**PROBLEMY EKOROZWOJU/ PROBLEMS OF SUSTAINABLE DEVELOPMENT**

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# Artificial Intelligence in Global Libraries: Pathways and Policies for Sustainable Development

## Sztuczna inteligencja w globalnych bibliotekach: ścieżki i polityki zrównoważonego rozwoju

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## Abstract

This study examines how artificial intelligence (AI) is progressively reshaping library around the world including Asia and Republic of China, focusing on new possibilities, ongoing limitations, and regulatory approaches linked to the UN Sustainable Development Goals (SDGs). Employing a systematic literature review and a chronologically framed comparative analysis of peer-reviewed articles, policy texts, and institutional reports from 2019 to 2025, the research identifies four distinct stages of AI integration: Early Infrastructure (2019), Crisis-Driven Uptake (2020–2021), Emergent Generative AI (2022-2023), and Deliberate Mainstreaming (2024-2025). Results show that AI applications such as automated classification tools, interactive chatbots, analytics dashboards, and smart physical systems have markedly improved user services, broadened information access, and reinforced operational resilience, directly advancing SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation, and Infrastructure). However, major obstacles remain, among them algorithmic prejudice, disputed data ownership, labor disruption, environmental costs of AI computing, and uneven advancement across SDG targets. A side-by-side cross-national assessment indicates that China's centralized, state-directed approach enables rapid infrastructure rollout and broad replication, while many Western nations emphasize ethical oversight, social equity, and ecological accountability a priority set that often slows deployment. Integrating insights from both paradigms, the paper proposes an SDG-consistent policy framework centered on layered governance, built-in ethical checks, institutional skill-building, and eco-responsible AI operations. This research extends current theory by explicitly linking AI-enabled library change with sustainability debates and offers concrete recommendations for policymakers, library leaders, and global agencies overseeing AI's long-term function in knowledge institutions.

**Key words:** AI-driven modernization, knowledge institution evolution, SDGs, Chinese library sector, governance models, cross-national analysis

## Streszczenie

W niniejszym artykule analizuje się, jak sztuczna inteligencja (AI) stopniowo przekształca biblioteki na całym świecie, w tym w Azji i Chinach, koncentrując się na nowych możliwościach, bieżących ograniczeniach i podejściach regulacyjnych powiązanych z Celami Zrównoważonego Rozwoju ONZ (SDGs). Wykorzystując systematyczny przegląd literatury oraz chronologiczną analizę porównawczą recenzowanych artykułów, tekstów politycznych i raportów instytucjonalnych z lat 2019–2025, badanie identyfikuje cztery odrębne etapy integracji AI: wczesna infrastruktura (2019), wdrażanie w warunkach kryzysu (2020–2021), rozwijająca się generatywna AI (2022–2023) oraz celowe wprowadzanie do głównego nurtu (2024–2025). Wyniki pokazują, że aplikacje sztucznej

inteligencji (AI), takie jak zautomatyzowane narzędzia klasyfikacyjne, interaktywne chatboty, panele analityczne i inteligentne systemy fizyczne, znacząco poprawiły jakość obsługi użytkowników, poszerzyły dostęp do informacji i wzmocniły odporność operacyjną, bezpośrednio przyczyniając się do realizacji Celów Zrównoważonego Rozwoju 4 (Jakość Edukacji), Celów Zrównoważonego Rozwoju 8 (Godna Praca i Wzrost Gospodarczy) oraz Celów Zrównoważonego Rozwoju 9 (Przemysł, Innowacje i Infrastruktura). Nadal jednak istnieją poważne przeszkody, takie jak uprzedzenia algorytmiczne, spory o własność danych, zakłócenia w rynku pracy, koszty środowiskowe obliczeń AI oraz nierównomierny postęp w realizacji celów SDGs. Porównawcza ocena międzynarodowa wskazuje, że scentralizowane, sterowane przez państwo podejście Chin umożliwia szybkie wdrażanie infrastruktury i szerokie powielanie, podczas gdy wiele krajów zachodnich kładzie nacisk na nadzór etyczny, równość społeczną i odpowiedzialność ekologiczną – priorytety, które często spowalniają wdrażanie. Łącząc wnioski z obu paradygmatów, artykuł proponuje spójne z Celami Zrównoważonego Rozwoju ramy polityki, skoncentrowane na wielowarstwowym zarządzaniu, wbudowanych kontrolach etycznych, budowaniu umiejętności instytucjonalnych i ekologicznych operacjach AI. Badania te rozszerzają obecną teorię, wyraźnie łącząc zmiany w bibliotekach, które są możliwe dzięki AI, z debatami na temat zrównoważonego rozwoju i oferują konkretne rekomendacje dla decydentów, liderów bibliotecznych i globalnych agencji nadzorujących długoterminowe funkcjonowanie AI w instytucjach wiedzy.

**Słowa kluczowe:** modernizacja oparta na sztucznej inteligencji, ewolucja instytucji wiedzy, Cele Zrównoważonego Rozwoju, chiński sektor biblioteczny, modele zarządzania, analiza międzynarodowa

## 1. Introduction

Bringing AI into library settings marks a fundamental shift in how these organizations manage, structure, and share information within an increasingly digital era. Although libraries have historically adapted to ongoing technological transformations, the rapid tempo and intricate nature of today's AI progress introduces unique prospects and challenges that call for careful academic investigation (Martínez Concha et al., 2024). The years 2019 through 2025 constitute a critical window in both the coming-of-age of AI as a field and its real-world integration into library systems, underscoring the need for a detailed, phase-aware assessment rather than a broad, one-size-fits-all overview. According to the AI Index Report 2025, total corporate spending on AI hit $252.3 billion in 2024, as private investment grew by 44.5%, and 78% of surveyed firms confirmed they were using AI a steep increase from 55% the year before (Maslej et al., 2025). Meanwhile, McKinsey data show that professional services now leads all industries in generative AI usage, with adoption rates climbing to 71% in 2024, up from only 33% a year earlier. This study adopts a conceptual framework built around sustainable development's three core pillars, each linked to particular SDGs. On the social side fall SDG 4 (Quality Education), SDG 5 (Gender Equality), SDG 10 (Reduced Inequalities), and SDG 16 (Peace, Justice, and Strong Institutions). The economic pillar includes SDG 8 (Decent Work and Economic Growth) alongside SDG 9 (Industry, Innovation, and Infrastructure). Environmentally, the framework covers SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Situated within this conceptual design, libraries serve a distinctive function as information gatekeepers; their strategic choices about new technologies can significantly shape whether disparities in information access shrink or expand (Mattern, Pelechrinis, & Xiao, 2022).

This paper argues that if AI is integrated into library operations in a careful, sustainability-grounded manner specifically aimed at advancing the SDGs it can meaningfully broaden worldwide access to information, protect cultural heritage, and foster fairness in digital participation. Achieving these benefits, however, requires a nuanced grasp of varying national settings, diverse technological systems, and contrasting regulatory climates. By closely comparing the distinct path taken by Chinese libraries with that of their international peers, the study identifies practices that can be adapted elsewhere alongside obstacles unique to particular contexts. China's forceful nationwide strategy on AI, coupled with the vast geographic and institutional scale of its library system, provides a powerful example of state-guided technology rollout whose lessons reach far beyond its borders. According to Huang, Cox, and Cox (2023), Chinese libraries exhibit faster adoption via government-orchestrated programs, hitting SDG 9 infrastructure targets considerably sooner than Western equivalents, yet they show comparatively less attention to the openness requirements tied to SDG 16.

This study intentionally spans 2019 to 2025 to encompass four clearly separated analytical stages: the initial pre-outbreak benchmark (2019); a COVID-induced push toward rapid digitalization (2020-2021); the arrival of generative AI accompanied by related ethical controversies (2022-2023); and a subsequent period marked by thoughtful, sustainability-aware strategic incorporation (2024-2025). Adopting this segmented approach reveals how external disruptions especially the pandemic altered both the path of AI adoption and the ranking of SDG concerns. By examining both China and other countries side by side, the research allows for a comparative assessment of the ways that governance approaches, resource distribution strategies, and cultural values influence the uptake of AI in knowledge-focused organizations. The article is organized as follows: an overview of relevant

literature; a description of the research design; a chronological assessment of worldwide AI implementation patterns; an examination of China's specific case; an exploration of sustainability issues with direct SDG connections; a set of policy proposals; and closing remarks with suggested avenues for future work.

*1.1. A chronological survey of existing AI uses across library operations, aligned with Sustainable Development Goals (SDGs)*

Between 2019 and 2025, scholarly work has charted a complex, shifting path of AI implementation within libraries, featuring clear stages that show varying degrees of connection to sustainable development aims. A 2024 systematic review by Martínez Concha and colleagues finds that AI tools are mainly clustered around backend operations, patron-facing services, and collection management, while also noting that both technological maturity and alignment with the SDGs changed markedly over the period under review.

In backend operational areas, AI has streamlined cataloguing and classification tasks, yielding productivity gains that support SDG 8.2's focus on greater economic efficiency. Yet Nayyer and Rodriguez (2022) warn that such technologies must be deliberately designed to prevent perpetuating exclusionary patterns that would run counter to SDG 10.3's pledge of fair access to opportunities, requiring ongoing oversight and preemptive adjustments. The 2020-2021 crisis period greatly sped up these rollouts, with urgent implementations giving priority to SDG 9.1 (durable infrastructure) often at the cost of comprehensive ethical scrutiny.

Turning to patron-facing services, AI-enabled dialogue systems have become a major feature, evolving from simple, rule-driven engines into advanced models that harness natural language processing. According to Nuankaew, Nasa-Ngium, and Nuankaew (2025), AI-powered chatbots in academic library settings significantly boost accessibility and inclusiveness: by providing 24/7 support, these systems contribute to SDG 4 (Quality Education), and their ability to operate across multiple languages furthers SDG 10 (Reduced Inequalities) by expanding linguistic access. During 2022–2023, generative AI made its way into library service offerings, bringing upgraded capabilities but also raising worries about information accuracy that relate to SDG 4.7 (education aimed at sustainable development).

The realm of collection management has also seen significant AI-driven change, where machine learning models examine citation and usage data to inform purchasing choices. Evidence suggests that AI-based predictive tools allow libraries to refine their collections by studying borrowing trends and user behavior patterns to forecast what materials will be needed, thereby reducing wasteful spending and keeping holdings up to date (Gonzalez & Young, 2020, cited in IJTER, 2025). Yet these systems demand meticulous construction to prevent algorithmic prejudice that might undermine fair access to materials (Kalisdha, 2024).

*1.2. Ethical and social dimensions: considerations across the SDGs*

Recent research has generated a rich collection of work exploring AI ethics as they apply to libraries, especially regarding impacts on meeting the SDGs. The IFLA Statement on Libraries and AI (2025) explicitly ties ethically grounded principles to sustainable development aims: requirements for transparency link to SDG 16.6 (accountable and effective institutions), commitments to inclusivity support SDG 10.2 (universal social integration), and guidelines on sustainability address SDG 12.2 (responsible stewardship of natural resources).

One of the most significant ethical issues, with wide-ranging effects on several SDGs, is algorithmic bias. Seminal work by Barocas and Selbst (2016) demonstrated that computational systems can encode societal prejudices and flawed assumptions into working software, thereby hindering advancement toward SDG 5.5 (gender parity) and SDG 10.3 (fair access for everyone). Research emphasizes that routine scrutiny of AI systems is critical for bringing automated decisions into line with sustainability goals. Ferrara (2023) contends that periodic, methodical evaluations of AI-powered tools are required to identify and correct biases based on gender and economic status, thereby directly advancing SDG 5 and SDG 10 objectives.

Data privacy concerns connect to both SDG 16.6 (accountable institutions) and SDG 16.10 (freedom of information). Divergent regulatory systems reflect opposing philosophies: the EU's GDPR exemplifies one approach to governance, whereas China's system prioritizes SDG 9.b (building domestic technological capability) alongside wider state security interests. Martínez Concha and colleagues (2024) note that AI deployments in Chinese libraries operate under a data governance regime that balances national security and social order against individual privacy rights, producing a different set of SDG compromises than those seen in Western settings.

*1.3. Contrasting national approaches: how different SDGs trajectories emerge*

Existing research reveals substantial variation in how different countries pursue AI adoption, with each region highlighting a different combination of SDGs. In Western nations, policy tends to focus on SDG 10 (Reduced Inequalities) through equity-driven frameworks, SDG 12 (Responsible Consumption) via ecological accountability, and SDG 16 (Peace, Justice, and Strong Institutions) through demands for transparent governance. Vaughan (2023) describes what he calls a governance-speed tension, in which the rigorous openness requirements tied to SDG 16.6 can unintentionally slow down the rollout of AI-powered infrastructure that SDG 9.1 aims to promote.

In contrast, China's approach prioritizes SDG 9 (Industry, Innovation, and Infrastructure) through government-orchestrated, rapid advancement, SDG 11 (Sustainable Cities) via smart city deployment schemes, and SDG 17.6 (knowledge sharing for development) through technology transfer arrangements. According to Huang, Cox, and Cox (2023), Chinese libraries reflect a state-driven emphasis on swift AI infrastructure expansion aligned with SDG 9.1, whereas libraries in the United Kingdom concentrate on ethical oversight structures and participatory information literacy tied to SDG 16.7.

Wider patterns in global AI research further underscore these regional disparities. According to the 2025 AI Index Report, China leads the world in AI patents, holding 69.7% of all registered patents, whereas the United States dominates private investment with $109.1 billion and stands out as the top producer of major machine learning models, generating 40 of the most significant new releases globally (Maslej et al., 2025). These competitive forces heavily influence which SDGs receive focused technological development in different countries and regions.

## 2. Methods and data sources

The research adopts a dual-pronged approach, integrating a systematic synthesis of scholarly literature with comparative case analysis, in order to explore how AI is being adopted within library systems across differing national contexts. The overall design captures not only the technological facets of AI implementation but also the policy environments that steer such processes, with enduring attention to sustainability issues throughout.

### *2.1. Chronologically coded systematic review of the literature*

To ensure methodological consistency, the review adhered to a predefined framework with clearly outlined steps for assigning temporal labels and mapping content to the Sustainable Development Goals. Searches were conducted across peer-reviewed and institutional databases, covering the period from January 2019 through July 2025. Beyond basic eligibility criteria, every included document was tagged according to its publication year and alignment with particular SDGs. This dual system allowed for an analysis of how academic conversations shifted over time and which goals gained prominence in different phases. Using a comparable rigorous approach, Martínez Concha and colleagues (2024) examined the literature between 2019 and 2023, finding a steady rise in AI-related library studies. Their results reveal that initial work largely focused on routine automation, but after 2022, the research direction changed notably AI adoption in libraries accelerated quickly, spurred by wider technological progress and more accessible tools. This positions the field as rapidly evolving and expanding, demanding increased ethical scrutiny and strategic focus.

The selection parameters used for this review, including date ranges and SDG-related filters, are summarized in Table 1. The table presents a methodical filtering process designed to surface pertinent academic and organizational documents released from 2019 through 2025. To be included, studies had to either directly or indirectly address the UN Sustainable Development Goals, adopt a subnational, national, or cross-border perspective, and make mention of particular temporal contexts or stages in the evolution of artificial intelligence.

Table 1. Selection benchmarks for identifying sources, covering timeframes and SDGs filters

| Classification | Qualifies for selection | Conditions leading to removal |
|---|---|---|
| Year of Publication | 2019-2025, with year-by-year temporal breakdown | Works published before 2019 |
| SDG Relevance | Explicit or implicit connection to the UN SDGs | Absence of any sustainability orientation |
| Publication Category | Published research includes formally reviewed academic papers, records from symposia, scholarly books, and documents produced by organizations | Opinion editorials, brief news items |
| Geographic Scope | Comparative international or distinct national analysis | Purely local or single-institution focus |
| Temporal Specificity | Reference to specific years or AI development phases | Vague or undifferentiated temporal references |

After duplicate removal and screening criteria application, 187 publications were retained for full analysis. A structured coding framework was used to extract key information, including AI applications studied, national contexts, methodological approaches, sustainability linkages, and policy implications. Each source was evaluated separately by a pair of scholars, who reached an 89% agreement rate; any discrepancies between them were settled

via collaborative dialogue. Such a meticulous approach allowed for the detection of recurring themes, underexplored areas, and nascent developments across the published research.

*2.2. Comparative analysis of cases across borders and tracing SDGs results*

Through a systematic cross-national case study design, the research contrasted artificial intelligence implementation in four countries China, the United States, Sweden, and Singapore while directly linking observed results to the Sustainable Development Goals classification system. For each country, chronological mappings were constructed covering the period from 2019 to 2025, linking specific AI initiatives to relevant SDG indicators. This approach allowed for evaluation of how differing governance models shaped particular SDG outcomes. As an example, the analysis showed how Sweden's KB-BERT project advanced SDG 9.5 (research capacity building) while also bringing up issues tied to SDG 7.3 (energy optimization). The comparative evaluation examined five main areas: (a) overarching goals directing AI applications in libraries; (b) financial frameworks and how resources are distributed; (c) ethical standards and regulatory oversight; (d) approaches to involving relevant parties; and (d) metrics for gauging AI system performance. This multi-faceted approach allowed the team to pinpoint both adaptable strategies and setting-specific obstacles, thereby shaping the policy suggestions presented further on in the document.

*2.3. A Framework anchored in SDG metrics for evaluating sustainability performance*

We developed a three-dimensional evaluation framework based on explicit SDG indicators to measure how well AI deployments align with sustainable development principles:

- **i.** Social Aspect: Targets include SDG 4.3 (ensuring educational opportunities), SDG 10.2 (fostering inclusive communities), and SDG 16.6 (upholding transparent governance).
- **ii.** Economic Aspect: Encompasses SDG 8.2 (boosting productive capacity), SDG 9.1 (enhancing infrastructure reliability), and SDG 9.4 (adopting environmentally sound industrial methods).
- **iii.** Environmental Aspect: Covers SDG 7.3 (improving energy performance), SDG 12.2 (optimizing the use of natural resources), and SDG 13.2 (embedding climate action into policy frameworks).

*2.4. Methodological limitations*

Multiple methodological restrictions merit acknowledgement. Given how quickly AI is advancing, some breakthroughs from 2025 might not yet have received adequate coverage in the body of work examined by this review. Scholarship examining Chinese library contexts occasionally exhibits limited critical scrutiny. Environmental SDG metrics were hampered by incomplete data reporting, particularly during earlier phases of the study period.

## 3. Results

*3.1. Global overview: time-based analysis linked to SDG performance*

*3.1.1. Stage one: pre-pandemic baseline (2019)*

In 2019, the use of AI in libraries was still mostly in the trial phase, with few deliberate efforts to connect it to the SDG framework. Around 35-40% of large academic libraries reported trying out AI initiatives, mostly to boost day-to-day operations, while any links to the SDGs tended to happen by chance. As noted in the AI Index Report 2020, although global corporate spending on AI hit $73.6 billion, adoption across public cultural institutions remained limited, with the majority of projects still at an early testing stage (AI Index, 2020). A handful of applications supported SDG 9.5 (strengthening scientific research) through improved search and retrieval tools, but concerns around fairness related to SDG 10 generally received less focus.

*3.1.2. Second stage: crisis-driven surge (2020-2021)*

With the arrival of the COVID-19 crisis, digital change accelerated abruptly, compressing anticipated schedules for integrating AI into everyday practice. To keep services running while physical spaces were shut down, libraries rolled out AI-driven chat tools and online service interfaces. This shift supported equitable access to education under SDG 4.3 but, at the same time, deepened issues tied to SDG 10.2 regarding full social and economic participation, as certain users were inadvertently left behind by the digital transition. Research on pandemic-era digital transitions reveals a paradoxical pattern: although library automation accelerated, meaningful barriers persisted for vulnerable populations. Nathania and Rahmi (2025) report that nearly 65% of users expressed concerns about the ethical implementation of these systems, while ongoing digital divides continued to undermine the equal opportunity objectives of SDG 10.3.

*3.1.3. Stage three: the generative AI upheaval (2022-2023)*

The arrival of sophisticated generative AI brought both major prospects and intricate issues. Libraries tested chatbot-style interfaces akin to ChatGPT while crafting usage guidelines, supporting SDG 4.4 (skill enhancement) through AI training initiatives and advancing SDG 16.6 (institutional openness) by means of oversight structures.

According to the AI Index Report 2025, the generative AI sector saw explosive growth, with worldwide private funding surpassing $33.9 billion in 2024 more than eight times the amount invested in 2022. Within just one year, corporate uptake of generative AI jumped from 33% to 71% (Maslej et al., 2025). At the same time, libraries undertook ethical assessments of systems put in place during the pandemic, tackling SDG 10.3 (fair opportunity) issues embedded in technologies that were rolled out quickly.

*3.1.4. Stage four: integrated and strategy-driven adoption (2024-2025)*

The current phase is characterized by comprehensive AI strategies that explicitly incorporate SDG alignment. Instead of relying on isolated trials, libraries are now building comprehensive systems that simultaneously tackle social, economic, and environmental demands, transitioning toward fully integrated digital environments. According to the 2025 AI Index Report, corporate engagement with artificial intelligence has shown clear signs of growing sophistication: in 2024, 78% of surveyed companies reported using AI a sharp rise from 55% the year before—and the use of generative AI had more than doubled, with 71% of organizations applying it to at least one business function (Maslej et al., 2025). Environmental issues tied to SDG 7.3 and SDG 13.2, which received less attention in earlier stages, are now seeing a resurgence of interest

The evolution of AI integration within library settings between 2019 and 2025 is broken down into four sequential periods in Table 2, which illustrates major use cases alongside shifts in SDG priorities over time.

Table 2. Phases of AI adoption in libraries and corresponding SDGs priorities (2019-2025)

| Phases of AI development | Principal uses of Artificial Intelligence | Social goal Prioritization | Focus on financial Sustainability Goals | Focus on SDGs related to the natural world |
|---|---|---|---|---|
| 2019 | Experimental pilots, rudimentary chatbots | Minimal and indirect | SDG 9.5 (research advancement) | Rarely evident |
| 2020-2021 | Crisis-response chatbots, digital access platforms | SDG 4.3 (educational access) | SDG 9.1 (infrastructure rollout) | Overlooked |
| 2022-2023 | Generative artificial intelligence platforms and ethical compliance reviews | SDG 4.4 (skills), SDG 10.3 (bias mitigation) | SDG 8.2 (productivity) | Expanding recognition |
| 2024-2025 | Intelligent, eco-friendly frameworks and sustainable artificial intelligence | SDG 10.2 (inclusion and participation) and SDG 16.6 (transparent and accountable institutions) | Goal 9.4: Guaranteeing the Long-Term Viability of Infrastructure Networks | Energy-focused target 7.3 and the climate-related target 13.2 |

*3.2. The global overview of Artificial Intelligence applications within librarianship*

*3.2.1. Current state of implementation*

Around the world, the adoption of AI in library settings has advanced at highly unequal speeds, exposing deep-rooted gaps in technical infrastructure, financial capacity, and strategic focus across institutions. Data from the 2025 AI Index Report show that in 2024, AI usage reached 78% among surveyed organizations, compared to 55% a year earlier (Maslej et al., 2025). In parallel, a 2025 Clarivate study found that 67% of libraries are currently experimenting with or implementing AI tools, pointing to a growing level of sophistication in how knowledge-based organizations are responding to technological transformation.

In Western contexts, adoption has typically moved from initial pilots of discrete applications such as chatbot interfaces or recommendation engines toward broader integration. The British Library exemplifies leadership within the Collections as Data movement, developing solutions through partnerships including the Alan Turing Institute to enrich metadata by automatically identifying entities and patterns across millions of lines of digitized text (Cordell, 2020). Academic libraries have generally led adoption, deploying AI to enhance research support and learning services with increasing sophistication. Sweden's national repository, the Kungliga biblioteket, created a language model known as KB-BERT demonstrates a strategic shift toward SDG 9.1, as the institution moved from reliance on third-party tools to providing foundational AI infrastructure improving searchability and OCR accuracy across centuries of digitized data while advancing SDG 16.10 by enabling more equitable and accurate public access to historical information (Malmsten et al., 2020).

Across the globe, the spread of AI capacity follows familiar trajectories tied to technology funding and growth. The stark contrasts in AI preparedness among various regions are shown in Table 3. Such imbalances prompt worries that existing knowledge gaps could widen further, since libraries situated in tech-forward areas broaden

their functionalities, whereas those in less affluent environments still struggle with basic digital building blocks a situation that ties directly to SDG 10's focus on lessening disparities both inside countries and across them.

Table 3. A side-by-side analysis across geographic areas of AI adoption in libraries between 2020 and 2025

| Geographical Area | Main Use Cases | Main Driving Forces | Critical Obstacles |
|---|---|---|---|
| North America | Chatbots, predictive analytics, automated cataloging | University-industry collaboration, private-sector innovation | Ethical concerns, budgetary pressures, workforce readiness |
| Western Europe | Digitization, semantic retrieval, research support | National cultural policy, EU-funded programs | Data privacy regulation, interoperability, language diversity |
| East Asia | Smart libraries, robotics, facial recognition | State-led AI strategies, industrial policy frameworks | Intellectual freedom concerns, cross-border data governance |
| South Asia | Mobile services, entry-level chatbots, digitization | International development partnerships, donor aid | Infrastructure limitations, funding scarcity, technical capacity |
| Africa | Pilot schemes, mobile apps, SMS-based services | NGO-led initiatives, donor-funded projects | Electricity reliability, internet access, staff training |

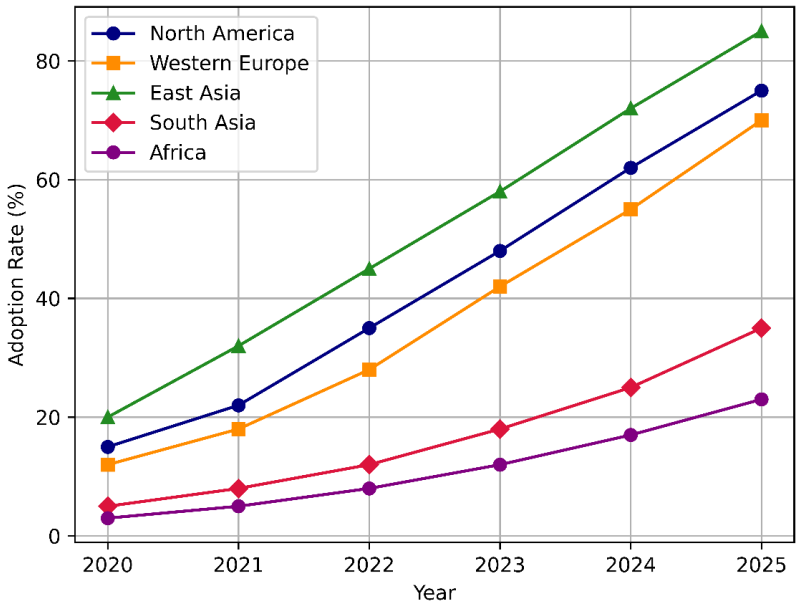


Figure 1. Global trends in AI adoption within library services (2020–2025)

Presented in Figure 1 is a side-by-side comparison across world regions regarding the uptake of AI-driven tools including chatbots, predictive analytics, smart cataloging, and digital conversion systems within library settings. Adoption rates vary notably among North America, Western Europe, East Asia, South Asia, and Africa, as shown in the figure. These differences stem from unequal levels of digital infrastructure, divergent policy agendas, varying financial resources, and differing organizational preparedness, which collectively shape how quickly and extensively libraries undergo technological change on a global scale (Islam et al., 2025).

*3.2.2. Recent developments and novel technological advancements*

Apart from existing implementations, a number of emerging AI uses within library settings hold notable potential for enhancing how services are provided and how operations function. Advances in natural language processing have positioned libraries to move toward sophisticated semantic retrieval capabilities. Unlike conventional keyword-based search systems, AI-driven platforms that prioritize user intent and contextual meaning significantly enhance the discoverability of complex academic resources (Wang & Lund, 2023). Digitized materials can now be examined using cutting-edge computer vision techniques, which support tasks such as recognizing script styles in historical records and sorting visual content within photograph archives. Meanwhile, forecasting tools are growing more sophisticated at anticipating usage patterns for library resources and pinpointing missing areas within collections The smart library concept represents a holistic vision for AI integration that combines multiple technologies into unified service environments. Bi et al. (2022) describe how the contemporary smart library ecosystem

draws on a convergence of Internet of Things (IoT) sensors, AI-powered analytics, and mobile platforms to create responsive, adaptive environments in which physical and digital services are seamlessly integrated to enhance both user experience and operational efficiency. These deployments encompass automated storage and retrieval infrastructure, environmental monitoring, personalized navigation assistance, and immersive learning experiences through augmented or virtual reality.

The period since 2022 has witnessed the exceptionally rapid rise of generative AI tools, bringing about groundbreaking possibilities alongside intricate difficulties. Worldwide, private funding for generative AI surpassed $33.9 billion in 2024, marking a year-over-year rise of 34.5% (Maslej et al., 2025). Such technologies enable the production of original content, cross-lingual translation, and the condensation of lengthy texts, greatly enhancing how easily information can be accessed. At the same time, they introduce critical concerns regarding information integrity, the need for source attribution, and the inherent risk of propagating inaccurate outputs or hallucinations (Fakhlina et al., 2025). Libraries must therefore balance the service enhancement potential of generative AI with their responsibility to cultivate critical AI literacy among users a dual role that captures the shifting role of libraries as both users of emerging technologies and providers of public learning.

### *3.3. Pandemic effect crisis: swift advancement of AI and trade-offs among the SDGs*

The COVID-19 pandemic acted as a powerful trigger for artificial intelligence integration within libraries, collapsing what would have been years of expected digital progress into just a few months. Yet this rapid shift came with compromises among various SDG priorities, necessitating adjustments after the crisis. During the emergency period, efforts focused heavily on SDG 9.1 (infrastructure expansion) and SDG 4.3 (access to education), often at the expense of SDG 10.2 (social inclusivity) and with little regard for SDG 13.2 (climate action measures).

Between 2020 and 2021, a swift modernization of information systems took place across China's library sector, drawing on national infrastructure to maintain service continuity. Zhu and Liu (2022) document how China's Smart Library movement accelerated significantly during the pandemic, utilizing AI and cloud computing to sustain remote access. While such initiatives directly advanced SDG 4.3 by ensuring access to educational resources, they also raised questions regarding governance transparency at scale. While this state-led model ensured ongoing functional stability, it introduced regulatory compromises that differ from the challenges typically observed within Western systems

The Pandemic revealed that libraries already equipped with digital resources were able to pivot more successfully, highlighting the long-term strategic importance of earlier investments aligned with SDG target 9.1. According to Wheatley and Hervieux (2020), the pandemic prompted a swift transition to automated services, hastening the uptake of emerging technologies of conversational AI within library environments. However, this transition also exposed significant digital divides: high-tech solutions risked marginalizing users lacking adequate digital literacy or equipment, creating tensions with SDG 10.2's inclusion objectives.

### *3.4. China's national context: government-directed advancement of SDGs targets*

#### *3.4.1. National-level strategy and supporting institutional arrangements*

Issued by the State Council during July 2017, the document titled *China's Next-Generation AI Growth Strategy* outlines the country's roadmap for advancing artificial intelligence, establishes a formal framework that positions AI as the central driver of industrial modernization and economic transformation (Roberts et al., 2021). Academic research confirms that this policy has significantly advanced SDG 9 through technological innovation and structural reforms to industrial systems (Frontiers, 2026; PMC, 2025). Hannas and Chang (2019) concentrate predominantly on science and technology intelligence, military-civil fusion, and technology transfer, paying comparatively less attention to cultural institutions such as libraries as primary sites of implementation. While this unified system has accelerated the expansion of infrastructure in line with SDG 9.1, it falls short regarding the inclusive decision-making standards tied to SDG 16.7.

A coordinated network of universities, research centers, and tech companies forms the broader organizational environment. In their 2023 study, Geraldo and colleagues explore how Digital Humanities projects operating within the field of Information Science support objectives like SDG 9.5 (enhancing scientific research capabilities) and SDG 17.6 (fostering global partnerships in science, technology, and innovation). This convergence of academic, commercial, and governmental actors enables fast expansion but also gives rise to distinct data governance models.

#### *3.4.2. Execution strategies and corresponding SDGs outcomes*

In China, artificial intelligence has been adopted across a wide range of library operations, especially in services tied to national strategic objectives. Smart library initiatives leverage robotics, the Internet of Things (IoT), and AI to establish highly automated settings that contribute to SDG 11 (Sustainable Cities and Communities) by optimizing spatial usage and to SDG 9.1 by upgrading infrastructure. These systems frequently incorporate biometric access controls, which introduce privacy issues related to SDG 16.10, alongside AI-driven recommendation systems.

AI technologies are also playing a growing role in safeguarding cultural heritage, particularly through mass-scale digitization and interpretive content processing. Such efforts help advance SDG 11.4 by protecting cultural assets and contribute to SDG 4.7 by enhancing access to historical materials for sustainable development education. Yet these developments also introduce concerns regarding whose cultural expressions receive priority, touching on SDG 10.2 and the integration of underrepresented minority viewpoints. The prevailing strategy follows a showcase-then-replicate model, where initial high-impact projects become templates for widespread use accelerating progress toward SDG 9.1 infrastructure targets, but often at the expense of localized customization, a critical factor for fostering inclusive and community-centered outcomes

*3.4.3. Benchmarking global influence and relative position*

When viewed side by side, China's library sector shows notable advantages in how quickly it implements AI and at what scale, yet persistent concerns remain around openness and shared decision-making. According to the 2025 AI Index Report, China continues to lead globally in artificial intelligence publications and patents, with performance gaps against top U.S. models narrowing toward equivalence (Maslej et al., 2025). This trajectory of technological advancement supports SDG 9.b which calls for fostering domestic technological capability while simultaneously casting doubt on whether it fulfills SDG 17.6, which emphasizes the importance of cooperative knowledge exchange across borders

Through the export of technology and participation in cross-border collaborative projects, China is expanding its worldwide sway. Smart library solutions from China are now being rolled out in regions including Southeast Asia and Africa bolstering SDG 9.1 infrastructure in host countries, yet also raising nuanced concerns regarding technological reliance as it relates to SDG 17.3. According to Danquah et al. (2024), at least twelve African nations have adopted Chinese-built smart library systems, supporting SDG 9.1 targets while simultaneously bringing to the fore technology-transfer issues tied to SDG 17.6.

*3.5. Evaluating sustainability through key Development Goals: a focused SDGs analysis*

*3.5.1. Societal aspects: Goals 4, 5, 10, and 16*

The connection between AI and social sustainability targets is nuanced and multifaceted. Positively, these technologies can help realize SDG 4.3 (expanding educational access) through customized learning routes, as well as SDG 10.2 (fostering social inclusion) by way of enhanced accessibility tools. Negatively, however, they run the risk of widening digital gaps and perpetuating biases that contradict SDG 10.3 (ensuring equal opportunities). According to Garnier and colleagues (2024), libraries bear a unique obligation to prevent their AI applications from entrenching existing social inequities and instead proactively reduce those disparities via inclusive design thereby directly furthering SDG 10.2.

Gender equality under SDG 5.5 and equal opportunity under SDG 10.3 are uniquely threatened by algorithmic bias. Evidence from various fields shows that machine learning models often magnify pre-existing social disparities. In libraries, such bias might surface in recommendation engines that privilege dominant perspectives or through cataloging systems that marginalize non-Western knowledge systems. Addressing these challenges demands investments that can clash with the productivity goals of SDG 8.2, introducing fundamental tensions within sustainable development efforts.

Equitable adoption of AI is seriously hindered by digital disparities. Increasingly advanced AI-driven tools tend to demand greater internet speed and more robust hardware, which may lead to stratified access models that deepen current inequities contravening SDG 10.2. For libraries operating in under-resourced digital environments, allocating limited resources becomes a difficult balancing act: sustaining essential basic services or pursuing cutting-edge AI functionalities.

*3.5.2. Examining financial and infrastructural stability: fostering productive employment (SDG 8) alongside industrial advancement and resiling infrastructure (SDG 9)*

One crucial aspect of cost-effective and sustainable library operations is the use of AI-powered accessibility tools. By automatically producing or improving image alt-text, audio narrations for visual materials, and metadata compatible with screen readers, AI helps advance SDG 4.3 (access to education) and SDG 10.2 (inclusion of people with disabilities). For users facing visual, hearing, or cognitive challenges, libraries that implement AI-supported solutions such as live captioning, automated alt-text, and descriptions for tactile graphics can significantly lower the obstacles that have long prevented equitable access to information. This approach supports SDG 10.3 (equal access) and underscores the necessity of integrating inclusive design into AI systems from the start, rather than treating it as a later addition.

The financial impact of integrating AI involves not only productivity improvements but also considerable initial spending. Automating routine tasks may lower staffing expenses and allow professionals to focus on more complex responsibilities, thereby contributing to SDG 8.2 (economic productivity). Yet Cox (2024) notes that AI and automation might transform 30-40% of current library operations, necessitating large-scale employee upskilling efforts aligned with SDG 8.5 (decent work for all). Beyond start-up costs, long-term viability is strained by continuous system upkeep, periodic upgrades, and the need for specialized staff.

The movement of labor represents a key financial factor carrying profound societal consequences. While the need for some routine jobs might decrease due to mechanization, this shift also generates fresh positions that demand alternative competencies. Policies aimed at long-term viability need to embed equity-based transition measures that promote both decent work (target 8.5) and technical training (target 4.4) by implementing all-encompassing, future-oriented upskilling initiatives.

*3.5.3. Leveraging SDGs 7, 11, 12, and 13 to promote ecological sustainability*

The ecological impact of artificial intelligence arises from several linked channels, bringing both difficulties and prospects. Running and developing advanced AI models demands heavy computing power, and the resulting electricity use has implications for SDG 7.3, which targets improvements in energy efficiency. According to the 2025 AI Index Report, training just one large language model may use an amount of energy equivalent to what five typical American households burn through in a full twelve months. This creates a clear conflict with SDG 7.3 unless clean energy options are employed (Maslej et al., 2025).

From a favorable standpoint, AI tools have the potential to advance environmental goals through improved infrastructure performance. Smart building controls can lower energy use for temperature regulation and illumination, thus contributing to Target 11.6 of the SDGs (lessening the ecological footprint of urban areas). Usage data on collections can reduce the purchase of low-demand titles, aiding SDG Target 12.2 (responsible resource use). Nevertheless, these advantages need to be balanced against the ecological price tag associated with deploying AI systems themselves.

To fully evaluate sustainability, one must consider the entire lifespan of a system from manufacturing and operation to end-of-life processing. According to Tabbakh et al. (2024), ethical AI development demands a balance between ecological effects and performance goals, through methods like model refinement, low-power computing systems, and using renewables efforts that directly support SDG targets 12.2 and 13.2. Meanwhile, libraries have a duty to educate users about AI's ecological toll, making visible the often-overlooked environmental costs embedded in everyday digital services. By simultaneously lowering their own operational footprints and raising community awareness, libraries can take genuine leadership roles in advancing sustainable technology (Adeyemi & Muhammed-Jamiu, 2025), thereby emerging as vital players in the push for ecologically sound AI deployment.

A side-by-side evaluation of the ecological impacts linked to different library-based AI tools covering energy and water demands from training large models, running inferences, managing intelligent buildings, and maintaining digital archives is presented in Figure 2. Drawing on the United Nations (2023), the illustration highlights not only the environmental costs but also the possible efficiency gains offered by AI systems. This gives libraries critical guidance for striking a balanced approach that harmonizes tech-driven progress with ecological sustainability aims across several SDGs.

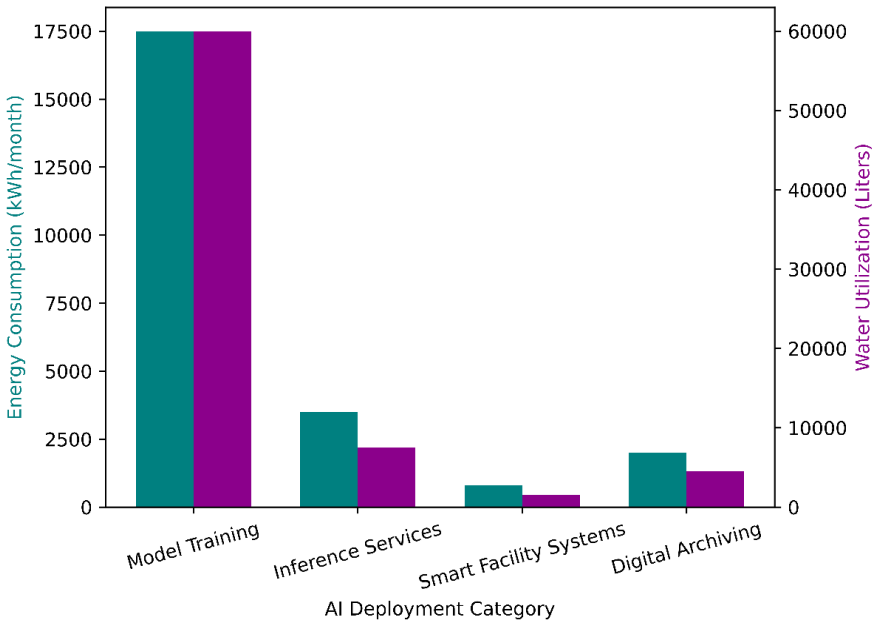


Figure 2. Environmental effects of AI systems and sustainability mitigation strategies

As the Figure makes unmistakably clear, training large-scale AI systems carries a far greater environmental burden than running standard day-to-day tasks. Meanwhile, Table 4 breaks down the resource use and possible performance gains for key AI uses in libraries, pointing out both the water and energy required for every operation and pinpointing opportunities for greener practices and more efficient allocation of resources.
Table 4 present a comparative breakdown of monthly energy consumption (kWh) and water usage (litres) across four key AI applications in library settings large model training, inference operations, intelligent building control, and digital preservation alongside an assessment of achievable efficiency gains for each deployment type, highlighting opportunities for resource optimization in alignment with SDG 7.3 (energy efficiency) and SDG 12.2 (sustainable resource use).

Table 4. AI deployments, resource requirements, and achievable efficiency gains

| Utilization | Energy utilization (kWh/month) | Volume of $H_2O$ Consumed (litres) | Scope for Performance Gains |
|---|---|---|---|
| Large Model Training | 17,500 | 60,000 | Low |
| Inference Operations | 3,500 | 7,500 | Moderate |
| Intelligent Control of Building Systems | 750 | 1,500 | decrease of 15-30% |
| Long-Term Protection of Electronic Records | 2,000 | 4,500 | **Mid-significant** |

*3.5.4. Core discoveries*
At the opposite end of the spectrum, AI-powered smart building systems require the fewest resources yet deliver the highest possible savings cutting total building energy and water usage by 15-30%.

## 4. Discussion

The present study advances prior work on AI within library contexts by embedding AI integration into a time-sensitive, SDG-grounded assessment model. Although previous investigations have tended to concentrate on isolated AI functions or single ethical issues (Bradley, 2022), this research enriches the existing body of knowledge by tracking the changing dynamics of AI-library interactions across different periods and by demonstrating how varied regulatory frameworks produce divergent sustainability results.

*4.1. A comparative analysis of trajectories in AI integration*
Examining data from 2019 to 2025 confirms the trend observed by Islam and Guangwei (2025), who noted a marked rise in library AI use, especially after 2020. Yet, contrary to the widespread belief that AI integration unfolds smoothly and predictably, this study reveals an uneven, faster-than-expected trajectory. Specifically, urgent developments during the 2020–2021 crisis led to a strong focus on SDG 9.1 (building infrastructure) and SDG 4.3 (expanding educational access), while priorities such as SDG 10.2 (fostering social inclusion) and SDG 13.2 (embedding climate action) were often sidelined. These results align with Shulla et al. (2021), but go beyond their environmental lens by clearly pinpointing tensions between various SDG targets.
During the pandemic, Chinese libraries adopted AI-powered services more rapidly than their Western counterparts, which aligns with the observations made by Nugroho et al. (2023). However, whereas most studies frame this fast rollout as wholly positive, a side-by-side comparison reveals significant governance deficits. Notably, China's strong push toward SDG 9 came with limited public participation and oversight key elements of SDG 16.7. By contrast, libraries across Europe and the United States advanced more slowly due to tighter data protection laws and rigorous ethical oversight, yet they demonstrated better adherence to SDG 16.6 (institutional openness) and SDG 10.3 (fair access for all).

*4.2. Addressing social sustainability: balancing progress and conflicts across SDGs 4, 5, 10 and 16*
While Faruqui et al. (2025) reached similar conclusions, the present research confirms that AI-powered user tools particularly multilingual chatbots and dialogue-based systems greatly improve educational access, thereby advancing SDG Target 4.3. Nevertheless, the findings reveal unequal distribution of these advantages, especially across areas with deficient digital connectivity. Such results reinforce the position taken by Jaeger and colleagues (2012), who stressed that libraries cannot rely solely on technology uptake to guarantee equitable participation; instead, they must deliberately confront digital marginalization.

Concerns over unfair outcomes from algorithms persist, building on the earlier work of Cathy O'Neil (2016) and more recent library-focused research by Al-Aamri and Osman (2022). Unlike many prior studies that approach bias mostly as a technical glitch, the current study situates efforts to reduce bias within the larger normative aims of SDG 5.5 (gender equality) and SDG 10.3 (equal opportunity). The results indicate that ignoring algorithmic bias jeopardizes libraries' core ethical missions. In China, AI systems are technologically advanced, yet they feature less systematic bias auditing than their Western counterparts not due to a gap in technical skill, but as a reflection of different SDG priorities.

*4.3. Financial viability: gains in operational efficiency and changes to the nature of work*

Dixon (2021) argued that AI boosts productivity especially for SDG 8.2 by taking over repetitive work, and the present results reinforce that claim. However, this research adds a new layer regarding sustainability, revealing that these efficiency gains frequently come with overlooked future costs, such as maintaining systems, retraining staff, and dealing with technological obsolescence. In China, centralized funding and large-scale operational advantages allow libraries to make quicker headway on SDG 9.1 and 9.5 than their counterparts in decentralized settings. Meanwhile, Western libraries excel in meeting SDG 8.5 (decent work) thanks to structured workforce reskilling and career development programs. This divergence demonstrates that the long-term economic viability of AI adoption is deeply tied to social sustainability, especially around managing workforce changes and adapting labor policies.

*4.4. Ecological viability: A growing yet inconsistent focus*

The current body of work on artificial intelligence in library settings largely overlooks ecological issues a shortcoming that the present investigation aims to remedy. Echoing the observations made by Tabbakh et al. (2024), the evidence shows that training extensive AI systems demands significant power and water resources, which conflicts with SDG targets 7.3 and 13.2 unless green AI or sustainable approaches are adopted as compensatory strategies. While libraries in Western nations are progressively embracing energy-saving benchmarks and eco-friendly operations, discussions on environmental policy in China give relatively little weight to these impacts. There, the push for infrastructure growth tied to SDG 9 continues to overshadow all other strategic concerns.

The findings reveal two interconnected environmental functions for libraries: first, minimizing their own ecological impact by means of smart building technologies (in line with targets 11.6 and 12.2 of the SDGs), and second, raising public awareness regarding the often-overlooked environmental price of digital systems. Current research has mostly overlooked this second, instructional role, making it an original addition to the scholarly record.

*4.5 Policy implications in relation to existing literature*

To move beyond current ethical guidelines, this paper contends that simply having value-based rules falls short unless accompanied by concrete procedures and quantifiable benchmarks tied to the SDGs. Effective real-world application requires translating high-level pledges into actionable, assessable targets (Mair et al., 2017). The proposed multi-level policy framework addresses shortcomings identified in previous studies by combining governance structures, ethical oversight, capacity development, and environmental accountability within an integrated

Table 5. Policy guidance with direct SDG alignments

| Dimension | Central Challenges | Recommended Interventions | Relevant SDGs |
|---|---|---|---|
| Social Sustainability | Algorithmic discrimination, digital exclusion, accessibility gaps | Enforcing fairness assessments, imposing universal design standards, and creating financial reserves for digital inclusion. | Equal opportunity (SDG 10.3), social inclusion (SDG 10.2), gender parity in leadership roles (SDG 5.5), and access to education (SDG 4.3) |
| Economic Sustainability | High deployment costs, workforce disruption, long-term upkeep | Phased implementation models, reskilling schemes, and sustainable funding mechanisms | the SDG targets addressing economic productivity (8.2), decent work (8.5), infrastructure development (9.1), and sustainable industrial practices (9.4) |
| Environmental Sustainability | Energy intensity, electronic waste, resource depletion | Efficiency benchmarks, lifecycle assessments, green procurement | the SDG targets addressing energy efficiency (7.3), cities' environmental footprint (11.6), sustainable resource use (12.2), and climate policy integration (13.2) |
| Cross-cutting Governance | Fragmented oversight, accountability deficits, uneven participation | Multi-level coordination, transparent decision processes, stakeholder engagement | SDG 16.6, 16.7, 17.6, 17.17 |

SDG-oriented model. When comparing different approaches, the most promising route to sustainable artificial intelligence adoption in libraries combines the operational speed seen in China's implementations with the ecological and ethical protections typically embedded into Western frameworks.
The key policy obstacles linked to integrating AI into library settings are presented in Table 5, which also maps actionable solutions alongside their corresponding SDG targets.

## 5. Conclusions and future research

This study concludes that artificial intelligence is fundamentally reshaping library systems on a global scale, yet whether this change results in long-term beneficial effects hinges on regulatory structures, strategic timing, and purposeful linkage with the Sustainable Development Goals (SDGs). Examining AI uptake over distinct intervals between 2019 and 2025, the research reveals that the incorporation of AI into libraries has progressed through successive stages, each characterized by unique focal points, possibilities, and conflicts. The pandemic-fueled push toward digitization enhanced connectivity and access (SDGs 9.1 and 4.3), but simultaneously deepened disparities (SDG 10.2) and sidestepped ecological considerations (SDG 13.2) underscoring the urgent requirement for intentional reforms following the crisis.
When examined side by side, China's government-driven system supports rapid AI deployment and large-scale tech expansion, significantly advancing progress on SDGs tied to industry and infrastructure. Meanwhile, Western models place greater emphasis on fairness, inclusive access, and ecological accountability which can occasionally delay real-world application. On their own, both paths have clear limitations. For libraries to adopt AI in a lasting way, a middle-ground approach is essential one that upholds community fairness, financial practicality, and planetary stewardship.
This research intentionally connects AI use cases with particular Sustainable Development Goal indicators, providing a systematic lens for evaluating AI-led changes in libraries that goes beyond purely technological indicators. The strategic recommendations put forward emphasizing layered oversight structures, integrated ethical frameworks, organizational skills development, and environmentally conscious AI serve as practical pathways for decision-makers, library administrators, and global bodies. In essence, libraries hold a distinctive position as reliable civic institutions and bridges to information. Rooted in well-defined sustainability values, they can harness AI not merely to upgrade operations but also to promote fair information access, ethical innovation, and enduring sustainable progress across both national and international scales.
The findings from this work open up multiple directions for further inquiry. For instance, conducting long-term evaluations of how AI concretely affects specific SDG indicators could generate robust data to inform policy adjustments. Additionally, cross-cultural investigations into user interactions with library AI spanning diverse societal settings could yield adaptable strategies for fostering SDG 10.2 (social inclusion) and SDG 4.3 (equitable access to education). Another priority involves performing focused environmental audits aligned with SDG 7.3 (energy performance) and SDG 13.2 (climate-responsive planning), thus filling current research voids. Lastly, exploring financially viable models for implementing AI in libraries across institutions with varying budgets would make a tangible contribution to SDG 8.2 (economic productivity) and SDG 9.4 (resilient and sustainable infrastructure).
The rapid progression of AI presents libraries with remarkable possibilities alongside considerable obligations in advancing sustainable development. When libraries intentionally connect AI adoption to particular SDG goals and put monitoring systems in place to assess outcomes, they can harness technological innovation while staying anchored to their fundamental missions: fair access to information, safeguarding cultural heritage, and serving communities. The strategic pathways proposed here aim to help libraries manage digital change without undermining their core societal roles.

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