AI Governance
Alliance

In collaboration with Accenture

Transformation of Industries in the Age of AI

Artificial Intelligence's Energy Paradox: Balancing Challenges and Opportunities

WHITE PAPER

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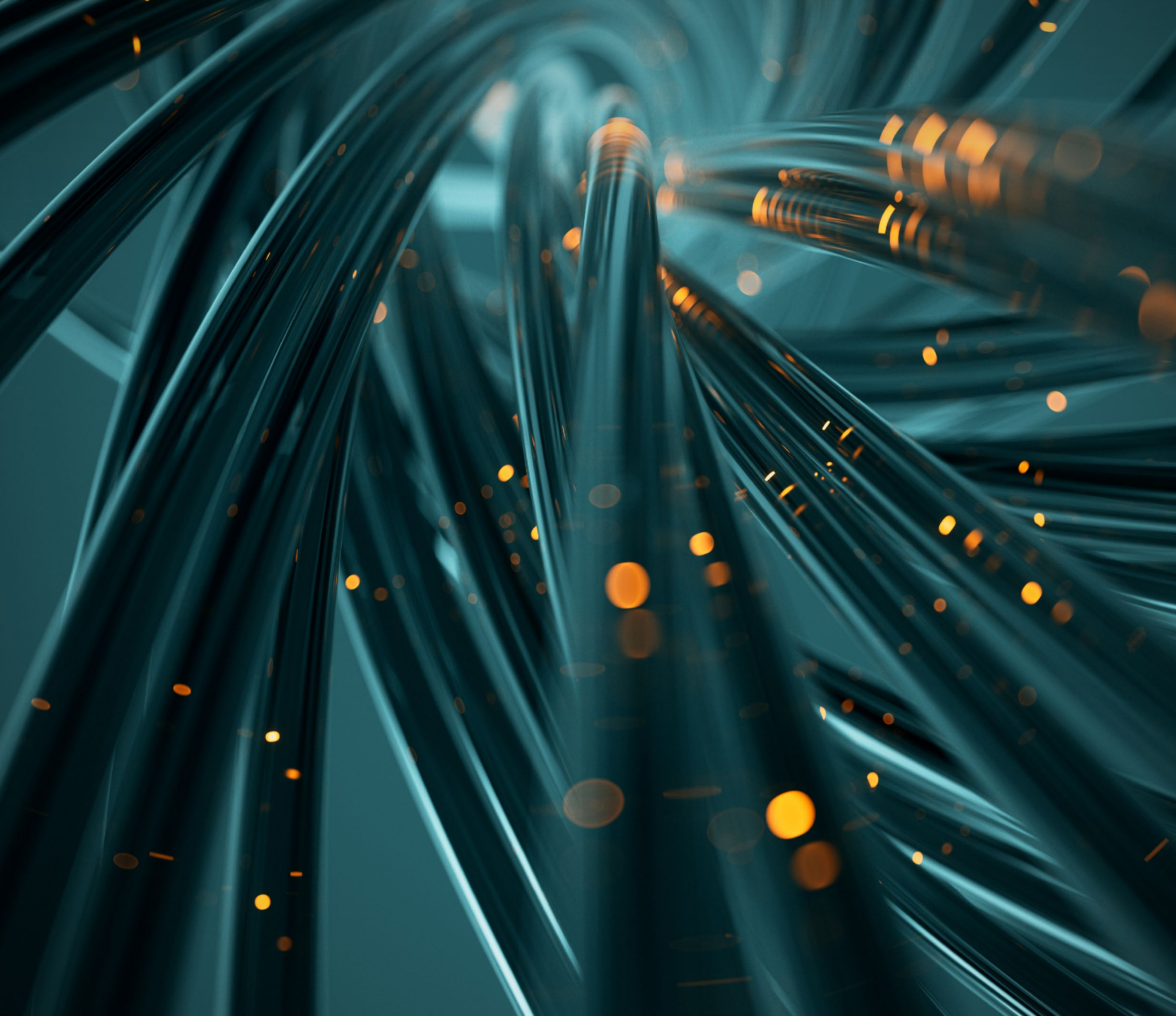

Images: Getty Images

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This white paper series explores the transformative role of AI across industries. It provides insights through both broad analyses and in-depth explorations of industry-specific and regional deep dives. The series includes:

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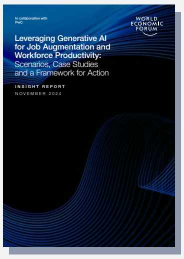

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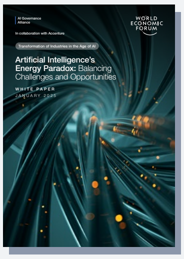
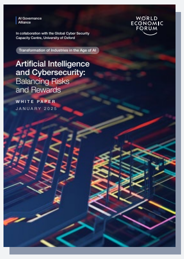


Artificial Intelligence's Energy Paradox: Balancing Challenges and Opportunities



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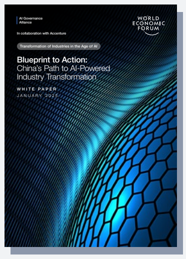

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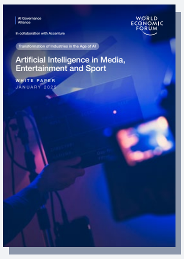

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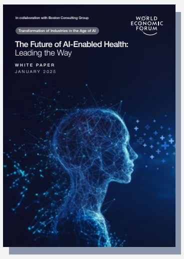

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As AI continues to evolve at an unprecedented pace, each paper in this series captures a unique perspective on AI – including a detailed snapshot of the landscape at the time of writing. Recognizing that ongoing shifts and advancements are already in motion, the aim is to continuously deepen and update the understanding of AI's implications and applications through collaboration with the community of World Economic Forum partners and stakeholders engaged in AI strategy and implementation across organizations.

Together, these papers offer a comprehensive view of AI's current development and adoption, as well as a view of its future potential impact. Each paper can be read stand-alone or alongside the others, with common themes emerging across industries.

Foreword

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In today's economy, artificial intelligence (AI) systems offer both challenges and opportunities. As integral components of digital infrastructure, the data centres that enable AI support a variety of applications, from cloud computing to complex data processing. AI's rapid expansion, however, is accompanied by growing electricity demand, with the largest facilities in the world using the same amount of power as small cities to ensure uninterrupted operation. Data centres come in varying sizes however, ranging from large, hyperscale facilities with more than 1 gigawatt (GW) of power capacity, to smaller, micro edge deployments that may draw less than 10 kilowatts (kW) of power.[1]

One estimate now expects data-centre-related electricity consumption to grow from approximately 1% of global electricity demand to over 2% by 2026, potentially reaching 3% by 2030 if forecasted growth continues.[2] Such projections have raised concerns about supporting this demand while also meeting net-zero commitments. Simultaneously, AI can be a powerful tool to positively support wider energy system transformation. For example, it is already being used to improve energy efficiency across industries, accelerate renewable energy integration and make power grids more resilient. This is the AI energy paradox – balancing these challenges against AI-enabled opportunities.

However, current estimates of AI's energy impact vary, and the magnitude of electricity demand growth remains unclear. Other issues include a lack of standardized taxonomies and definitions. The extent to which electricity demand growth will be offset by efficiency gains – from advancements in technologies (e.g. chips, algorithms etc.), data centre design and changing regional dynamics – is also uncertain. While a near-term rise in AI's electricity consumption is expected, the future magnitude of this growth may decline due to the achievement of efficiency gains. To achieve this, it's pivotal to understand innovative mitigation strategies and solutions that can effectively facilitate this balance.

Over the past year, the World Economic Forum's AI Governance Alliance has united industry and government with civil society and academia, establishing a global multistakeholder effort to ensure AI serves the greater good while maintaining responsibility, inclusivity and accountability. Players from across the AI value chain are convened to cultivate meaningful dialogue on emerging AI issues.

With Accenture as a knowledge partner, the alliance's AI Energy Impact Community (composed of over 40 global members) has facilitated cross-industry discourse towards consensus and surfaced applied use cases on AI's energy impact.

This paper highlights cross-industry insights from a diverse stakeholder group to outline mitigation strategies:

- Identifying electricity use reduction strategies for AI systems
- Touching upon AI's potential for the wider energy transition
- Outlining key partnerships, frameworks and policies to support sustainable AI adoption

The increase in AI adoption, alongside other market factors is contributing to increased electricity use. Annual global electricity demand growth is now forecasted to reach nearly 3.5% in the coming years.[3,4] This challenge is amplified by global competition for AI projects across regions. This will require stakeholders across the value chain to navigate market pressures for computing power, while balancing sustainability targets, grid constraints and community impacts.

Executive summary

Artificial intelligence presents energy opportunities and challenges – strategic mitigation can help to maximize benefits while reducing burdens.

Artificial intelligence (AI) is facilitating a new era of innovation, with nearly three in four companies using AI for at least one business function.[5] This innovation brings many benefits, including enhanced productivity, new ways of working and revenue growth. AI-related electricity consumption is expected to grow by as much as 50% annually from 2023 to 2030. AI data centre consumption, while growing rapidly, is projected to remain a small fraction of global electricity demand, starting at just 0.04% in 2023 (see Figure 4). However, when combined with other market factors (such as growing electricity demand for transport, buildings and more), AI's accelerated adoption could potentially increase the strain on power grids and electricity providers. However, such projections can vary.[6] Uncertainty remains around how profound AI's overall energy impact will be and which strategies could mitigate challenges that arise or enable new solution opportunities. In this context, it's essential to assess how AI could accelerate the energy transition in line with net-zero goals, as well as which supporting ecosystem enablers can support this. This paper focuses on AI's electricity impacts while addressing the broader energy landscape, including generation and fuel sources supporting AI.

Work under the AI Governance Alliance (AIGA) AI Energy Impact Initiative has surfaced key insights on these topics. The initiative collaborates with over 40 global organizations across more than nine industries driving AI adoption.

This analysis highlights key findings relevant to three distinct areas related to AI's role in transforming energy systems:

1. **Electricity consumption of AI:** Reviewing the AI life cycle, strategies for reducing its consumption and new opportunities for process digitalization

   – AI adoption varies by sector, with electricity demand expected to rise sharply. However, projections remain uncertain, underscoring a need for ongoing assessment.

   – Optimizing AI's consumption includes harnessing technological innovations such as energy-efficient AI chip hardware and AI-optimized cooling solutions.

   – Companies are reducing data centre electricity consumption through operational strategies like AI-driven environmental controls, server virtualization and workload distribution.

2. **AI-enabled energy transition:** Exploring innovative, emerging company use cases and the potential for scaling across industries

   – Existing use cases demonstrate reduced energy consumption of 10-60% in some instances, with potential for further optimization.

   – AI is helping electricity providers optimize operations via energy storage, enhanced battery efficiency and smart grid.

   – AI can support decarbonization, helping to lower emissions, reduce waste and improve resource use.

3. **Primary challenges and ecosystem enablers:** Analysing regulation, policy and partnerships necessary for sustainable AI adoption at scale

   – Enabling sustainable AI requires a multifaceted approach spanning: regulation and policy, financial incentives, technological innovation and market development.

   – Regulatory, policy and financial enablers can incentivize responsible AI through compliance frameworks and funding mechanisms.

   – Technological innovation and market development foster research, collaboration and sustainable AI adoption.

This white paper is a preliminary exploration of AI's energy-related impact, and outlines the key challenges and opportunities that emerge as AI adoption grows across industries. It concludes by sharing four areas to monitor for continued understanding of AI's evolving energy impact:

– AI deployment for decarbonization

– Transparent and efficient AI electricity use

– Innovation in technology and design

– Effective ecosystem collaboration

Introduction

AI is revolutionizing industries, resulting in growing electricity demand, but predicting AI-specific energy impacts remains complex.

Growing demand for AI across industries

Artificial intelligence (AI) is transforming several aspects of daily life. From automating simple tasks to enabling complex problem-solving, AI is driving innovation, increasing efficiency and changing how society operates. In particular, generative AI has emerged as a powerful transformational catalyst capable of automating tasks and reinventing processes across value chains, thereby enhancing performance and competitiveness.[7]

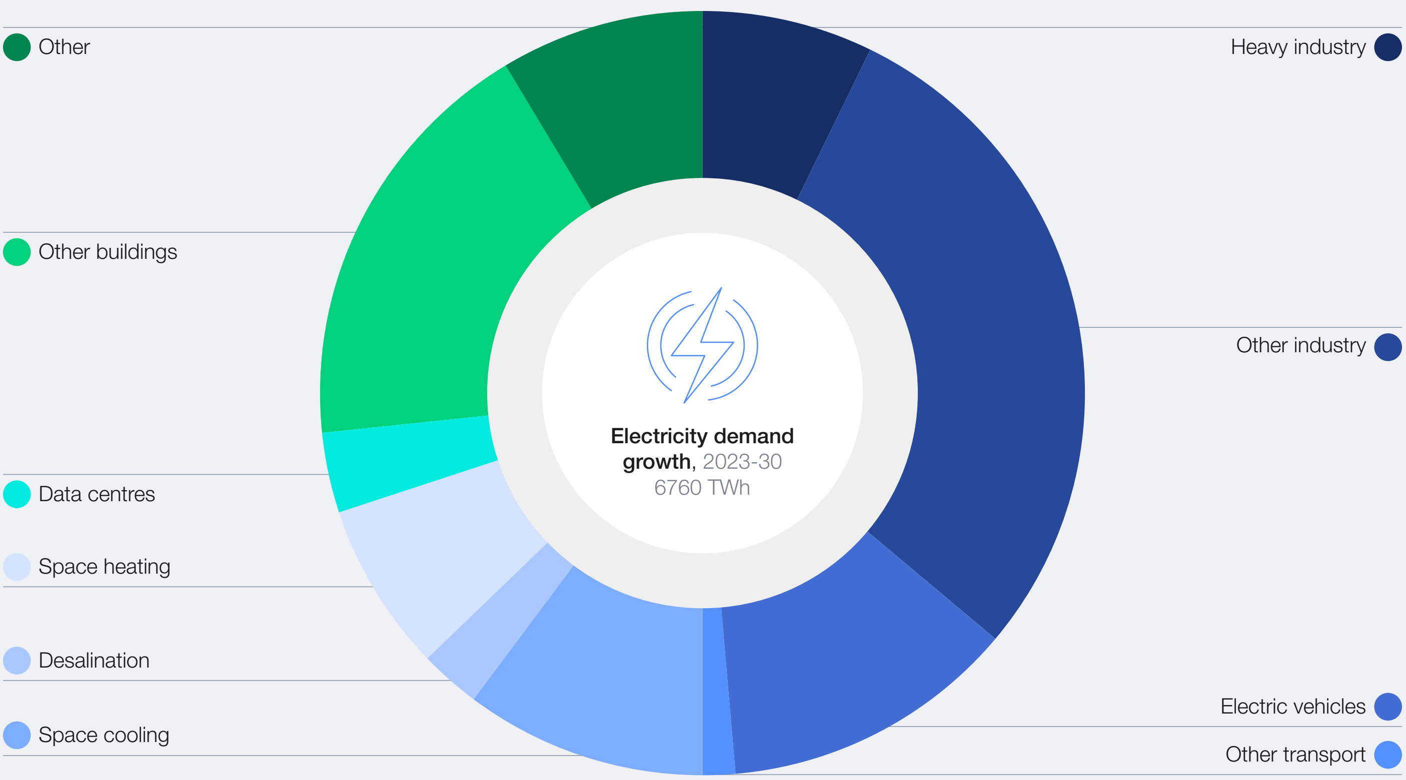
Overall electricity demand growth drivers

Several market factors contribute to increased global electricity demand. Aside from AI and the electrification of both transport and buildings, other growth drivers include industrial shifts towards electric motors, urbanization, population growth and the rising adoption of digital economy solutions.

Projecting AI-specific growth is challenging, however, as technological advancements and differing adoption rates complicate predictions.

While Figure 1 gives some indication, further research is needed to elucidate the role that AI-related electricity demand growth plays in the context of global energy trends.

FIGURE 1 **Electricity demand growth by end use in the Stated Policies Scenario (STEPS) 2023-2030, and data centre sensitivity cases**



Source: International Energy Agency (IEA). (2024). *World Energy Outlook*.

1 Electricity consumption of AI

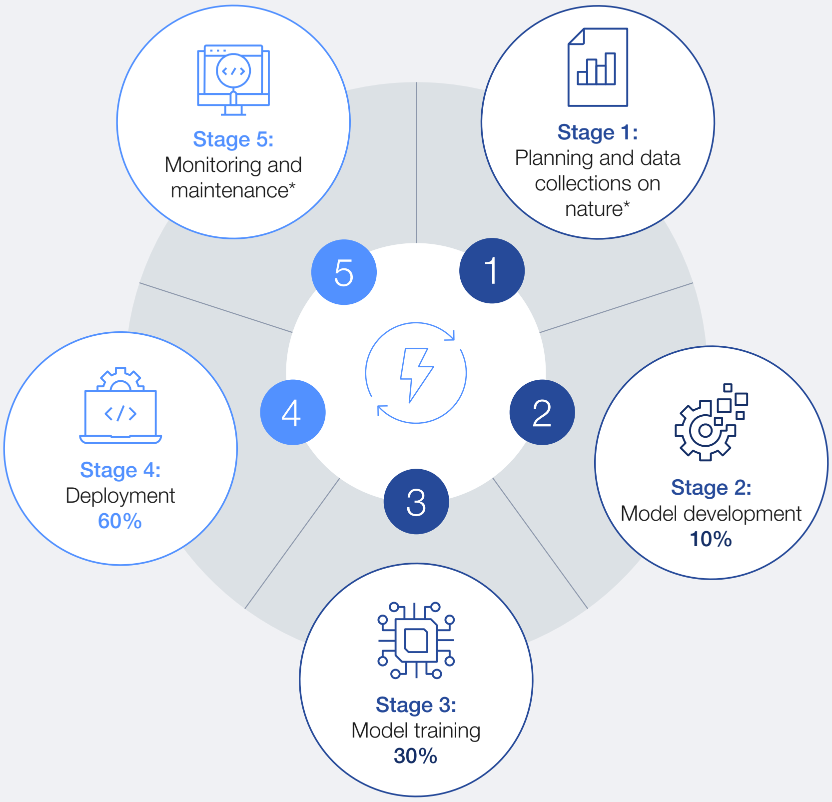
Model deployment is AI's most energy-intensive stage (accounting for approximately 60%) – innovative strategies can mitigate consumption.

1.1 The AI life cycle

The AI lifecycle begins with planning and data collection, during which data is gathered, processed and stored.[8] Next, the model development phase includes design, problem analysis and data preparation. Model training then optimizes the model through iterative data exposure. Model deployment subsequently opens the model for real-world application. Lastly, monitoring and maintenance support ongoing refinement.

Further research is needed to estimate consumption for stages 1 and 5, however estimates exist for stages 2-4. Within these three stages, model deployment is the most energy-intensive (approximately 60-70% of combined electricity consumption), but will likely continue growing in the long term. Model training is the next most energy-intensive, accounting for 20-40% of consumption, followed by model development at up to 10%.[9] These estimates however, will likely vary across differing AI model types.

FIGURE 2 **Electricity consumption across the AI life cycle**



*Insufficient data available for estimation

Source: Electric Power Research Institute (EPRI). (2024). *Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption*. International Energy Agency (IEA). (2023). *Tracking Data Centres and Data Transmission Networks*. https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks; D. Patterson et al. (2022). The Carbon Footprint of Machine Learning Training Will Plateau, Then Shrink. *Computer*, vol. 55, no. 7, pp. 18-28. https://ieeexplore.ieee.org/document/9810097.

1.2 The role of data centres

Harnessing powerful servers, specialized hardware and advanced networking capabilities, data centres enable the high-speed computations and data processing required for AI.

Within data centres, electricity consumption includes three main components:[10]

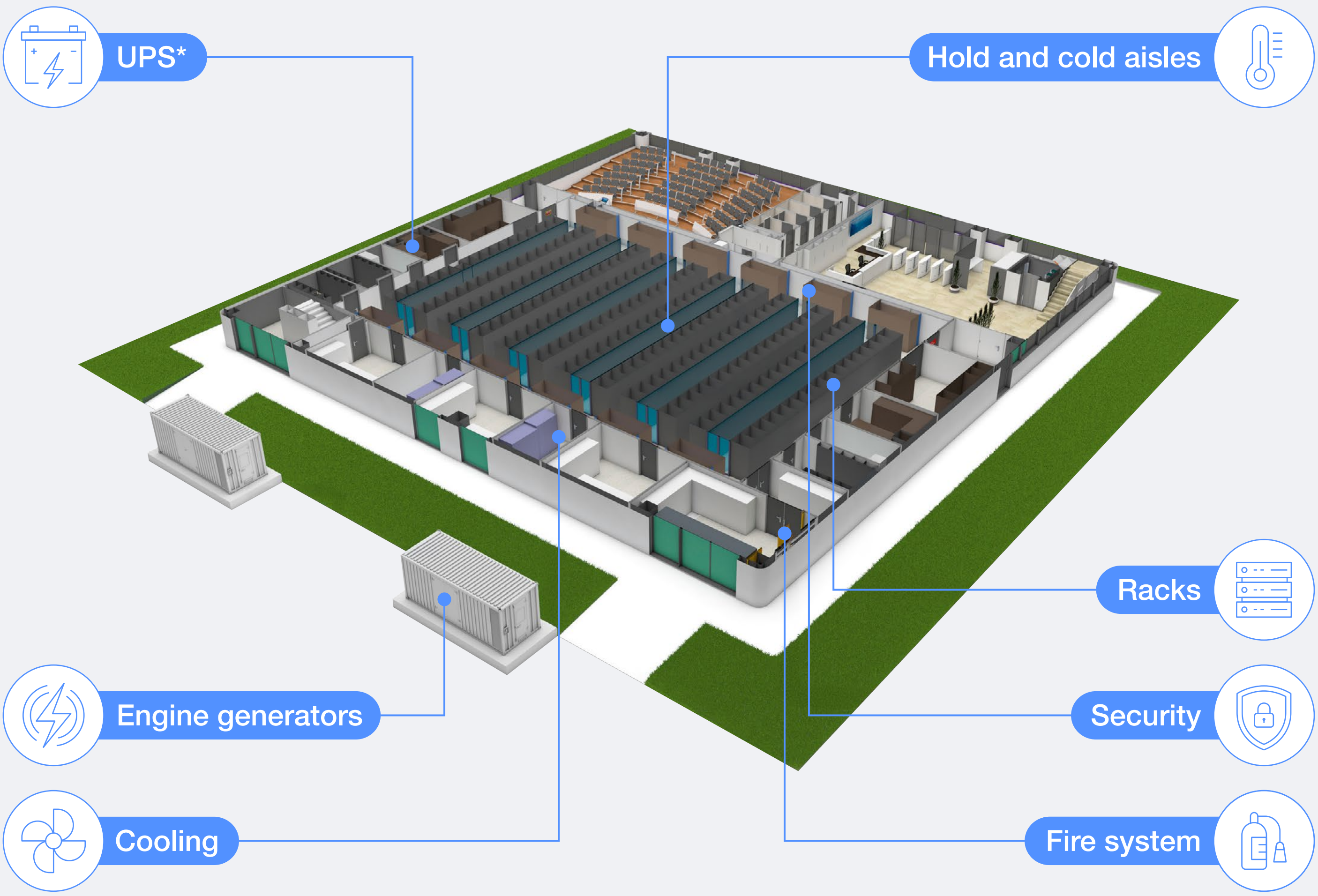
– IT equipment (40-50%), including servers, storage and network systems.

– Cooling systems (30-40%) to maintain optimal temperatures.

– Auxiliary components (10-30%), including power supplies, security and lighting.

Note that these proportions will evolve over time as AI use becomes more prevalent.

FIGURE 3 **Example data centre layout**



*Uninterruptible power supply

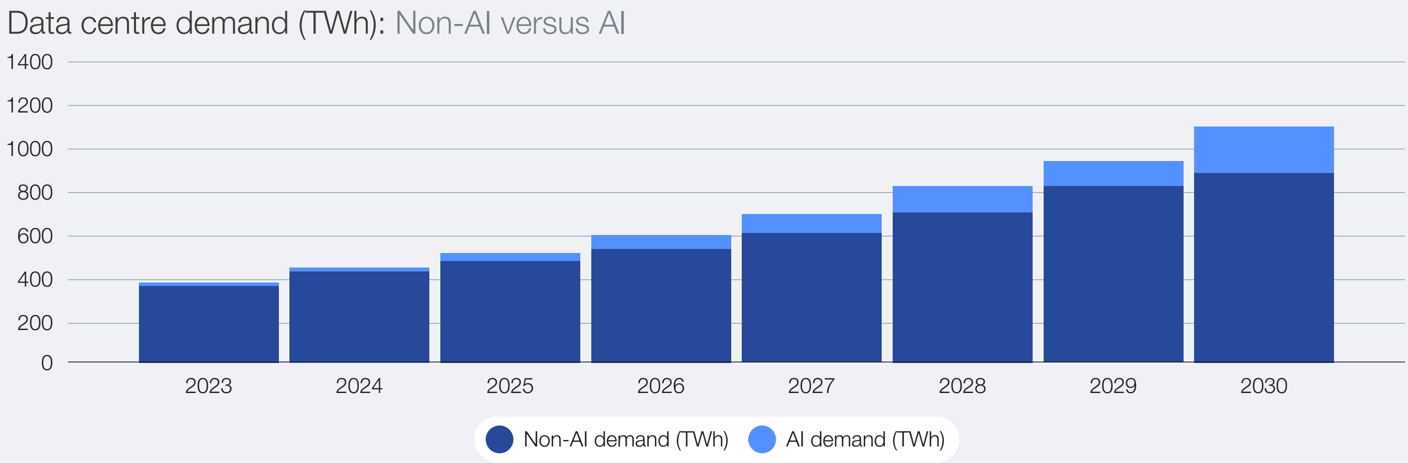
Source: Vianova. (n.d.). *Data Center offer*. https://www.vianova.it/en/data-center/.

1.3 Opportunities to reduce AI system electricity consumption

Data centre consumption includes both AI and non-AI elements. AI processing, particularly for generative AI, is more energy-intensive due to large model complexity, longer training durations and substantial data processing.

This increased energy intensity, however, is accompanied by the additional benefits that capabilities like generative AI can provide, including the ability to perform more complex work and to enable expanded value opportunities.

FIGURE 4 **Data centre demand over time**



Note: This is an extrapolated scenario that extends the IEA's forecast from 2023 to 2026 through 2030 using a combination of 2021-2023 historical growth and their proposed growth rate from 2023-2026.

Source: International Energy Agency (IEA); Goldman; Accenture.

Enabling a more energy efficient AI system includes exploring opportunities within data centres to reduce electricity consumption. Accordingly, a non-exhaustive inventory of example strategies are explored below.

Data management strategies

Within AI's first stage (planning and data collection), "digital decarbonization" techniques can address "dark data", which occupies server space and consumes electricity without providing value. For some organizations, dark data may account for as much as 60-75% of stored data.[11]

Digital decarbonization strategies can identify and eliminate dark data, reducing storage and electricity consumption. Opportunities may also exist to repurpose dark data to generate value.

TABLE 1 **Featured data management use case**

Loughborough University: automotive industry collaboration: unlocking dark data for sustainable industrial maintenance		
Situation/context	**Approach**	**Results**
"Dark data" remained in storage, underused due to poorly structured formats.	A knowledge management system with data scraping and enrichment techniques was developed to integrate and structure dark data, organizing it into valuable datasets for decision-making, and waste categories for disposal.	In total, 10-20% of dark data was transformed into actionable knowledge, improving fault analysis and maintenance, enhancing data reliability, reducing downtime, lowering the environmental footprint and highlighting waste data.

Source: Community consultation.

Technological strategies

Several technological strategies can help enable sustainable AI:

– Energy-efficient hardware (e.g. chips) and models reduce electricity consumption throughout the AI life cycle.

– Innovative, insulated building materials reduce the need for heating, ventilation and cooling (HVAC) efforts.

– Data centre infrastructure management software optimizes electricity use, improving system operation and maintenance.

– Advanced cooling techniques can reduce consumption, compared to traditional methods.

TABLE 2 **Featured technological use case**

Virgin Media O2: AI-powered cooling optimization		
Situation/context	**Approach**	**Results**
Virgin Media O2 partnered with EkkoSense to improve data centre efficiency.	Virgin implemented EkkoSense's AI-enabled approach to optimize thermal, power and capacity performance across 20 data centres.	Benefits included cooling savings worth over £1 million per year, a 15% cooling electricity reduction and a 760 tonnes of CO_2 saving.

Source: Community consultation.

Operational strategies

Several operational strategies can also support sustainable AI:

– Incorporating target end use (model development versus training versus deployment) into site selection helps optimize efficiency based on workload.

– Using scalable building designs that grow as demand increases mitigates oversizing.

– Virtualization techniques reduce physical server requirements and consumption.

– Temperature optimization and humidity management reduce overcooling and consumption.

– Dynamic power management adjusts processing based on workload, reducing consumption.

TABLE 3 **Featured operational use case**

SAP: Aiming for "green" data centres		
Situation/context	**Approach**	**Results**
Green data centres are key to SAP's sustainability strategy.	SAP data centres track resource use and minimize waste by using thermal cameras to optimize airflow and insulation, while also implementing cool/hot aisle containment to save energy.	In 2023, SAP achieved carbon neutrality and is now on track to achieve net zero along its value chain by 2030.

Source: Community consultation.

2 AI-enabled energy transition

AI solutions can drive energy efficiency across sectors, offering decarbonization opportunities by optimizing operations and reducing resource consumption.

Extensive decarbonization opportunities are emerging as AI expands. Exploiting these opportunities can support the achievement of global climate targets and macro electricity demand goals.[12]

As demonstrated in featured use cases in this paper, AI can play a pivotal role in the energy transition by optimizing assets, driving innovation and enabling sustainable technologies. In renewable power generation, AI can enhance forecasting models, while in grid operations, it can improve energy distribution, outage management and boost system reliability.

AI can also help accelerate clean energy adoption and integration into existing infrastructure. Across end-use sectors – buildings, transport and industry – AI is already being used to optimize energy consumption, enable predictive maintenance and enhance efficiency throughout the energy value chain.

2.1 Non-exhaustive example opportunities for AI-enabled electricity savings reduction

> AI can optimize EV charging based on grid demand and electricity prices, reducing costs and enhancing grid stability.

- **Building management**: AI-enabled HVAC optimizes consumption by learning user habits and adjusting operations accordingly.
- **Manufacturing quality control**: AI-enabled "machine vision" identifies defects quickly and reduces unnecessary electricity consumption from additional manual efforts and wasted materials.
- **Predictive maintenance**: AI analyses equipment data to predict failures, reducing downtime and energy waste from malfunctioning machinery.
- **Logistics and fleet management**: AI-enabled routing harnesses traffic, fuel and route data to optimize product delivery, reducing consumption and emissions.
- **Electric vehicle (EV) charging**: AI can optimize EV charging based on grid demand and electricity prices, reducing costs and enhancing grid stability.
- **Grid optimization**: AI can enhance grid operations, outage management and renewable energy and storage integration. In storage, AI improves battery charging in real time, predicts battery life and improves storage system placement, enhancing efficiency and reliability.

By capitalizing on opportunities like these, organizations may be able to achieve electricity savings that offset or even exceed the increased electricity consumption associated with enabling AI. In this regard, more research is needed to understand the potential that lies here.

2.2 Sample use cases

This paper highlights select AI use cases for improving energy efficiency. These examples, however, are not intended to represent a comprehensive inventory of all potential AI applications.

TABLE 4 **Use cases by sector**

Sector: Building and space heating/cooling		
AI-enabled building management		
Situation/context	**Approach**	**Results**
This solution enabled macro-optimization of HVAC operations across multiple buildings.	This autonomous AI solution extended beyond simple sensors, incorporating internal and external data (energy cost, weather, occupancy, etc.) to co-optimize locations simultaneously.	Using individual forecast models for each HVAC zone enabled electricity consumption reductions of 9-30%, and annual cost savings of $100,000-150,000.
Sector: Communications		
Comcast: AI-driven network transformation for energy efficiency		
Situation/context	**Approach**	**Results**
Comcast implemented a network transformation to virtualized, cloud-based technologies, with AI/machine learning (ML).	Comcast implemented a comprehensive network transformation initiative, harnessing cutting-edge cloud, AI/ML technology, virtualization and digital optics, and revolutionizing network operations.	As a result, there has been a 40% reduction in the amount of electricity required to deliver data across the network.
Sector: Manufacturing		
Johnson & Johnson: Enhanced manufacturing		
Situation/context	**Approach**	**Results**
To address growing energy demands and reduce environmental impacts, Johnson & Johnson constructed a state-of-the-art manufacturing site.	Johnson & Johnson implemented advanced capabilities, including AI algorithms for process control, internet of things (IoT)-based intelligent cleaning and digital twins.	There has since been a 47% reduction in material waste, 26% decrease in greenhouse gas emissions and 23% reduction in electricity consumption.
Schneider Electric: Site emissions reduction		
Situation/context	**Approach**	**Results**
Schneider 's Hyderabad site aims to be zero carbon for Scope 1 and 2 emissions by 2030.	The system is powered by real-time data generation and cloud analytics for facility assets that interlink with shop-floor operations using industrial internet of things (IIoT) capabilities and AI-based predictive monitoring.	As a result, there has been a 59% reduction in electricity consumption, 61% decrease in emissions, 57% water consumption reduction and 64% reduction in waste generation.
Siemens: Facility energy management		
Situation/context	**Approach**	**Results**
To become a zero-carbon pioneer, Siemens' Chengdu factory deployed advanced technologies and capabilities.	The company deployed a digital energy management system, predictive maintenance capabilities, AI-based automation and applied eco-design features, improving circularity and dematerialization.	This reduced unit product electricity consumption by 24% and production waste by 48%.

TABLE 4 | **Use cases by sector** (continued)

Sector: Energy		
Enel collaboration		
Situation/context	**Approach**	**Results**
Enel had a business challenge around the processing and accessibility of operational intelligence KPIs delaying control over worldwide operational performance.	Enel collaborated with a tech company to provide real-time insights for company stakeholders. The conversational AI solution was adopted globally in eight countries, available in five languages, and deployed across 400 generation units.	Conversational AI with 90% lower capital expenditure, increased business efficiency, and 50% savings in storage and computing power.
Moeve: "Green AI"		
Situation/context	**Approach**	**Results**
Moeve uses ML and generative AI to accelerate the energy transition and empower employees and customers.	They monitor and optimize the carbon footprint of ML and generative AI models. They then support the generative AI factory to develop fast, secure use cases, ensuring efficient resource use. Optimal large language models (LLMs) are selected based on cost, accuracy and energy efficiency.	As a result, Moeve saw cost optimization (50%), as well as reductions in development time (65%) and electricity consumption (15%) using optimal LLMs.
Aker BP: Data-driven carbon efficiency		
Situation/context	**Approach**	**Results**
Aker, a large oil company, aims to be among the world's most carbon-efficient operators.	They partnered with a software as a service (SaaS) company to deploy an advanced AI platform for safer, more efficient offshore operations with data-driven, autonomous capabilities.	Aker BP aims for autonomous operations at Yggdrasil. These would be periodically unmanned and remotely managed by two onshore operators with real-time data integration.
US energy provider: Transforming energy analytics		
Situation/context	**Approach**	**Results**
Visual inspection of electrical distribution systems is typically manual.	The company uses ML for efficient electrical infrastructure inspections, enabling drone imagery storage, data attribution, and model evaluation for faster corrective actions	Reduction in company's end-to-end cycle time to build and deploy new computer vision models by over 50%.

Source: Community consultations.

3 Primary challenges and ecosystem enablers

Balancing AI's potential with its growing energy needs will require multistakeholder collaboration and scalable solutions to challenges.

Multistakeholder collaboration is needed to address challenges across industries and enable sustainable AI. To balance AI's transformational value with costs and negative impacts, two key elements must be addressed: infrastructure and environmental challenges.

3.1 Infrastructure challenges

Given infrastructure upgrade needs, financing concerns have arisen as stakeholders debate fair cost allocation across customer groups to support data centre expansion.

As AI demand grows, companies developing data centres may face challenges in sourcing sufficient volumes of power, particularly from carbon-free generation sources. New, large-scale data centres often have significant power requirements, which, depending on the target build jurisdiction, may require costly, time-consuming new infrastructure solutions. Integrating renewable energy is also challenging due to variability and storage issues, which hinder consistent power delivery. Transmission additionally brings complexity as high-voltage lines are near capacity in some regions. In the US, some utility companies have even halted new service requests or begun rationing power.[13]

Hyperscalers are exploring opportunities to use renewables to power data centres, an option that may not be feasible for some industry players. According to industry feedback, an increased interest has been observed from oil and gas players meaning to invest in renewables to meet the demand for clean energy and growing AI power needs.

Given infrastructure upgrade needs, financing concerns have also arisen as stakeholders debate fair cost allocation across customer groups to support data centre expansion.[14,15] Accordingly, utility companies face significant challenges in designing customer rate pricing structures that can support this growth while balancing factors like fairness, affordability and sustainability.

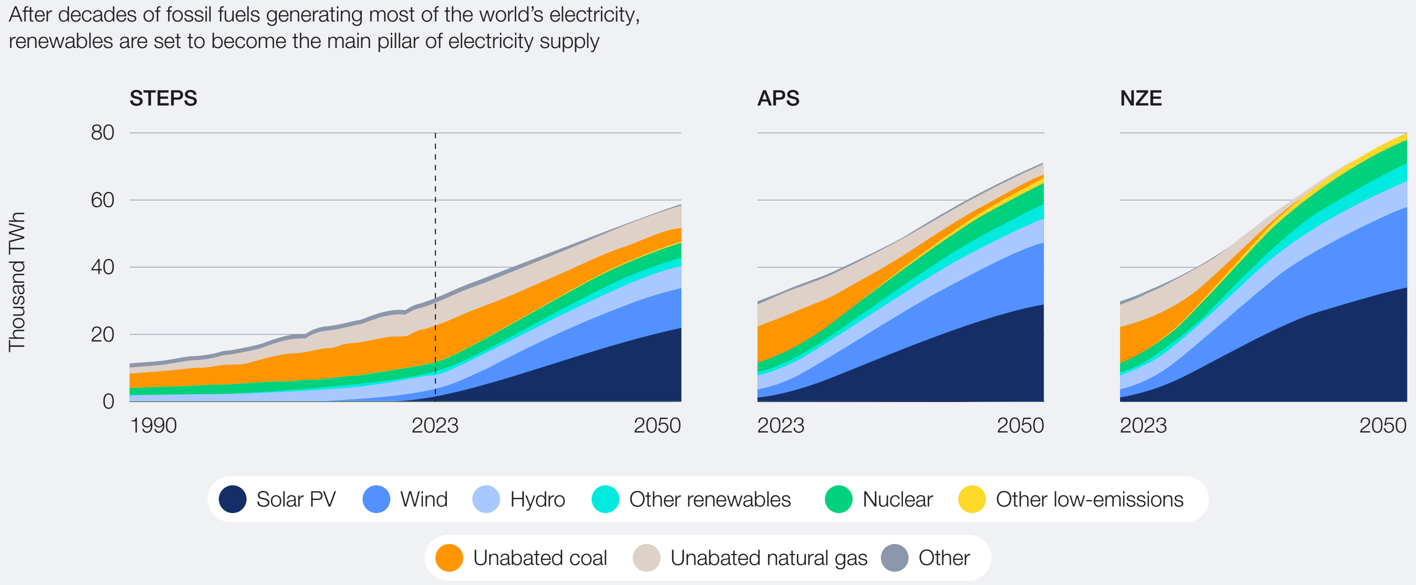
Grid impacts must also be analysed, as managing data centre loads may require advanced demand response and load balancing. Regulatory, environmental and supply chain issues, such as delays in key grid assets, can also extend approval and construction timelines.

3.2 Environmental challenges

Another fundamental challenge in expanding AI solutions is addressing their environmental impact. All energy, even clean energy, has an environmental impact.[16] As AI becomes increasingly integral across varied aspects of life, it's crucial to consider energy scarcity as a key design principle (rather than assuming unlimited resources) when developing AI's future infrastructure. This approach will help ensure AI supports the energy transition.

To facilitate sustainable AI, it will be crucial to maintain a balance between optimizing the speed of progress on market goals and prioritizing net-zero emissions targets or 24/7[17] carbon-free energy targets. Growing global data centre demand, alongside other emerging energy market factors, could potentially leave a gap between forecasted emissions in 2050 and net-zero targets.

FIGURE 5 | **Global electricity generation by source and scenario, 1990-2050**



Note: TWh = terawatt-hours; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. "Other renewables" includes bioenergy, geothermal, concentrating solar power and marine; "Other low-emissions" includes fossil fuels with CCUS, hydrogen and ammonia. "Other" includes non-renewable waste.

Source: International Energy Agency (IEA). (2024). *World Energy Outlook*.

As data centre demand grows, firm, dispatchable generation is needed. Given generation infrastructure challenges and net-zero ambitions, this requires innovation and investment in carbon-free solutions. Renewables, such as wind and solar, support sustainability, but without sufficient energy storage capabilities, their intermittency can cause availability fluctuations, which are troublesome for data centres given their need for consistent, high-demand energy with reliable power quality. Other relevant options include nuclear, geothermal and long-duration storage, as well as harnessing energy sources (such as natural gas and bioenergy) alongside carbon capture and storage (CCS).[18]

Within nuclear, several companies are following through on the momentum built during COP28 and the declaration to triple global nuclear energy capacity by 2050 by harnessing nuclear solutions to support data centre growth with carbon free energy. This includes a variety of strategies built around the use of both large-scale plants as well as small modular reactors (SMRs), which offer flexible, low-carbon energy with reduced land use and construction time. In the US, for example, Amazon, Google and Microsoft have all explored nuclear options, each with varying benefits and complexities.[19]

In addition to the intermittency issue, other relevant mismatches exist between data centres and power generation/grid infrastructure that make clean energy procurement challenging. Included in this list is the geographical disconnect between data centre locations and renewable generation sites, which can result in inefficiencies and high transmission costs. Beyond energy, broader understanding and research efforts on natural resource concerns are also critical for achieving sustainable AI.

A non-exhaustive list of several enablers that can help address the challenges outlined above is explored in the following section.

3.3 Overview of ecosystem enablers

Enabling sustainable AI will require a multifaceted approach consisting of actions across four key areas:

- **Regulatory and policy enablers** for establishing policies and frameworks that promote responsible AI development and use, ensuring compliance with environmental standards and energy policies
- **Financial incentive enablers** that can provide funding and investment mechanisms to support sustainable AI initiatives
- **Technological innovation enablers** focused on promoting research and development (R&D) to drive cutting-edge technologies that enhance sustainability in AI applications

- **Market development enablers** that can create a conducive environment for sustainable AI solutions, encourage collaboration among stakeholders and facilitate adoption of green technologies
- Together, these ecosystem enablers could form a robust foundation for advancing sustainable AI. While not explored in this paper, the above could also include ethics and governance considerations. Learn more in the Forum's 2024 white paper: *Governance in the Age of Generative AI: A 360º Approach for Resilient Policy and Regulation*.[20]

3.4 Regulatory and policy enablers

Within infrastructure, regulators can promote rate designs that ensure data centres help to upgrade costs while maintaining affordability for customers.

Of the ecosystem enablers, regulators and policy-makers in particular are critical to ensuring a sustainable AI future. In considering regulations, both government regulations and industry-led initiatives are crucial, as government rules provide legal frameworks while industry-led initiatives and voluntary actions depend on self-enforcement. Together, they play different but complementary roles in enabling AI.

One example is the EU AI Act, which categorizes AI systems by risk, imposing strict requirements on high-risk applications for safety, transparency and accountability, while also cultivating innovation.[21] While these regulations aim to drive efficiency and accountability, they may incur compliance costs and unintended consequences. Well-designed incentives, on the other hand, can facilitate continuous improvement and innovation, emphasizing the need for a balanced regulatory approach.

Another key consideration is balancing data sovereignty requirements with efforts to locate data centres near clean energy sources. While renewable energy reduces environmental impact, data laws often mandate local storage for privacy and security. This creates tension between the goals of minimizing emissions and meeting regulatory demands, necessitating strategic planning to align both goals.

Within infrastructure, regulatory frameworks and policies can support several critical areas including transmission system planning and siting, improving electricity market structures and enabling greater access to carbon-free electricity sources. Customer affordability is also an important area of note, as rate designs are meant to drive fair allocation of costs for customers while ensuring reasonable rates. A key challenge in rate design for data centre growth is balancing the need for scalable, cost-effective electricity pricing with the goal of protecting customer affordability. As demand for AI increases, rates will need to be structured to support large-scale electricity needs without placing undue cost burdens on customers, while also promoting efficiency and sustainability. This is challenging however, and can take many forms.[22,23]

Additionally, establishing green mandates, aligning with regional emissions targets and improving access to renewable energy are also key steps for sustainability, along with implementing water conservation and energy reduction policies. Together, measures such as these can promote more sustainable AI.

3.5 Financial incentive enablers

Financial support for sustainable AI can come in several forms (e.g. tax credits or deductions), including incentives for using renewable energy and selecting environmentally friendly sites. Companies like Crusoe are using incentives, such as Bill C-59 in Canada, to support CCS activities.[24] As similar financial incentives are made available, frameworks can be expanded to require societal benefits, such as job creation, economic development and community investment.

Government investments in infrastructure and financial support for land development and environmental mitigation could further enhance the appeal of data centre locations and facilitate growth.

Designing these incentives appropriately with relevant stakeholders can enhance the overall economic impact of data centres and promote a greener future.

3.6 Technological innovation enablers

Future innovations could include specialized processors to reduce electricity use, with emerging technologies like quantum and neuromorphic computing enhancing efficiency. Quantum computing offers faster solutions, while neuromorphic computing enables low-power AI processing, transforming data centres for next-generation applications.

Technological innovations in sustainable data storage can also support sustainable AI. Breakthroughs like biological data storage using synthetic DNA could revolutionize storage and computing, enabling massive scalability without overwhelming energy supply.

Competitions rewarding energy-efficient data centre solutions can drive innovation, while case studies of data centres transitioning to renewable energy can inspire broader adoption of sustainable practices by showcasing economic, operational and environmental benefits.

As these enablers progress, they offer various pathways for sustainable AI, balancing performance with environmental footprint.

3.7 Market development enablers

Within market development, efforts can potentially focus on supporting data centres in becoming more active grid participants. Additionally, broader opportunities for added benefits could be explored, such as using automated energy management technologies to enhance grid flexibility, demand response and peak shaving.

Encouraging advanced clean energy procurement (for instance, by matching hourly consumption with local clean energy) could also be prioritized. This approach recognizes the importance of where and when clean power goes onto grids, and how electricity is consumed (an element that could be beneficial to the energy transition).

Additionally, identification of data centre development zones could be valuable, especially if integrated with grid planning and supporting policy efforts. Lastly, equipment upgrades and responsible IT asset recycling incentives could be explored to address growing e-waste generation (which could reach 2.5 million tonnes annually by 2030).[25]

By adopting these strategies, companies could reduce environmental impacts while still advancing AI solutions.

4 Future outlook of AI energy impact

AI's energy impact remains uncertain; proactively monitoring its evolving intersection can clarify challenges, uncover opportunities and guide transformative solutions.

4.1 The deployment and collaboration landscape

A clearer understanding of the opportunities and challenges pertaining to AI's energy impact could help unlock opportunities and remove roadblocks. As highlighted earlier, companies are already deploying AI solutions with energy impacts. Several existing innovations are depicted in Table 5, including grid modernization, network performance optimizations through real-time monitoring and data centre cooling optimization.

FIGURE 6 **A snapshot of cross-industry AI solutions and projects being deployed by global companies**

Energy efficiency and sustainability in infrastructure

Approximate

10%

increase in data centre efficiency

Gains achieved:
Energy savings, reduced data centre cooling costs and increased energy efficiency

Example solutions:

Google – data centre carbon-aware load shifting and heat recovery

Iron Mountain information management – data centre efficiency using cooling optimization

Foxconn Industrial Internet – data centre liquid cooling

Renewable energy and decarbonization efforts

2 MW

of off-grid solar deployed and battery storage pilot project

Gains achieved:
Reduced carbon footprint, renewable energy support, lower emissions

Example solutions:

Crusoe Energy Systems – new gas generation with carbon capture and sequestration to power data centres, pilot using data centre waste heat, 2 megawatts in renewables and battery storage

North American oil and gas company – geothermal powered data centres

European chemicals and advanced materials company – solid oxide fuel cell tech pilot for data centres

Cisco Systems – renewable energy procurement powering data centres under net-zero goals

AI in predictive maintenance, smart networks and operational efficiency

10%

lowered energy bill from self-organizing networks

Gains achieved:
Improved equipment uptime, reduced maintenance costs, optimized network performance via real-time monitoring, energy efficiency

Example solutions:

South-East Asian tech company – predictive maintenance energy monitoring

Liberty Global – network performance optimization, self-organizing networks

FIGURE 6 | **A snapshot of cross-industry AI solutions and projects being deployed by global companies** (continued)

AI-driven partnerships and ecosystem collaboration

Digital transformation collaboration in Africa

Gains achieved:
Collaborative innovation projects launched, streamlined supply chains, enhanced dialogue on policy alignment

Example solutions:

AKER – supply chain alliances

Moeve – industrial partnerships

European technology company collaboration with international organization – digital transformation collaboration project in Africa

Digital transformation and AI for smart grids and power systems

50%

energy company savings through real time data access

Gains achieved:
Enhanced grid stability, efficient energy storage, smart grid management, proactive maintenance planning

Example solutions:

US tech company collaboration with European utility – real-time grid dispatch in Europe

Sample services from respective European advanced energy solutions companies – battery storage optimization, digital twin AI predictive maintenance for renewables and batteries

Southern Company – grid modernization

European tech and energy company collaboration – energy efficiencies achieved with global thermal generation

European engineering and construction company – grid modernization in Europe

Relevant policy and decision-making tools

Digital decarbonization assessment tool researched

Gains achieved:
Support for net-zero ambitions, research insights and enhanced stakeholder dialogue to align on decarbonization strategies and global policy

Example solutions:

Loughborough University – researched decarbonization tool

GEIDCO – multistakeholder policy research and dialogue activities with industry, international organizations, universities and government

Note: Further research is needed to differentiate solutions that can be scaled versus deployed at company level.

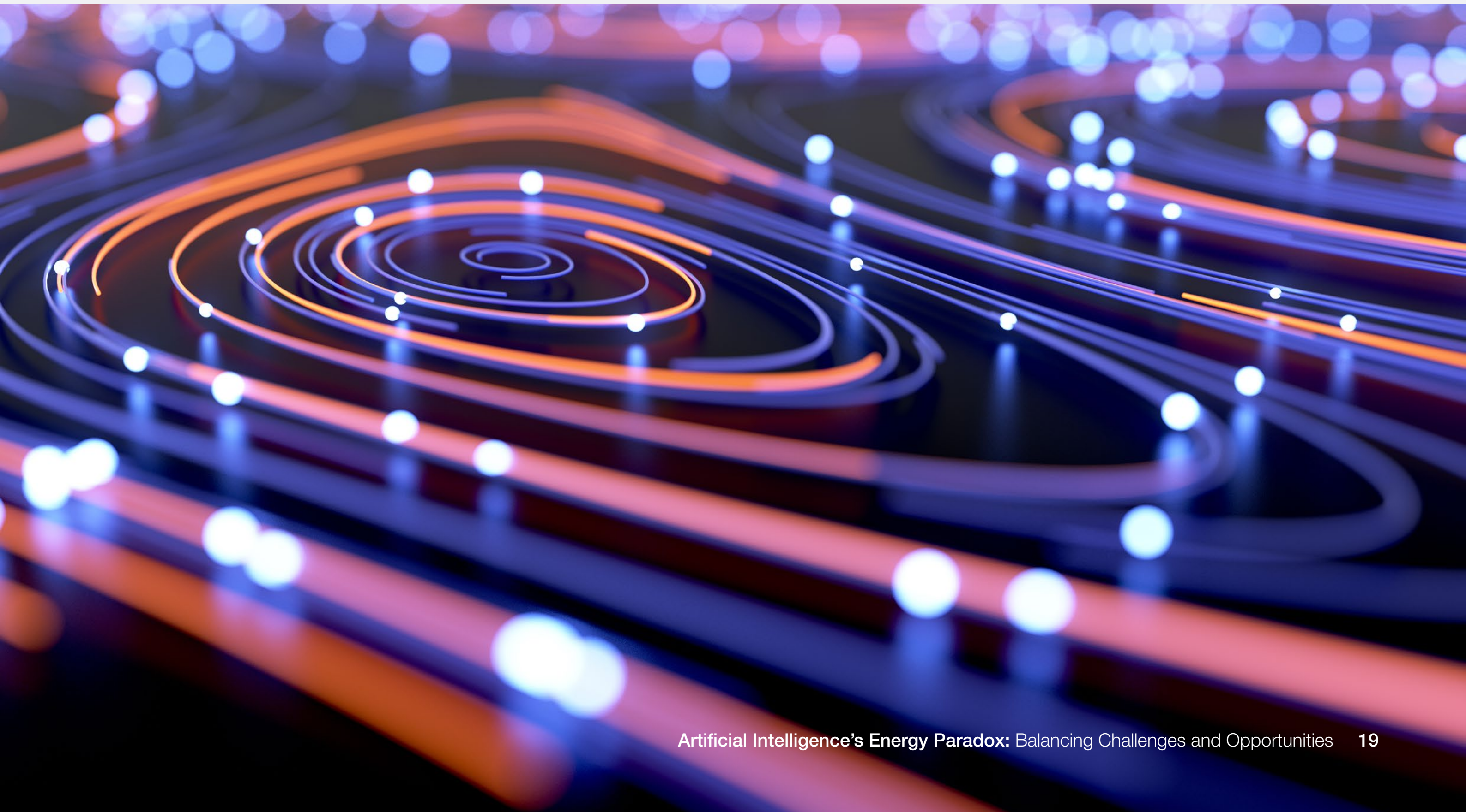


TABLE 5 | **Challenges faced in sustainable AI applications**

Challenge	Challenge details
Energy infrastructure and availability	– **Power reliability**: Delayed utility upgrades to meet data centre demand can disrupt operations when required demand isn't delivered. – **Cooling needs**: Increasing temperatures due to climate change led to heightened cooling demands, straining power during peak summer months.
Data and computational	– **Data mobility and optimization**: While data processing can move across locations, optimizing data workloads based on energy availability remains complex. – **Data quality**: Poor data quality can reduce AI's energy efficiency, e.g. necessitating frequent retraining due to inefficient model performance.
Regulatory and policy	– **Lack of standards**: A lack of uniform global standards, taxonomies and definitions for AI energy use and digital systems creates challenges in scaling and assessing impact. – **Regulatory complexities**: Regional differences in regulations complicate compliance, especially as AI-focused regulations emerge. – **Industry-specific regulations**: Some regulations, (e.g. for building efficiency and renewable adoption) vary widely across industries and regions.
Industry collaboration and partnerships	– **Complex value chains**: Difficulty in mapping supply chains and gathering supplier data impacts collaboration. – **Dependence on key players**: Concentration of R&D within a few companies limits innovation accessibility. – **Lack of local capacity**: There is inadequate local infrastructure and an insufficient volume of skilled partners for implementing global AI systems. Additionally, there is a shortage of talent skilled in both AI and energy, limiting innovation and implementation speed. – **Risk aversion**: Telecommunication and energy sectors are hesitant to adopt disruptive technologies, focusing instead on incremental changes.
Mindset, awareness, and cultural shifts	– **Awareness barrier**: There is low awareness about the financial benefits of sustainable AI. – **Mindset shift**: Across supply chains, there is hesitation to adopt energy-efficient practices, often due to fears around disrupting established profit margins. – **Geographic variations in attitudes**: Different regions prioritize AI and sustainability goals based on their socioeconomic and environmental context
Operational and technical challenges	– **Data privacy and security**: As AI models require vast data, privacy and security concerns become a significant barrier, especially in regions with strict regulations. – **Energy security concerns**: Dependency on external energy sources and concerns about energy reliability due to geopolitical issues can create hurdles in AI applications. – **Real-time forecasting and optimization**: There is a need for accurate forecasting tools to optimize resource allocation and identify energy hotspot

Source: Stakeholder consultations.

While not comprehensive, the thematic areas outlined in Figure 6 are emerging as potential opportunities for global collaboration, based on observed efforts to date.

FIGURE 7 **Visualization of potential collaboration opportunities for AI energy sustainability applications**

Grid resilience and energy infrastructure

Collaborative grid modernzation and renewable energy projects to improve resilience

Partnerships with renewable energy providers and technology companies to ensure power reliability and sustainable growth

Data management and standardization

Cross-border data management frameworks for energy-efficient data relocation that are secure and prioritize privacy

Shared platforms for data standardization and quality improvement, especially within global value chains

Regulatory and policy alignment

Harmonized regulatory frameworks across regions, particularly in the EU and US, to streamline compliance

Partnering with policy-makers to support sustainable AI regulatory developments and funding initiatives

Establishing cross-industry, AI-energy metric standards (e.g. joules per operation)

Resource sharing and regional collaboration

Collaborative efforts to secure and share computational resources with regions lacking infrastructure

Encouraging partnerships between tech giants, energy providers and local enterprises to enhance capacity and resource access

Multistakeholder initiatives to improve transparency and data sharing across supply chains

Skills development and cultural shifts

Cross-industry initiatives to bridge the AI-energy skills gap, particularly in regions with limited expertise

Educational programmes and awareness campaigns highlighting the economic benefits of sustainable AI

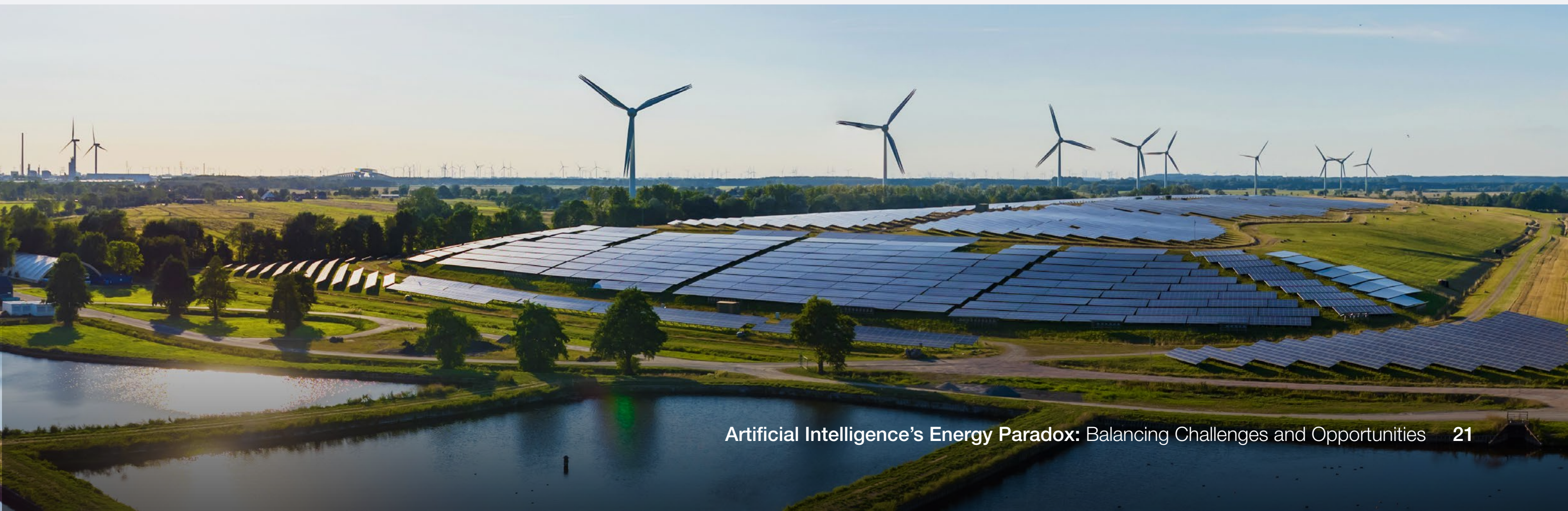
Cultivating cultural shifts towards sustainable AI practices

Operational efficiency and technological innovation

Joint investments in real-time forecasting and other optimization tools to improve operational efficiency

Collaborating with telecommunications providers to integrate AI-enabled predictive maintenance and monitoring solutions

Source: Stakeholder consultations.



4.2 AI and energy – 2024 to 2025 outlook

> Partnerships between AI developers, energy stakeholders and policy-makers can help reduce inefficiencies, address regulatory gaps and promote regional decarbonization.

As explored previously, AI's rapid expansion and increased electricity demand will likely present energy system challenges. However, the technology also brings opportunities and benefits, including enhanced renewable infrastructure, grid stability, and demand management, which reduce electricity consumption and support decarbonization. Monitoring the four key areas highlighted below will be crucial for assessing these impacts.

AI deployment for decarbonization

Prioritizing AI applications in energy management could significantly support climate and environmental goals by helping grids meet rising electricity demand while advancing decarbonization targets. Enhanced research and collaboration in these areas may yield substantial environmental and economic benefits by driving efficiency and accelerating the integration of renewables.

Transparent and efficient AI electricity use

Reliable data collection and research on AI's electricity demand and energy efficiency will be crucial for developing realistic AI growth frameworks. Understanding the energy differences between generative AI and traditional ML can support regulations and innovations that balance AI's benefits with its environmental impact. Effective data management can also play a role in reducing AI's energy footprint in the interim ahead of application of more large-scale solutions.

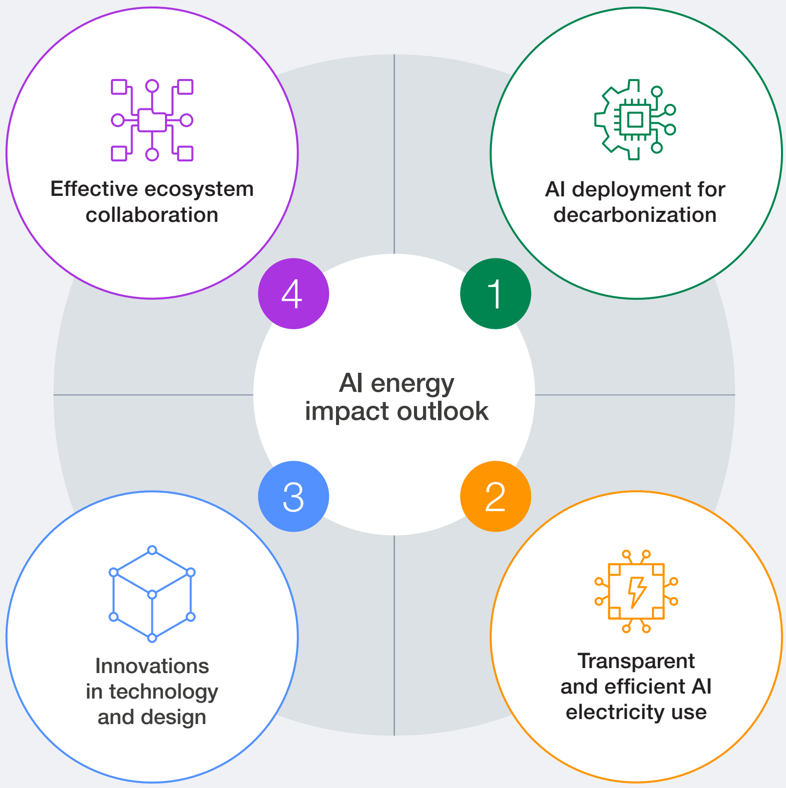
Innovations in technology and design

Energy-efficient innovations in areas such as chip development, model design, data centre design and operations, and cooling will help to manage growing electricity demand and reduce AI's carbon footprint.

Effective ecosystem collaboration: Partnerships, policy support and global alignment

Collaboration and policy support are key to sustainable AI. Partnerships between AI developers, energy stakeholders and policymakers can help reduce inefficiencies, address regulatory gaps and promote regional decarbonization. For example, with support from the Forum's global AI Energy Impact Initiative, the Centre for the Fourth Industrial Revolution Azerbaijan is leading work on the adaptation of global use cases into multistakeholder pilots within the local context aligned with energy transition ambitions. Global alignment with localized solutions will be crucial for driving transparency, building acceptance and creating pathways for AI-driven energy innovations, while ensuring adaptability and strengthening AI's social license to operate. Learn more in the Forum's 2025 [A Blueprint for Intelligent Economies] white paper.

FIGURE 8 **Key areas to monitor concerning AI's energy impact, 2024-2025 outlook**



Conclusion

After analysing these themes, two main questions remain. Firstly, how significant will AI's energy impact be, and what solutions can mitigate challenges while unlocking optimization opportunities? Additionally, how can AI accelerate the energy transition towards net-zero goals and what ecosystem enablers are needed to support this shift?

Emerging solutions have begun to provide insight into these issues, but further research is needed on the areas critical to AI's energy impact. While AI adoption continues to accelerate across industries, several examples outlined in this report show how this growth is being countered by electricity consumption reductions stemming from new technological, operational and data management strategies.

As AI systems improve in efficiency, new solutions will need to be scaled to counterbalance rising electricity consumption. With electricity providers adopting AI for grid management and companies using AI and ML to optimize electricity use, emerging cross-industry examples will highlight AI's transformative role in advancing a secure, sustainable and equitable energy transition.

There are significant opportunities for enabling sustainable AI. Within infrastructure, electricity providers are addressing generation and transmission challenges, ensuring fair cost allocation to data centres rather than vulnerable customers. Net-zero ambitions are also paramount as companies explore emission reduction strategies. Multistakeholder collaboration will be essential for maximizing AI's transformative value while minimizing cost and negative impacts.

Based on the content shared in this white paper, the answers to the questions posed will continue to evolve through ongoing evaluation of the four key areas outlined below and any progress made on some standout calls to action.

1. AI deployment for decarbonization
   - Encourage AI integration within electricity grids, data centres and industrial sectors to optimize electricity consumption, improve grid stability and reduce waste.
2. Transparent and efficient AI electricity use
   - Establish frameworks to quantify electricity savings potential, promote practices that optimize data storage and processing, and reduce consumption.
3. Innovation in technology and design
   - Drive innovation in data centre hardware, cooling and power management to reduce consumption while supporting growing AI demands.
4. Effective ecosystem collaboration
   - Promote collaboration between electricity providers, AI developers, governments and academia to support the energy transition.

While monitoring these areas will yield valuable insights in the short term, as trends change and new AI developments occur, the leading indicators for addressing key questions may likewise change. As such, proactively monitoring the evolving intersection of AI and energy will be important for understanding emerging challenges and unlocking transformative opportunities.

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Endnotes

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