



FROM EFFICIENCY TO IMPACT: THE EXECUTIVE CASE FOR SUSTAINABLE AI: STRATEGIES AND METRICS

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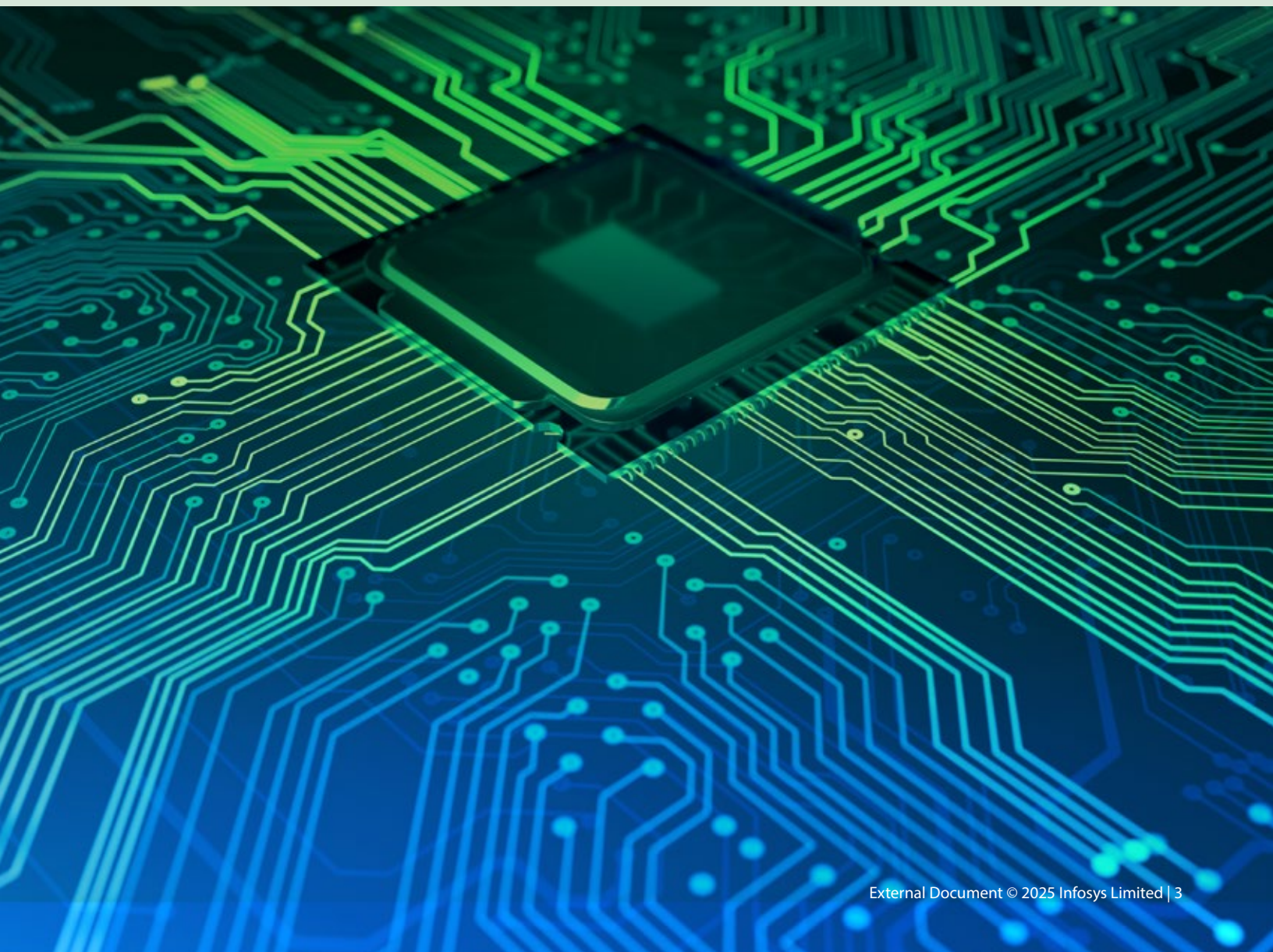
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Executive Summary

Artificial Intelligence (AI) is accelerating beyond automation into a new era of autonomous, adaptive systems: reshaping industries, economies, and everyday life. As AI becomes deeply embedded in global infrastructure, its environmental impact is scaling in parallel. The future of AI must be defined not only by intelligence and capability, but also by its alignment with planetary boundaries. Sustainable AI is no longer optional: it is a strategic and ethical imperative. Emerging practices such as energy-efficient algorithms, low-power hardware, and renewable-powered compute infrastructure are setting the foundation for low-impact AI systems. These innovations are already demonstrating measurable benefits, with energy consumption reductions of up to 40% and carbon emission cuts of up to 50% in optimized environments. Lifecycle

assessments, real-time energy monitoring, and performance-per-watt metrics are becoming essential tools for engineering AI systems that are both high-performing and environmentally responsible. As AI continues to evolve, so must the frameworks that govern its sustainability: ensuring transparency, fairness, and accountability at every stage. The challenges are real: high energy demands, e-waste, resource intensity, and algorithmic bias. But so is the opportunity. By embedding sustainability into the core of AI design and deployment, we can unlock a future where AI drives progress without compromising the planet. The path forward demands innovation, collaboration, and a shared commitment to building AI that is not only powerful but also purpose-driven.



AI's Evolution

In recent years, Artificial Intelligence (AI) has evolved rapidly: from rule-based automation to systems capable of autonomous decision-making. The journey began with Robotic Process Automation (RPA), which streamlined repetitive, structured tasks, like data entry and transaction processing. While RPA improved efficiency, it lacked the ability to understand context or adapt to change.

The next phase, cognitive automation, introduced machine learning and natural language processing. This allowed AI to

interpret unstructured data, such as text, images, and speech, and make decisions based on patterns and context. It marked a shift from static automation to systems that could learn and improve over time.

Today, we are entering the era of Agentic AI (systems that can act independently, learn from their environment, and make complex decisions without human oversight). These agents are capable of strategic planning, problem-solving, and adapting to dynamic scenarios to unlock transformative potential across industries.

Focus on Sustainable AI: Towards Environmentally Responsible Intelligence

As AI systems become increasingly integral to global infrastructure, it is imperative that the future of AI is inherently sustainable. The next generation of AI innovation is being shaped by the urgent need to align technological advancement with planetary boundaries. Emerging developments point toward a future where AI is not only powerful but also environmentally responsible by design.



Next-gen energy-efficient algorithms will be foundational. Techniques such as neural architecture search for low-energy models, adaptive sparsity, and continual learning will enable AI systems to self-optimize for minimal energy use across diverse tasks and environments.



Full-spectrum lifecycle intelligence will track and minimize environmental impact from the conception of models to their decommissioning, using real-time telemetry and blockchain-based transparency for carbon and resource accounting.



Ultra-low-power AI hardware, including neuromorphic processors and quantum-inspired accelerators, will redefine the energy-performance trade-off, enabling real-time AI at the edge with near-zero emissions.



Global sustainability governance frameworks will emerge, driven by initiatives such as the Coalition for Environmentally Sustainable AI, which will establish enforceable standards for environmental accountability in AI development and deployment.



Autonomous green infrastructure will become the norm in AI. AI-driven data centers will dynamically manage workloads, cooling, and energy sourcing, operating entirely on renewables and focusing on carbon-aware scheduling optimization.



Circular AI systems will close resource loops by designing for reuse, automating disassembly, and optimizing material flows across supply chains, all using predictive intelligence.



AI-optimized energy ecosystems will orchestrate smart grids, decentralized storage, and demand-response systems, accelerating the global transition to clean energy.



Regenerative AI applications will transform agriculture, enabling autonomous systems that restore ecosystems, enhance biodiversity, and sequester carbon at scale.

While these innovations are on the horizon, the path forward demands proactive investment, interdisciplinary collaboration, and a commitment to integrating sustainability into the core design of AI systems. The future of AI is not just intelligent: it is regenerative, resilient, and aligned with the ecological systems it inhabits.

The Future of AI and Sustainability: A Dual Frontier

As we look ahead, the intersection of Artificial Intelligence (AI) and sustainability is poised to become one of the defining challenges (and opportunities) of the coming decades. AI is expected to play a pivotal role in shaping a sustainable future, but only if its development is guided by intentional, environmentally conscious strategies.

On the horizon, AI holds immense promise for transformative sustainability gains:

Next-generation energy systems



will be orchestrated by AI, optimizing smart grids, forecasting renewable energy supply with precision, and dynamically balancing demand.

Autonomous resource



will minimize waste across industries, using real-time data to drive circular economy models that prioritize reuse, recycling, and regeneration.

AI-driven climate modeling



will enable hyper-local, adaptive responses to environmental changes, enhancing resilience in agriculture, infrastructure, and urban planning.

Yet, the environmental cost of AI is projected to rise as models grow in scale and complexity. Without intervention, the energy demands of training and deploying advanced AI systems could outpace sustainability gains. Future data centers, if not powered by renewables and optimized for efficiency, may become significant contributors to global emissions.

To navigate this dual frontier, future AI strategies must embed sustainability by design:

Green AI architectures will prioritize energy efficiency through innovations in model compression, neuromorphic computing, and federated learning.

Lifecycle-aware AI development will track and minimize environmental impact from data acquisition to model retirement, supported by transparent, standardized reporting frameworks.

Sustainable AI infrastructure will be powered by decentralized, renewable energy sources and governed by carbon-aware scheduling algorithms..

Ethical and ecological alignment will become core design principles, ensuring AI systems not only serve human goals but also respect planetary boundaries.

In this envisioned future, AI is not just a tool for sustainability; it becomes a co-architect of a regenerative, low-carbon world. Realizing this vision will require cross-disciplinary collaboration, forward-thinking governance, and a commitment to aligning technological progress with ecological stewardship.

Best Practices for Sustainable AI: Designing for a Greener Future

To build AI systems that are both powerful and planet-friendly, future-ready best practices must be embedded across the AI lifecycle:

Efficient by Design: Use model compression, pruning, and quantization to reduce computational load without sacrificing performance.

Low-Power Hardware: Deploy AI on energy-efficient processors like TPUs, FPGAs, and neuromorphic chips to minimize power consumption.

Smarter Training: Adopt data-efficient methods, such as transfer learning, synthetic data, and few-shot learning, to cut training time and energy use.

Lifecycle Monitoring: Track energy use, carbon emissions, and resource impact from development to deployment using real-time telemetry.

Carbon-Aware Scheduling: Optimize AI workloads based on grid carbon intensity and renewable energy availability.

These practices are not just technical optimizations but strategic imperatives for ensuring AI innovation aligns with environmental sustainability.

Sustainability and Efficiency Metrics for AI: Blueprint for Scalable Implementation

As AI systems scale in complexity and impact, the future demands a metrics-driven framework that embeds sustainability into every layer of AI development and deployment. Implementation begins with pilot-driven experimentation and evolves into system-wide integration through continuous monitoring, adaptive optimization, and cross-functional collaboration. These efforts focus on areas such as energy efficiency, carbon footprint, resource optimization, sustainable supply chains, ethical sourcing, circular economy, lifecycle management, environmental

impact assessments, social and economic metrics, governance, ethical considerations, performance, and scalability. In future AI systems, efficiency will be a foundational design principle, not an afterthought. Precision metrics will be integrated into autonomous monitoring frameworks, enabling real-time diagnostics, predictive maintenance, and adaptive optimization. These metrics will drive intelligent, sustainable scaling and ensure AI systems remain reliable, responsive, and aligned with human needs across compute, data, and user experience layers.

Sustainability & Efficiency Metrics* Categories for AI: A Dashboard View

Category	Aspect
Energy Efficiency, Carbon Footprint, Supply Chain, Circular Economy	Energy Use, Efficiency Ratios, E-Waste Generation, Circular Economy & Lifecycle Management, Environmental Impact Assessments, Sustainable Supply Chains & Ethical Sourcing
Algorithm Efficiency	Runtime Efficiency, Memory Efficiency
Performance per Watt	Energy-Performance Ratio, Inferences per Watt, Inferences per TOPS, TOPS/Watt, Performance per Watt, MACs per Inference, Floating Point Operations per Second (FLOPS), FLOPS Utilization
Data Center Efficiency	Infrastructure Efficiency, Data Centre PUE
Resource Utilization	Compute Utilization, System Throughput
Deployment and Utilization	Utilization Rate, Idle Power Consumption, Boot Time
Memory and Bandwidth	Memory Bandwidth Utilization, Memory Footprint, Cache Hit Rate
Latency	Inference Speed/Inference Time/Latency, Training Time
Scalability	Horizontal Scaling, Vertical Scaling, Speedup Ratio, Parallel Efficiency
Error Rate Reduction	Accuracy, Improvement Over Time
Data Efficiency	Data Usage, Processing Speed
Technical Debt Impact (TDI)	Maintainability
Process Throughput	Task Completion, System Availability
Thermal and Power Metrics	Power Draw, Thermal Design Power (TDP)
User Experience	User Satisfaction, Productivity Gains, ROI from AI Deployment, Task Automation Rate
Social and Economic	Equity and Inclusion, Bias and Discrimination, Accessibility, Productivity Gains, Cost Savings, Economic Value Added, AI literacy
Governance and Ethical Considerations	AI Policy Compliance, Governance Maturity Index, Auditability, Responsible AI Adoption Rate, Stakeholder Engagement Index

*Not comprehensive – indicative



Sustainable AI: Confronting the Challenges, Defining the Metrics, Shaping the Future

The next era of AI will not be defined by scale alone, but rather by its ability to operate within the limits of our planet. As AI systems grow more powerful, so too does their environmental footprint. The challenge is clear: we must re-engineer AI for sustainability, not as an afterthought, but as a core design principle. The future of AI will be defined not only by intelligence but also by its ability to operate within ecological and ethical boundaries.

Emerging Challenges in Sustainable AI

High Computational Demand: Next-Gen AI models (especially large-scale language and vision systems) consume vast energy, amplifying carbon emissions. Future systems must be designed for energy-aware computation and carbon-aware scheduling.

E-Waste Acceleration: Rapid hardware turnover fuels electronic waste. Circular design principles (modularity, recyclability, and repairability) must be embedded into AI hardware ecosystems.

Resource-Intensive Infrastructure: AI's growing hunger for data and compute places significant strain on storage, bandwidth, and power grids, creating challenges that demand attention. Intelligent orchestration and edge computing will be critical to reduce centralized load.

Bias and Fairness: Sustainable AI must be socially inclusive. Future models will require dynamic fairness auditing, diverse training datasets, and real-time bias mitigation.

Invisible Carbon Footprints: Most organizations lack visibility into the emissions of their AI systems. Carbon-aware computing must become the default, not the exception.

Transparency and Accountability: Black-box AI is incompatible with sustainability. Systems must expose their environmental impact through standardized, machine-readable disclosures.

Cost versus Sustainability Trade-offs: Upfront investments in green infrastructure and efficient algorithms must be justified by long-term gains in resilience, compliance, and brand equity.

The Metrics That Will Define Responsible AI

Dimension	Key Metrics
Energy & Emissions	Real-Time Energy Use, Carbon Intensity per Model, Performance per Watt
Hardware Lifecycle	E-waste Volume, Hardware Lifespan, Recyclability Index
Algorithmic Efficiency	Time/Space Complexity, Training/Inference Energy Per Task
Data Efficiency	Utilization Rate, Synthetic Data Ratio, Preprocessing Time
Scalability	Elasticity Under Load, Resource Scaling Efficiency
Social Impact	Equity & Inclusion, Digital Divide, Productive Gains, Economic Growth
Governance	GRI/SASB Alignment, Transparency Score, Audit Frequency

The Path Forward: From Metrics to Momentum

- **Mandate Transparency:** Every AI system should disclose its environmental impact automatically, continuously, and publicly.
- **Design for Circularity:** Hardware and software must be built for longevity, reuse, and minimal waste.
- **Power with Purpose:** AI infrastructure must run on renewables, with carbon-aware scheduling baked into every workload.
- **Incentivize Impact:** Reward AI applications that directly advance sustainability, such as climate modeling, regenerative agriculture, and smart infrastructure.
- **Unite the Ecosystem:** Developers, enterprises, regulators, and researchers must co-create a global framework for sustainable AI.

The future of AI is not just about scale, it's about sustainable intelligence. Navigating this frontier requires a unified effort across developers, enterprises, and regulators to ensure AI accelerates progress without compromising the planet.



A Call for Sustainable AI Practices

The future of Artificial Intelligence (AI) is not just about technological advancements but also about our responsibility to ensure these innovations align with environmental and ethical standards. As AI continues to integrate into every aspect of our lives, the need for sustainable practices becomes more urgent than ever. It is important that developers, policymakers, industry leaders, and all stakeholders in the AI ecosystem prioritize sustainability in their AI strategies. By adopting energy-efficient algorithms, utilizing renewable energy sources, and implementing comprehensive lifecycle assessments, we can significantly reduce the environmental footprint of AI technologies.

Integrating sustainability into AI practices is not only achievable but also beneficial, leading to substantial reductions in carbon footprints and operational costs. However, overcoming the challenges of sustainable AI requires innovation, collaboration, and a steadfast commitment to sustainability principles.

The time to act is now. Let us harness the power of AI to drive progress while safeguarding our planet for future generations. Together, we can lead with responsibility, ensuring that AI technologies contribute to a sustainable and equitable future for all. Join us in this critical mission to make AI a force for good in the world.



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