business costs [Press release]. (2022, March 28). *Hotels & Restaurant Times*. https://www.hotelandrestauranttimes.ie/2022/03/28/irish-hotel-federation-ihf-members-report-escalating-business-costs/

Ivanov, S., & Webster, C. (2021). Willingness-to-pay for robot-delivered tourism and hospitality services – an exploratory study. *International Journal of Contemporary Hospitality Management*, *33*(11), 3926–3955. https://doi.org/10.1108/IJCHM-09-2020-1078

Jones, P., Hillier, D., & Comfort, D. (2016). Sustainability in the hospitality industry: Some personal reflections on corporate challenges and research agendas. *International Journal of Contemporary Hospitality Management*, *28*(1), 36–67. https://doi.org/10.1108/IJCHM-11-2014-0572

Ka, X., Ying, T., & Tang, J. (2023). A conceptual model for developing digital maturity in hospitality micro and small enterprises. *Journal of Theoretical and Applied Electronic Commerce Research*, *18*(3), 1511–1528. https://doi.org/10.3390/jtaer18030076

Karvounidi, M.D., Alexandropoulou, A.P., & Fousteris, A.E. (2024). Towards sustainable hospitality: enhancing energy efficiency in hotels. *IRJEMS International Research Journal of Economics and Management Studies*, *3*(6), 410–420. https://doi.org/10.56472/25835238/IRJEMS-V3I6P145

Kim, S.Y., & Park, M.S. (2022, August). Robot, AI and service automation (RAISA) in airports: The case of South Korea. In *2022 IEEE/ACIS 7th International Conference on Big Data, Cloud Computing, and Data Science (BCD)* (pp. 382–385). IEEE. https://doi.org/10.1109/BCD54882.2022.9900831

Kong, M., Dong, B., Zhang, R., & O'Neill, Z. (2022). HVAC energy savings, thermal comfort and air quality for occupant-centric control through a side-by-side experimental study. *Applied Energy*, *306I(Part A)*, Article 117987. https://doi.org/10.1016/j.apenergy.2021.117987

Kozlovska, M., Petkanic, S., Vranay, F., & Vranay, D. (2023). Enhancing energy efficiency and building performance through BEMS-BIM integration. *Energies*, *16*(17), Article 6327. https://doi.org/10.3390/en16176327

Mikhaylov, A., Moiseev, N., Aleshin, K., & Burkhardt, T. (2020). Global climate change and greenhouse effect. *Entrepreneurship and Sustainability Issues*, *7*(4), 2897–2913. https://doi.org/10.9770/jesi.2020.7.4(21)

Mondejar, M.E., Avtar, R., Diaz, H.L.B., Dubey, R.K., Esteban, J., Gómez-Morales, A., Hallam, B., Mbungu, N.T., Okolo, C.C., Prasad, K.A., She, Q., & Segura S.G. (2021). Digitalization to achieve Sustainable Development Goals: Steps towards a smart green planet. *Science of the Total Environment*, *794*, Article 148539. https://doi.org/10.1016/j.scitotenv.2021.148539

Nikopoulou, M., Kourouthanassis, P., Chasapi, G., Pateli, A., & Mylonas, N. (2023). Determinants of digital transformation in the hospitality industry: Technological, organizational, and environmental drivers. *Sustainability*, *15*(3), Article 2736. https://doi.org/10.3390/su15032736

Nunnally, J.C. (1978). *Psychometric theory* (2nd ed). McGraw-Hill.

Oloso, S.E. (2025). Evaluating the role of government policies in enhancing sustainable practices in hospitality industry. *International Journal of Research and Innovation in Social Science*, *9*(5), 4176–4191. https://doi.org/10.47772/IJRISS.2025.905000318

Osei, B.A., Ragavan, N.A., Kandappan, B., & Mensah, H.K. (2020). "Hospitality Revolution 4.0": A literature review on a unified typology of IR 4.0 technologies for the tourism and hospitality industry in the era of COVID-19. *Asia-Pacific Journal of Innovation in Hospitality and Tourism*, *9*(1), 25–45. https://fslmjournals.

taylors.edu.my/wp-content/uploads/APJIHT/APJIHT-2020-9-1/APJIHT-2020-P2-9-1.pdf

Ozdemir, O., Dogru, T., Kizildag, M., & Erkmen, E. (2023). A critical reflection on digitalization for the hospitality and tourism industry: Value implications for stakeholders. *International Journal of Contemporary Hospitality Management*, *35*(9), 3305–3321. https://doi.org/10.1108/IJCHM-04-2022-0535

Pastor, R. (2025). Digital transformation and sustainability in the hospitality industry: Pathways for innovation and competitiveness. *Journal of Business and Tourism Management (JBTM)*, *1*(1), 32–43. https://doi.org/10.64976/jbtm.2025.004

Rogers, E. (1983). *Diffusion of innovations* (3rd ed.). The Free Press.

Rogers, E.M., Singhal, A., & Quinlan, M.M. (2014). Diffusion of innovations. In D.W. Stacks & M.B. Salwen (Eds.), *An integrated approach to communication theory and research* (pp. 432–448). Routledge.

Sharma, I., & Aggarwal, A. (2024). Innovating for tomorrow: The role of artificial intelligence, robotics, and service automation in travel, tourism, and hospitality. In A.J. Nair, S. Manohar, A. Mittal & W. Ahmed (Eds.), *Balancing automation and human interaction in modern marketing* (pp. 225–247). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-2276-5.ch012

Sustainable Energy Authority of Ireland. (n.d.). *Sligo Park Hotel: Energy savings*. https://www.seai.ie/case-studies/sligo-park-hotel-energy-savings

Thomas, S. (2022, October). *European Commission response to the energy crisis of 2022*. University of Greenwich. https://gala.gre.ac.uk/id/eprint/37893/7/37893_THOMAS_European_Commission_response_to_the_ebergy_crisis_of_2022.pdf

United Nations – Department of Economic and Social Affairs Population Division. (2022). *World Population Prospects 2022: Summary of results* (UN DESA/POP/2021/TR/NO. 3). https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

Webster, C., & Ivanov, S. (2019). Robotics, artificial intelligence, and the evolving nature of work. In B. George & J. Paul (Eds.), *Digital transformation in business and society: Theory and cases* (pp. 127–143). Palgrave Macmillan. https://doi.org/10.1007/978-3-030-08277-2_8

Webster, C., & Ivanov, S. (2023). Robots, artificial intelligence and service automation in tourism and quality of life. In M. Uysal & M.J. Sirgy (Eds.), *Handbook of tourism and quality-of-life research II: Enhancing the lives of tourists, residents of host communities and service providers* (pp. 533–544). Springer. https://doi.org/10.1007/978-3-031-31513-8_36

Yan, Z., Konar, R., & Balasubramanian, K. (2025). The future of hotels robotics, AI, and service automation in practice. In E. Ozen, A. Singh, S. Taneja, R. Rajaram & J. Davim (Eds.), *Sustainability, innovation, and consumer preference* (pp. 249–278). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-9699-5.ch011

Yang, Y., Xiang, K., Zeng, J., Au, N., Han, B., & Li, J. (2024). Digital transformation paradigm involved in high-star hotels and budget hotels: Sensory and innovation diffusion perspective. *Tourism Management Perspectives*, *53*, Article 101274. https://doi.org/10.1016/j.tmp.2024.101274

Yousef, A., & Chaer, I. (2025). Utilisation of IoT and smart meter for energy savings in the hotel sector. In H. Masri, N. Elkadhi, K. Abdellah & S. Aldulaimi (Eds.), *Projects, processes, systems and networks in the digital age: Proceedings of the 4th International Conference on the Leadership and Management of Projects in the Digital Age – ICLAMP 2025* (pp. 532–551). Springer. https://doi.org/10.1007/978-3-031-99025-0_42

Zaragoza-Sáez, P., Marco-Lajara, B., Úbeda-García, M., & Manresa-Marhuenda, E. (2024). Exploratory and co-exploratory innovation. The mediating role of digitalization on competitiveness in the hotel industry. *Technological Forecasting and Social Change*, *199*, Article 123069. https://doi.org/10.1016/j.techfore.2023.123069