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METRICS FOR ASSESSING THE IMPACT OF ARTIFICIAL INTELLIGENCE ON HOTELS' SUSTAINABLE DEVELOPMENT

Artificial intelligence (AI) is rapidly transforming hotel operations through demand forecasting, dynamic pricing, predictive maintenance, smart building management, automated service delivery, and personalized guest interaction. These applications are often positioned as drivers of sustainability because they enable reductions in energy consumption, water use, food waste, and operational inefficiencies. At the same time, AI introduces new sustainability risks, including rebound effects, privacy and fairness concerns, labor implications, cybersecurity exposure, and the environmental footprint of AI computing itself. Recent hospitality research increasingly emphasizes that AI's sustainability contribution must be measured systematically rather than described conceptually [1–3].

The main difficulty lies in the multidimensional nature of both AI and sustainable development. AI affects multiple hotel departments simultaneously – engineering, rooms division, food and beverage, procurement, human resources, and marketing. Sustainability, in turn, is commonly evaluated through Environmental–Social–Governance (ESG) or triple bottom line frameworks. Empirical studies demonstrate that AI capabilities can contribute to sustainability through green innovation, knowledge management, and complementary organizational competences [4]. However, without a consistent system of metrics, hotels risk misallocating investments, overstating benefits, or ignoring hidden environmental costs associated with AI infrastructure and computing processes [5].

In this context, the purpose of these theses is to propose a structured metrics framework for assessing the impact of AI on the sustainable development of hotels. The framework integrates ESG outcome indicators, AI process and value-chain metrics, AI governance and ethics indicators, and metrics for measuring the carbon footprint of AI computing. This approach is informed by recent peer-reviewed research

on AI adoption in hospitality and on environmental accounting for machine learning systems [1–5].

AI acts as an operational sustainability lever in hotels primarily through integration with IoT sensors, building management systems, property management systems, and data-driven decision platforms. Studies show that AI combined with IoT supports energy efficiency, waste management, and operational optimization, though barriers such as data readiness, staff skills, and integration complexity remain significant [1]. At the same time, AI's contribution to sustainability is strongly mediated by organizational and intellectual capital. Research in tourism and hospitality emphasizes that AI benefits are realized when supported by knowledge management, human competences, and effective governance structures [3]. Evidence from related industries also indicates that AI capability stimulates green innovation and sustainable performance, especially when combined with big data analytics [4].

An often overlooked aspect of AI sustainability is the environmental footprint of AI computing. While AI may reduce hotel energy use, the energy consumed by model training, inference, data storage, and cloud services can partially offset these gains. Recent studies propose methods to quantify the carbon emissions associated with machine learning processes, highlighting the importance of measuring AI compute energy and converting it into emissions using grid factors and lifecycle assumptions [5]. For hotels seeking credible sustainability reporting, AI footprint metrics must be included alongside traditional energy and waste indicators.

The proposed framework begins with ESG outcome metrics, which represent observable sustainability results in hotel operations. Environmental metrics include energy intensity per occupied room-night, greenhouse gas emissions per guest-night, peak load reduction, water consumption per room-night, and waste indicators such as food waste per guest and recycling rates. AI systems contribute to improvements in these metrics through predictive HVAC control, occupancy-based energy management, waste forecasting in kitchens, and optimized laundry and housekeeping schedules [1].

Social outcome metrics relate to workforce well-being, guest experience, and community engagement. These include employee training hours in digital systems, workload balance, staff retention, service accessibility for guests, and perception of privacy and trust. AI-driven scheduling, automation of repetitive tasks, and personalization systems influence these indicators, but require monitoring to prevent

discrimination or over-surveillance [2–3]. Governance metrics include the presence of AI risk assessments, cybersecurity indicators, incident response time, and data governance compliance. These reflect the institutional capacity of hotels to manage AI responsibly and sustainably.

The second layer of the framework focuses on AI process and value-chain metrics. These indicators evaluate how AI systems are built and used. They include data quality measures such as completeness, timeliness, and system integration coverage; model performance indicators such as forecasting accuracy for energy demand and food consumption; and sustainability-adjusted performance measures that link AI predictions to real reductions in resource use. Adoption metrics, such as user engagement rates and override frequency in automated control systems, provide insight into whether AI solutions are trusted and effectively integrated into operations.

The third layer addresses AI governance, ethics, and risk. Metrics in this layer monitor fairness, privacy, and safety. They include disparity indicators in service allocation, auditability of automated decisions, consent coverage for personalized AI services, number of privacy incidents, and frequency of security testing. These indicators are essential for ensuring that AI contributes positively to the social and governance dimensions of sustainability and maintains stakeholder trust [2–3].

The fourth layer introduces AI footprint metrics. These measure the energy consumed by AI model training and inference, hardware utilization, cloud configuration efficiency, and resulting carbon emissions. A key indicator is the net CO₂ benefit of AI, calculated as the reduction in operational emissions minus the emissions caused by AI computing. This metric prevents overstating AI's environmental benefits and supports transparent sustainability reporting [5].

A critical methodological issue in evaluating AI impact is attribution. Sustainability improvements may result from renovations, behavioral campaigns, or occupancy changes rather than AI itself. Therefore, the framework recommends defining a clear baseline period, using counterfactual comparisons where possible, and connecting AI process metrics with ESG outcome metrics while accounting for AI footprint. This approach enables hotels to demonstrate causal links between AI adoption and sustainability improvements [1–3].

For practical implementation, hotels should begin with a metric selection workshop involving engineering, IT, sustainability, and operations departments. A limited but meaningful set of indicators should be selected and integrated into a shared dashboard. Pilot projects should

focus on high-impact areas such as HVAC optimization or food waste forecasting. Monthly monitoring and quarterly audits of AI models, privacy practices, and staff training should follow. Evidence suggests that AI-driven sustainability outcomes are strongest when supported by knowledge management and analytics infrastructure [4].

In conclusion, while AI holds significant potential to enhance the sustainable development of hotels, its impact must be evaluated through comprehensive, multidimensional metrics. The proposed framework integrates ESG outcomes, AI process metrics, governance indicators, and AI footprint accounting to enable credible assessment of AI's net sustainability effect. Recent research demonstrates that AI contributes to sustainability when embedded within organizational capabilities and governed responsibly [1–4], and that accounting for AI's own environmental footprint is necessary for transparent reporting [5]. Future empirical studies should test this framework across different hotel types and develop sector-specific benchmarks for AI-related sustainability performance.

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