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AI integration in energy management: enhancing efficiency in Italian hospitals

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Abstract

Background In the rapidly evolving healthcare landscape, artificial intelligence (AI) is revolutionizing hospital operations by enhancing operational efficiency and patient care. This study focuses on the integration of AI in energy management within Italian hospitals and the role of energy managers.

Methods A comprehensive questionnaire was developed to understand current practices, challenges, and opportunities in AI adoption within hospital energy management. The study targeted regions in Italy with the highest concentration of hospital energy managers. A quantitative approach was employed, and the collected data were statistically analysed for reliability and validity using SPSS.

Results The analysis revealed significant benefits of integrating AI in energy management, including optimized energy consumption, predictive maintenance, and greater sustainability. Energy managers' roles are evolving to leverage AI technologies effectively, ensuring compliance with energy regulations and promoting eco-friendly practices.

Conclusions This research underscores AI's transformative potential in creating smarter, greener, and more efficient hospital environments. The findings highlight the importance of adopting AI-driven energy management solutions to enhance hospital efficiency. Future trends indicate further advancements in AI applications, necessitating ongoing adaptation and training for energy managers to exploit these technologies fully.

Keywords Artificial intelligence, Energy management, Hospital efficiency, Healthcare, Disruptive technology

Introduction

Artificial intelligence (AI) is revolutionizing hospital facilities in the rapidly evolving healthcare landscape by enhancing operational efficiency and patient care. AI-driven predictive systems are transforming emergency departments, enabling real-time estimation of service workloads and optimizing resource allocation [22]. This innovation extends to the role of energy managers, who leverage AI to streamline energy consumption, reduce costs, and ensure sustainable operations within hospital environments [13]. By integrating AI technologies, hospitals can achieve higher accuracy in demand forecasting, minimize wastage, and maintain an optimal balance between energy use and patient needs [17, 24, 27]. The synergy between AI, hospital facilities, and energy management is paving the way for smarter, greener, and more efficient healthcare systems worldwide, contributing significantly to global sustainability goals and improved patient outcomes [26]. In Europe, AI is transforming healthcare and energy management across the European Union's 27 member states. In hospitals, AI enhances diagnostic accuracy, streamlines administrative processes, and improves patient outcomes by predicting diseases and personalizing treatment plans [19]. AI-driven tools are also being integrated into hospital facilities to optimize resource allocation, manage patient flow, and reduce operational costs [30]. Energy management in hospitals benefits from AI through the

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automation of energy systems, predictive maintenance of equipment, and efficient use of renewable energy sources contributing to sustainability goals [1, 7]. The role of the energy manager is becoming increasingly pivotal, tasked with implementing AI solutions to monitor and control energy consumption, ensuring compliance with EU energy regulations, and promoting eco-friendly practices [10]. These advancements in AI enhance hospital efficiency and support the EU's broader objectives of reducing carbon emissions and achieving a greener economy. As AI technology continues to evolve, its application in hospital facilities and energy management is expected to grow, offering innovative solutions to complex challenges [23]. Recent advancements in AI applications in healthcare focus on improving diagnostic accuracy, workflow efficiency, and personalized patient care, while addressing ethical considerations, transparency, and regulatory compliance. Explainable AI methods such as SHAP, LIME, and Grad-CAM are increasingly integrated into radiology, predictive analytics, and wearable health monitoring, enhancing interpretability and trust in medical decision-making. AI-powered workflow optimization tools and deep learning models for imaging diagnostics, including X-ray, MRI, and CT scan analysis, are helping to mitigate shortages in specialized medical personnel while improving efficiency. However, the widespread adoption of AI in healthcare depends on overcoming algorithmic bias, data privacy concerns, and cybersecurity challenges, requiring interdisciplinary collaboration among clinicians, AI researchers, and policymakers. The integration of Contextual Explanation Networks (CEN), Self-Explaining Neural Networks (SENN), and AI-driven predictive maintenance is also driving real-time monitoring and personalized treatment plans, ensuring that AI applications align with both clinical and ethical standards while supporting global digital healthcare transformation [37–39]. The synergy between AI, healthcare, and energy management exemplifies the transformative potential of technology in improving public services and promoting sustainability within the European Union [21]. Within this framework, AI is significantly transforming hospital facilities and energy management in Italy. Italian hospitals are increasingly adopting AI-driven tools for resource allocation, patient flow management, and operational cost reduction. AI also plays a crucial role in energy management within hospital facilities, automating energy systems, enabling predictive maintenance, and optimizing renewable energy sources. The role of the energy managers in Italy is becoming more critical, focusing on implementing AI solutions to monitor and control energy consumption, ensuring compliance with national and EU energy regulations, and promoting sustainable practices. These AI advancements improve hospital efficiency and support Italy's commitment to reducing carbon emissions and achieving a greener economy. As AI technology progresses, its application in hospital facilities and energy management is expected to expand, providing innovative solutions to complex challenges. This integration of AI in healthcare and energy management highlights the potential of technology to enhance public services and promote sustainability in Italy [3]. Building on the introduction, and linked literature review, we can create a comprehensive questionnaire aimed at understanding the integration of AI in hospital facilities and the role of energy managers in Italy. The questionnaire will help gather insights from professionals in the field, providing valuable data on current practices, challenges, and opportunities for improvement. The questionnaire aims to collect detailed information from energy managers, healthcare administrators, and other relevant professionals in Italy. The data gathered will provide insights into the current state of AI integration, the role of energy managers, and the challenges and opportunities in optimizing hospital facilities. After the introduction, we explore the relevant literature on the topic. Moreover, we detail the methodology employed, present our research findings, and discuss the implications for policy and practice. Finally, we highlight the study's limitations, future implications and practical strategies for enhancing the implementation of AI for Energy Managers in Healthcare.

Literature review

Incorporating Artificial Intelligence (AI) into hospital energy management is transforming how facilities handle their energy consumption, efficiency, and sustainability [14]. As technology advances, the role of the energy manager is also evolving, with AI being used to optimize energy use, reduce costs, and ensure regulatory compliance [34, 35]. This review examines the influence of AI on energy management within Italian hospital facilities and the changing responsibilities of energy managers in this landscape. Hospitals are energy-intensive structures, meaning they consume a large amount of energy to provide healthcare services and ensure high-quality performance levels [15]. AI in energy management can improve energy consumption monitoring and optimization through actions of real-time monitoring: AI systems continuously monitor energy consumption across hospital facilities, providing real-time data that helps identify inefficiencies and areas for improvement [11]. This granular level of monitoring allows for immediate adjustments and long-term strategic planning and load management: AI can predict energy demand patterns and optimize load distribution [18]. This ensures that energy is used efficiently, avoiding peak demand charges and reducing overall energy costs [20]. Furthermore, AI highlights a predictive maintenance role in the equipment monitoring with algorithms that analyze data from various hospital equipment to predict potential failures before they occur. This proactive approach to maintenance minimizes downtime, extends equipment life, and ensures continuous operation of critical systems. Furthermore, it positively impacts cost savings, particularly in preventing unexpected breakdowns and optimizing maintenance schedules. Moreover, AI-driven predictive maintenance reduces repair costs and improves the overall reliability of hospital infrastructure. Nevertheless, AI can be used for energy efficiency projects in terms of hospital facilities, retrofitting, and upgrades, which are concrete actions that AI helps to identify with particular attention to the most cost-effective energy efficiency projects by analyzing data on current energy use and potential improvements. This includes upgrading lighting systems, HVAC units, and other energy-intensive equipment. It is important, in energy intensive structures to implement performance tracking linked to AI systems that track the performance of energy efficiency projects, ensuring they deliver the expected savings and allowing for adjustments as needed [8, 31]. Energy efficiency projects are linked to renewable energy integration with implementation of smart grid management where AI optimizes the integration of renewable energy sources, such as solar panels and wind turbines, into the hospital's energy grid [9]. This includes balancing energy loads, storing excess energy, and reducing reliance on non-renewable sources where AI manages energy storage systems, ensuring efficient use of stored energy and maintaining a steady supply during periods of low renewable energy production [16]. In this scenario, the role of the energy manager is planned and intervenes in both the horizontal and vertical dimensions of energy management [12]. The role of the energy manager is strategic concerning implementation of AI technologies with particular attention to strategic planning; energy managers are responsible for planning and implementing AI-driven energy management systems. These activities provide continuous improvement, or energy managers must stay informed about the latest AI and energy management advancements to continually improve the hospital's energy efficiency and sustainability. Maintaining energy-intensive structures means implementing, as core activity, data analysis and decision making, in this case, data interpretation assume a strategic relevance where the energy managers use AI-generated data to make informed decisions about energy use, maintenance schedules, and efficiency projects. This data-driven approach enhances the precision and effectiveness of energy management strategies and provides scenario planning AI that allows energy managers to conduct scenario analysis and forecast future energy needs. This helps in strategic planning and preparing for potential changes in energy demand or regulatory requirements [4]. These strategic activities are important for implementing regulatory compliance with particular attention to monitoring and reporting activities, AI systems ensure that hospital energy use complies with local and national regulations by continuously monitoring energy consumption and generating detailed reports [25]. This helps avoid penalties and ensures adherence to environmental standards and realize sustainability goals where the energy managers play a key role in meeting sustainability targets by leveraging AI to reduce carbon emissions and promote the use of renewable energy. Following these research streams and aiming to accelerate the process of knowledge accumulation, it is possible to apply to the role of Italian energy managers, within hospital structures that use, or do not use, artificial intelligence, a structured questionnaire that answers the following Research Questions (RQ):

- (RQ 1) What are the best practices for Italian energy management in healthcare facilities applying AI?
- (RQ 2) What are the future trends in Italian AI for hospital management?

These two RQs are in the theoretical domain of limited resource management, using technological innovation applied to the hospitals, as a strategic pillar of the National Health Service.

Particularly RQ 1

It considers that energy management is a critical aspect of hospital administration, with significant implications for operational efficiency and sustainability. Best practices in energy management involve implementing AI technologies to optimize energy use and reduce waste [29]. AI-driven energy management systems can automate the control of heating, ventilation, and air conditioning (HVAC) systems, lighting, and other energy-consuming devices, ensuring that they operate at optimal efficiency only when needed [2]. Predictive maintenance enabled by AI can also reduce energy waste by identifying and addressing equipment issues before they lead to significant energy loss or downtime [2]. Moreover, energy managers play a pivotal role in implementing these technologies and promoting sustainable practices within hospitals. They are responsible for monitoring energy consumption, ensuring compliance with energy regulations, and advocating for adopting renewable energy sources. According to the Italian Association of Energy Managers reports [33], ongoing training and education in the latest energy management technologies and strategies are essential for energy managers to remain effective [33].

Particularly, RQ 2

It considers that the future of AI in hospital management is poised for significant advancements, with several emerging trends likely to shape the sector [32]. One key trend is the increased use of AI for predictive analytics. This technology can forecast patient admissions, bed occupancy rates, and staffing needs, enabling hospitals to manage their resources better and reduce bottlenecks in patient care [5]. Another trend is the integration of AI with devices, creating innovative hospital environments. These devices can collect real-time data on various aspects of hospital operations, from patient vital signs to equipment performance, and use AI to analyze this data and make actionable recommendations [28]. Furthermore, AI is expected to play a more significant role in enhancing patient engagement and communication. AI-powered chatbots and virtual assistants can provide patients with timely information, medication reminders, and answers to common questions, improving the overall patient experience and reducing the burden on healthcare staff [6]. Finally, the continuous evolution of AI algorithms and the increasing availability of big data will further refine AI's capabilities in healthcare. As AI systems become more sophisticated, they will be able to provide even more precise and personalized care, leading to better patient outcomes and more efficient hospital operations.

Methodology

In Italy, only companies operating in the industrial, civil, and transport sectors, which in 2021 exceeded an average amount of energy consumption equal to 33% of the overall distribution of final energy consumption across various economic sectors at the national level [33]. According to Italian Law n.10/91, for these economic sectors, the figure of Energy Manager is required, while the hospitals are not required to comply with energy consumption below 1,000 tep/year. In Europe, in the 27 Member States, the obligation exists, except for the following countries: Italy, Poland, Czech Republic, Bulgaria, Romania, Cyprus, Hungary, Slovenia, Slovakia, 9 States out of a total of 27 as indicated in recent European legislation by EU Health Policy, 2024; EU Energy Directive, 2023. This clarification is useful to explain the methodology because the development of the questionnaire was agreed with the regions where there is the highest number of energy managers in hospitals, namely, Northern Italy, Lombardy, Central Italy, Lazio, and Southern Italy, Campania. In fact, given the varying regulatory frameworks, these regions were selected to ensure that the study captures the perspectives of hospitals where energy management practices are more structured, despite the absence of a national legal mandate. Once the pre-test phase was validated, an institutional email, agreed with the three regions involved, was sent with the link to the online questionnaire, which is attached after the bibliography, annex "*Energy manager Energy efficiency and AI implementation in Italian Hospitals*" explaining the genesis of the research and the research questions, reported at the end of the previous paragraph. The questionnaire is based on research exploring AI integration in hospital energy management, focusing on efficiency, predictive maintenance, and sustainability [17, 27]. Studies highlight how building typology and energy consumption patterns influence AI-driven optimization strategies [14, 30]. The role of energy managers is examined in relation to AI-supported decision-making, regulatory compliance, and renewable energy adoption [10, 21]. AI-driven solutions in HVAC automation, lighting, and energy forecasting provide operational benefits [11, 18]. The questionnaire also assesses AI-powered predictive maintenance, reducing system failures and optimizing resource use [8]. Future planning sections align with research on AI's role in smart hospital environments and policy development [2, 29]. Additionally, the questionnaire was carefully structured to minimize the risk of bias, adopting mainly objective questions and neutral formulations that reduce possible distortions in the answers. However, to further strengthen the reliability of the data collected, an information letter was attached to the administration email that explains the main cognitive biases to the participants and provides instructions on how to avoid them. The attached letter aimed to raise awareness among respondents, encouraging them to answer consciously and objectively, thus improving the overall quality of the information collected. Following the indications of Choi and Pak [36] in their catalogue of distortions in questionnaires, the most relevant biases for the present study were identified, in order to minimize their impact. In particular, confirmation bias was taken into account to prevent respondents from privileging information consistent with their pre-existing beliefs, while ignoring potentially contrary data, anchoring bias was carefully monitored to reduce the influence of initial values on subsequent evaluations, ensuring that pre-set references did not condition responses; the social desirability effect was identified to mitigate that participants could be induced to provide responses perceived as socially acceptable rather than an authentic reflection of their opinions and behaviors; and recency bias, which leads to overestimating more recent information at the expense of less recent but equally relevant information, was mitigated through a balanced formulation of questions and response options. Finally, availability bias, which leads participants to base their responses on easily recallable examples, was managed by asking questions encouraging a broader and more representative analysis of reality. The questionnaire was loaded in April 2024 and downloaded as the last date of compilation in June 2024, the questionnaire had an estimated completion time of 50 min. A quantitative approach was used to answer our research questions. A structured questionnaire comprised 23 pre-developed macro-area questions, with over 100 sub-questions. Likert (scale) statements were also used to assess the degree of criticism concerning each item. These macro areas were referred to a scientific literature review on the importance of the topic. The collected data were statistically analyzed using the Statistical Package for the Social Sciences (SPSS) version 22.0. The methodology has been focused on following key statistical analyses:

1. Reliability analysis

   1.1. Cronbach's Alpha: This is a measure of internal consistency, i.e., how closely related a set of items is as a group. A Cronbach's Alpha value above 0.70 is generally considered acceptable, indicating that your questionnaire items reliably measure the same construct.

2. Validity analysis

   2.1. Construct validity: This can be assessed using Factor Analysis.
   2.2. Exploratory factor analysis (EFA): EFA helps identify the underlying structure of your questionnaire items. It shows which items are grouped, indicating they measure the same construct. Key statistics to report include:

   - Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy: A value above 0.60 indicates appropriate factor analysis.
   - Bartlett's test of sphericity: A significant result ($p < 0.05$) indicates that your data is suitable for factor analysis.
   - Factor loadings: These should ideally be above 0.40, showing that items significantly contribute to their respective factors.

3. Descriptive statistics

   3.1. Mean, median, and standard deviation: These provide a summary of responses and help in understanding the distribution of responses for each item.

4. Item-total correlation: this analysis examines the correlation of each item with the total score of the questionnaire.
5. Response rate and missing data analysis

   5.1. Response Rate: A high response rate (above 60–70%) indicates good engagement and representativeness of your sample.
   5.2. Missing Data Analysis: Assess the extent and pattern of missing data. If missing data is minimal and randomly distributed, it's less likely to bias your results.

The submitting of the questionnaire allowed us to present significant data for the interviewed energy managers. To collect all the data, the questionnaire was online for about two months, and using a quantitative approach, shown – with the right use of the Likert chart—the relationship between some areas of AI application in healthcare and some structural gaps in Italian Hospital. All the results are presented in the next paragraph.

Results

Of the 996 Italian hospitals, the research focused on 438 hospitals – total amount of Lombardia, Lazio, and Campania regions. The statistical sample represent about the 44% of 996 Italian hospitals. Of a total of 438 hospitals, 398 declare to have the figure of an energy manager who has been confirmed in the last three years. This data is important to have from the interviewee's structural data and a consolidated experience in the hospital about the questions in the questionnaire. Of the 398, 300 responded to the questionnaire, therefore, well over 50% of the energy managers responded. The 300 energy managers who answered the online questionnaire were equally distributed in the three macro geographical areas, north, centre, and south. The statistical results relating to the questionnaire are reported below (Figs. 1 and 2) (Tables 1, 2 and 3).

These tables provide a clear summary of the key statistical results from SPSS analysis, demonstrating our questionnaire's reliability, validity, and structure. Instead, with the main critical issues reported in the 300 interviews, we have the following energy manager profiles, critical areas and related assessments from the energy managers. Over 75% of the 300 interviewees have a degree in Engineering, with specializations in Mechanics and Computer Science, and are male with 10 years of seniority of service, in public hospitals, not in the same hospital but within the same region. The average estimated value of the structure is 120 thousand square meters, the rooms are on average 2.60 m high, and 83% of the cases are equipped with false ceilings in panels. The development of the structures in

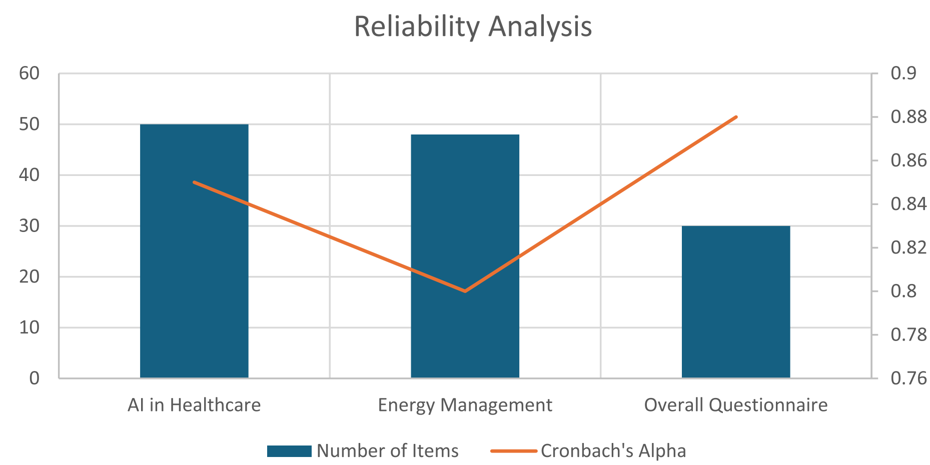

Fig. 1 Reliability analysis

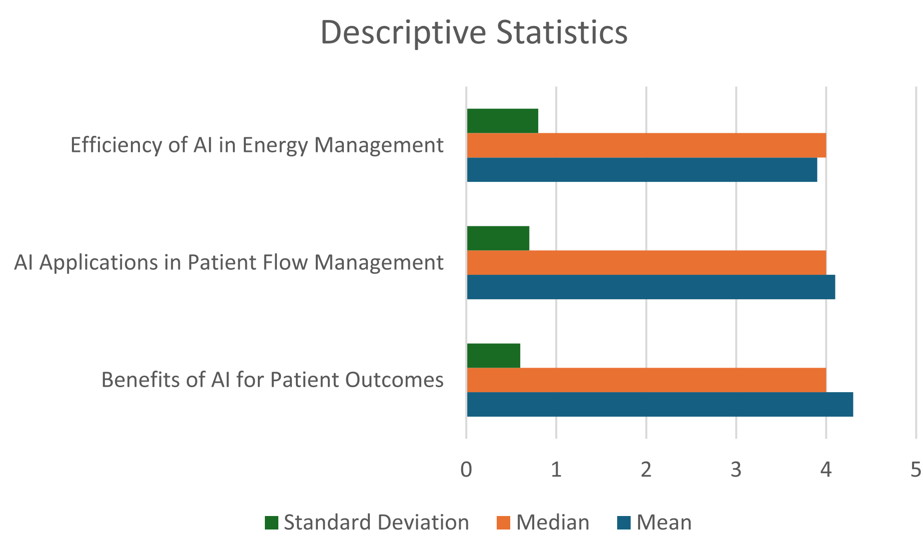

Fig. 2 Descriptive statistics

Table 1 Factor analysis results

Statistic	Value
Kaiser–Meyer–Olkin (KMO)	0.82
Bartlett's Test of Sphericity (p-value)	< 0.001
Number of Factors Extracted	3
Range of Factor Loadings	0.45—0.78

Table 2 Item-total correlation

Item	Item-Total Correlation
AI in Building Maintenance Diagnostic Tools	0.55
AI in Integration Flow Management	0.60
AI in Control Flow Management	0.57
AI in Energy Systems Automation	0.50
Predictive Maintenance with AI	0.52

83% is vertical, consisting of a multi-storey monoblock (over 4 floors). The average is 314 ordinary hospital beds. The average number of beds per room is 5. In 84% of the local units, day hospital activities are carried out and the estimated square meters fall into the 8,000–12,000 class. Renewable sources are expected in the future in 96% of cases. The orientation of the interviewees, in the absence of structural analyses on renewable sources, is positioned towards solutions that prefer wind and solar thermal with a geographical differentiation that prefers the first in

Table 3 Response rate and missing data

Statistic	Value
Response Rate	75%
Missing Data Percentage	2%
Pattern of Missing Data	Random

the structures of the centre north and the second in the south and the islands. Cogeneration/trigeneration plants exist in 23% of cases and are present in all four geographical areas considered. Summer air conditioning is present throughout 98% of the structure. There is no continuous circulation of steam, global thermal consumption is managed directly in 89% of cases, and this percentage is divided into the four geographical areas considered. The management of energy services sees in 93% of cases the very effective air conditioning value of 5, Heating in 90% of cases 4, while for ventilation, in 85% of cases the value 3, while in 84% of cases, lighting and domestic hot water value 1. The annual electricity consumption for each cubic meter of the building was approximately 29.6 kWh/m^3, and heat was again estimated at 110.5 kTOE/year. The structural characteristics of the structure in the geographical areas considered present a percentage of 88% in the 40—60-year class. In most of the structures, 90% have implemented renovation works related to the extraordinary maintenance of the buildings, implemented in the 2000 s, the judgment given by the 300 interviewees is in 82% of the cases considered in the value 3 and therefore we can consider it not very significant. Concerning the part of the questionnaire regarding the adoption of artificial intelligence for energy efficiency, there are no artificial intelligence implementations in 98% of cases, the bottlenecks are represented by the age and obsolescence of the buildings'value 5 and by the lack of dedicated structures and overlapping functions in the decision-making process value 4. For the part regarding future planning and suggestions, the 300 energy managers believe that the technological solutions are valid and can be implemented, but the roles and medium-long term planning of interventions that involve energy managers must be clear, also through the obligation for Italian hospitals of the figure and skills represented by energy managers. The need for a European law on the role of energy managers within the 27 Member States of the Union is also recalled, in 98%. This action is considered significant if relations are established with member countries where the role of energy managers is structured and well planned in terms of energy efficiency, use of renewables and construction of smart hospitals is at an advanced stage, such as Sweden, Finland, Latvia, Denmark, Estonia, Portugal, Austria, Malta, Belgium, Luxembourg.

Discussion

Efficient energy management is essential for the sustainability and cost-effectiveness of Italian hospitals. AI technologies enable the automation and optimization of energy systems, reducing consumption and costs. Based on AI, predictive maintenance helps prevent equipment failures and ensures the regular functioning of energy systems. Italian hospitals, among the energy managers interviewed, highlight the existence of a substantial delay in adopting the solutions proposed by the technological innovation summarized in the AI. On the one hand, the need for energy management different from the past, based on AI to improve sustainability, is highlighted. Still, on the other hand, a series of bottlenecks are highlighted, not only internal to the Italian hospital but also in the low weight assigned to the energy manager role. To address these gaps, policy interventions should include the institutionalization of energy managers within hospitals and financial incentives for AI-driven energy solutions to accelerate adoption and ensure regulatory compliance.

The energy managers interviewed play a fundamental role in implementing and supervising energy management strategies in hospitals. They are aware of having to play a role of responsibility, for example in monitoring energy consumption, compliance with regulations, and promoting sustainable practices. These responsibilities are fragmented by the fixed-term role of energy managers in Italian hospitals, with fixed-term contracts not required by law, even though hospitals are energy-intensive structures that, if not managed, weigh on Italy's energy debt. There is therefore a need for strong planning of this profile and its skills, for example with the importance of continuous training and education on the latest energy management technologies to remain effective in their roles. A national regulatory framework for energy management in hospitals is essential to establish clear governance structures, standardize AI adoption, and define accountability for energy efficiency improvements. Integrating AI, energy managers and Italian hospital structures can create smart hospital environments that improve patient care and operational efficiency. The development of smart hospitals should be considered from what emerges from the questionnaire regarding the high antiquity of buildings and the low budget allocated by the national government and Italian regional governments. Smart hospitals collect real-time data on various aspects of hospital operations, which AI algorithms analyze to provide actionable information. However, the study underscores that budget limitations, regulatory uncertainty, and the absence of a clear national strategy constrain the development of smart hospitals in Italy.

AI has the potential to enhance energy Italian hospital outcomes through various applications significantly. AI-driven tools that improve the accuracy and speed of efficiency, leading to more timely and effective energy use. These tools, including machine learning algorithms and predictive analytics, can analyze vast amounts of energy data to identify patterns that may be missed by human practitioners, thereby reducing errors. In addition, AI is being used to personalize hospital energy use. By analyzing data, AI can identify individualized energy plans, this personalized approach can lead to better energy outcomes and cost satisfaction. AI can also monitor hospitals in real-time, alerting energy managers to potential issues before they become critical, which is particularly beneficial for managing energy crises. Regarding energy management, this integration is not yet present in Italian hospitals, highlighting the lack of continuous monitoring, for example, equipment and overall hospital performance. The first RQ can be answered by saying that there are no best practices within Italian hospitals and for the significant sample of energy managers who responded to the questionnaire, the premises must be built to achieve good practices of integration between the skills of energy managers, the solutions offered by AI for energy management and the current Italian hospital facilities. Future trends, therefore, the second RQ, namely the application of AI to the healthcare sector and in particular the hospital sector, is certainly possible and especially for our field of investigation essential to make energy-intensive structures such as Italian hospitals more efficient. The birth and growth of smart hospitals are essential. Still, they result from a decision-making process that involves both national and local government and requires a necessary source of financing. The future of AI in Italian hospitals and energy managers includes advances in predictive analytics, greater involvement of Italian energy managers, and strong national and regional government planning. The actions to relaunch the role of Italian energy managers at both national and regional levels can help recover the technological disadvantage in Italian hospital facilities. Still, these actions must consider that healthcare and hospitals, one of the health facilities in the area, must see investments in the coming years in structures that make buildings and their management sustainable, especially for energy. Implementing these actions can determine the premises for creating best practices, and therefore ensure that Italian healthcare facilities can effectively manage their energy consumption, reduce operating costs and promote sustainability. In line with these assumptions, artificial intelligence plays a crucial role in achieving these goals, providing advanced tools and insights that improve the efficiency and effectiveness of energy management strategies. Future trends indicate a shift toward more sophisticated, integrated, and efficient systems that will enhance sustainability and operational performance.

Conclusion

Integrating AI in energy management within Italian hospitals offers numerous benefits, including optimized energy consumption, predictive maintenance, and greater sustainability. Advancements in AI-powered workflow optimization tools, predictive analytics, and deep learning models in healthcare have demonstrated their ability to enhance hospital operations, from diagnostic imaging to patient flow management. These applications improve clinical efficiency and serve as a model for optimizing hospital infrastructure and energy use. The role of energy managers should evolve to exploit these technologies effectively. Their role should be ensured by planning this professional profile and its specific skills. This compliance not only with regulations but also with promoting sustainable practices. Explainable AI techniques such as SHAP, LIME, and Grad-CAM are increasingly being applied in healthcare, providing transparency in AI decision-making. Similar interpretability approaches can be leveraged in hospital energy management to enhance trust and adoption among stakeholders. At the current stage, trends point towards even greater progress, with AI creating smarter and more efficient hospital environments. Enhanced predictive capabilities, integration with advanced energy efficiency projects, and smarter renewable energy management, characterize the future of AI in energy management for Italian hospitals. The success of AI in personalized medicine, wearable health monitoring, and predictive maintenance in healthcare demonstrates its potential for revolutionizing hospital energy consumption strategies, aligning with global sustainability goals. These trends will enable energy managers to optimize hospital energy consumption, improve sustainability, and reduce operational costs. Embracing these advancements will be crucial for Italian hospitals to stay at the forefront of energy management and sustainability efforts. Future research should focus on best practices for AI-driven energy optimization in hospitals, assessing its cost–benefit impact and long-term sustainability. Comparative studies with successful smart hospital models in Europe can provide insights into barriers and enablers of AI adoption in Italy. Further investigation is needed on how AI-powered automation influences hospital resilience and energy efficiency, particularly in aging infrastructures. Additionally, research should explore policy frameworks and funding mechanisms that facilitate AI integration in hospital energy management. Concerns the study limitation, the research focused on Italian hospitals, limiting the generalizability of findings to other healthcare systems with different regulatory frameworks and infrastructure conditions.

Supplementary Information

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Supplementary Material 1

Authors' contributions

A.M. and P.P. wrote the main manuscript text and supervised it. M.P. wrote the correction and the structure of the manuscript, including the Tables and the grammar check. All authors reviewed the manuscript.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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