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AI in sustainability: AI in eco-friendly product innovation and lifecycle management

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Abstract
This research paper explores how Artificial Intelligence (AI) supports eco-friendly product innovations and lifecycle management. It talks about how AI helps in building a sustainable environment and awareness about climate change. This study even includes that AI plays significant role for companies and startups to bring out their products and ideas that are good for our environment. We have mainly focused that AI helps in design sustainable products, promotes recycling and supports manufacturing. Through our research we have identified that AI is useful in our lifecycle too. Going through our research we will be knowing the transformation, our environment has got after AI came into use and how it has changed the environment. We have studied the AI's support in energy saving, food sustainability, awareness on climate change and reducing waste. AI is helping innovators and individuals with ideas to promote their new eco-friendly products by designing, testing the product, making it less harmful and removing waste. It helps in making the product more efficient and sustainable for our environment. We have spoken and identified the AI's role in preventing climate change and supporting lifecycle management. AI also assists in guiding people towards greener choices and helping to move towards a smarter and greener future. Overall, we have identified AI's growing role in preventing climate change, supporting lifecycle management and helping society to move forward. In conclusion, AI has become a powerful tool that not only supports innovation but also strengthens our global efforts toward sustainability and environmental responsibility.

Keywords: Artificial intelligence (AI), climate change, eco-friendly, environment, lifecycle management

Introduction
AI helps sustainability by optimizing energy use, improving waste management, and enhancing resource efficiency across sectors. It allows for smart energy consumption in buildings and grids, a type of precision agriculture with reduced waste of resources, and effective tracking of the carbon footprint both at the level of an individual and a business. AI also aids in climate monitoring, renewable energy system optimization, resulting in lower emissions and more effective ecological decision-making. These applications help make processes more efficient and reduce environmental impact, thus supporting a transition to a more sustainable future. This multi-faceted role of AI drives both ecological benefits and economic gains within sustainability efforts.

Business face pressure to balance profitability and environmental care. AI assists in achieving sustainability through optimized resource use, waste reduction, and real time monitoring. It supports transparency and helps meet global sustainability goals [e.g., UN SDGs]. AI in green marketing, enables personalised eco-marketing and transparent green claims. AI chatbots encourages sustainable consumer behaviour and eco-awareness.

AI is helping eco-friendly product innovations by enhancing design and material selection to minimize environmental impact, reduce waste, and cut energy use, while simulations and predictive modelling speed up the cycle of sustainable product development. AI can assist in creating energy-efficient products, smooth supply chains, and support a circular economy based on recycling and modular design. With AI-enabled tools, businesses can make informed decisions much earlier in the design process, thereby reducing the carbon footprints of products and making them more sustainable. This is very important, given the fact that 80% of any product's environmental impact is decided in its design phase, and AI enables industries to innovate responsibly to meet increasing regulatory and consumer demands for greener products.

AI is changing eco-friendly product lifecycle management [PLM] by enabling intelligent design, optimized production, and sustainable supply chains using real-time data analysis and simulation. This accelerates the identification of sustainable materials and design choices, minimizes waste and energy consumption, enhances lifecycle assessments for environmental impact, and facilitates recycling and reuse to help circular economy practices. AI-powered PLM allows for faster and more accurate decision-making, proactive risk management, and continuous improvement, enabling companies to become more sustainable innovators in cost and carbon footprint reduction to meet growing regulatory and consumer demand for greener products.

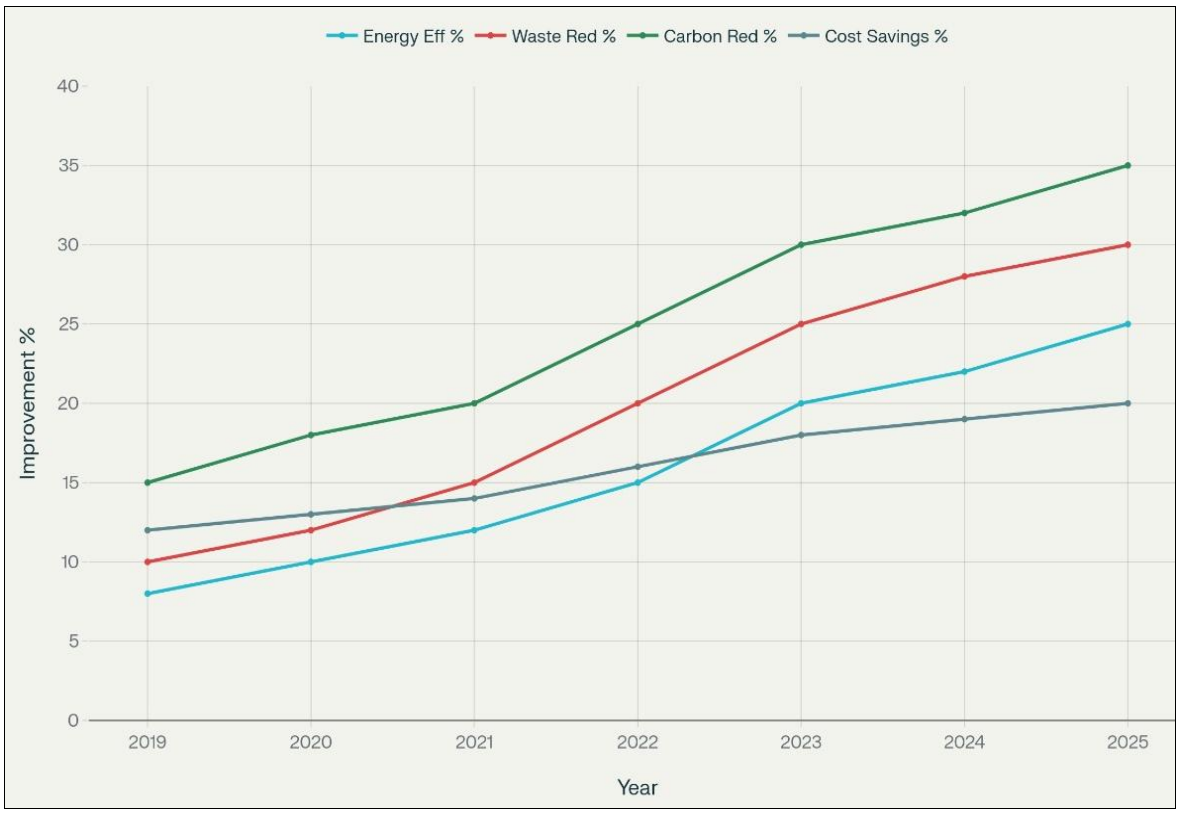


Fig 1: AI Eco Innovation Trends 2019-2025

Crudu, A. (2025, May 19). AI for Sustainable Product Development Latest Trends & Methods. *MoldStud-Custom Software Development Company*. https://moldstud.com/articles/p-ai-for-sustainable-product-development-latest-trends-methods

The above graph shows the growth of sustainability using AI.

Research Methodology

This study is based on secondary data. Qualitative data is collected through literature reviews and case studies. Information was taken from journals, research papers, company reports, and online articles.

The research focuses on understanding how AI supports eco-friendly product design, production, and lifecycle management. It also highlights the benefits and challenges of using AI in promoting sustainability.

Literature Review

AI in Lifecycle management

AI in PLM systems is a paradigm shift from traditional product data management to intelligent ecosystems that empower better decision-making across the stages of product design, manufacturing, and service according to Batalha *et al*. (2024) [18].

Capabilities such as market analysis, rapid and collaborative design, optimization of manufacturing resources, quality inspection using vision systems, and predictive maintenance are some of the key functionalities enabled by AI techniques such as machine learning, deep learning, and augmented reality.

All these contribute to enhanced efficiency, cost reduction, accelerated innovation cycles, and the increased sustainability of products. In general, however, data standardization, system integration, algorithm reliability, and user acceptance have still been seen as challenges for large-scale deployment.

In sustainable materials science, AI reduces the slowness and complexity of conventional experimental methodologies by accelerating the discovery and optimization of green materials for energy applications.

AI models now enable predictive design, generative design, optimize processing through environmentally friendly routes, and even real-time lifecycle monitoring and intelligent recycling.

However, these come with limitations in the form of data availability, integration of domain knowledge, and model transferability across materials. Federated learning, physics-informed neural networks, and multimodal AI are some of the emerging recent solutions to respond to these challenges that can foster computational sustainability by Fernández-Arias & Antón-Sancho (2024).

As far as new product development is concerned, the main impacts of AI are felt at the front end, primarily in idea

generation through sentiment analysis and knowledge extraction, design customization through expert systems, and advanced analytics for demand forecasting. While AI tools increase the level of innovation and responsiveness, its usage is fragmented, with nascent applications in concept testing, validation, and post-launch optimization. Cooper, 2024 Effective adoption of AI in NPD requires organizational readiness, strategic alignment, and integrated frameworks across isolated AI deployments in the product life cycle. In summary, AI is a game-changing enabler for smarter, data-driven, more adaptive product lifecycle processes. The study reveals good improvements in efficiency, innovation, and sustainability but identifies some persistent challenges on technological integration, standardization, data quality, and human-AI collaboration. Future work should be directed toward the development of industrially adaptable algorithms, establishing unified standards, and improving transparency and security to realize the full potential of AI within product lifecycle for sustainable material management. This synthesis underlines the need for an interdisciplinary approach in combining AI, domain knowledge, and system engineering toward intelligent and sustainable product ecosystems.

AI in start-ups

The energy sector is undergoing a major change due to advancements in artificial intelligence (AI) and quantum computing (QC). Start-ups are leading the way in this evolving landscape (Jorzik *et al*., 2023) [17]. AI technologies like machine learning, predictive analytics, and optimization algorithms are crucial for improving energy efficiency, managing the grid, and integrating renewable energy sources (AI in Energy Review, 2023). These AI tools use extensive datasets from smart meters, IoT devices, and weather stations to allow accurate demand forecasting, real-time monitoring, and automated decision-making. Together, these efforts contribute to smarter and more sustainable energy systems (Jorzik *et al*., 2023) [17].

Quantum computing is still in the early stages of practical use but offers unique computational abilities (World Economic Forum, 2025). By using qubits' superposition and entanglement, QC can solve highly complex, nonlinear optimization problems found in the management of distributed energy resources (DERs), smart grid stability, and energy storage optimization. These challenges exceed the limits of classical computation (IET, 2025). Notable examples include better forecasting of renewable energy by integrating various data sources like weather and environmental sensors, as well as optimized grid operations for balancing supply and demand in real-time (World Economic Forum, 2025). Collaborations such as the one between Pasqal and EDF (Pasqal-EDF Collaboration Report, 2025) show early real-world applications of quantum algorithms that improve renewable energy integration and optimize electric vehicle (EV) charging schedules.

The combination of AI and QC, especially in the area of quantum machine learning (QML), offers a promising new frontier. This has the potential to fast-track innovation in energy system optimization and sustainability transitions (Frontiers in Quantum Science, 2025). However, most current QML applications are still in exploratory stages. This highlights the need for more technological progress and real-world validation before they can have a significant commercial impact (Frontiers in Quantum Science, 2025).

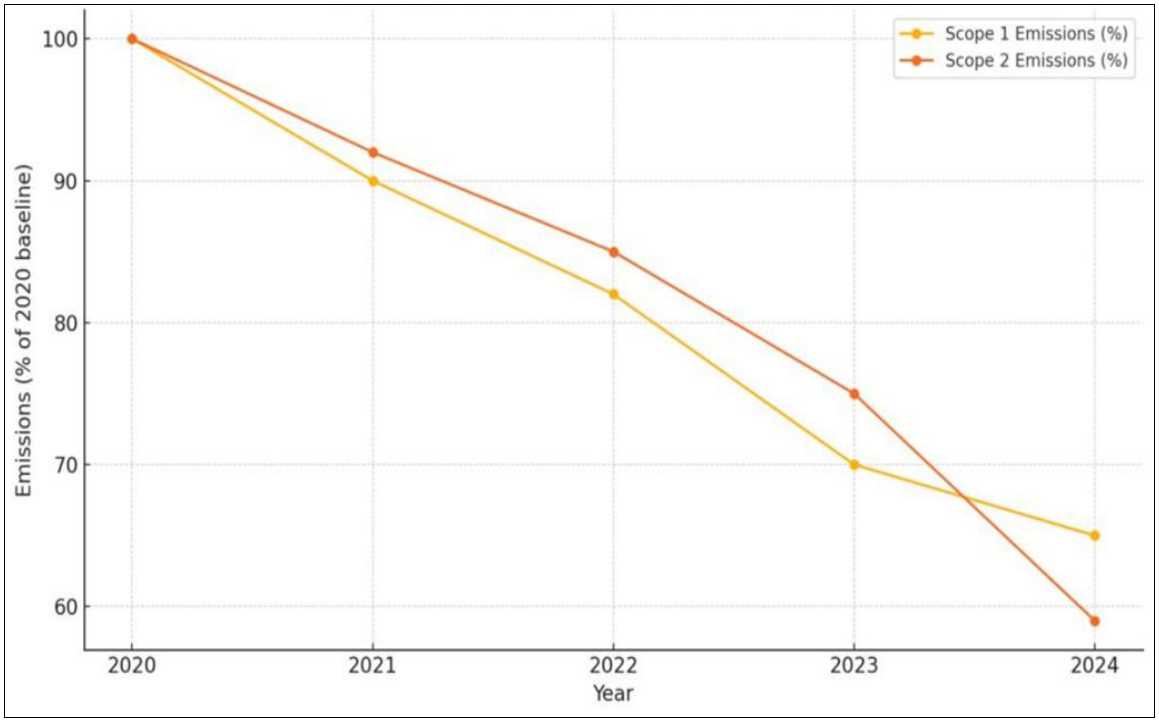
Start-ups in this field are creating new business models that focus on green entrepreneurial orientation, AI-driven knowledge management, and dynamic capabilities for sustainability (Jorzik *et al*., 2023) [17]. These companies innovate through AI-enabled operational efficiency, resource optimization, circular economy integration, and predictive decision-making. They aim to balance rapid growth with environmental responsibility (AI-Driven Start-up Scaling Study, 2024). Despite AI's high energy demands, especially in the data centers that support AI computations, efforts are underway to develop more energy-efficient algorithms and incorporate renewable energy sources to reduce environmental impacts (AI-Driven Startup Scaling Study, 2024). Ethical issues regarding AI governance, bias, and social impacts also influence the practices of sustainable startups (Jorzik *et al*., 2023) [17].

Startup ecosystems differ by region. The US leads in investment and numbers, while Switzerland, Germany, and the UK have higher startup success rates (Global Startup Ecosystem Report, 2024). The high failure rates of early-stage startups emphasize the need for interdisciplinary collaboration, knowledge sharing, and supportive policies to foster innovation that meets sustainability goals (Global Startup Ecosystem Report, 2024). The Resource-Based View (RBV) and Dynamic Capability Theory (DCT) offer helpful frameworks for understanding how AI-driven knowledge management creates sustainable competitive advantages by enabling real-time sensing, seizing, and transforming capabilities in unstable markets.

AI is currently the main driver of innovation in sustainable energy startups, leading to improvements in efficiency and business model innovation (AI in Energy Review, 2023). Quantum computing complements these initiatives by providing solutions to complex optimization problems that are essential for grid resilience and renewable energy integration (World Economic Forum, 2025). Merging AI and QC strategically will be key to achieving a greener, smarter energy future. Ongoing investment, practical research, and cross-sector partnerships are crucial to fully unlock the potential of these technologies for sustainable startup growth and transformation of energy systems (Frontiers in Quantum Science, 2025).

Case Study

The graph exemplifies Tesla's increased efficiency in battery recycling and emission reduction in the period spanning 2020 to 2024. This progress is largely driven by the company's use of Artificial Intelligence (AI) across its operations. AI systems analyze data from electric vehicles and energy products to predict battery performance, optimize charging cycles, and enhance the efficiency of recycling processes. These technologies enable Tesla to recover more materials, reduce waste, and lower the carbon footprint of its production. With AI-driven monitoring and energy management, Tesla continues to head toward a cleaner, greener future.



Source: The Sustainable Innovation, 2025

Fig 2: Tesla Emissions Reduction Trend (2020-2024)

Conclusion

Artificial Intelligence is transforming green product innovation and lifecycle management, making design and manufacturing more data-driven and sustainable. AI fosters the use of alternative materials with lower environmental impact, optimizes manufacturing to minimize waste and energy use, and foresees customer preferences in order to position products according to sustainable consumer behaviour. Furthermore, AI enables lifecycle assessments that track environmental impact from cradle to grave, allowing businesses to apply circular economy principles via modular designs and product reuse strategies. While AI offers unparalleled opportunities to reduce carbon footprints and catalyse circularity, further research and development are required to surmount current technological limitations in achieving a strategic integration of ecological sustainability in commercial product development. In the final analysis, AI represents a catalysing yet fundamentally indispensable driver for sustainable innovation, ushering industries toward greener and more responsible futures.

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