



**Politecnico
di Torino**

Politecnico di Torino

MSc in Management Engineering

A.a: 2024/2025

April 2025

Leveraging AI for Sustainable Futures

Net-Zero Strategies and Innovations in High-Tech Companies through
Advanced Data Management

Relatori:

Ravetti Chiara

Candidati:

Burato Marco (s314149)

1.	ABSTRACT	3
2.	INTRODUCTION	4
2.1.	AI-DRIVEN DATA MANAGEMENT AND NET-ZERO STRATEGIES	4
3.	BACKGROUND	6
3.1.	CLIMATE CHANGE AND ORGANIZATIONS	6
3.2.	DATA AND INFORMATION SYSTEMS	9
3.3.	CURRENT LANDSCAPE IN HIGH TECH COMPANIES.....	11
4.	LITERATURE REVIEW	19
4.1.	THE POTENTIAL OF ARTIFICIAL INTELLIGENCE.....	20
4.2.	KEY MEDIATING FACTORS IN AI-DRIVEN SUSTAINABILITY	35
4.3.	TOWARD AN INTEGRATED UNDERSTANDING OF AI FOR SUSTAINABILITY: KEY RESEARCH GAPS	43
5.	METHODOLOGY	45
5.1.	LITERATURE REVIEW.....	45
5.2.	PRIMARY DATA FROM HIGH-TECH COMPANIES	47
5.3.	PATENTS	55
6.	RESULTS	61
6.1.	LITERATURE REVIEW.....	61
6.2.	PRIMARY DATA FROM HIGH-TECH COMPANIES	68
6.3.	HIGH TECH COMPANY INTERVIEWS – ANALYSIS	79
6.4.	PATENTS	81
7.	CONCLUSION.....	89
7.1.	STUDY LIMITATIONS AND IMPLICATIONS	90
7.2.	FUTURE OPPORTUNITIES AND CHALLENGES.....	91
8.	REFERENCES	91
8.1.	BIBLIOGRAPHY	91
8.2.	SITOGRAPHY	99

1. Abstract

In the context of mounting environmental urgency and technological acceleration, this thesis investigates how Artificial Intelligence (AI) and advanced data management can support high-tech companies in achieving net-zero strategies. Through an integrated approach combining literature review, primary data analysis from seven high-tech firms, and patent exploration, the study highlights the transformative role of AI in driving green innovation and sustainability. AI enables real-time data analysis, supports decision-making, enhances energy efficiency, and improves supply chain transparency. However, challenges such as high energy consumption, ethical concerns, and infrastructure disparities hinder its effective sustainable deployment. The integration of Green Information Systems (GIS) within companies shows promising internal benefits, but faces limitations in supply chain adoption due to data silos and stakeholder misalignment. Patent analysis confirms growing global efforts to align AI innovations with sustainability goals. This study proposes that AI can act not only as an operational tool but also as a strategic enabler for environmental governance and green innovation. The conclusion of this analysis identifies new recommendations for future research and policy development to ensure that AI adoption is ethical, inclusive, and environmentally sustainable.

Keywords: Artificial Intelligence, Sustainability, Net-Zero Strategies

2. Introduction

2.1. AI-driven Data Management and Net-Zero Strategies

The rapid advancement of artificial intelligence (AI) and its transformative potential within all sectors in the industry has changed the landscape in how companies handle data and strategize for sustainability in the future. AI-driven data management employs advanced algorithms and machine learning techniques to improve data collection, management, storage, sharing and analysis. This provides organizations with a tool to handle massive amounts of information, enabling an easier decision making and facilitating green innovations, while promoting environmental sustainability (Rasheed et al., 2024).

In parallel, the concept of net-zero strategies emerged as an urgent topic to mitigate climate change while tackling most of the seventeen Sustainable Development Goals (SDG). They are “an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests” (United Nations, 2015).

This ambitious plan requires a very rigorous and science-based strategy as the final aim is to reduce Green House Gases (GHG) emissions, by balancing the emissions produced and the ones removed from the earth’s atmosphere.

While SDGs are intended to be pursued by nations, high-tech companies are uniquely positioned to support and achieve this target by reducing their emissions and environmental burden across all activities as much as possible. Climate change is a very urgent challenge that requires both national commitments and ambitious action from corporate leaders. In doing so, high-tech companies should concentrate their efforts by lowering down all three emissions’ scopes, according to the GHG Protocol Standard classification: direct emissions from owned resources (Scope one), emissions coming from the production of the energy that companies buy (Scope two) and all residual emissions coming from the whole value chain, which often accounts for the majority (Scope three).

AI steps in this scenario, providing different tools and new ways to accomplish these challenges, as highlighted in recent studies which suggest that “Through the integration of AI into energy management systems, companies can track and reduce their carbon emissions more effectively” (Di Vaio et al., 2020) and that “AI solutions are uniquely suited to managing complex systems like energy grids and industrial supply chains, allowing for dynamic adjustments that directly reduce emissions and improve operational efficiency” (Kwon & Lee, 2019).

The integration of AI-driven data management and net-zero strategies represents a promising opportunity to leverage current technologies for a fast and smooth transition towards a more sustainable future for the whole humanity, as “tackling climate change is considered impossible without the implementation of AI, robots, and technological industrial assessment, as supported by compelling evidence” (Rasheed et al., 2024).

This thesis deep dives into this, highlighting the relationship between AI data management and its innovations’ spillovers, all linked to a high-level, comprehensive net zero strategy that aims at lowering down emissions and promoting a greener future.

The scope of this study is indeed set to high-tech companies, as they are particularly relevant in the framework under analysis, in terms of technological capabilities, vision, current and future impacts. Moreover, AI has huge impact especially in this field as this industry is already integrating developed production systems with digital tools to tackle rapid and technological innovations year over year.

Why does this result matter? The significance of studying AI-driven data management and net-zero strategies together lies in their potential to drive transformative change in the high-tech industry. As the world faces constant environmental challenges, high-tech companies play a central role in pioneering solutions that can lead the way for a better and sustainable future.

By using AI-driven systems for data management and resource optimization, these companies can not only achieve net-zero targets but also set a precedent for other industries to follow, as companies of every size and sector can certainly implement more sustainable business models, to quickly implement the Sustainable Development Goals (SDG) through technological innovations and multi-stakeholders’ involvement (Di Vaio et al., 2020).

Additionally, sustainable innovations coupled with AI-integration can enrich the current industrial landscape by expanding and unlocking new opportunities, “Sustainable production and circular economy capabilities, driven by Industry 4.0, hold the potential to unlock new business opportunities while preserving natural resources for future generations” (Bag, Yadav, et al., 2021).

At the same time, we do see arising challenges in this landscape. First, AI models and technologies require vast amount of energy and electricity consumption specially to run data centers, which in turn results in carbon emissions. Data availability and quality is another key aspect that needs to be addressed. To effectively leverage AI for sustainability, companies must instill a data culture within the organization. Additionally, while tackling SDGs leveraging AI it is fundamental to address potential privacy and ethical concerns, building up standards and solid frameworks to ensure a responsible digitalization, avoiding potential misuse of data (Del Río Castro et al., 2021).

All topics will be covered throughout the analysis, starting with a background related to climate change and AI, a comprehensive literature review coupled with both quantitative and qualitative analysis of primary data from high-tech companies and patents about AI innovative solutions for sustainable purposes. The final result chapter will sum up the overall discussions and findings, providing new insights in this brand new and fast-growing topic.

3. Background

3.1. Climate Change and Organizations

Climate change is one of the most pressing challenges of our time, highlighting a need for concentrated efforts from the entire society and industries, including high-tech companies. Human activities are putting under huge strain the entire planet system.

Nowadays sustainability has become a well-established, compulsory concept, that is also affecting the valuation of any organization (Del Río Castro et al., 2021).

This section introduces the urgency of reaching net-zero by leveraging a recent report discussed by Mario Draghi, an Italian politician, economist, banker who served both as prime minister of Italy and as the president of the European Central Bank (ECB). His report outlines an impellent need to rapidly address environmental issues through technological innovations in the European Union (EU).

3.1.1. Urgency of Reaching Net-Zero

According to the Intergovernmental Panel on Climate Change (IPCC), limiting global temperature increase to 1.5°C requires rapid and unprecedented changes in all areas of society, including energy, land use and infrastructure building.

The adverse effects can unfortunately already be seen worldwide through more frequent extreme weather episodes, droughts, wildfires, melting of the permafrost, radical changes of the ecosystems and rising sea levels. Achieving net-zero is mandatory to avoid worse side effects and to ensure a sustainable future both for humans and the Earth.

A recent report by Mario Draghi, “Future of European Competitiveness” (2024) underscores the necessity of contemporaneous decarbonization and competitiveness to secure Europe’s long-term growth.

In the report, he points out three main critical areas to reignite sustainable growth: innovation, decarbonization and security.

The first pillar, Innovation, highlights the current European industrial landscape, populated by mid-technologic companies, which are mostly already at a mature stage. Furthermore, the top-investing companies in R&D field are the same of twenty years ago.

Since 2008, the 30% of ‘Unicorns’, so start-ups which reach a market value of one billion – the most successful innovators - moved to America, furtherly emphasizing Europe’s limits and lack of innovations, especially in the digital tech sector. To close the gap with the America economy and scenario, Europe must be ready to catch and exploit the new opportunities coming with the AI revolution, in all fields.

The second point is related to decarbonization coupled with competitiveness: Europe’s ambitious climate goals must go together with industrial strategies that reduce emissions but which are at the same time able to foster leadership in clean technologies, so to increase their supply to finally promote and sustain decarbonization. This synergy is essential to ensure a more sustainable future and to build a more resilient and competitive European Union, especially in key fields like energy-intensive industries, clean tech, automotive and energy markets.

In this context, high-tech companies integrating AI-driven solutions, decarbonization technologies, data management and generally by leveraging net-zero strategies, can set a global example in net-zero leadership.

The last area of the report focuses in decreasing economic dependencies and increase overall security, because of the worsening of geopolitical landscape in the past ten years. Trade agreements and direct investments with resource-rich countries and secure supply chain for key and clean technologies are mandatory to ensure a competitive and sustainable Europe in the future.

These challenges and opportunities outlined in the Draghi's report illustrate the urgency of integrating innovation and sustainability at scale, particularly through the adoption of advanced technologies. In this landscape, global tech leaders like Amazon are stepping up with concrete commitments toward sustainability and net-zero strategies.

Amazon is indeed aligned to this vision and it's committed to sustainability, the actual goal of the company is to lower down carbon emissions by an amount of 7% per year. The final aim is to reach net-zero carbon emissions by 2040, a decade ahead of the Paris Climate Agreement (Amazon, 2024).

In 2024 the company achieved a great milestone in this sense, fully employing renewable resources for the generation of its needed energy.

The actual EU and UK sustainable portfolio and initiatives of the company is built looking at the aforementioned mission and it counts an overall total of 412 different projects as of end 2024, spread across EU and UK areas:

- MEU (Middle Europe: France, Germany and Poland): 132 projects.
- SEU (South Europe: Spain and Italy): 101 projects.
- UK (United Kingdom): 114 projects.
- EU (Rest of Europe): 65 projects.

Sustainable projects are divided into different categories:

- Carbon: EC3 carbon emission data collection (7) and a pilot (1) for innovative project.
- Energy: all projects and initiatives aiming at lowering down and tracking energy consumption (submetering), motion sensors, Aether projects.
 - Energy – End of Life: projects which focus on the responsible disposal, recycling, or repurposing of systems and components such as Heating Ventilation Air Conditioning (HVAC) systems, LED lighting, and high-efficiency motors.
 - Energy – Pilot: Amazon is starting to explore wind turbines projects to enhance its sustainable commitments. In particular, 2 projects have been successfully delivered in Spain (Barcelona and Madrid). Now wind turbines are installed next to two sites, within Amazon land, and they started to provide clean energy to the buildings.
 - Solar & PV Panels: installation of PV Solar Panels in fulfillment centers' roofs to provide solar energy for its day-to-day operations.
 - Water: projects associated with water efficiency or projects aiming at lowering down its consumption.

- Sustainability BAU: Business As Usual (BAU) projects to maintain sustainability focus and existing projects.

- Others: minor projects and ESG initiatives.

Reliable and meaningful data, together with solid information systems and tools are mandatory to enable the tracking of these huge portfolios, involving multiple type of projects, in different regions across the world and spreading through thousands of different stakeholders, both internal and external.

The next section will deep dive in data and information systems, which is an interlinked concept with sustainability.

3.2. Data and Information Systems

The ability of collecting and managing huge quantities of data in a structured and effective way can lead to a major competitive advantage in the industry. In the modern society data is undeniably one of the most valuable assets for companies.

This section delves into the central role of the information systems and the current issues that companies are facing while collecting and managing vast amounts of information.

3.2.1. Information Systems Complexity

High-tech companies mostly rely on advanced information systems to manage the entire business and operations, as well as to highlight and track past and future trends and data, while pursuing innovations path.

A globalized economy creates a need to integrate different data sources into a pivotal and coherent framework to ensure a robust decision-making process.

Information systems satisfy these new requirements, but this is coupled with handling interconnected components including databases, cloud solutions and a huge number of different user interfaces. This poses new challenges as information and data sharing is not always so effective and straightforward. Companies can indeed face issues about systems' interoperability or data isolation, which can lead to misalignments, ineffective communication and possible data loss, together with all the side chain effects of this, as a slower pace in fostering innovations, do strategic planning and conducting the business.

Moreover, the growing adoption of new emerging and innovative technologies like Internet of Things (IoT), Machine Learning (ML) or Artificial Intelligence (AI) adds a supplemental layer of complexity. Information systems must be able to scale up and to adapt to the constant change of external conditions.

Additional challenges arise from the global breadth of high-tech companies, as they're spread across multiple countries, impacting different stakeholders, environments and time zones.

Amazon Web Services (AWS) is one of the main leaders in this field. The company is helping organizations by facilitating management of their cloud infrastructure, helping them to modernize, scale and being cost efficient. Later in "The Role of Artificial Intelligence – Actual vs Future", a case study about the modernization of an high-tech company will be cited.

A recent study was conducted by Decision Sciences on 2360 Spanish firms with a minimum number of 50 employees. It focuses on the relation of information systems capabilities, intended as the organizations' ability to deploy and integrate IT resources all together (IT assets, infrastructure and processes that leverage IT effectively), with the overall company performance, underlying the mediating role of organizational agility.

Three main results are highlighted: at first, that the influence of IS capabilities on firm performance is fully mediated by organizational agility. Second, to realize greater performance, firms must develop adequate competencies in the different levels and aspects of IS capabilities and organizational agility, ensuring an holistic approach.

The article also includes a key industry factor in the study, which fully aligns to the scope of this thesis: the technology intensity of the industry on the relationship analyzed. The final outcome, in fact, points out that the relationship between IS capabilities and organizational agility is significantly greater in the high-tech companies' sample, rather than in the medium-tech one. High-tech firms, competing in highly intensive technology environments, must embed and develop deep IS capabilities to increase their overall performance, being able to quickly respond to market and industry changes, meeting new customer demands and creating new business opportunities (Felipe et al., 2020a). In particular, the IS capabilities under scope are the ones related to the collection and management of strategic data, which can facilitate a fast response to arising challenges and enhance the companies' flexibility in today's fast-paced environments.

To close the section about data and information systems, the next final chapter will describe actual issues regarding data security and privacy concerns.

3.2.2. Challenges in Data Collection and Management

One of the primary issues in the process of data collection and management is data quality. This refers to the accuracy and reliability of data, which in turn will be used to generate reliable insights and trends, to ultimately drive decision making on a high level. Ensuring high data quality is a very complex task but it's mandatory to achieve company success. Data errors can arise in different timings, from collection to storage, passing through processing. They must be avoided to ensure robust analyses and effective strategic planning.

Data integration is a huge point of attention as high-tech companies rely on a wide variety of sources including internal systems, customer interactions and third-party business partners. This translates in a vast amounts of data type, formats, formulas and structures which are difficult to integrate in a unique source of truth point. There exist sophisticated tools and tested methodologies to ensure data consistency across all the organization.

Nowadays companies are also becoming vulnerable to data breaches and cyberattacks. Data security is certainly the third major concern in the current landscape. It is vital to protect strategic data, personal and financial information from unauthorized access. This requires a vast implementation of security measures as monitoring systems or hard encryption, which can guarantee data integrity and to comply at the same time with legal requirements.

The following section will provide an effective overview about how High-tech companies are ramping up and adopting data management practices and especially how AI is shaping their strategies, focusing on actual and possible future role and opportunities of this tech revolution.

3.3. Current Landscape in High Tech Companies

High-tech companies are the vanguard for innovations, exploring new ways to better handle data and in turn to achieve competitive advantage in the market. This section details the current data management practices, the emerging and evolving role of Artificial Intelligence and ultimately the current adoption of innovative technologies with the final aim of achieving net-zero.

3.3.1. Current Data Management Practices

In the realm of high-tech companies, data management practices have evolved significantly, influenced by the need to handle ever-increasing volumes of data and the demand for real-time analytics. Current practices are characterized by the widespread adoption of cloud computing, big data technologies, and advanced analytics platforms.

Cloud computing has become the backbone of modern data management, offering scalable and flexible solutions that allow companies to store and process vast amounts of data without the need for on-premises infrastructure.

A recent article by Betley B., Cariati T, and other McKinsey partners, “Cloud-powered technologies for sustainability”, explore how cloud-based solutions can also sustain and accelerate decarbonization efforts across industries.

If technologies like artificial intelligence (AI), machine learning (ML) and the Internet of Things (IoT) were moved to the cloud, we would have abated current data centers emissions by more than 55% (about 40 megatons of CO₂e, equivalent to the total carbon emissions of Switzerland) (McKinsey, 2022)

AWS is going in this direction, helping millions of final customers to migrate their workloads and facilitate their innovation path. A notable case study refers to 3M Health Information Systems, one of the world’s largest providers of software for the healthcare industry. The company, after having partnered with AWS to modernize its data infrastructure, gained scalability in processing millions of health records daily, accelerated product development cycles, unlocked cost efficiency and enhanced security and compliance (Amazon Web Services, 2018).

Illumina, a leading developer of life science tools, significantly enhanced its sustainability and reduced costs by leveraging Amazon Web Services (AWS). Facing exponential data growth—from 1 PB to 100 PB over eight years—Illumina sought efficient storage solutions. By adopting Amazon S3 Intelligent-Tiering, the company streamlined data management and achieved substantial savings. Key benefits were 89% decrease in carbon emissions (compared to owning on-premises data centers), 60% cost reduction and improved data management and accessibility (Amazon Web Services, 2023).

In addition to cloud adoption, there is a growing emphasis on big data technologies that can handle the complexity and scale of data generated by high-tech companies. These technologies include distributed computing frameworks, such as Hadoop and Apache Spark, which allow for the parallel processing of large datasets. The use of these frameworks enables companies to perform complex data analyses, such as predictive modeling and machine learning, on a scale that was previously unattainable.

Amazon and Amazon Web Services also partnered to create Quicksight, a Business Intelligence (BI) tool in a cloud environment, with machine learning integrations that can be used to deliver easy-to-understand insights of the company. This provides outstanding support in data sharing across the various teams and ultimately, the entire organization. In a single dashboard Quicksight can include AWS data, big data, B2B data, third-party data, and more. As a fully-cloud service the tool also provides enterprise-level security and global availability.

To show a possible application of it, this tool is employed in the Amazon GES (Global Engineering Services) department by the PMO (Program Management Office) and other sustainability teams.

It is leveraged to manage and track vast portfolios of sustainability programs, each containing thousands of different data points from diverse sources, as it offers the possibility to enhance data management and analysis, with the creation of dashboards and detailed insights that ensure a precise tracking of the projects' milestones, risks, changes and possible issues.

This is coupled with the chance of sharing these insights with all the relevant stakeholders, ultimately delivering pivotal projects for a net-zero future, such as solar panels installations, water management, electronic vehicle chargers, HVAC optimization or light control projects.

These data management practices are setting the stage for unlocking full AI potential within organizations. The next chapter explores how AI is currently used in high-tech companies and how its evolution can open the way for sustainable futures.

3.3.2. The Role of Artificial Intelligence – Actual vs Future

AI is currently revolutionizing the way of working inside the high-tech companies, but also the entire world itself. Nowadays, it is employed to optimize and speed up data management and analysis, through precise and automated algorithms that enhance and offer new possibilities, as forecasting market demand in few years or optimize entire supply chains, in new ways and by offering diverse and accurate insights, impossible to obtain through traditional methods.

Additionally, the incorporation of AI-driven tools, techniques and methods is fundamental for analyzing company data and to develop applications and processes which enable the effective utilization of natural resources, thereby enhancing organizations' environmental sustainability. (Ferreira et al., 2023).

A practical example in this case emerges with the introduction of Amazon Q. It is an AI generative assistant which supports and enhances data management and analysis (Amazon Q Business) or for more efficient software development (Amazon Q Developer). It is labelled as “The most capable generative AI-powered assistant for accelerating software development and leveraging companies’ internal data” (Amazon Web Services, 2025). Applications are diverse: automating routine tasks as report generation, or leveraged for data analysis and insights to support decision-making. It's also currently integrated in QuickSight, even if it is still in the early stage of adoption. In the future it will support and enhance project tracking and reporting, also looking at sustainable realms.

Besides Amazon Q, Amazon Web Services is currently at the forefront of the development, deployment and selling of Cloud AI, offering cloud platforms as managed services, machine learning platform where to build, test and run Machine Learning models at scale, providing cost reduction and flexibility, modernizing its customers.

According to the Financial Times (2025), Amazon Web Services (AWS) is planning to invest \$100 billion in artificial intelligence initiatives in 2025 alone. This substantial commitment is driven by several factors, including the rapid acceleration of the AI sector, the need to maintain technological leadership, competitive pressures such as the emergence of potential challengers like DeepSeek, and a clear response to the “significant signals of demand” (Andy Jassy, Amazon CEO, 2025) for AI-driven services and products across industries.

Looking at the future of AI, NVIDIA has been one of the leader company in AI development and innovation and it has recently made significant announcements regarding the vision for the forthcoming of AI.

At the Consumer Electronics Show (CES) 2025, in fact, the NVIDIA CEO Jensen Huang emphasized how 2025 will be a central year for the development of AI.

In particular, he highlighted some main points of innovation and attention:

- Cosmos: a comprehensive platform designed to accelerate the development of AI systems such as autonomous vehicles or robots. It’s a World Foundational Model as it is trained with massive amounts of hours of videos which simulate real world life, from humans’ behavior to animal life and are able to make highly-reliable predictions for possible future scenarios, data generation to then train other LLMs or for robotics’ development. This platform is available in open-license access, allowing knowledge sharing and giving the possibility to build advanced AI systems to everyone, without significant entry cost.

- Computer for autonomous vehicles: the current NVIDIA DRIVE Orin system generation is set to be passed by NVIDIA DRIVE Thor platform. It is designed to serve as a centralized car computer, unifying advanced driver assistance systems (ADAS), in-vehicle infotainment, digital instrument clusters, and automated driving capabilities into a single, cost-effective system. Leading Electric Vehicle (EV) manufacturer are including Thor for their next generation of EVs: BYD, Hyper, XPENG, Li Auto and ZEEKR, accelerating the way for more sustainable futures. (NVIDIA, 2024).

- General Robotics: this sector has been defined as ‘one of the largest technologic market ever’ and a ‘multitrillion-dollar opportunity’ (Huang J., 2025). The innovations’ development focus on 3 main types of robots: Agentic AI; Self-driving cars and Human robots. In particular, Agentic AI necessitates deeper reasoning as it could revolutionize the future work in our society, as well as sustainability matters.

- Agentic AI: these AI agents will be capable of collecting user requests; perform complex reasoning skills to decompose the request in simple and multiple steps; retrieve needed data or employ tools to then generate an high-quality response. They’re not limited to a simple response: they can analyze challenges, develop strategies, execute tasks They will be a sort of ‘experts’ and domain specific: industrial facility management, customer service, content creation, product R&D, cybersecurity. The expectation is to see agentic AI as a digital workforce working together with employees in offices and companies, to enhance overall productivity and accelerate innovations. These agents would need specific train and NVIDIA built a platform called Nemo which serves this purpose and it helps to onboard the agents inside organizations as normal employees. Even if not specifically mentioned in the conference, these agents can be developed and leveraged to address sustainable challenges and concerns, to accelerate green innovations and to force the push towards a sustainable future, especially in high-tech companies, which will be the first ones that are capable and willing to integrate these huge opportunities in their businesses.

The next chapter will provide a high-level overview on the current technologies available for pursuing a net-zero path. Afterwards, the literature review will focus on the specific fields and ways in which AI is currently employed within organization to achieve sustainable goals.

3.3.3. Current Innovative Technologies for Net-Zero

The urgency of reaching net-zero has catalyzed significant technological innovations, always with high-tech companies at the center of this process, by deploying solutions that contribute to a sustainable future. These entail various domains, from renewables to smart grid technologies.

1. Renewable Energy Technologies

All companies are increasingly turning to renewables as energy source and this turned out in huge improvements and costs in the last years, particularly for solar and wind energy, thanks to technological development and economies of scale.

- **Solar Energy Innovations:** The development of advanced photovoltaic (PV) technologies has been pivotal in increasing the efficiency of solar panels. Companies are now exploring multi-junction solar cells, which can capture a broader spectrum of sunlight compared to traditional silicon-based cells, thereby achieving higher conversion efficiencies.

- **Wind Energy:** Modern turbines are now equipped with sensors and AI-driven systems that optimize blade angle and rotation speed in real-time to maximize energy output. Offshore wind farms, which harness stronger and more consistent winds at sea, have become increasingly feasible due to advances in floating turbine technology, allowing for deployment in deeper waters where traditional fixed turbines are not viable.

2. Energy Storage Solutions

Effective energy storage is critical for overcoming the intermittency of renewable energy sources, such as solar and wind, which do not produce power continuously. High-tech companies are leading the way in developing next-generation energy storage solutions that enable the reliable and efficient use of renewable energy.

- **Battery Technology:** Lithium-ion batteries remain the dominant technology for energy storage, but ongoing research is focused on improving their energy density, lifespan, and safety. Solid-state batteries, which replace the liquid electrolyte in conventional lithium-ion batteries with a solid electrolyte, promise to offer higher energy densities and reduced risk of fires, making them particularly attractive for large-scale energy storage and electric vehicles (EVs).

- **Grid-Scale Storage:** In addition to battery innovations, other forms of grid-scale energy storage, such as pumped hydro storage, compressed air energy storage (CAES), and emerging technologies like liquid air energy storage (LAES) and flow batteries, are being developed and deployed. These technologies enable the storage of large amounts of energy for use during periods of high demand or when renewable generation is low, thereby stabilizing the grid and enhancing the reliability of renewable energy.

3. Carbon Capture, Utilization, and Storage (CCUS)

Carbon Capture, Utilization, and Storage (CCUS) technologies are essential for reducing emissions from industries that are difficult to decarbonize, such as cement, steel, and chemicals. High-tech companies are at the forefront of developing and scaling these technologies.

- **Direct Air Capture (DAC):** DAC technology involves capturing CO₂ directly from the atmosphere using chemical processes. The captured CO₂ can then be stored underground or used to produce carbon-neutral fuels or other valuable products. Companies like Climeworks and Carbon Engineering are pioneering DAC technologies, aiming to reduce the overall concentration of CO₂ in the atmosphere and mitigate climate change.

- **Carbon Utilization:** In addition to storage, captured carbon can be utilized in various ways, such as in the production of synthetic fuels, building materials, and even in enhancing oil recovery. Innovators are exploring the potential of converting CO₂ into valuable products like carbon fiber, which can be used in aerospace, automotive, and construction industries, creating a circular carbon economy.

4. Smart Grids and Energy Management Systems

Smart grid technologies are revolutionizing the way electricity is distributed and consumed, enabling more efficient and resilient energy systems. These technologies are critical for integrating renewable energy into the grid and managing the complex demands of modern power systems.

- **Smart Meters and Sensors:** Smart meters and sensors are being deployed to monitor and manage energy consumption in real-time. These devices provide detailed data on energy usage, allowing consumers and grid operators to optimize energy consumption, reduce waste, and respond to fluctuations in energy supply. The integration of AI and machine learning algorithms into these systems enables predictive maintenance, demand forecasting, and dynamic pricing models that encourage energy efficiency.

- **Distributed Energy Resources:** The rise of distributed energy resources, such as rooftop solar panels, small wind turbines, and home battery storage systems, is transforming the traditional centralized power grid into a more decentralized and resilient network. High-tech companies are developing platforms that allow these distributed resources to be aggregated and managed as part of the overall energy system, enabling greater flexibility and resilience in the face of energy demand fluctuations.

5. Sustainable Materials and Circular Economy

The development of sustainable materials and the promotion of a circular economy are key aspects of achieving net-zero emissions. High-tech companies are exploring innovative materials that reduce environmental impact and promote resource efficiency.

- **Circular Economy Models:** High-tech companies are increasingly adopting the 9 or 6Rs circular economy models that focus on reducing waste, reusing materials, and recycling products at the end of their lifecycle. For example, companies in the electronics industry are designing products with modular components that can be easily replaced or upgraded, extending the product's lifespan, and reducing electronic waste. Additionally, innovative recycling technologies are being developed to recover valuable materials from end-of-life products, such as rare earth metals from electronic devices.

6. AI-Driven Optimization for Net-Zero

AI is playing an increasingly central role in optimizing energy usage and reducing carbon emissions across various sectors. AI-driven systems can analyze vast amounts of data to identify inefficiencies, predict energy needs, and optimize resource allocation.

- **Energy Optimization in Buildings:** AI is being used to optimize energy consumption in buildings by controlling heating, ventilation, and air conditioning (HVAC) systems, lighting, and other energy-intensive operations. By learning from occupancy patterns and external factors like weather conditions, AI systems can minimize energy use while maintaining comfort and functionality. This is better highlighted in the literature review with a case study.

- **Supply Chain Optimization:** AI is also being applied to optimize supply chains, reducing carbon emissions by improving logistics, transportation, and inventory management. For example, AI algorithms can optimize delivery routes to minimize fuel consumption, predict demand to reduce overproduction, and identify opportunities to switch to lower-carbon transportation modes.

Technological advancements are accelerating the net-zero transition, but their impact depends on integration, scalability, and supportive ecosystems. High-tech companies must align innovation with systemic change to deliver lasting sustainability outcomes.

This chapter articulated the logical foundation of the upcoming literature review and analysis, by introducing the urgency of reaching net-zero and the need for a global push towards a greener future.

It then examined data management and information systems' role in high-tech environments, highlighting current practices and issues. AWS, Amazon and NVIDIA were cited to showcase current landscape regarding Cloud and AI actual and future potential.

By bringing sustainability and AI concepts together, this chapter sets the base for the next literature review chapter which explores the nexus of these domains, starting with a main research question.

4. Literature Review

This section will deep dive into the existing literature about AI, innovations and sustainability, by considering top-ranked and reliable papers, reports and case studies with the purpose of answering the following research question, which can pave the way for new insights and future discussions: “How can AI-driven data management enhance the development and implementation of net-zero strategies and innovations in high-tech companies?”

High-tech companies are the focus of this analysis, as they are very well-positioned to leverage digital technologies for sustainability, thanks to their infrastructures, capabilities and vision.

This literature review will provide new insights on the topic of digital technologies (Artificial Intelligence in particular) and sustainability, as despite growing awareness, the current use of these technologies for sustainable purposes is still limited and in pilot phases (Schöggl et al., 2023).

Or, digital technologies’ applications are mostly incremental, focusing on efficiency improvements and optimizations rather than radical changes (Rusch et al., 2023).

Authors and literatures will be cited as the analysis progresses, starting with the knowledge base of AI and its applications to both mitigate climate change and enhance data management, while stimulating green innovations and aligning sustainable objectives and high-level strategies.

Also, some major challenges, as AI energy consumption, will be highlighted in the literature review, providing a holistic view on the theme.

Mediating factors about the relationship between AI adoption and sustainable outcomes are identified, together with the current gaps in research.

Ultimately, a framework is developed in the analysis section, together with an overview about Agentic AI opportunity for sustainability.

All with the final objective of effectively tackling research gaps and providing a solid foundation for building further analysis and considerations regarding an AI-driven sustainable future.

4.1. The Potential of Artificial Intelligence

The evolution of AI has transformed industries across the globe, particularly in the realm of sustainability. AI's capacity to process and analyze large datasets, model complex systems, and optimize processes has rendered it a critical technology in the pursuit of net-zero targets.

By leveraging AI, industries can enhance efficiency, reduce resource consumption, and minimize environmental impact.

This section investigates AI's dual role in practical field applications first, and in enhancing sustainability through fostering decision making and unlocking flexibility, providing a comprehensive overview on the potential and actual use of AI to achieve environmental goals.

4.1.1. Applied AI for Climate Action: Sectoral Innovations and Environmental Impact

AI's deployment in field applications has shown promising potential in mitigating climate change by optimizing resource use, reducing emissions, and improving overall environmental performance. These applications span across various sectors, from energy management to transportation. AI is in fact found to positively influence environmental and social sustainability indicators. Manufacturing Multinational Enterprise which implement AI can achieve their goals and at the same time fulfill the SDGs (Ferreira et al., 2023).

In this section four particular areas of application are analyzed: energy management and optimization, transportation and logistics, smart buildings and infrastructure and ecodesign and packaging, drawing on current research and real-world case studies.

4.1.1.1. Energy Management and Optimization

Energy systems are among the most critical areas where AI can make a significant impact on sustainability. The combination of big data and AI is a milestone that helps to increase the reliability of energy systems, their optimization (increased maintenance and asset management), and improved demand management. (Ahmad et al., 2021).

Integrating the blockchain (and IoT) with microgrids opens the way to more decentralized, flexible and resilient energy systems and communities, moving from simple P2P trading to more sustainable and efficient energy ecosystems (Wu et al., 2022).

Carbon Lighthouse, a technology company combating climate change, is collaborating with Amazon Web Services to enhance energy efficiency in commercial buildings. Leveraging AWS Machine Learning and AI capabilities and by deploying advanced sensors the company analyzes buildings and quickly identifies and implements energy-saving measures. This approach has led to significant reductions in energy consumption and CO₂ emissions, with over 260,000 metric tons of emissions reduced to date (Amazon Web Services, 2021).

AI-driven systems are central to managing and optimizing energy consumption, particularly within smart grids and smart buildings. The conventional grid does not have enough capacity to compensate for the diversity of renewable energy sources and power companies are trying to control the stability of power grid to ensure demand meeting. AI techniques and the smart transactive energy framework will improve centralized energy control centers and provide new integration capabilities for microgrids (Ahmad et al., 2021). Smart grids operate with the bi-directional operation and perform real-time load adjustments and monitoring thanks to the combination of different types of energy sources and IoT infrastructure, with AI that catalyzes a large number of datasets (Ahmad et al., 2021).

Moreover, there exist AI-based anomaly detection in building energy consumption which can help prevent waste and improve the overall energy efficiency, contributing at lowering down carbon emissions. Through six different anomaly detection techniques (Unsupervised Learning (U), Supervised Learning (S), Ensemble Learning, Feature Extraction (F) Hybrid Learning (H) and other techniques (O)), AI can be applied to identify abnormal energy consumptions, detecting possible faulty appliances, preventing energy losses and keep monitoring electric consumptions (Himeur et al., 2021).

Main challenges in this field are a lack of clear policies which helps the widespread adoption of decentralized markets, or cybersecurity and data privacy concerns regarding users' habits, real-time energy consumptions and possible profiling issues, where 3rd parties can infer user habits just from data points. (Wu et al., 2022).

4.1.1.2. Transportation and Logistics

AI's role in transforming transportation networks is well-documented in the literature, particularly concerning its potential to reduce greenhouse gas emissions. AI-powered systems can optimize logistics by analyzing traffic patterns, predicting congestion, and optimizing delivery routes, which reduces fuel consumption and emissions.

Furthermore, freight and personal vehicles are equipped with sensors (cameras, GPS...) that analyze the surrounding environment with the potential of avoiding dangerous situations and improving the overall security (Sanders et al., 2019).

Besides that, the advent of autonomous vehicles, driven by AI, is projected to drastically cut emissions in the transportation sector. These vehicles are designed to operate more efficiently than human drivers, reducing unnecessary accelerations and decelerations, which contribute to fuel wastage. "Every major company in the transportation sector is significantly investing in this technology" (Sanders et al., 2019).

A comprehensive overview of AI adoption in this sector is highlighted in the paper "Sustainable Supply Chains in the Age of AI and Digitization", which emphasize the relevant benefits of it, as the cut of labor costs by driving more hours with fewer drivers, improved fuel efficiency and enhanced safety.

Potential drawbacks are highlighted as well, such as jobs which are potentially lost, unacceptance by the public realm and regulatory frameworks which are still to be consolidated as well (Sanders et al., 2019). This could be a matter of study for future research to better understand the pivotal role of AI and the most suitable framework to ensure its deployment and effectiveness in the transportation field.

A remarkable example of AI application in this context comes from the United Parcel Service (UPS), a global package delivery and supply chain management company.

The organization has adopted AI in its operations with the purpose of innovating and optimizing deliveries, enhancing sustainability and focusing on customer satisfaction.

The key application is the ORION (On-Road Integrated Optimization and Navigation) system, which can calculate the best delivery route in real time. This goes beyond the pure optimization, as decisions need to be made considering a constantly changing environment and its variables, such as traffic patterns, weather conditions or package volume.

Carsten Krause, author of the article, says that "his adaptability is what sets ORION apart as an agentic AI rather than a mere workflow or automation". The benefits of the system are huge: 100 million miles saved, reduced fuel consumption, cut of 100.000 metric tons of greenhouse gas emissions, together with an increase in the overall operational efficiency, ultimately improving customer satisfaction.

4.1.1.3. Smart Buildings and Infrastructure

AI's integration into building management systems has the potential to revolutionize energy use in the built environment. Smart buildings, equipped with AI-driven HVAC (Heating, Ventilation, and Air Conditioning) systems, lighting controls, and environmental sensors, can dynamically adjust their energy consumption based on occupancy patterns and external environmental conditions. For example, AI can optimize heating and cooling systems by learning from historical data and predicting future needs, thus reducing energy waste.

BrainBox AI, a Canadian cleantech company, leverages AWS cloud services to transform building energy efficiency by employing Artificial Intelligence. Real-time data about environmental conditions and energy consumptions is collected and further processed using machine learning algorithms hosted on AWS platforms. Through these procedures, ML autonomously optimizes HVAC systems within the buildings.

The main sustainable outcomes are: up to 40% reduction in greenhouse gas emissions, up to 25% savings in HVAC-related costs and improved overall indoor comfort and systems' lifespan through a smart control and management (Amazon Web Services, 2023).

A case study by Zhang et al. (2023) on AI-enabled smart buildings in urban areas reported a 30% reduction in energy consumption through optimized HVAC management. Additionally, AI contributes to the design and management of green infrastructure, such as energy-efficient urban planning and sustainable construction methods, which further reduce the carbon footprint of cities and buildings. The main areas of application in this context are: smart infrastructures to optimize urban mobility, public safety (cybersecurity, surveillance), environmental monitoring (pollution levels, climate patterns), healthcare and education (disease prediction, patient monitoring). (Yigitcanlar et al., 2020).

Siemens' Stadt Square project is one of Europe's largest urban redevelopment sites and a very insightful case study that shows how AI can be applied in different fields to ensure a sustainable future.

With an investment of €4.5 billion to design and develop a carbon-neutral urban district which integrates digital and physical infrastructure, this project is leveraging digital twin technology, sustainable building management, AI insights and e-mobility, to improve neighborhood's conditions.

One of the core elements is the advanced digital twin technology, an AI-driven solution that creates a three-dimensional, digital representation of the urban district. The immediate benefit is a more robust and comprehensive decision-making and a consequent improved sustainable outcome throughout the district life cycle.

Siemens will couple renewable energy sources, intelligent building management systems and effective energy usage.

AI-driven solutions will drive the entire redevelopment of the district:

- Building X Energy Manager is employed to monitor, analyze and optimize energy consumption, cost and carbon footprint of all the buildings and infrastructures, delivering energy savings of a magnitude of 30%.
- Desigo CC enables central monitoring and control of the entire HVAC operations across the district, providing increased efficiency and energy savings, in turns benefitting the environment.

Additionally, the project focuses also on sustainable mobility, with adequate infrastructures for e-mobility, including electric vehicle charging points (Siemens, 2022).

Siemensstadt is going to become a model for sustainable urban transformation in a global landscape, and this case study is a straightforward example of how high-tech companies like Siemens, that exploits the vast number of possibilities given by AI to ensure a sustainable future, can foster innovations that can be scaled globally and in turn be applied to different fields: from urban context, spanning to small and big companies.

4.1.1.4. Ecodesign

AI-driven ecodesign focuses on creating products and systems that minimize environmental impact across their entire lifecycle, from raw material extraction to end-of-life disposal. AI can simulate multiple design iterations, evaluating each one for its environmental performance and selecting the most sustainable option. This approach is particularly valuable in industries such as electronics, where product design has a significant impact on resource use and energy consumption. For instance, AI can optimize the design of electronic devices to reduce material waste during manufacturing, extend product lifespans, facilitate easier recycling and to evaluate sustainable alternatives to harmful, fossil-fuel-derived materials, thus contributing to circular economies (Ethan Mirsky, 2023). Additionally, AI-driven ecodesign can contribute to sustainable packaging solutions by identifying materials that balance performance with environmental impact.

AI is set to accelerate both the discovery and the adoption of eco-friendly packaging materials, by making the research process faster, more efficient and less costly, such as discovering replacement of hazardous materials with biodegradable alternatives (Blog Post PDF Download Eco Plastics in Packaging Article, n.d.).

This has important spillovers as nowadays eco design is a very sensitive argument, "Ecodesign plays a critical role in modern sustainability efforts by ensuring that products and systems are designed to minimize their environmental impact throughout their lifecycle. From the extraction of raw materials to end-of-life disposal, incorporating eco-innovative attributes into product design can greatly enhance consumer adoption, as consumers increasingly prioritize environmental concerns in their purchasing decisions" (Paparoidamis et al., 2019).

A notable case study comes from Digimind, a DeepTech startup that is developing the first AI platform focused on packaging, which helps to design and manufacture safe, sustainable and cost-effective plastic packaging. This solution will also be applicable to other fields as carton, aluminum and even Medium Density Fiberboards (MDF) packaging (Katharina Eissing, 2021). The key features of the cloud-based AI platform are:

- AI-powered design advisor: helps packaging engineers to create sustainable and cost-effective designs, without decreasing safety.
- Light weighting tool: helping customers reduce weight and explore lighter designs. In one case it was achieved a 13.7% of reduction in weight of a 1.5L PET bottle for one of the largest edible oil companies in the world, without compromising performance (Katharina Eissing, 2021).
- Virtual testing environment: allows companies to virtually test designs in a faster way, thanks to the digital twin technology.

Another significant case study comes from NobleAI, a pioneering company that focuses on using Science-Based AI to accelerate the development of sustainable materials and products, particularly in packaging. Their AI-driven solutions help companies discover eco-friendly alternatives to harmful materials, like BPA, by running thousands of virtual experiments. This allows for rapid identification of promising materials that are safer and more environmentally friendly, speeding up the traditionally long and costly material development processes (Ethan Mirsky, NobleAI CSO, 2023).

For example, NobleAI has been crucial in helping industries like packaging and chemicals to replace toxic substances and reduce environmental impact. Their approach optimizes the selection and formulation of biodegradable materials, reducing harmful chemical leaching and enhancing the overall sustainability of packaging. By leveraging AI, companies can not only reduce development time but also introduce more sustainable products to market faster, which is a significant win for eco-friendly innovation (Ethan Mirsky, NobleAI CSO, 2023).

NobleAI's Science-Based AI models are unique in combining scientific laws with data, resulting in more accurate predictions and insights. This leads to material innovation with less data required, cutting down on costs and environmental impact.

As illustrated in this chapter, AI entails many field applications to effectively mitigate climate change, from energy management and transportation, to smart infrastructure and ecodesign. Its capabilities to process large amounts of datasets, generate insights and enable predictive and autonomous decision-making position AI as an innovation milestone for high-tech companies willing to follow sustainable strategies.

Beyond operational improvements, AI shapes strategic, sustainable decision making and enables flexibility to navigate environmental challenges. The next chapter will shift the view to the indirect but still deeply transformative effects of AI on high-tech organizations' structure, helping in bringing them towards greener realms.

4.1.2. From Practice to Strategy: Unlocking AI's Indirect Impacts on Organizational Sustainability

This chapter will focus more on the indirect applications of AI, providing a high-level overview of its effects and challenges while being applied within high-tech organizations.

More in detail, AI and data management's roles will be analyzed considering their impact in the decision-making process and in unlocking flexibility. These two areas in turn will affect the organizations' effectiveness in meeting or not their environmental goals and strategies, or in going beyond.

That's why the starting point of this chapter is a pressing need to thoroughly embed sustainability into the core of high-tech companies, which is then supported and enhanced by AI capabilities and development.

Moreover, the potential of Artificial Intelligence (AI) to transform sustainability strategies in high-tech organizations remains still underexplored, especially within information systems research (Collins et al., 2021).

As sustainability becomes a critical priority, organizations must integrate green decision-making into their business strategies to address rising environmental demands and foster a greener future (Lopes et al., 2024), while satisfying at the same time the new types of arising demands.

The integration of sustainability into core business strategies is no longer optional but a strategic imperative for organizations aiming to thrive in today's competitive and environmentally conscious market.

A McKinsey article "Organizing for sustainable success: Where, and how, leaders can start" highlights the necessity of embedding sustainability into the heart of corporate decision-making and business operations.

This include focusing on specific areas such as decarbonization o green product development, prioritizing governance and processes to ensure flexibility and a quick response to the evolving sustainability challenges. Then, empowering central sustainability teams and aligning sustainability with capital allocation and Research and Development (R&D) funding, to reflect sustainability priorities. (De Smet et al., 2021).

These strategies underscore the importance of adopting a systematic, data-driven approach to sustainability. AI-powered data management emerges as a game changer in this context, enabling organizations to harness actionable insights, streamline decision-making, and achieve transformative impacts across strategic domains. By integrating AI into their operations, high-tech companies can enhance green decision-making processes, foster organizational flexibility, and address sustainability goals with greater precision and efficiency.

This section aims to shed light and add insights on top of current research about how AI-powered data management can drive high-level transformative impacts within high-tech organizations, in particular in advancing sustainable practices across strategic domains.

By enhancing green decision making and fostering flexibility, this chapter, in fact, highlights how AI empowers organizations and unlocks new opportunities to create sustainable value.

4.1.2.1. AI in Sustainable Decision-Making

While some sources argue that AI's primary value lies in empowering individuals to reduce resource intensities—such as energy, water, and land use—the broader potential of AI may lie in its capacity to foster efficient environmental governance and play a transformative role in decision making processes within the high-tech companies (Nishant et al., 2020).

For instance, AI has the ability to support comprehensive environmental oversight by reducing information asymmetry and enabling data-driven decisions that are free from cognitive biases, thus offering a strategic solution to environmental sustainability challenges (Nishant et al., 2020). This capacity is particularly valuable in volatile environments, where uncertainty and resource constraints often constrain the implementation of green practices and the overall decision-making process.

By bridging these gaps, AI provides high-tech companies with tools to optimize resource management and streamline circular economy practices, thereby enhancing business performance even under conditions of environmental uncertainty (Riggs et al., 2024).

Advanced tools such as IoT, AI, and blockchain are indeed pivotal enablers of innovation and sustainability, transforming traditional operations into interconnected, adaptive systems.

For instance, (Jiang et al., 2024) highlights how these technologies enhance decision-making, optimize resource use, and significantly reduce carbon emissions, aligning supply chains with decarbonization targets. Strategically deploying digital tools ensures that sustainability objectives are embedded within core business strategies, fostering operational efficiency while supporting long-term environmental goals.

Moreover, the integration of AI and data management allows for advanced, systematic approaches that dynamically respond to environmental demands. This adaptability enables organizations to meet sustainability goals at both strategic and operational levels (Song et al., 2019), further enhancing strategic planning matters.

For example, AI-driven systems can predict resource needs, automate complex processes, and ensure that sustainability strategies remain effective despite external uncertainties.

The convergence of AI and Corporate Social Responsibility (CSR) initiatives further illustrates its potential in fostering green innovations and strengthening the link between decision making and sustainability in uncertain scenarios.

Firms in volatile environments, in fact, struggle to utilize green practices effectively due to limited resources and unpredictable conditions. AI mitigates these challenges by improving the scalability and reliability of green strategies, ensuring that firms can navigate volatility while meeting their environmental objectives (Aftab et al., 2024).

Additionally, large-scale data applications enabled by AI facilitate green innovation by supporting the development of eco-friendly technologies and enabling more efficient environmental governance. AI's ability to process complex data structures allows companies to better understand and address environmental impacts across both production and consumption levels. (Song et al., 2019).

This capability enhances decision-making by providing high-level visibility to leaders, empowering them to make informed, reliable, and sustainability-oriented choices.

The effective integration and development of AI and data management within organizations translates into more efficient environmental governance, equipping leaders with the tools to align their decisions with long-term sustainability goals. By addressing complex challenges through real-time insights and predictive analytics, AI ensures that organizations remain adaptive and proactive in their pursuit of sustainability.

As high-tech firms face increasingly competitive and disrupted landscapes, the need for flexibility becomes paramount.

The next subchapter, '4.1.2.2. Unleashing Flexibility through AI', delves deeper into how AI-driven data management enhances organizational agility and responsiveness, enabling firms to adapt to rapid technological changes while maintaining their competitive edge and sustainability goals.

4.1.2.2. Unleashing Flexibility through Artificial Intelligence

Flexibility is increasingly recognized as a critical capability for building and maintaining a competitive advantage, especially in the high-tech sector, which constantly faces rapid technological shifts.

This section explores the relationship between organizational flexibility, AI-driven data management, and sustainability, drawing on insights from existing research.

The integration of AI into Information Systems (IS) and organizational processes plays a significant role in fostering both operational and customer agility—essential capabilities for high-tech firms operating in chaotic environments. Research indicates that embedding AI into an organization's processes directly enhances firm performance by improving adaptability and responsiveness to change (Fosso Wamba, 2022).

Other research confirm that AI accelerates sustainability innovation by fostering a balance between "exploration" (developing new capabilities) and "exploitation" (enhancing current capabilities), a concept known as sustainability ambidexterity. This balance is critical for companies seeking to achieve sustainable growth while remaining adaptable to market demands (Lu et al., 2023).

In this context, AI adoption is seen as a dynamic capability enabling firms to manage environmental turbulence effectively, ensuring effective sustainable strategies (Chatterjee et al., 2023).

This adaptability not only helps organizations maintain a competitive edge but also drives sustainability by enabling swift adjustments to evolving environmental and market demands. Moreover, this agility is critical for seizing green, customer-driven innovation opportunities.

Organizational flexibility also serves as a moderating factor in the relationship between AI and sustainability performance. Companies with higher levels of flexibility are better equipped to integrate AI technologies, optimize processes, and enhance sustainability outcomes. This capacity allows businesses to adapt effectively to technological changes, enhance supply chain performance and align their strategies with long-term environmental goals (Khan et al., 2024).

For instance, a study analyzing 219 automotive manufacturing companies in South Africa demonstrated that the successful adoption of Big Data Analytics (BDA)-AI and circular economy capabilities depends heavily on organizational flexibility. The study concluded that "the higher (or lower) the level of organizational flexibility, the higher (or lower) the enabling effect of BDA-AI on Circular Economy (CE) capabilities" (Bag, Pretorius, et al., 2021). This finding underscores the central importance of being adaptable in ensuring the successful implementation of AI and in achieving sustainable outcomes.

At the same time, AI and advanced data management systems not only enhance sustainability but also unlock new dimensions of organizational flexibility. This dualistic and interdependent relationship highlights AI's pivotal role in facilitating real-time adjustments to strategic and operational decisions, contributing to long-term environmental and business success.

Additionally, specific AI applications, such as chatbots, exemplify how technology enhances agility by dynamically and effectively managing customer interactions. By enabling firms to pivot in response to changing customer demands, these tools are vital for ensuring long-term competitiveness (X. Wang et al., 2022). This ability reinforces the alignment of organizational capabilities with sustainability goals and supports the broader objective of building a competitive and sustainable future (Fosso Wamba, 2022).

In conclusion, organizational flexibility serves as both a prerequisite for and a beneficiary of AI-driven data management. By integrating AI into their processes, high-tech companies can enhance agility, optimize resource use, and drive sustainability, ensuring their relevance and success in an increasingly dynamic and environmentally conscious market.

Despite the promising benefits of AI in supporting sustainable decision-making and enhancing organizational flexibility, its widespread and effective implementation is not without significant challenges. As high-tech companies increasingly integrate AI into their operations to meet sustainability goals, they must also navigate a complex scenario of various constraints.

The following chapter will explore these limitations, providing insights on possible blockers while analyzing AI adoption to unlock sustainable transformations.

4.1.3. Barriers to Sustainable AI Integration

While artificial intelligence and data management hold immense potential for advancing sustainability in high-tech organizations, their adoption is not without significant challenges.

This chapter underscores some of the major barriers preventing AI to be effectively implemented, leveraged or integrated in a sustainable way within high-tech companies, ultimately losing the opportunity to build a net-zero future.

4.1.3.1. Energy-Intensive Nature of AI

AI applications, especially the ones involving large-scale data processing and machine learning methods require huge amounts of energy, which in turn translates into carbon emissions.

As Natalie Bennet, an Australian politician and journalist, points out in a very recent article on 'The Guardian', that Ireland is already seeing a third of its electricity going into datacenters and she asks herself how much AI this planet can afford. (Bennet Natalie, 2025).

"Training a single AI model can emit as much carbon as five cars in their lifetimes" (Hao Karen, 2019), which translates into 626,000 pounds of CO₂ equivalent. This outstanding number is the result of a research by the University of Massachusetts, Amherst, which performed a life cycle assessment for training several AI large models.

As AI models become more capable and complex, these carbon emissions' amounts are expected to grow drastically, assuming energy sources remain the same (Nishant et al., 2020).

Moreover, companies like Microsoft, Google, NVIDIA are integrating AI into many applications, thus contributing to increasing energy demands (Alzoubi & Mishra, 2024).

Another research confirms this scenario and highlights an additional adverse effect to be considered while discussing about AI: the data centers and servers' energy consumptions.

To operate these types of buildings and to store relative data, the number and complexity of these machines will constantly increase, meaning that massive amounts of energy will be implied to run and cool them, ultimately leading to significant greenhouse gas emissions (Q. Wang et al., 2024), (Zechiel et al., 2024).

The same issue remains also for other AI applications such as blockchains, as certain networks can have huge energy consumptions (Schmidt et al., 2024).

In this context, new frameworks are being developed to provide a holistic life cycle assessment of data centers' sustainability (Nishant et al., 2020). This will provide better understanding and additional insights about AI's environmental impact, paving the way to start researching different and advanced solutions to mitigate this downside.

Also, main high-tech companies are making their first steps to contrast and mitigate this rebound effect: Amazon is including initiatives such as the usage of renewable energy, the improvement of cooling systems and the utilization of recycled steel with lower embodied energy in its data centers, aiming at lowering down their overall environmental impact. Meta follows this strategy by offering a Carbon Explorer tool which models data center design, to ultimately minimize CO2 emissions. Additionally, Microsoft's 'AI for Earth' program includes AI tools to monitor water, waste and carbon emissions in buildings, further contributing to address this environmental issue (Zechiel et al., 2024).

Additionally, green AI initiatives are arising in order to limit AI environmental burden or to facilitate green objective achievement: model efficiency, which optimizes AI models to use fewer compute resources and energy requirements, carbon footprint tools to track and reduce AI environmental impact or green AI communities and research to advance and develop a more sustainable technology.

A very recent example of model optimization came with the R1 model from DeepSeek, a Chinese AI startup founded in 2023. In January 2025, the model was released and reported to be trained with an estimated cost of \$5.6 million, leveraging nearly 2000 NVIDIA chips (Thomas Barrabi, 2025), (Grace Eliza Goodwin, 2025).

Compared to over \$100 million spent for training OpenAI's latest models as GPT-4, this implies much lower computational resources which in turn results to lower energy demands and an overall fewer carbon footprint.

Anyway, many of these tools and researches must be furtherly advanced as now they're in early development or they lack empirical validation (Alzoubi & Mishra, 2024).

4.1.3.2. Infrastructure and Technological Disparities and Costs

AI effective implementation and development in sustainable matters is hindered by uneven and lacking infrastructures and technological disparities, as well as implementation costs.

This section explores these barriers and their implications for a sustainable AI adoption across companies.

Smart infrastructures (i.e: IoT enabled grids, smart buildings...) are essential to effectively unlock AI potential and ultimately amplify sustainable outcomes. Research shows that China's investments in smart infrastructure helped in lowering down carbon intensity on the city level. However, their impact is complex and dependent on factors like innovation and infrastructure density (Tao, 2024).

In the context of manufacturing companies, to support circular Supply Chain Management through Circular Economy efficient information systems and a minimum technical infrastructure is needed. Often, the absence of well-organized information systems and effective technology utilization hinders Supply Chain organizations from efficiently managing their Circular Economy operations (Nayal et al., 2022).

These dynamics suggest that strategic investments in technology infrastructure can significantly amplify sustainability outcomes.

Moreover, the lack of infrastructure may widen the gap between developed and developing regions instead of narrowing it. There is a need to ensure infrastructure and equal internet access to achieve the holistic goal of reducing inequalities and finally aligning with the need to provide digital education to the final users (Mondejar et al., 2021).

The integration of these technologies along the supply chain is often very costly due to: hardware costs (sensors, smart objects, RFID technologies, installation and maintenance); software costs for system's development; maintenance and others like training (Venkatesh et al., 2020). This can hinder the widespread implementation of AI applications, especially for small and medium enterprises, which often possess limited financial resources (Schmidt et al., 2024). This document is indeed focused on high-tech industry, but for future analysis the AI adoption within Small and Medium-sized Enterprises (SMEs) can be deep-dived to further highlight and unveil sustainable opportunities.

The same concern about costs is reflected in another research while discussing the integration of blockchain into energy communities for sustainable purposes. One of the key challenges is the economic viability of the integration, as high initial costs of blockchain may hamper its widespread adoption (Wu et al., 2022), especially for most vulnerable and poorer communities, limiting equitable energy access and efficiency, thus limiting environmental benefits.

Another study “Exploring Enablers and Inhibitors of AI-Enabled Drones for Manufacturing Process Audits: A Mixed-Method Approach”, investigates, among others, factors that drive and hinder AI-enabled drones’ adoption within organizations. The research methodology is both qualitative and quantitative, involving interviews with 25 industry experts on one hand and survey data coming from 302 different managers in Indian manufacturing firms on the other. While environmental value is one of the key enablers, sunk cost barrier is seen as one of the key barriers, where firms hesitate to invest in drones due to previous investments in traditional systems (Shankar et al., 2024).

Moreover, relevant stakeholders are struggling just in understanding costs related to Artificial Intelligence: they may lack the specific expertise, AI models often have a complex cost structure based on its usage or compute time, workloads are very often non-linear and businesses may not pursue the right strategy while approaching a huge digital transformation through AI (Mary Mesaglio, 2025).

4.1.3.3. Ethical Concerns

Ethical concerns regarding data privacy and transparency can significantly influence the trust and the equitable implementation of AI solutions. Debates are associated to safety risks and network integrity of these services.

While implementing AI-enabled drones, the vulnerability barrier is one of the key challenges, highlighting possible concerns about data privacy and privacy risks (Shankar et al., 2024).

These threats must be considered but not seen as a barrier which avoids these technologies’ applicability to face sustainable challenges (Mondejar et al., 2021).

Information and data stored in AI applications such as blockchain is usually permanent and immutable, thus contributing to enhance awareness on this aspect. A balance between transparency and data privacy necessitates the development of suitable technical and regulatory solutions (Schmidt et al., 2024).

Privacy concerns also come from Artificial Intelligence when applied to Smart Cities’ field. AI-driven surveillance and data collection may raise ethical questions and risks (Yigitcanlar et al., 2020).

These concerns are also reflected in a recent ESG Research by Morgan Stanley Capital International, “Sustainability & Climate – Trends to Watch 2024” where data privacy is seen as a potential issue that require regulators to “catch up to the tech” on one hand, and companies that needs to catch up to the regs” on the other (MSCI ESG Research LLC, 2023). In particular, the focus is in regards of Generative AI models and their application. In fact, their development relies on training on massive datasets, which may harvest behavior data without clear consent. This data is then furtherly used to train other models as well. Moreover, image-rendering apps can also collect users’ biometric data.

These challenges must indeed be acknowledged and thoroughly addressed to ensure an effective implementation and leverage of AI potential for a greener future.

The current limits, in fact, should not discourage stakeholders in discovering new ways to integrate AI inside the organizations.

Moreover, the next chapter will shift the focus of this document to the key mediating factors while analyzing the Artificial Intelligence role inside the high-tech organizations and how these factors can facilitate or hinder its integration, unlocking or limiting its potential. In particular, together with a data driven culture and leaders, people and skills, also some policy measures are seen as mediating factors, as they are developed in order to mitigate and control the massive AI development and potential downsides, as the above cited privacy issues.

4.2. Key Mediating Factors in AI-Driven Sustainability

The success of AI-driven innovations in achieving sustainability goals is not solely dependent on the technology itself.

Several mediating factors influence how AI is adopted, implemented, and scaled within organizations, shaping the overall success of AI-powered net-zero strategies. By fostering a conducive organizational environment, these factors enable organizations to align their technological advancements with sustainability objectives effectively.

4.2.1. Building a Data-Driven Culture

In today’s rapidly evolving business landscape, cultivating a robust data-driven culture is essential for organizations striving to enhance performance and achieve sustainable development. Such a culture emphasizes the systematic collection, analysis, and application of data across all business operations, ensuring informed decision-making and effective resource utilization.

A McKinsey article, “Why Data Culture Matters,” underscores the pivotal role of organizational culture in leveraging data analytics effectively. The article identifies key principles for fostering a robust data culture, emphasizing that “a healthy data culture is becoming increasingly important” in addressing modern business challenges (Díaz et al., n.d.).

Companies with a structured digitalization strategy tend to adopt digital technologies more extensively and effectively. This has important spillovers, as there exist a strong correlation between an organization’s digital technologies adoption and its use for sustainable purposes (Schöggel et al., 2023).

This insight highlights the foundational role of data culture in bridging AI capabilities with organizational goals.

Studies further illustrate that a data-driven culture moderates the relationship between AI capabilities and firm performance, enabling organizations to track resource use, improve efficiency, and drive eco-friendly innovations (Song et al., 2019).

By leveraging AI capabilities, organizations can directly enhance firm performance, aligning their strategies with the Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production) (Fosso Wamba et al., 2024).

The importance of cultivating internal data capabilities cannot be overstated. These capabilities provide a competitive advantage and accelerate progress toward sustainability by enabling organizations to harness the full potential of AI. Managers play a critical role in shaping this culture, as their focus on developing AI capabilities influences the overall performance of the organization.

This perspective aligns closely with the broader scope of this thesis, emphasizing the strategic role of managerial decision-making in fostering sustainability. High-tech companies must invest in internal technological and data capabilities not only to enhance their competitive edge but also to ensure a sustainable pathway for future growth. This dual focus on performance and sustainability underscores the centrality of a data-driven culture in addressing environmental challenges effectively.

The next subchapter will delve deeper into the role of leadership in achieving net-zero strategies, further examining how leadership moderates the relationship between AI and the development of consistent, sustainable pathways for high-tech organizations.

4.2.2. Leadership, Digital Capabilities and People for Sustainability

Leadership serves as a pivotal mediating factor in aligning AI adoption with sustainable outcomes in high-tech organizations. Leaders' decisions and capabilities are essential in shaping organizational strategies that prioritize green innovation and embed sustainability as a core business objective.

One critical way leaders drive sustainability is by fostering green creativity, defined as “the formation and development of environmentally sustainable and innovative ideas” (Ogbeibu et al., 2021).

By empowering teams and creating an environment that supports creative problem-solving, leaders ensure employees remain motivated and focused on delivering impactful results. (Chen et al., 2023). On one hand, this ability to inspire and engage teams enables organizations to effectively address sustainability challenges. On the other, a culture emphasizing flexibility, trust and collaboration is proved to better leverage AI technologies for operational gains. (Cadden et al., 2022).

As (Fosso Wamba et al., 2024) note, managers must also carefully integrate AI capabilities to ensure that data-driven practices align with both organizational goals and sustainability objectives.

Several studies emphasize a broader range of capabilities essential for sustainability, beyond AI integration.

Successful leaders, in fact, strengthen the relationship between Corporate Social Responsibility (CSR) and green innovation by investing in Green Dynamic Capabilities (GDCs). These capabilities focus on “integrating, producing, and regenerating internal and external resources related to environmental preservation” (Aftab et al., 2024).

The main GDCs, such as sensing, seizing and reconfiguring, further support high-tech organizations to respond to complex demands and challenges, by promoting flexibility and environmental agility (Mousavi et al., 2019).

By investing in GDCs, leaders not only help firms adapt to market changes but also promote eco-friendly innovations that deliver both long-term financial and environmental benefits. This dual focus on performance and sustainability underscores the transformative role of leadership in driving meaningful change.

Another research deep dives into the dynamic capabilities for sustainability, pointing out two main key dimensions to define them: the novelty degree of Sustainability-Oriented Innovations (SOI) (if the innovation is incremental or radical) and level of stakeholders' integration (high or low involvement of external stakeholders in decision-making and innovation processes). The outcome reveals 4 different types of capabilities as:

- Firm-Level Eco-Efficiency (Incremental Innovation, Low Stakeholder integration),
- Firm-Level Transformation (Radical Innovation, Low Stakeholder Integration),
- Supply Chain/Network-Level Eco-Efficiency (Incremental Innovation, High Stakeholder Integration),
- Systemic Transformation (Radical Innovation, High Stakeholder Integration).

More in detail, firm level eco-efficiency focuses just on internal and incremental innovations, as energy efficiency and waste reduction, minimizing external collaboration. Firm-level transformation introduces radical changes such as green products or whole sustainable business models but it still remains internally driven. Supply chain eco-efficiency entails incremental advancements across the network, leveraging supplier collaboration, thus enhancing overall resilience and sustainability. Systemic transformation is the most advanced model, providing radical innovations across many stakeholders, ultimately driving significant shifts across industries (Ortiz-Avram et al., 2024).

In addition to fostering green creativity and GDCs, leaders leverage advanced technologies such as Smart Technologies, Artificial Intelligence, Robotics, and Algorithms (STARA). These tools enhance organizational capabilities by reducing project complexity, improving operational efficiency, and fostering productivity (Ogbeibu et al., 2021).

The strategic deployment of STARA technologies unlocks green innovation and ensures organizational efforts are aligned with long-term sustainability goals.

Moreover, these technologies shape and influence the dynamics between AI and human resources within organizations.

A recent study involving 461 managers found that organizations with strong STARA capabilities experienced significant improvements in sustainability performance and green human resource practices.

However, deploying these capabilities strategically is essential to avoid potential pitfalls such as employee resistance or overburdening (Ogbeibu et al., 2024).

AI technologies can also enhance employee learning behaviors when integrated thoughtfully. This approach avoids over-reliance on technology and ensures employees remain motivated, ultimately delivering sustainable outcomes (Chen et al., 2023).

However, further research is needed to explore the long-term effects of AI collaboration on employee well-being and innovative capacities.

The nexus between Green Talent Management (GTM) practices, Transformational Leadership (TL), and AI highlights their combined impact on employees' Innovative Work Behavior (IWB). Transformational leadership, when paired with AI, has direct positive effects on fostering creativity and reducing inefficiencies (Odugbesan et al., 2023). Integrating AI thoughtfully with GTM practices can complement human creativity, ensuring that employees remain key contributors to innovation and sustainability.

Digital capabilities also play a vital role in moderating the relationship between AI and sustainability.

Research by (Lu et al., 2023) underscores the importance of digital technologies in enabling organizations to adapt rapidly to change and meet sustainability goals. Recommendations to leadership include prioritizing investments in digital capabilities, fostering cross-functional collaboration to enhance innovation, and developing systems that support both short- and long-term sustainability objectives.

Research also highlights the central role of Information Systems Capabilities (ISC) in the enhancement of business performance in uncertain environments.

A study of Spanish industries revealed that aligning ISCs with circular economy practices improves both sustainability and organizational outcomes, even in unstable conditions (Riggs et al., 2024). Digital skills play a crucial role in this context, ensuring that organizational goals and sustainable practices are effectively integrated.

Considering capabilities' impact inside the organizations, firms should prioritize workforce digital literacy and invest in AI integration alongside complementary organizational capabilities to maximize value (Fosso Wamba, 2022).

Within the realm of digital capabilities, a study involving 594 manufacturing firms, deep-dive into the relationship between Big Data Analytics (BDA) ones and net-zero economy-oriented practices for sustainable innovation. In particular, Big Data Management Capabilities (BMC) and Big Data Talent Capabilities (BTC) help firms process meaningful environmental data and drive sustainable innovations.

BMC refers to organization's ability to manage and utilize big data resources (data storage, integration capabilities to support decision making). BTC represents the human skills to handle big data analytics (how to analyze and interpret big data-driven insights). Together they form the general BDA capabilities which contribute to the implementation of green innovations and alignment to a net-zero economy (Mehmood et al., 2024).

Leadership remains central in this process, acting as the bridge between advanced technologies, organizational capabilities, and sustainability goals.

By fostering a culture of green creativity, investing in Green Dynamic Capabilities, and leveraging technologies like AI and STARA, leaders empower their teams to address complex environmental challenges.

On the other hand, people and their capabilities inside companies are vital to ensure the execution of leaderships' vision. Thus, high-tech organizations must view leadership, capabilities, and people as interdependent factors, each essential to achieving sustainable success.

This approach ensures that sustainability becomes an integral part of the organization's strategy, balancing human innovation and technological progress.

The following sub-chapter will deep-dive into the last mediating factor pointed out in this document. Policies can indeed influence AI adoption and the related sustainable spillovers and it's noticeable that early regulatory frameworks are already being developed.

4.2.3. Policies and the EU AI Act

Effective regulations mechanisms are a central milestone to ensure the alignment of core strategies and technological innovation with sustainable objectives and to mitigate and address some of the challenges related to AI integration within organizations.

Stricter environmental regulations improve global value chain by forcing enterprises to adopt green technologies, improve production efficiencies and innovate processes (Gao, 2023).

They assure that new advancements also serve societal goals, in particular the United Nations Sustainable Development Goals (SDGs) (Truby, 2020).

Without proper governance, the risk of inequities, environmental degradation and technological misuse could overshadow their potential benefits (Del Río Castro et al., 2021).

Unchecked AI development, in fact, poses risks to achieving SDGs such as algorithmic bias, lack of transparency, unethical governance, which in turn threaten equitable progress (Truby, 2020).

To overcome these challenges, governments must align digitalization policies with sustainability goals. Integrating AI and Big Data into SDG tracking systems can enhance monitoring and impact assessment, providing actionable insights to policymakers and stakeholders (Tseng et al., 2022).

Regulatory frameworks must also incorporate international principles, emphasizing accountability to ensure AI effectively benefits sustainable development (Tseng et al., 2022). The EU AI Act is an effective example of the first legal and forward-looking framework 'which addresses the risks of AI and positions Europe to play a leading role globally' (European Commission, 2024). Its main aim is to ensure that AI technologies are trustworthy, respect basic rights and adhere to ethical standards and principles. The risk-based approach of the act categorizes AI systems into 4 levels of risk:

- Unacceptable Risk: systems that threaten safety, livelihoods and rights of people are banned. An example is the social scoring by the governments.
- High Risk: it includes AI technologies employed in: critical infrastructures (e.g., transports), educational or vocational training (e.g., exam scoring), safety components of products (e.g., robot-assisted surgery), employment processes (e.g., CV-sorting software), essential services (e.g., credit scoring), law enforcement, migration and border control, and administration of justice. These systems are subject to strict obligations, including risk assessments, data governance measures, and human oversight.
- Limited Risk: it refers to risks associated to lack of transparency while using AI systems (e.g., chatbots). Users must be informed that they're interacting with a machine and not with a human operator.
- Minimal Risk: the act allows the free use of AI systems with minimal or no risks (e.g., AI-enabled video games). Most AI systems fall under this category.

As Artificial Intelligence is rapidly evolving, this regulation will allow rules to change and adapt to the future technological advancements that will be developed. This ensures that AI systems will remain safe and trustworthy also after their entry in the market.

The European AI Office was established in February 2024, with the purpose of overseeing the act's regulations and enforcement (European Commission, 2024). This AI act aims to foster innovations and collaborations, while ensuring that AI technologies respect fundamental human rights and dignity. It also serves as a base to position Europe as a leader in the sustainable and ethical development of AI systems, stimulating other countries to do the same and align the efforts globally.

Previously, AI field applications chapter showed the transformative role of AI when applied to physical and specific solutions. Industrial intelligence, characterized by this integration of AI and automation in production processes, has shown huge opportunities in climate change mitigation and in reducing carbon intensity.

This impact of AI and industrial intelligence, however, varies a lot across countries and regions, due to disparities in technological readiness and proper infrastructures. Policies promoting and supporting industrial intelligence can serve as catalysts for local and regional green transitions (Meng et al., 2022). China's regional disparities in industrial AI adoption are just an example of the pressing need for flexible and adaptive regulations (Meng et al., 2022).

Industrial intelligence facilitates and strengthens the transition to industry 4.0, crucial for fostering sustainable production and circular economy principles. This transition faces challenges, including operational risks, lack of resources. Regulatory incentives, as subsidies for green logistics and circular design practices, can drive and support the adoption of Industry 4.0 (Bag, Yadav, et al., 2021).

Moreover, to further augment environmental benefits in this scenario, policymakers must prioritize regulations that align industrial development with renewable energy adoption to ensure balanced and sustainable growth (Rasheed et al., 2024).

This need comes also from the energy-intensive nature of AI systems, as discussed earlier in the 'Challenges' subchapter. Policies should encourage the development of energy-efficient AI technologies and promote the adoption of renewable energy in powering data centers and servers (Rasheed et al., 2024).

Institutional pressures, such as government mandates and customer demands, further influence the adoption of AI and sustainable practices. These pressures should be formalized within regulatory frameworks to ensure consistency and effectiveness (Bag, Pretorius, et al., 2021).

Policymakers should also consider the timeframe in their analysis, as at the early stages in science and technology parks, companies are more responsive to institutional pressures. Anyway, over time, they also tend to shift their focus towards economic rationality, thus privileging cost efficiency over environmental engagement. Incentivizing long-term environmental commitments is central to ensure sustainability remains a core priority while firms mature (Moyano-Fuentes et al., 2018).

Risk of inefficiencies, frauds and poor subsidy allocation can limit policies' effectiveness. In response to severe air pollution and the urgent need to reduce carbon emissions, the Chinese government has made substantial investments in the New Energy Vehicle (NEV) sector.

While subsidies have played a key role in accelerating research and innovation in NEV technologies, the absence of robust decision-making mechanisms—alongside instances of fraud—has limited the overall impact of these initiatives. To address this, the government implemented a three-way decision model aimed at enhancing the precision and transparency of NEV subsidy distribution, ultimately supporting the achievement of broader environmental goals (Zuo et al., 2019).

In conclusion, several mediating factors moderate and influence the relationship between AI adoption and sustainable outcomes. A robust data-driven culture ensures companies can effectively employ AI for decision making and strategic alignment with sustainable objectives. Leadership is at the forefront of innovation development, fostering green creativity and building right organizational capabilities.

In particular, focus and investments in digital competencies and literacy, green dynamic capabilities and in general human talent are essential for ensuring a stable and long-term impact of AI within the organizations. Finally, regulation and its frameworks provide structure, incentives and oversight which unlocks the alignment between technological advancement and sustainable development.

Also, AI-powered data management can enable firms to harness both operational efficiencies and innovative capacities, allowing them to respond to sustainability challenges and regulatory pressures effectively (Felipe et al., 2020b).

Both internal and external enablers can create the conditions for AI to become a holistic and transformative force in shaping net-zero within high-tech companies.

4.3. Toward an Integrated Understanding of AI for Sustainability: Key Research Gaps

Despite the growing body of literature on AI and sustainability, several gaps remain that require further investigation. Addressing these gaps will be critical for advancing the field and ensuring that Artificial Intelligence can fully realize its potential as a driver of net-zero strategies.

In the chapters '5.Methodology' and '6.Results', several analyses will fill in the below gaps, contributing in adding value to the existing research base.

In particular, from the literature review 3 relevant research gaps emerge:

1. Existing studies and research tend to focus more on AI isolated applications to specific sectors or solutions, rather than presenting a holistic and unified approach for organizations to effectively implement AI for sustainability at scale. To overcome this gap, a comprehensive framework effectively highlights and integrates key insights and challenges about AI (Physical impacts, Organizational flexibility, Leadership and Regulatory enablers), in terms of pro, cons and mediating factors which enable or hinder AI's sustainability potential.

This approach leaves space for further advancements, one of which is agentic AI, that is set to play a transformative role in this context. Research should deep dive on it, by considering its application in sustainable aspects, discover new way to employ this opportunity within high-tech companies and better understand the needs and the possible adverse effects of this solution. Highlighting challenges across industries, countries, case studies will contribute to understand this brand-new advancement, thus contributing in unlocking AI sustainable potential and provide more understanding on this topic. How can AI systems' capabilities proactively enhance sustainability in a structured and safe manner?

2. Additionally, literature just scratched the surface of concepts as the integration of AI and Information Systems for unlocking flexibility, but there exists a need to further address key concepts like the integration of these information systems within companies from a sustainable point of view, along with related challenges.

Moreover, literature shades a light on AI's role for specific logistics' optimization or emissions' reduction, but still very few studies deep-dive on how AI can augment the overall supply chain transparency and data sharing across relevant stakeholders, especially for sustainability-focused operations. This topic is particularly debated as governments are tightening regulations to enforce ethical and environmental standards in supply chains (MSCI ESG Research LLC, 2023). High-tech organizations must be ready to embrace changes and stick to new regulations.

This document analyzes several data about Green Information Systems' implementation within High-Tech companies as a starting point, and sets the bar also to understand if AI can unlock deeper value in this context and how. Can AI be a revolutionary opportunity in this landscape?

3. Growing interest surrounds the expansion of AI and its wide-ranging opportunities. However, its potential for advancing sustainability is often overlooked. Despite the relevance of this intersection, there is still limited empirical research capturing how AI innovations for green purposes are evolving across sectors, regions, and over time.

The patent-based analysis fills these gaps by mapping the real-world trajectory of AI for sustainability applications, analyzing sectors of application, geographic distribution and innovation trends. Secondly, it helps in understanding if AI development is shifting to more radical innovations, ready to revolutionize green strategies and final outcomes. Lastly, the analysis builds on the discovered needs and current challenges of high-tech companies from primary data analysis, to understand if developments are going towards that direction.

Before deep-diving into the analysis section, the next section presents the methodology together with data sources followed per each part of analysis: literature review, primary data from High-tech companies and patents.

5. Methodology

This section of the document will describe the sources of data and the type of analysis done by the author. The deep dive comprehends three main sections:

1. Literature Review: regarding how AI enhances innovations and sustainability within high-tech companies.
2. Primary data from High-tech Companies review: based on answers given through questionnaires and direct interviews with directors on green information systems' adoption inside organizations.
3. Patents: holistic analysis of 110 patents to get an understanding about the actual landscape on AI sustainable innovations.

This study combines diverse types of data: primary-type for the companies' interviews and questionnaires (from December 2023 to March 2024), secondary-type for the literature review and the patents' analysis. All sources will be detailed in the next sections and in the '8.References' chapter as well.

5.1. Literature Review

For this document, an initial list of 200 options has been cut down to the final cluster of 84 final sources.

Figure 1 clearly points out the different sources' types:

- 58 of them are journals: 1 Gold Star ranked, 48 Gold ranked, 6 Silver, 3 Others.
- 26 of them comprehend websites: 8 articles (i.e: McKinsey), 10 portals (i.e: European Commission), 6 case studies.

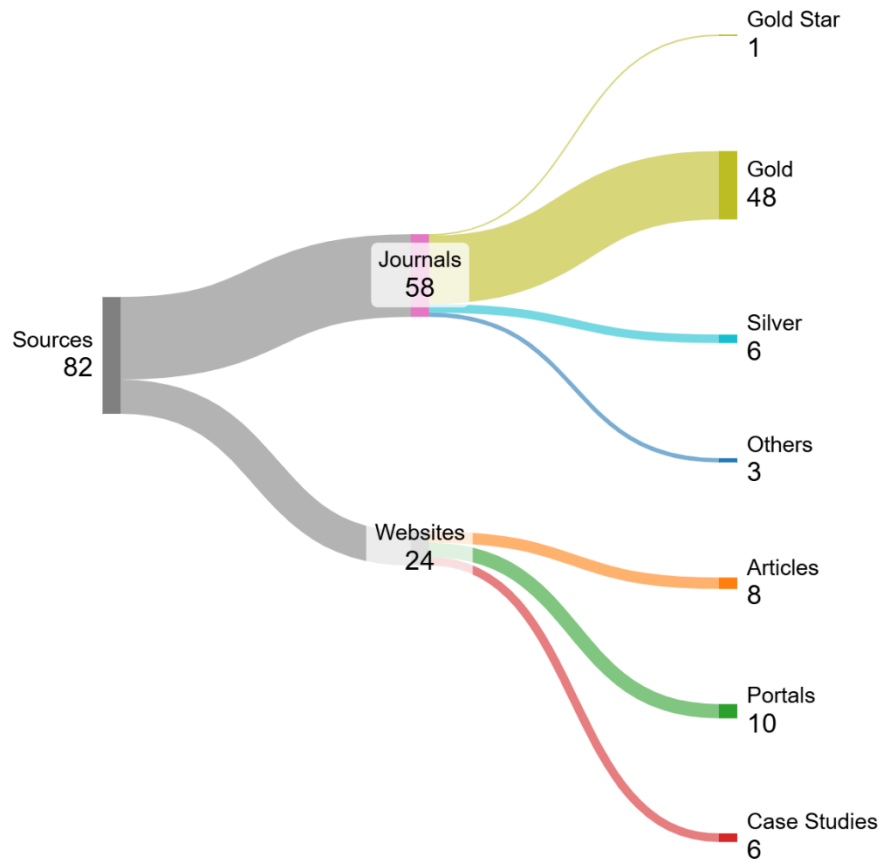


Figure 1 - Sources Sankey Diagram

5.1.1. Articles Keywords and Sources Inclusion Criteria

58 articles have been cited in this document. The articles were researched and collected through Scopus, “the world’s largest, comprehensive and trusted academic database’ (Elsevier, n.d.) and a few of them from Google Scholar.

Research was conducted by exploiting different combination of keywords, leveraging logical operators as: AND; OR; *. The different combinations used are:

- Artificial intelligence AND net zero AND tech company OR tech companies OR innovations
- Compan* AND sustainab* OR net zero AND artificial intelligence OR ai
- Compan* AND sustainab* OR net zero AND artificial intelligence OR ai AND big data OR high-tech OR high tech OR big tech companies
- Big data AND information systems AND challenges AND sustainab*
- Sustainab* AND tech companies AND big tech
- Sustainability AND ai OR artificial intelligence AND data management
- Information system AND high-tech companies OR high-tech OR high-tech company

Before deep diving into the article, the first check is to consider the reliability of the journal. For this document, the rankings from 'Associazione italiana di Ingegneria Gestionale' (AiIG), which is the Italian Association of Management Engineering, were considered.

It provides a reference list of relevant journals for research purposes. Journals are classified into 5 different classes, from the most reliable to the least ones: Gold-Star, Gold, Silver, Bronze and Copper sources. Specifically, this list is dated 20 May 2022.

The second step is to collect articles based on their title, keywords, research question, abstract and key findings. After having checked the consistency with the themes and topics of this document, articles were confirmed and collected.

More than 100 articles were then analyzed and filtered to ensure high quality and reliable sources in the final cluster of 58 scientific articles.

As showed by Figure 1, in fact, more than 80% of the final articles are classified as 'Gold' (82.8 % of the total articles), with 1 'Gold Star' (1.7% of the total articles), 6 'Silver' ones (10.3% of the total articles) and 3 'Others' (5.2% of the total articles), meaning relevant sources not classified as scientific article.

Other leveraged sources were relevant websites for specific articles or case studies.

In particular, as illustrated in Figure 1, the split between the 26 total websites is: 8 'Articles' (33.3% of the total websites), 10 'Portals' (41.7% of the total websites) and 6 'Case Studies' (25.0% of the total websites).

For direct links and more details, in the 8.References chapter the reader can find all leveraged resources.

5.1.2. Articles' Analysis

The articles were clustered based on the research question, overall topics and findings. Each article has been reviewed, starting by looking at the title and abstract relevance. After this step, the article was read and some key points have been noted. Then, a combination of approaches has been used to directly cite them in the review or to use them to support the narrative of the literature review.

5.2. Primary Data from High-Tech Companies

This sub-chapter provides insights about the primary data collected from seven different main high-tech companies.

Because of data privacy and integrity, organizations' names will not be disclosed in the text.

Primary data refers to the integration of Green Information Systems (GIS) and Green Product Innovation (GPI) within the high-tech companies.

Drawing on both quantitative (questionnaires' scoring) and qualitative (interviews) data, the analysis will explore how these companies approach sustainability through technology, innovation and implementation of new solutions.

The first part delves into the analysis of the results of questionnaires which were assigned to each company. The second section instead will focus more on the analysis of the interviews, extrapolating common topics.

5.2.1. Data Source

The primary data from high-tech company comes from questionnaires where 16 questions are categorized into four primary sections:

1. Green Information Systems adoption within the organization,
2. Green Information Systems adoption within the supply chain,
3. Green product innovation,
4. Main Environmental Objectives intended to be pursued through a Green Information System.

The answer scale is set from 1 to 5 points, where '1' refers to a very low agreement towards the proposed sentence and '5' indicates instead a very high one. For the last section, 'Main environmental objectives to be pursued through a green information system', high-tech companies were targeted to select up to three choices among those proposed in the questionnaire. The scores reflect the dummy variable used for the subsequent analysis: the value '1' stands for an intended objective to be pursued from the company, instead a value of '0' characterizes the objectives which are not selected or prioritized by the company.

Table 1, Table 2, Table 3 and Table 4 reveal questionnaires' results, showing varying degrees of commitment to sustainability across the companies and providing a nuanced picture of their actual environmental efforts.

Additionally, for company 'I' three values are missing for the section 'GIS adoption within the supply chain' and this can bias a bit the analysis, even if the magnitude is not very significant.

Figure 2 better showcases the distribution of the main environmental objectives scores. Many companies are prioritizing the resource optimization (chosen by 6 companies) and the conduction of Life Cycle Assessment for their products (chosen by 5 companies) aims. This can be due to the need to decrease waste and resource consumption, thus lowering down operational costs by increasing efficiency, or to adhere to the increasingly arising regulatory pressures cited before: from the EU AI Act to the Europe Emission Trading System (EU ETS).

The EU ETS is a cap-and-trade system that limits the amount of GHGs that can be emitted for companies under its scope. By 2023, the system has helped lowering down emissions from European power and industry plants by approximately 47%, compared to 2005 levels. The cap is reduced year over year, aligning to EU 's climate target, making companies accountable for their emissions and reports. The system includes many sectors, such as the maritime one from 2024 onwards and the new version of it (EU ETS-2) will aim to cover emissions coming from buildings and road transportation (United Nations, 2023).

For the qualitative analysis, the interviews' transcripts were collected per each company.

GIS adoption within the Organization

Question	A	C	D	E	F	H	I
We formally track and report the environmental performance of our products and operations	4	5	5	4	3	3	5
We have a well-developed database to track and monitor environmental issues within our company	3	5	5	4	1	2	5
We regularly track, monitor, and share environmental information within our company	4	5	5	4	2	3	5

Table 1 – Green Information System Adoption within the Organization Score

GIS adoption within the Supply Chain

Question	A	C	D	E	F	H	I
Our customers openly share environmental information with us	3	3	3	3	2	1	
Our suppliers openly share environmental information with us	1	4	2	2	2	1	2
The environmental information shared by participants (suppliers and customers) in our supply chain is available on real-time basis	3	1	1	1	1	1	2
We are able to respond to supply chain partners (both suppliers and customers) needs more quickly by sharing environmental-related information (e.g., amount of emissions or waste, energy consumption, etc.) with them	3	3	4	4	4	3	
We have an Information System through which environmental information flows seamlessly between the suppliers, manufacturers, and customers in our supply chain	3	2	1	1	2	2	1
We openly share environmental information with our suppliers and customers	3	4	4	4	4	1	

Table 2 - Green Information System Adoption within the Supply Chain Score

Green Product Innovation

Question	A	C	D	E	F	H	I
Products are designed for easy storage and handling during transportation	1	4	5	5	2	2	2
Products are designed to avoid or reduce the use of hazardous materials	5	5	5	4	4	2	5
Products are designed to facilitate disassembly, reusability and recyclability	3	5	5	1	4	2	5
Products are designed to produce less by-products and waste	5	5	5	2	4	2	5
Products are designed to reduce resource consumption during production phases	5	5	5	3	4	4	5
Products are designed to use less energy during production phases	5	5	5	3	3	1	4

Table 3 - Green Product Innovation Score

Main environmental objectives to be pursued through GIS

Question	A	C	D	E	F	H	I
Conducting LCA (Life Cycle Assessment) of our products	0	0	1	1	1	1	1
Eco-design (i.e., the consideration of environmental aspects at all stages of the product development...	1	1	1	1	0	0	0
Improving decision making by executives by highlighting environmental sustainability issues	0	1	0	1	0	0	0
Limiting carbon and other emissions related to our processes and operations	1	0	0	1	1	1	0
Monitoring environmental information, such as resource use, emissions, and waste production	0	1	0	1	0	1	0
Others - Regulatory disclosure requirements	0	0	0	0	0	0	1
Reducing energy consumption related to our processes and operations	0	0	0	1	0	0	0
Reducing other environmental impacts related to our processes and operations (i.e. resource consumption,...	0	0	0	1	0	0	0
Reducing the environmental impact of our products	1	0	1	1	1	1	1
Supporting the generation and distribution of renewable energy	0	0	0	1	0	0	0

Table 4 - Environmental Objectives to be pursued through GIS Score

Bar Chart | Score distribution | Environmental objectives to be pursued through Green Information Systems

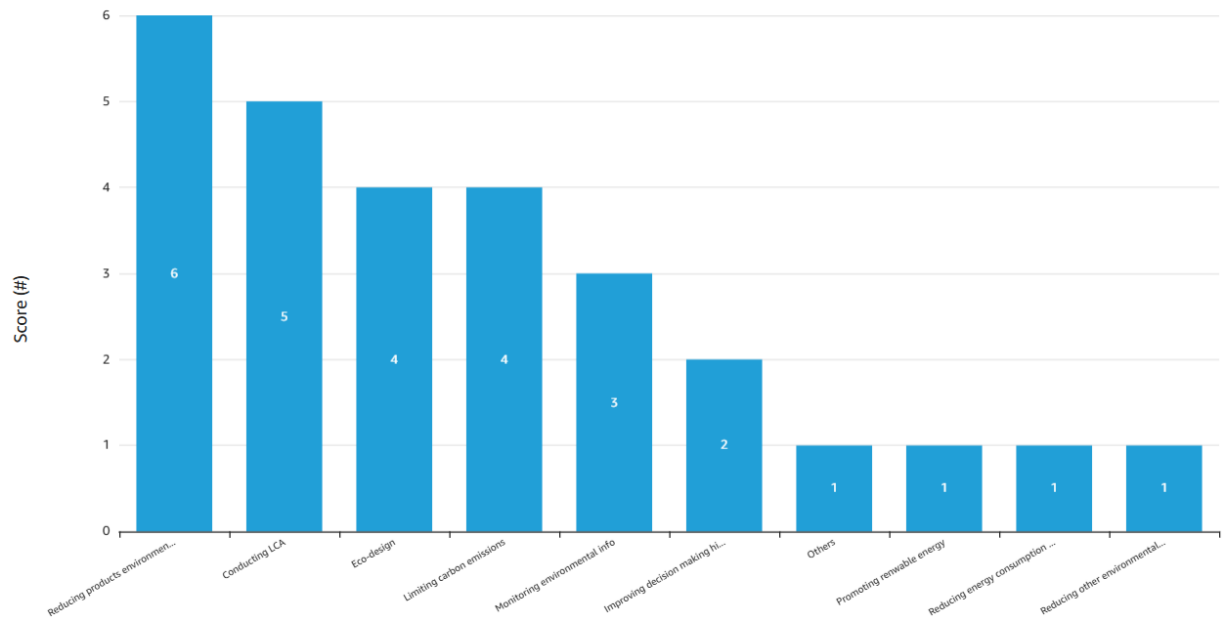


Figure 2 - Main Environmental Objectives Distribution

5.2.2. Questionnaires – Data Analysis

5.2.2.1. Basic Statistics

For the purposes of this analysis, tables and figures for data overview and basic statistics were built through Amazon QuickSight tool.

As first step, an Excel file has been prepared collecting and structuring all data coming from the questionnaires. The file has been then uploaded into QuickSight to create meaningful visuals.

In particular, the file is uploaded in the ‘Dataset’ section of the tool, in order to create an initial dataset which can be properly structured. After its creation, an ‘Analysis’ can be designed, leveraging the dataset which has been built before. In the ‘Analysis’ workspace, the user can create various tables, pivot tables, visuals, KPIs or heatmaps. Data overview and basic statistics’ tables were built leveraging the tools’ functionalities, just by selecting the desired table or visual (i.e: Vertical Bar Chart) and by including the needed fields (i.e: questionnaire_field) or values (i.e: questionnaire_score) to be displayed. For basic statistics development, the specific field value can be set as ‘Sum’, ‘Mean’, ‘Standard Deviation’, ‘Count’, ‘Variance’.

Figures have been furtherly formatted to display data clearly, for example specifying better X or Y axis’ labels, adjusting overall aesthetic and including data labels where relevant.

Table 5, Table 6, Table 7 provide a clear overview of the basic statistics for the questionnaires. Figure 3 displays the average score per each section.

Table | Basic Statistics | GIS Adoption within the Organization

Field	Mean	Median	Standard Deviation	Variance
We formally track and report the environmental performance of our products and operations	4.14	4	0.9	0.81
We have a well-developed database to track and monitor environmental issues within our company	3.57	4	1.62	2.62
We regularly track, monitor, and share environmental information within our company	4	4	1.15	1.33

Table 5 - GIS Adoption within the Organization, Basic Statistics

Table | Basic Statistics | GIS Adoption within the Supply Chain

Field	Mean	Median	Standard Deviation	Variance
Environmental info shared in our supply chain is available on real-time basis	1.43	1	0.79	0.62
Our customers openly share environmental information with us	2.5	3	0.84	0.7
Our suppliers openly share environmental information with us	2	2	1	1
We are able to respond to supply chain partners needs more quickly by sharing environmental related info	3.5	3.5	0.55	0.3
We have an IS through which environmental info flows seamlessly between partners and customers	1.71	2	0.76	0.57
We openly share environmental information with our suppliers and customers	3.33	4	1.21	1.47

Table 6 - GIS Adoption within the Supply Chain, Basic Statistics

Table | Basic Statistics | Green Product Innovation

Field	Mean	Median	Standard Deviation	Variance
Products are designed for easy storage and handling during transportation	3	2	1.63	2.67
Products are designed to avoid or reduce the use of hazardous materials	4.29	5	1.11	1.24
Products are designed to facilitate disassembly, reusability and recyclability	3.57	4	1.62	2.62
Products are designed to produce less by-products and waste	4	5	1.41	2
Products are designed to reduce resource consumption during production phases	4.43	5	0.79	0.62
Products are designed to use less energy during production phases	3.71	4	1.5	2.24

Table 7 - Green Product Innovation, Basic Statistics

Pie Chart | Average Score per Section

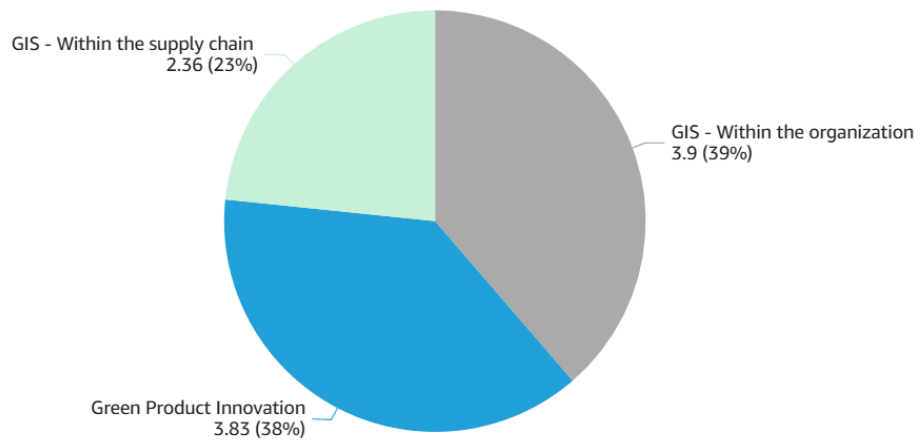


Figure 3 - Average Score per Section

5.2.2.2. Advanced Statistics

The correlation matrix and the final regression model have been built leveraging Excel 'Data Analysis' functionalities. In particular, by employing the 'Analysis ToolPak' add-ins of the application.

The correlation matrix has been developed by selecting the questionnaires' data points related to the 16 questions as input interval for the correlation.

The resulting table has been furtherly elaborated through layout adjustments and conditional formatting (applied rule: 'Graded Color Scale' to the entire table, excluding non-numerical cells) to provide a clear final visual.

To develop a feasible regression model, for each independent variable a mean value was taken to effectively build a multiple regression.

The independent variables used in the model are displayed in Table 8:

1. Green Information Systems adoption within the organization (X1 variable): that reflects companies' effort to implement internal systems to track and report environmental data and performance.
2. Green Information Systems adoption within the supply chain (X2 variable): that highlights the companies' integration of environmental information and the subsequent sharing of data across the entire supply chain, from suppliers to end customers.
3. Main environmental objectives intended to be pursued through the information systems (X3 dummy variable): which is a dummy variable reflecting the number of environmental objectives intended to be pursued by each company through their information systems.

Regression | Final Model Variables

Company	(X1) GIS adoption within the organization	(X2) GIS adoption within supply chain	(X3) Dummy	(Y) Green product innovation
A	4	3	0.33	4
C	5	3	0.33	5
D	5	3	0.33	5
E	4	3	1	3
F	2	3	0.33	4
H	3	2	0.44	2
I	5	2	0.22	4

Table 8 - Regression Model Variables

These final variables have been used as input data for the regression analysis through Excel Data Analysis functionalities.

Regression option was utilized, specifying '(Y) Green product innovation' values as data for 'Input Y Range' and '(X1) GIS adoption within the organization', '(X2) GIS adoption within supply chain', '(X3) Dummy' values as data for 'Input X Range'. Confidence level has been set to a standard 95%. The final regression table was then formatted and placed in this document.

Three scatterplots were built to better visualize the relationships between variables in the regression model. Also these graphs have been built through Excel functionalities, taking as input values: X1 and Y data points, X2 and Y data points and X3 and Y data points.

For company interviews analysis, the transcripts were thoroughly reviewed; common topics and challenges were extrapolated.

5.3. Patents

This chapter will highlight the data source for all gathered patents and the followed methodology for their analysis, together with some figures displaying the final collection of 110 different AI innovations for green outcomes.

5.3.1. Data Source

The proposed patents in this thesis were collected from three main databases:

- Orbit: a patent search and analysis platform to support researchers conduct intellectual property research by Questel,
- Patentscope: a global patent search system provided by the World Intellectual Property Organization),

- Google Patents: a search engine for patents and patents applications developed by Google.

The innovations were gathered through rigorous research, exploiting different combination of keywords, selecting the most recent innovations (in particular, with a year of publishment spanning between 2021 and 2025) and by considering the scope and breadth of this document.

In particular, the main keywords used for the deep dive were: artificial intelligence, sustainability, energy, data management, green, high tech, innovation and smart buildings, combined with different logical operators (AND, OR) to ensure a comprehensive collection of patents. The use of logical operators has indeed enabled more specific research considering AI innovations only in sustainable applications and fields.

The data was then categorized into sector of application, year of publication, country of application and main characteristics, aiming at identifying trends, sectoral focus, geographical distribution and finally the temporal evolution of the innovations' publishment.

The final dataset of patents is composed of 110 different innovations, with applications that span from supply chain to energy management, always focusing on the nexus between sustainability and artificial intelligence within the high-tech sector.

5.3.2. Data Analysis

For the sectoral analysis, patents were initially classified based on their description and technology type. An additional layer of detail was then added by furtherly detailing patents' application domain.

Then, data was embedded within an Excel file (Figure 4, Figure 5, Figure 6, Figure 7) and uploaded into Amazon QuickSight tool, which helped to structure meaningful visuals. The donut chart (Figure 13) is an example of this, as QuickSight highlighted the sectoral division together with related percentages.

Patent Title	Country	Year of Publication	Application Domain
AI BASED ENERGY SUSTAINABILITY IN SMART CITIES	India	8/6/2021	Smart Cities
AI-INTEGRATED RENEWABLE ENERGY MANAGEMENT SYSTEM FOR SMART HVAC AND REFRIGERATION IN SUSTAINABLE BUILDINGS	India	6/14/2024	Sustainable Buildings
ARTIFICIAL INTELLIGENCE AND SUPPLY CHAIN MANAGEMENT- ASSESSMENT OF THE PRESENT AND FUTURE ROLE PLAYED BY AI IN SUPPLY CHAIN PROCESS	India	5/5/2023	Supply Chain
ARTIFICIAL INTELLIGENCE BASED APPROACH TO STUDY THE ISSUES ASSOCIATED WITH FUEL CELLS TO REDUCE COST AND INCREASE SUSTAINABILITY	India	11/11/2022	Electric Vehicles
ARTIFICIAL INTELLIGENCE-BASED SUSTAINABILITY CONTROL	USA	5/16/2024	Others
ARTIFICIAL INTELLIGENCE, BIG DATA, INTERNET OF THINGS, AND BLOCK CHAIN TECHNIQUES AND APPLICATIONS IN SMART ENERGY MANAGEMENT	India	4/7/2023	Energy
CLOUD BASED HVAC MANAGEMENT APPARATUS AND SYSTEM FOR AIR PURIFICATION, INDOOR AIR QUALITY MONITORING, AND METHODS FOR IMPLEMENTING THE SAME	USA	10/8/2024	Sustainable Buildings
METHOD FOR ENHANCING EFFICIENCY AND SUSTAINABILITY IN GLOBAL SUPPLY CHAIN OPERATIONS	India	5/10/2024	Supply Chain
SUSTAINABILITY EVALUATION OF GREEN BUILDING BASED ON ARTIFICIAL INTELLIGENCE AND ENERGY CONSUMPTION	India	10/12/2023	Sustainable Buildings
SUSTAINABILITY PLANNER FOR REGULATED INDUSTRIES	USA	12/7/2023	Others
SUSTAINABLE ZERO WASTE MANAGEMENT PRACTICES FOR GREEN ENVIRONMENTAL SUSTAINABILITY	India	9/29/2023	Waste Management
AI Big Data and AI-Based Automatic Carbon Emission Monitoring System for Logistics Warehouses Stationary Carbon Sources in Logistics Companies	Korea	4/8/2024	Supply Chain
AI-DRIVEN BLOCKCHAIN DEVICE FOR SUSTAINABLE AND TRANSPARENT SUPPLY CHAIN MANAGEMENT WITH IOT INTEGRATION	India	10/11/2024	Supply Chain
AI-DRIVEN PREDICTIVE STRATEGIES FOR ENHANCING ELECTRIC VEHICLE BATTERY CHARGING LIFE CYCLE SUSTAINABILITY	India	3/8/2024	Electric Vehicles
AI-DRIVEN PREDICTIVE STRATEGIES FOR ENHANCING ELECTRIC VEHICLE BATTERY CHARGING LIFE CYCLE SUSTAINABILITY	India	5/17/2024	Electric Vehicles
AI-DRIVEN PREDICTIVE STRATEGIES FOR ENHANCING ELECTRIC VEHICLE BATTERY CHARGING LIFE CYCLE SUSTAINABILITY	India	6/21/2024	Electric Vehicles
AI-POWERED CODE OPTIMIZATION TOOL FOR ENERGY-EFFICIENT SOFTWARE DEVELOPMENT	India	9/20/2024	Energy
AN AIOT BASED SUSTAINABLE TRASH MANAGEMENT SYSTEM	India	10/11/2024	Waste Management
Digital platform for sustainability	Not specified	1/1/2022	Sustainable Data Sharing
ENVIRONMENTAL SUSTAINABILITY TECHNOLOGIES IN BIODIVERSITY, TRANSPORTATION AND WATER MANAGEMENT USING ARTIFICIAL INTELLIGENCE	India	2/17/2023	Environment
ROLE OF AI IN RELATIONSHIP BETWEEN HUMAN RESOURCE MANAGEMENT PRACTICES AND ORGANIZATIONAL SUSTAINABILITY	India	3/8/2024	Others
Sustainable Development Goals achieving using AI technology	Australia	4/22/2021	Others
SUSTAINABLE POWER GENERATION IN SMART CITIES USING IOT, ML, AND AI-DRIVEN WASTE-TO-ENERGY SYSTEMS	India	8/30/2024	Smart Cities
SYSTEM AND METHOD FOR SUSTAINABILITY EXCHANGE	India	8/27/2021	Sustainable Data Sharing
AI-based sustainability data management system	Taiwan	2023	Sustainable Data Sharing
A system and method for ai and iot integration for urban sustainability and efficiency	India	2/9/2024	Smart Cities
AI-ENHANCED POWER DISTRIBUTION OPTIMIZING EFFICIENCY AND RESILIENCE FOR SUSTAINABLE ENERGY MANAGEMENT	India	1/19/2024	Energy

Figure 4 - Patents Data Source 1

AI-DRIVEN SMART ENERGY METERING SYSTEM FOR REAL-TIME CONSUMPTION ANALYSIS AND OPTIMIZATION USING IOT AND MACHINE LEARNING ALGORITHMS	India	10/18/2024	Energy
Energy analysis management system based on artificial intelligence advanced algorithm	China	1/12/2024	Energy
Intelligent system for energy demand forecasts and sustainable energy management by machine learning and artificial intelligence	Germany	12/29/2022	Energy
SMART AI SYSTEM FOR ENERGY GENERATION FROM WASTE MATERIAL	India	1/12/2024	Energy
BLOCKCHAIN DRIVEN ENERGY DISTRIBUTION OPTIMIZATION USING GENERATIVE AI: TOWARDS SUSTAINABLE AND EFFICIENT RESOURCE ALLOCATION	India	10/25/2024	Energy
ENERGY DEMAND FORECASTING AND SUSTAINABLE ENERGY MANAGEMENT USING MACHINE LEARNING	Ireland	10/27/2022	Energy
HVAC system with sustainability and emissions controls	USA	4/16/2024	Sustainable Buildings
INNOVATIVE WASTE MANAGEMENT MACHINE INCORPORATING MECHANICAL SHREDDING AND AI-BASED SORTING	India	11/22/2024	Waste Management
AI LCA LCA Full-cycle Carbon Accounting Data Evaluation and Verification System Using AI and Big Data	South Korea	4/16/2024	Sustainability Scoring and Evaluation
SMART POWER GRID MANAGEMENT SYSTEM	India	6/12/2024	Energy
SMART WASTE: AI-POWERED GREEN WASTE MANAGEMENT PLATFORM	India	11/29/2024	Waste Management
Intelligent pavement systems for smart cities	India	10/15/2024	Smart Cities
ARTIFICIAL INTELLIGENCE BASED SMART SYSTEM TO ENHANCE THE BETTER PERFORMANCE IN THE SUPPLY CHAIN MANAGEMENT USING BIG DATA AND BUSINESS ANALYTICS	India	11/24/2023	Supply Chain
AN INTEGRATED APPROACH TO ENVIRONMENTALLY FRIENDLY SMART CITIES WITH THEIR CONVERGENT AI, IOT, AND BIG DATA TECHNOLOGIES AND SOLUTIONS	India	8/18/2023	Smart Cities
Enhancing sustainability and resilience in supply chains: a holistic approach to risk management and mitigation strategies	India	4/5/2024	Supply Chain
ARTIFICIAL INTELLIGENCE FRAMEWORK FOR OPTIMIZED SUSTAINABLE MANUFACTURING IN INDUSTRY 5.0	India	12/13/2024	Supply Chain
Data Center Energy Supply Management with Artificial Intelligence	Turkey	2024	Energy
AI SYSTEM FOR LEVERAGING INTELLIGENT WASTE MANAGEMENT IN SMART CITIES	India	12/20/2024	Waste Management
TERRAGREEN: SMART, SUSTAINABLE COMPOSTING WITH AI	India	12/13/2024	Waste Management
WIRELESS IOT SENSOR NETWORK FOR EFFICIENT ENVIRONMENTAL MONITORING	India	12/6/2024	Environment
INNOVATIVE E-WASTE MANAGEMENT UTILIZING EMERGING TECHNOLOGIES FOR ENVIRONMENTAL IMPACT	India	12/13/2024	Waste Management
LI-ION BATTERY PERFORMANCE ENHANCEMENT BY MACHINE LEARNING ALGORITHMS	India	12/13/2024	Energy
Energy management method of photovoltaic energy storage system	China	12/31/2024	Energy
DESIGN OF LEAN OPERATION TECHNIQUES IN THE PRODUCTION CYCLE TO BE ECONOMICALLY SUSTAINABLE	India	8/12/2024	Supply Chain
AUTONOMOUS CLIMATE TECHNOLOGY ECOSYSTEM FOR COMPUTER- GENERATED UNIFORM CARBON CREDIT CERTIFICATES	USA	12/5/2024	Sustainable Data Sharing
DATA-SHARING SYSTEMS AND METHODS, WHICH USE MULTI-ANGLE INCENTIVE ALLOCATION	China	1/5/2023	Sustainable Data Sharing
A SYSTEM AND METHOD OF AUTONOMOUS TRASH-COLLECTING ROBOT FOR SUSTAINABLE WASTE MANAGEMENT	India	10/27/2023	Waste Management
ARTIFICIAL INTELLIGENCE-BASED SUPPLY CHAIN MANAGEMENT SYSTEM FOR SUSTAINABLE SOURCING AND PROCUREMENT	India	10/20/2023	Supply Chain

Figure 5 - Patents Data Source 2

Recycling vendor for sustainability with artificial intelligence-based reward system	Turkey	Not specified	Supply Chain
AI-driven sustainable shopping using bar code scanner	India	1/12/2024	Others
Artificial intelligence integrated human paradigm through organizational agility and sustainable performance	India	9/16/2022	Others
AI system and method for recommending and transforming global sustainability in the telecommunications industry	India	9/29/2023	Others
AI-assisted low-carbon footprint concrete mixtures for sustainable construction	India	9/6/2024	Sustainable Buildings
Artificial intelligence system to develop solutions for sustainable energy systems	Turkey	Not specified	Energy
Artificial intelligence based sustainability scoring and curation of recommendations	USA	2/29/2024	Sustainability Scoring and Evaluation
Electric vehicle swapping battery charging station using artificial intelligence	India	1/19/2024	Electric Vehicles
EFFICIENT EV CHARGING SCHEDULING THROUGH ARTIFICIAL INTELLIGENCE	India	12/15/2023	Electric Vehicles
Design of lean operation techniques in the production cycle to be economically sustainable	India	8/16/2024	Supply Chain
AI based bms system for sustainable vehicles	India	9/1/2023	Electric Vehicles
DYNAMIC GRID INTERACTION PROTOCOL ENHANCED WITH ARTIFICIAL INTELLIGENCE FOR ELECTRIC VEHICLE INTEGRATION	India	4/19/2024	Electric Vehicles
Artificial intelligence-enhanced control systems for pv cell integration in smart grids	India	6/21/2024	Energy
Artificial intelligence-driven drones: transforming forest ecology and management	India	3/8/2024	Environment
Artificial intelligence based electric vehicle charging station	India	7/7/2023	Electric Vehicles
AI-driven smart city mobility solution that integrates autonomous vehicles with public transportation	India	3/8/2024	Smart Cities
Monitoring key performance indicators of supply chain retail using artificial intelligence	India	10/28/2022	Supply Chain
Artificial intelligence-based carbon value analysis method and system	China	1/7/2025	Sustainability Scoring and Evaluation
Artificial intelligence based plastic waste management system	India	8/11/2023	Waste Management
Integrated system and method for sustainable project management in large-scale enterprises	India	12/20/2024	Others
Artificial intelligence based charge balancing between electrical vehicles in real-time	India	2/9/2024	Electric Vehicles
Exploring challenges and implementation of ai for developing environmentally sustainable logistics	India	12/23/2022	Supply Chain
Efficient grid-to-vehicle communication protocol utilizing artificial intelligence for demand response management	India	4/19/2024	Electric Vehicles
Artificial intelligence and iot based smart trash bin for efficient waste management	India	7/5/2024	Waste Management
AI-driven catalytic process optimization for green chemistry applications	India	9/13/2024	Others
Intelligent electric vehicle charging system using ai and iot	India	6/23/2023	Electric Vehicles
AI-DRIVEN ELECTRIC VEHICLE CHARGING SYSTEM	India	12/1/2023	Electric Vehicles
PREDICTIVE ANALYTICS FOR REAL-TIME HEALTH ASSESSMENT OF EV LI-ION BATTERIES THROUGH ARTIFICIAL INTELLIGENCE	India	7/5/2024	Electric Vehicles

Figure 6 - Patents Data Source 3

Artificial intelligence application for monitoring and control of smart grid	India	7/5/2024	Energy
Generative ai powered system for electric vehicle battery grid integration and management	India	10/11/2024	Electric Vehicles
Environmental monitoring and alert system using artificial intelligence	India	7/26/2024	Environment
Artificial intelligence based model for power control and management slope one scheme	India	5/19/2023	Energy
Artificial intelligence-based energy optimization method and system	China	1/7/2025	Energy
System and method for energy consumption optimization in smart homes using artificial intelligence	India	9/13/2024	Energy
AI-integrated predictive inventory management system for manufacturing supply chains	India	12/22/2023	Supply Chain
Analysis method for analyzing influence of artificial intelligence application on enterprise energy consumption mode	China	10/25/2024	Energy
The emerging data-driven smart city and its innovative applied solutions for sustainability	India	5/17/2024	Smart Cities
AI-driven system for predictive analysis in sustainable supply chain management	Germany	6/6/2024	Supply Chain
Artificial intelligence data management method	China	8/27/2024	Sustainable Data Sharing
Advanced ai-powered battery saver system revolutionizing energy efficiency	India	6/14/2024	Others
AI-powered carbon footprint tracker for sustainable living	India	5/10/2024	Sustainability Scoring and Evaluation
Artificial intelligence-based system for optimizing energy consumption in electrical grids	India	10/18/2024	Energy
Predictive sustainability analytics for software deployments	USA	1/2/2025	Sustainability Scoring and Evaluation
Smart ai-driven drones: revolutionizing wildlife monitoring and first aid rescue	India	11/1/2024	Environment
Smart lithium ion phosphate battery swapping station with ai integration for electric vehicles	India	5/31/2024	Electric Vehicles
AI based battery management system for electric vehicles	India	2/23/2024	Electric Vehicles
AI-powered environmental pollution control system for smart cities	India	3/22/2024	Smart Cities
Artificial intelligence and internet of things technology through differential equations in the development of stable and resilient smart grids with high penetration of renewable energy sources and management system	India	2/9/2024	Energy
AI based transparent and traceable supply chain management using blockchain	India	4/19/2024	Supply Chain
AI-based predictive maintenance and efficiency enhancement for photovoltaic cells in smart grids	India	6/21/2024	Energy
Intelligent energy management and control system based on artificial intelligence	China	8/23/2024	Energy
Integrated energy management and optimization system based on artificial intelligence	China	1/26/2024	Energy
Artificial intelligence-based hybrid electric vehicle energy management system using cloud technology	India	3/31/2023	Electric Vehicles
Smart grid management using ai and blockchain	India	11/15/2024	Energy
Building the future: an integrated framework for iot and ai in smart energy management	India	6/21/2024	Energy

Figure 7 - Patents Data Source 4

For the geographical distribution, patents' filing locations were considered (refer to the 'Country' column of Figure 4, Figure 5, Figure 6, Figure 7). For each patent, locations were extracted, put into an Excel file and then an ad-hoc heatmap (Figure 14) was built, always leveraging Amazon QuickSight.

In particular, once the Excel file is uploaded in the tool as a dataset, an analysis can be created. The user can build the visual just by selecting 'Insert' in the analysis workspace and then choose 'Points on map' visual type. The next step is to include the relevant fields from the 'Data' tab: 'Country' as geospatial field type and 'Patent count' (ad-hoc column in the back-end Excel file which displays the value '1' per each row) as size field type.

The temporal evolution section was structured considering the year of publication of each patent. All dates were put into an excel file (refer to the 'Year of Publication' column of Figure 4, Figure 5, Figure 6, Figure 7) and uploaded into QuickSight, to then create the histogram (Figure 15) to visualize publications' trend across the years.

The followed methodology is the same: the user can build the visual just by selecting 'Insert' in the analysis workspace and then choose 'Vertical Bar Chart' visual type. The next step is to include the relevant fields from the 'Data' tab: 'Year of Publication' as X axis field type and 'Patent count' (ad-hoc column in the back-end Excel file which displays the value '1' per each row) as value field type.

6. Results

This section will showcase the results of the analysis explained in the '5.Methodology' chapter. Per each section (Literature Review, Primary Data from High Tech Companies and Patents) results and graphs will be detailed, deep-diving into the final outcomes.

Then, in the '7.Conclusion' chapter, a final summary about AI and sustainability will be provided together with possible future opportunities, study limitation, others deep dives needed in research.

6.1. Literature Review

6.1.1. AI Holistic Framework

The following framework (Figure 8) serves as a solid base to start to assess and integrate AI for sustainability within high-tech companies:

- Physical Impacts

- Organizational Sustainability
- Leadership, People and Policies
- Challenges

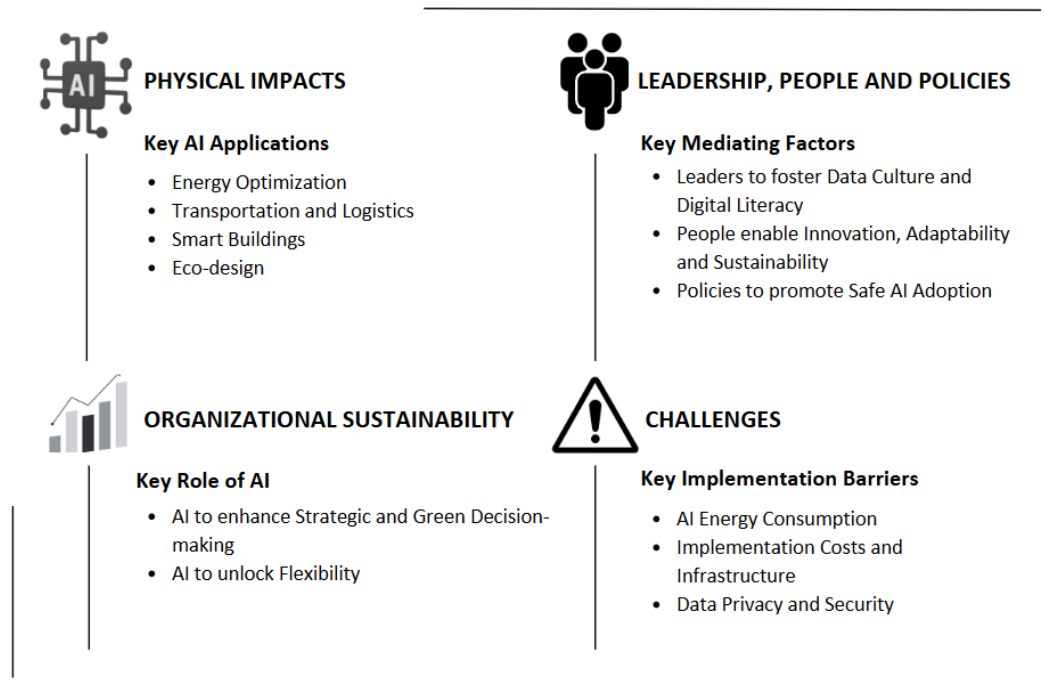


Figure 8 - Holistic Framework

The purpose is to offer a comprehensive approach while tackling sustainable challenges through AI, cover multiple perspective in high-tech companies and propose some solutions in each section to effectively enrich the actual literature on the nexus of AI and sustainability. This framework emphasizes the interplay between these dimensions, proposing a novel way to evaluate and implement AI technologies that align with sustainability goals.

1. Physical Impacts

Definition: The tangible and more easily measurable outcomes of AI adoption across high-tech organization, focusing on: energy efficiency, emissions reduction through green logistics and smart buildings and resource optimization thanks to eco design for products and packaging.

Key insights from literature: AI has shown huge potential in accelerating sustainability by reducing resource usage and carbon footprint and optimize energy management and consumption. On the other hand, its energy-intensive nature is one of the main challenges to solve.

Proposed solution: Development and adoption of green AI models (less model complexity, lower computational and energy power required), move part or entire data centers to cloud solutions, focus on deploying and developing AI in sustainable products and services, to grasp environmental benefits.

2. Organizational Sustainability

Definition: It refers to AI's role in enhancing strategic decision-making and organizational flexibility within high-tech organizations, enabling them to adapt to sustainability demands over the short and long term.

Key insights from literature: AI is capable of unlocking flexibility which in turn leads to green innovations' acceleration and the development of new capabilities inside the company. On the other hand, measurable metrics for agility and adaptability in a sustainable landscape remain underdeveloped.

Proposed solution: Development of metrics to measure organizational agility regarding sustainable-related changes, improvements in decision-making speed regarding pressing environmental matters.

3. Leadership, People and Policies

Definition: Role of culture, leaders, employees and policies in moderating the adoption of AI for green purposes.

Key insights from literature: Strong and efficient leaders deeply enhance AI adoption for sustainable strategies inside organizations. Policies and incentives are pivotal to enhance or limit AI adoption within companies.

Anyway, a lack of data driven culture and training hinders the full potential of AI technologies. Furthermore, policy frameworks often lag behind quick technological advancements, limiting sustainable strategies' effectiveness.

Proposed solution: Government and companies should establish and fund trainings to build digital capabilities, especially within high-tech organizations. Also, leadership programs aimed at sustainable AI development should be developed and prioritized, to ensure a successful implementation and leverage of these technologies for environmentally-friendly strategies inside companies.

On the policy side, providing tax subsidies to green companies could overcome possible issues. The development of standardized global policies addressing AI responsible use, ensuring alignment with environmental standards and stakeholder expectations can enhance sustainability.

4. Challenges

Definition: This section addresses both external and internal barriers to successful AI integration and development within organizations

Key insights from literature: Major barriers include the energy consumption of AI models and data centers, high and unclear implementation costs and possible concerns about data integrity.

These four dimensions are strictly interconnected as policies definitely shape physical and immediate effects of AI adoption, by increasing or limiting field applications.

Leadership drives cultural change and aligns organizational strategy with policy goals, while physical benefits such as resource optimization enable greater organizational adaptability.

What emerges from the framework is the urgent need to face environmental challenges through a holistic approach. Sustainability cannot be achieved in silos.

A successful integration of AI indeed requires a holistic and systematic approach, linking technological, societal and organizational perspective. By exploiting synergies, major limits and barriers can be overcome to unlock the full sustainable potential of Artificial Intelligence.

This framework lays the groundwork for further analysis and application.

6.1.2. Agentic AI: a Powerful Opportunity

To enhance sustainability by fulfilling these needs and by overcoming challenges the Agentic AI emerges as a game changer in this context. As highlighted in '3.3.2.The Role of Artificial Intelligence – Actual vs Future', 2025 and the future years will see this multi-trillion market developing faster.

However, its environmental applications remain still underexplored, with most of the attention focused on customer service, software engineering or for automation. This document is intended to spotlight the potential of agentic AI in reshaping current sustainability strategies, transforming how Artificial Intelligence is applied for a greener future.

Figure 9 shows the proposed framework based on the literature review.

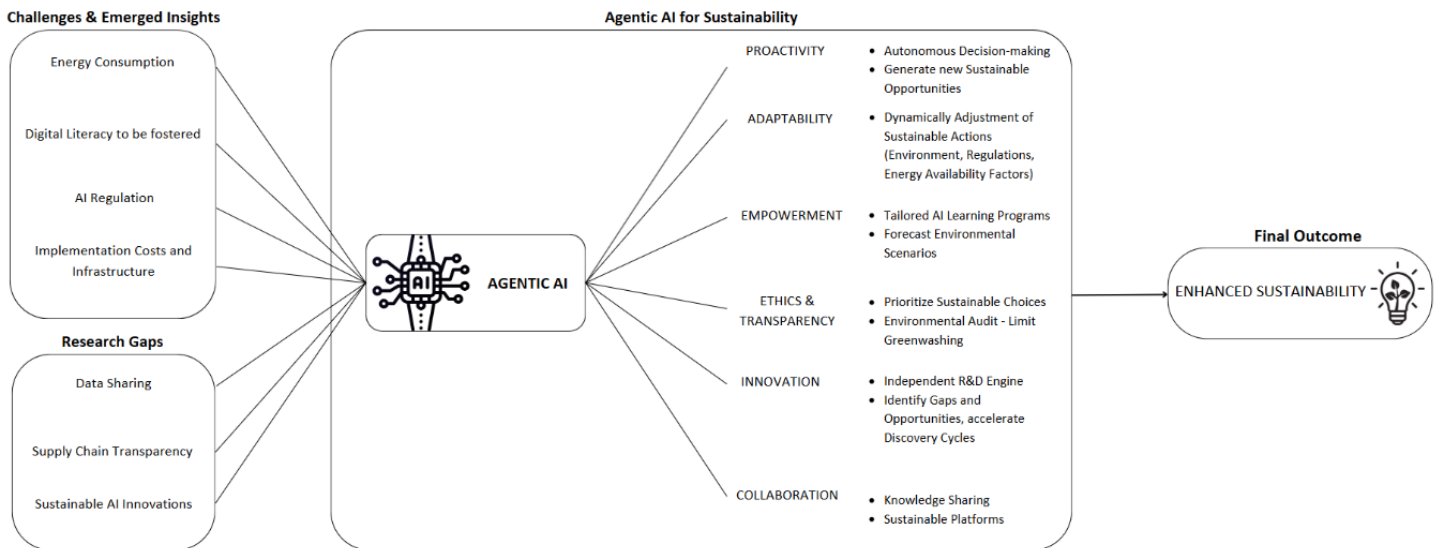


Figure 9 - Agentic AI for Sustainability

- Proactivity

Most of current AI applications rely on programmed and predefined models and algorithms, lacking the ability to make decisions and seek new opportunities to further enhance sustainability. In this landscape, an agentic AI can autonomously analyze inputs, identify inefficiencies, generate new sustainable opportunities and at the same time implement optimizations without human intervention.

A future opportunity can be an industrial AI agent capable of identifying underutilized materials in an entire supply chain and autonomously suggest possible Circular Economy initiatives and opportunities. Then, it can start negotiating with company’s suppliers or with local organizations to implement these green strategies.

- Adaptability

AI systems can indeed adapt and learn, but they’re still limited to human interventions and programming. Agentic AI go beyond this as it can be fully adaptable in various domains within high-tech organizations, dynamically adjusting sustainability actions depending on the evolution of regulation, climate conditions, or energy availability. This can make supply chains more resilient and adaptive to sustainable constraints. This is especially valid as we saw EU AI Act.

AI agents can indeed autonomously redesign supply chains, with the purpose of reducing energy consumptions and minimize carbon footprints, continuously re-adjusting shipments based on real-time data, climate policies, traffic patterns or geopolitical and environmental risks. A more developed version of the ORION system by UPS, which has the capabilities to be considered an early stage of an agentic AI.

- Empowerment

Agentic AI can empower people and leaders within high-tech organizations. As digital literacy is considered fundamental to effectively address environmental challenges, it can design ad-hoc sustainable-related trainings and programs, identifying current knowledge gaps among employees, delivering tailored learning programs and paths and constantly monitoring progress and feedback, ensuring all programs remain up to date. For leaders, together with trainings, AI agents can provide plausible environmental scenarios and forecasts based on different strategies pursued, bringing green decision making on a new level.

By supporting leaders with decision making and fostering a data culture within the organizations, AI agents empower people to accelerate sustainability.

- Collaboration

Agentic AI can build networks that ultimately enhance collaboration across companies, industries or even countries. These agents can be seen as intermediators that facilitate communication and align sustainability strategies, efforts or policies through a wide variety of stakeholders.

A practical opportunity is the creation of sustainable coalitions or platforms where specific AI agents for each company can negotiate agreements on carbon offsets strategies, verify sustainable data and validate ESG reports ensuring transparency. Moreover, the platform can be a decision-support system for sustainability teams within high-tech companies. The platform can autonomously monitor progresses, suggest best practices, improving overall collaboration and coordination.

- Innovation

AI agents can have a huge impact in innovations as well. With their enhanced judgement and power of execution, they can independently scan, analyze and identify gaps in sustainability technologies. They can become a fully independent R&D engine, proposing or identify new research directions, new breakthrough technologies in renewable energy, carbon capture systems or advanced and more sustainable materials which can be then adopted globally, accelerating discovery cycles.

In this context, Sciagents is a framework that integrates LLM and an AI agent for breakthrough green discoveries. Currently, the framework and the linked agents are applied to bio-inspired materials and they revealed novel relationships, like enhancing silk's mechanical properties with dandelion pigments, reducing energy consumption by 30%, and achieving innovative and greener design principles (Ghafarollahi & Buehler, 2024).

In the future, an AI agent can be employed to autonomously scan environmental datasets, green patents and scientific literature to propose novel solutions to current environmental challenges.

- Ethics and Transparency

Agentic AI can be designed embodying strong ethical frameworks, so that they can autonomously make the most suitable decision based on the context, such as rejecting unsafe solutions, prioritizing choices with the highest sustainable benefits (and not just based on the returns or costs) and ensuring corporate strategies remain aligned with global climate goals.

A new compliance AI agent can autonomously audit companies' environmental claims and compare them with financial statements, final products and internal operations to identify discrepancies. This is particularly valuable as of 2023 in Europe:

- “53% of green claims give vague, misleading or unfounded information,
- 40% of claims have no supporting evidence,
- Half of all green labels offer weak or non-existent verification,
- There are 230 sustainability labels and 100 green energy labels in the EU, with vastly different levels of transparency.”

And EU is taking actions to protect customers and the environment, such as a proposal for a Directive on Green Claims, aimed at verifying with robust and scientific methods the environmental claims (European Commission, 2023). Agentic AI can support and make advancement in this scenario, by contributing to lowering down greenwashing practices.

While Agentic AI potential for sustainability seems promising, it's fundamental to also acknowledge some limitations.

Firstly, many of the proposed applications need technical and practical validation as they are not yet supported by evidence nor widespread implementations.

Secondly, barriers regarding environmental and ethical risks of this solutions still remain. The huge energy consumption required to train and handle such models and applications can have deep negative environmental impacts. Regarding ethical risks, they will be also discussed in the closing part of this document.

6.2. Primary Data from High-Tech Companies

The quantitative analysis highlights some consistent trends and variability in how high-tech companies are integrating green information systems and fostering green product innovation. An initial analysis is provided through basic statistics such as mean, mode, standard deviation, range, standard error and sample variance across each dimension.

1) GIS Adoption within the Organization

Table 5 displays how's the current landscape of GIS integration across the targeted companies.

- Mean: the highest value (4.143) corresponds to 'We formally track and report the environmental performance of our products and operations', showcasing that the majority of the companies have implemented basic environmental tracking tools, metrics and procedures. Instead 'We have a well-developed database to track and monitor environmental issues, with the lowest mean score of 3.571, exhibits a possible underdeveloped area which needs further attention and study.

- Standard deviation: this metric varies significantly across the three metrics. This is a further confirmation that most companies formally track their environmental performance (lowest standard deviation of 0.9), but just a few are putting effective efforts in sophisticating their database.

In a nutshell, while high-tech companies are aware of the importance of environmental performance tracking, fewer have invested in building more robust and integrated systems to manage and monitor environmental data to track and share possible issues.

2) GIS Adoption within the Supply Chain

Table 6 provides additional insights on the level of adoption of GIS across companies' supply chains, with different levels of integration.

- Mean: the highest value (3.500) relates to companies' ability to 'respond to supply chain partners by sharing environmental-related information'. This shows that companies are able to effectively communicate green data across their supply chain, even though it is not yet widespread. On the other hand, having a seamless and smooth flow of data throughout the whole value chain seems to be a very underdeveloped capability (1.429).

- Standard deviation: the variability is most pronounced for openly sharing information with suppliers (1.211), signaling a possible gap in how different high-tech companies are able to collaborate and communicate with their suppliers regarding sustainable matters. Conversely, responding to different partners more quickly and addressing their requests exhibits the lowest value (0.548), suggesting more consistency in this field.

Companies are able to effectively share green data and information, but the lack of real-time data sharing and of a transparent flow of information limits the possibility of full integration of sustainability throughout the value chain, which in turns is essential to consistently improve sustainability and mitigate climate change.

3) GIS Adoption within the Supply Chain

Table 7 exhibits the incorporation of sustainability within companies' product innovation processes.

- Mean: the highest score (4.429) pertains to 'products designed to reduce resource consumption', showcasing that resource and cost optimization is a top priority for high-tech companies at this stage. Meanwhile, designing products for easy storage and handling during transportation has the lowest mean score (3.000), highlighting that the sustainable logistic aspect is less of a focus as of now.

- Standard deviation: the variability across all the fields is quite high, showing spread efforts in green product innovation, except for the need of reducing resource consumption in the design phase, which has a relatively low standard deviation (0.787).

Companies are indeed focusing on optimizing resource usage in their products which may be due to regulatory pressures or the establishment of new market segments characterized by green customers that favor environmentally friendly products, thus paying a premium price.

In conclusion, high-tech companies are showcasing efforts in different areas of sustainability, and this is a significant starting point in addressing climate change and being able to guarantee a net-zero future, but still there are evident gaps in integrating new solutions and information systems, both internally and across the value chain. This initial analysis displays many potential rooms of improvements, particularly in enhancing real-time information sharing and expanding the scope of green product innovation across companies.

6.2.1. Correlation Analysis

This analysis is intended to offer insights into how the various parameters under study interact with each other. The correlation values range from '-1' to '+1', where positive values closer to '1' highlights strong positive relationships, values near to '-1' indicate a strong negative relationship and ultimately values around 0 showcase no significant correlation among the parameters. The outcome of the analysis is shown in Table 9.

	We formally track and report the environmental performance of our products and operations	We regularly track, monitor, and share environmental information within our company	We have a well-developed database to track and monitor environmental issues within our company	We are able to respond to supply chain partners (both suppliers and customers) needs more quickly by sharing environmental related information (e.g., amount of emissions or waste, energy consumption, etc.) with them	We openly share environmental information with our suppliers and customers	We have an information system through which information flows seamlessly between the suppliers, manufacturers, and customers in our supply chain	Our suppliers openly share environmental information with us	Our customers openly share environmental information with us	The environmental information shared by participants (suppliers and customers) in our supply chain is available on a real-time basis	Products are designed to reduce resource consumption during production phase	Products are designed to facilitate disassembly and reusability and recyclability	Products are designed to avoid or reduce the use of hazardous materials	Products are designed to produce less by-products and waste	Products are designed for easy storage and handling during transportation	Products are designed to use less energy during production phases
We formally track and report the environmental performance of our products and operations	1														
We regularly track, monitor, and share environmental information within our company	0.963	1													
We have a well-developed database to track and monitor environmental issues within our company	0.965	0.981	1												
We are able to respond to supply chain partners (both suppliers and customers) needs more quickly by sharing environmental related information (e.g., amount of emissions or waste, energy consumption, etc.) with them	0.000	-0.156	0.000	1											
We openly share environmental information with our suppliers and customers	0.554	0.330	0.438	0.603	1										
We have an information system through which information flows seamlessly between the suppliers, manufacturers, and customers in our supply chain	-0.420	-0.382	-0.525	-0.728	-0.366	1									
Our suppliers openly share environmental information with us	0.556	0.433	0.515	0.000	0.603	-0.220	1								
Our customers openly share environmental information with us	0.802	0.716	0.732	0.218	0.790	-0.159	0.436	1							
The environmental information shared by participants (suppliers and customers) in our supply chain is available on a real-time basis	0.135	0.183	0.037	-0.447	-0.135	0.520	-0.424	0.293	1						
Products are designed to reduce resource consumption during production phases	0.605	0.550	0.430	-0.447	0.067	0.240	0.212	0.293	0.462	1					
Products are designed to facilitate disassembly, reusability and recyclability	0.621	0.446	0.427	0.000	0.438	-0.117	0.515	0.293	0.037	0.823	1				
Products are designed to avoid or reduce the use of hazardous materials	0.785	0.649	0.635	0.156	0.800	-0.085	0.449	0.920	0.408	0.598	0.635	1			
Products are designed to produce less by-products and waste	0.655	0.510	0.437	-0.124	0.486	0.156	0.354	0.568	0.449	0.899	0.874	0.847	1		
Products are designed for easy storage and handling during transportation	0.454	0.442	0.568	0.530	0.543	-0.075	0.510	0.486	-0.649	-0.259	0.000	0.183	-0.144	1	
Products are designed to use less energy during production	0.778	0.675	0.629	0.000	0.674	0.063	0.446	0.878	0.405	0.688	0.629	0.958	0.867	0.205	1

Table 9 - Correlation Analysis Outcome

1) Strong Internal Consistency in GIS Adoption

All the GIS Adoption within organization's parameters exhibit strong positive correlations, suggesting that companies that perform well in one aspect of GIS adoption are likely to excel in other related areas.

- “We formally track and report... of our products and operations” and “We regularly track, monitor, and ... within our company” have a high correlation value of 0.963, indicating that high-tech companies investing in formal environmental performance of products and operations, are also able to share and streamline environmental information effectively through the organization. This can be an indicator of a comprehensive approach to environmental data management.

- “We have a well-developed database to track environmental... company” is also strongly correlated with both above parameters (correlation value of 0.965 and 0.981), further reinforcing the above notion. Companies willing to track environmental data are likely to invest in more advanced data management infrastructure.

This overall strong internal consistency among GIS internal adoption parameters suggests that these high-tech companies are making real progresses toward a thorough environmental reporting.

2) Limited Correlation between Internal GIS and Supply Chain GIS

There is limited to moderate correlation between internal GIS adoption metrics and GIS adoption within the supply chain:

- All three metrics about GIS adoption within organization show negative correlation with “We have an Information System... in our supply chain”. Being able to track, report and share environmental data within the company is not coupled with having strong information systems which grant an agile flow of information.

- All three metrics about internal GIS adoption show indeed a positive correlation with “Our customers openly... with us” (correlation value of 0.802, 0.716, 0.732). This highlights the central role of having data throughout the value chain, as organizations with high sharing and monitoring of environmental data, also have customers which provide environmental information in a seamless way.

While internal GIS adoption appears to be well-integrated, supply chain GIS adoption is more fragmented. The relatively weaker correlations suggest that extending environmental tracking and monitoring to the supply chain is a challenge for most companies. Strengthening external partnerships and improving data sharing between suppliers and customers could improve the overall supply chain sustainability, thus benefitting all stakeholders.

3) Strong Correlations within Green Product Innovation

Regarding green product innovation, the correlations' values suggest that companies excelling in one area of product sustainability are likely to innovate across multiple dimensions and aspects of their products:

- As an example, "Products are designed to reduce... production phases", "Products are designed to facilitate... recyclability", "Products are designed to avoid... hazardous materials" all present high correlation values with "Products are designed... and waste" (0.899, 0.874, 0.847).
- Moreover, "Products are designed to avoid or... hazardous materials" and "Products are designed for easy... during transportation" exhibits robust correlation indicators with "Products are designed to use less... production phases" (values of 0.958, 0.867), furtherly enhancing this outcome.

Strong and positive correlations' outcomes are to be found in the relationship between GIS adoption within companies and effective Green Product Innovation. In fact, all the three metrics about GIS internal adoption are positively related to the Green Product Innovation ones. High-Tech Companies that are actively adopting GIS for internal processes are better positioned towards Green Product Innovation in high-tech companies.

The additional outcome of this section is that high-tech companies are currently exploring green innovations by taking a holistic approach. Rather than focusing just on isolated improvements, they're covering different and wide aspects of products' sustainability, from less resource consumption to improved energy efficiency during production processes.

4) Conclusion and Strategic Implications

The correlation analysis reveals several key patterns in GIS adoption and green product innovation among High-Tech Companies:

1. Strong Internal Consistency: Companies are adopting GIS holistically within their organizations, but the challenge lies in extending these practices to their supply chain. There is a clear opportunity for improvement in integrating supply chain partners into environmental data tracking and sharing systems.

2. Green Product Innovation Synergies: High-performing companies in product innovation show a consistent approach to reducing resource consumption, hazardous material use, and energy consumption. Focusing on these interconnected sustainability goals allows for a more comprehensive impact across the product lifecycle.

3. Cross-Domain Integration: Internal GIS adoption and green product innovation are moderately correlated, indicating that investing in internal environmental monitoring and tracking systems can positively influence product innovation. Companies should consider leveraging GIS not just as a tool for tracking but as a driver for innovation in product design.

In conclusion, high-tech Companies are taking effective steps to approach a sustainable future by monitoring and sharing environmental data and by focusing on green innovations at the same time.

Anyway, there exist opportunities for high-tech Companies to furtherly increase their sustainability efforts and improve sustainable outcomes, by improving communication and information flows throughout supply chains and all relevant stakeholders.

6.2.2. Regression Model

In this section a multiple regression model is presented with the main objective of understanding the various factors that influence the dependent variable “Green Product Innovation” among seven different high-tech companies.

1) Overview of the Results

<i>Regression Statistics</i>	
Multiple R	0.957
R square	0.915
Adjusted R square	0.831
Standard error	0.440
Observations	7

<i>ANOVA (Analysis Of Variance)</i>					
	<i>ddl</i>	<i>SQ</i>	<i>MQ</i>	<i>F</i>	<i>Significance F</i>
Regression	3	6.276	2.092	10.805	0.041
Residual	3	0.581	0.194		
Total	6	6.857			

<i>Predictor</i>	<i>Coefficients</i>	<i>Standard error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95,0%</i>	<i>Upper 95,0%</i>
Intercept	-0.967	1.196	-0.809	0.478	-4.772	2.838	-4.772	2.838
Variable X 1	0.432	0.157	2.756	0.070	-0.067	0.932	-0.067	0.932
Variable X 2	1.525	0.380	4.008	0.028	0.314	2.735	0.314	2.735
Variable X 3	-2.436	0.719	-3.385	0.043	-4.725	-0.146	-4.725	-0.146

Table 10 – Regression Model Outcome

The regression model was fitted using 28 total data points and the outcome in Table 10 shows a strong fit with a multiple R of 0.957, indicating an extended correlation between independent variables and the green product innovation. The R squared is 0.915 and express that 91.5% of the variation of the dependent variable can be referred to the change of the independent ones, highlighting the strength of the model fit.

The model comes with an inevitable standard error of 0.44 which depicts some minor variability in the innovation score that remains still unexplained.

Considering an alpha of 0.1 for the analysis, the overall F-statistic of 10.81 and its corresponding p-value of 0.041 exhibits that the regression model is statistically meaningful and that the null hypothesis (H0) can be rejected.

2) Analysis of Independent Variables

X1: Green Information Systems adoption within the organization

- Coefficient: 0.432
- t-statistic: 2.76
- p-value: 0.070

The positive coefficient for X1 suggests that the adoption of green information systems within an organization has a positive relationship with green product innovation. Companies that improve their data management and tracking capabilities tend to innovate more frequently and effectively in their business and strategy. This relationship is better highlighted in the scatterplot (Figure 10).

However, the p-value of 0.070 indicates marginal statistical significance at a 10% level of confidence, meaning the effect is not as robust as desired at the conventional 5% significance level.

The confidence interval for X1 ranges from -0.067 to 0.932, implying that while the effect is positive, there is some uncertainty surrounding the magnitude of the impact. This result suggests that further investment in internal green information systems might lead to improvements in green product innovation, though this relationship may not be universally strong and evident across all high-tech companies.

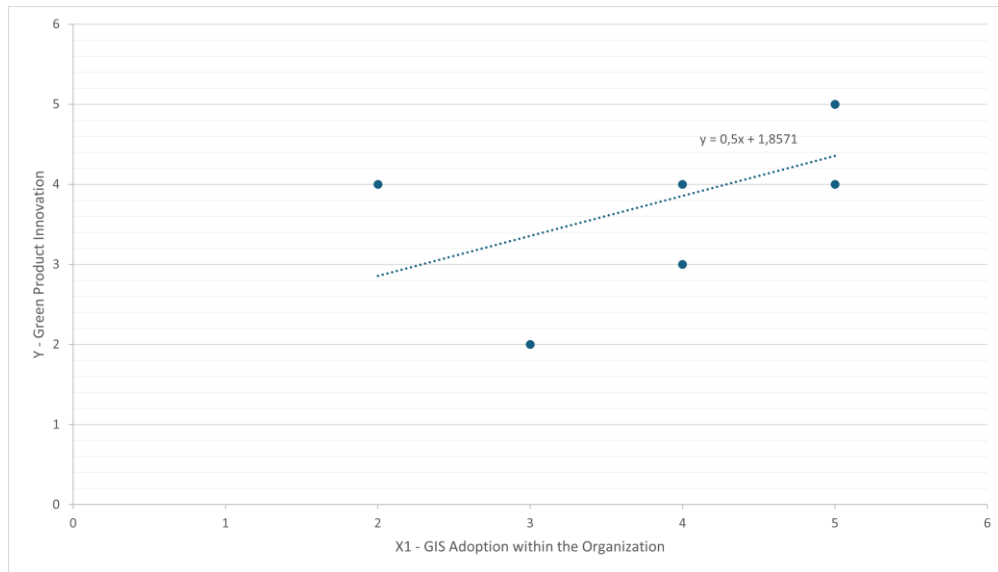


Figure 10 - Scatterplot X1:Y

X2: Green Information Systems adoption within the supply chain

- Coefficient: 1.525
- t-statistic: 4.010
- p-value: 0.028

The independent variable X2 shows a huge positive effect over green product innovation variable. With a coefficient of 1.525 and a very low p-value of 0.028, the adoption of green information systems within supply chain is vital for high-tech companies that intend to pursue green innovation in their long-term vision and strategy. Sharing environmental data in an effective and integrated way with consumers and suppliers is the milestone to stimulate future green innovations.

This relationship is also highlighted in the below scatterplot (Figure 11).

The quality of the fit and the reliability of the relationship between X2 and the dependent variable is clearer by looking at the confidence interval for X2, that ranges from 0.314 to 2.735, comprehending just positive values.

Companies will successfully innovate in sustainable areas if they are able to implement green information systems throughout the supply chain, ultimately benefitting from greater transparency, real-time data flow and more coordination across various stakeholders.

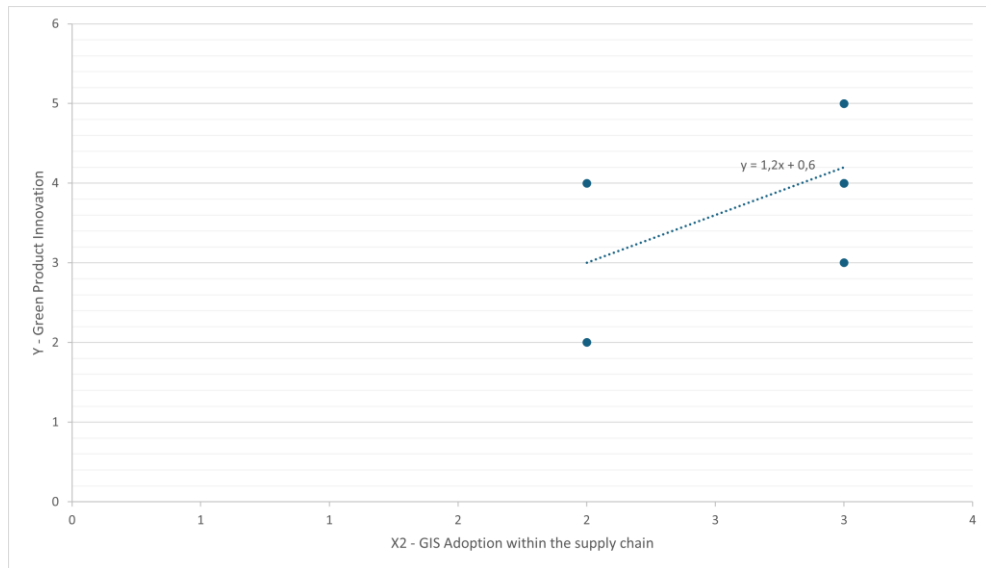


Figure 11 - Scatterplot X2:Y

X3: Main environmental objectives pursued through information systems (Dummy Variable)

- Coefficient: -2.436
- t-statistic: -3.390
- p-value: 0.043

The independent dummy variable X3, which represents the total number of different objectives to be pursued by each high-tech company through its information systems, has a significant negative coefficient of -2.436. This reveals that putting effort on a large number of environmental projects, in turn lowers down the levels of green product innovation. This is also depicted in the scatterplot (Figure 12).

The p-value of 0.043 indicates that this relationship is statistically significant at the 5% confidence level. The negative effect could imply that while pursuing multiple environmental goals is essential, it may initially detract from innovation by overburdening the company with competing priorities, resource demands or operational complexity. This is consistent with research that highlights the potential trade-offs and resource constraints companies face when pursuing aggressive sustainability goals.

The confidence level for X3 ranges from -4.725 to -0.146, which further validates that this negative relationship is spread and consistent across the companies.

High-tech companies should adopt a focused, comprehensive, and phased approach to pursue multiple environmental goals and projects for a long-term sustainable scenario, to avoid hindering green innovation.

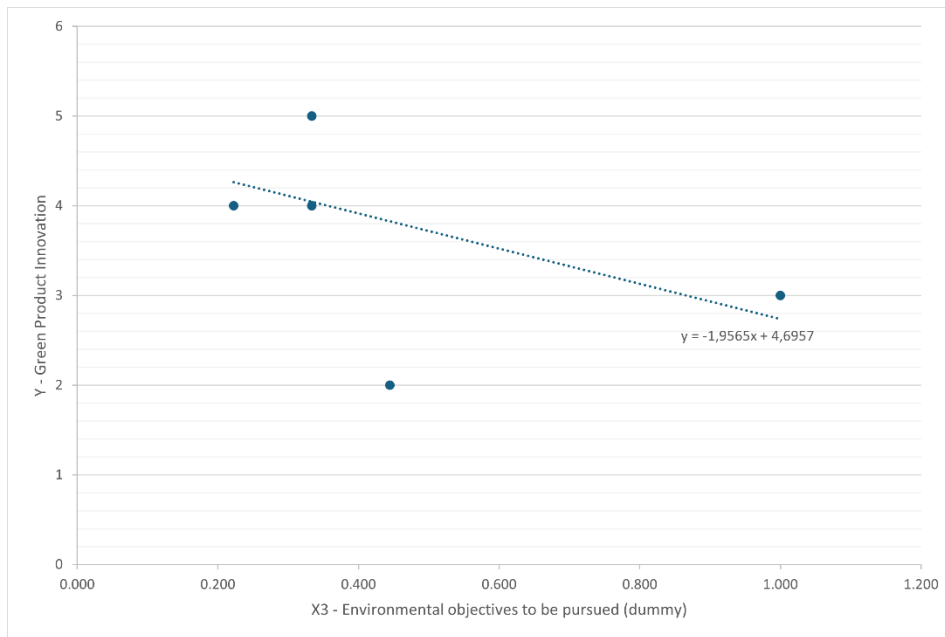


Figure 12 - Scatterplot X3:Y

3) Model Fit and Residual Analysis

The regression model fits the data with a good quality. The residual analysis shows a total of 0.581 for the residual sum of squares (RSS), compared to the total sum of squares (TSS) of 6.857, highlighting that the model itself explains most of the the independent variable's variability.

The presence of some residuals, anyway, cannot be neglected as other factors not included in the scope of this model such as company size, external market conditions or pressures, may also influence green product innovation.

4) Conclusion and Implications

This regression analysis provides new valuable insights into the factors influencing green product innovation in high-tech companies:

1. Supply chain integration as key driver: the most impactful factor is the adoption and integration of green information systems within the supply chain (X2 variable)
2. Green information systems internal adoption needs further studies: while this variable (X1) has a positive effect on green innovations, it is just marginally significant. Companies should surely invest in information system adoptions, but transparency and data sharing across supply chain remain crucial to ensure maximum results.

3. Challenges of seeking multiple environmental goals: the other most impactful factor, in negative terms, shows that pursuing too many objectives at once might hamper green innovation. A more focused, strategic approach may be necessary to balance long-term sustainability goals with immediate innovation demands.

Overall, this analysis marks the pivotal role of advanced data management and supply chain integration in driving green innovations in high-tech companies.

These insights reinforce the broader thesis that advanced data management, especially when extended across organizational boundaries, acts as a key enabler of sustainable innovation and net-zero strategies in the high-tech sector.

6.3. High Tech Company Interviews – Analysis

This sub-chapter delves into the interviews conducted with several high-tech companies to explore the adoption of Green Information Systems and their implications for sustainability strategies.

By analyzing these conversations, key needs and challenges are identified, alongside opportunities where AI could further enhance these practices.

Five different key themes have been highlighted during the companies' interviews:

1. Multi-Tier Supplier Management

Most of the high-tech companies prioritize Tier 1 suppliers due to resource constraints, data availability, and immediate impact. However, there is a growing recognition of the importance of addressing also lower-tier suppliers to enhance ESG compliance and reduce material supply risks.

The main challenge is the limited visibility and control over Tier 2 and Tier 3 suppliers, which in turns create hurdles in enforcing sustainability standards.

2. Bargaining Power Dynamics in Supply Chains

High-tech companies with higher market share or critical positions in the supply chain leverage their influence to push sustainability agendas. However, smaller players often lack the leverage to enforce compliance among big or key suppliers.

AI-powered decision support systems can simulate and forecast the impact of sustainability requirements on supply chains, helping companies negotiate effectively with suppliers and align incentives. This ultimately helps the players across the supply chain to enhance their sustainable strategies and to be comply in terms of green regulations.

3. Emerging Standards and Data Biases

Several of the interviewed companies are transitioning from voluntary compliance to more structured requirements, such as integrating sustainability clauses in supplier contracts and using platforms and sustainable tools like EcoVadis or IntegrityNext for ESG scoring.

The main blockers in this context are data quality and information sharing issues. Suppliers, in fact, are often resistant in providing transparent and reliable information. This aggravates data biases in ESG reporting, as the input data is not fully accurate or reliable. The output, in turn, will be inaccurate and misleading as well.

There exist AI opportunities with blockchain to improve data sharing and quality and AI-driven audit tools which can automate ESG data collection and validation, ensuring higher accuracy and consistency in reporting and in complying with regulations, while reducing manual efforts at the same time.

4. Innovation through Green Product Development

Sustainability goals and strategies often catalyze innovations, such as the replacement of hazardous materials with eco-friendly alternatives.

However, these innovations are often constrained by cost considerations and technological feasibility.

AI could step in to optimize material selection and process design, identifying cost-effective green alternatives and simulating their performance across the product lifecycle.

5. The Cascading Effect of Client Demands

Clients, particularly large corporations, increasingly demand detailed sustainability data and practices from suppliers. This cascading effect drives changes upstream, even among reluctant suppliers.

AI can act as a mediator by creating intelligent dashboards (ex: through QuickSight) that provide clients and suppliers with real-time visibility into compliance levels, fostering trust, collaboration and information sharing.

The interviews highlight that companies are making strides in adopting Green Information Systems.

The integration of AI presents transformative opportunities in this scenario: from automating supplier assessments to optimizing green product innovations, AI could act as a pivotal enabler in overcoming challenges like data quality, compliance resistance, and cost barriers. By embedding AI in GIS frameworks, companies can achieve greater scalability, precision, and impact in their sustainability efforts.

The following chapter will progress with the analysis of some patents which showcase the current trends and sector of application of AI innovations.

The aim of the next section of the analysis is to understand if current innovations are going in the direction highlighted before.

In particular, if AI-focused innovations are emerging in fields like Supply Chain Management, data sharing and transparency or for green platforms for sustainability.

6.4. Patents

Building on the insights gathered from the company interviews, this chapter presents the results of patents' analysis.

Patents are a unique lens to evaluate technological innovation in AI-driven data management and sustainability. They offer concrete evidence about the actual innovation trends and trajectories. By examining innovations' filings, it can be evaluated whether they align with the challenges, needs, and opportunities identified in the interviews' analyses.

Patents filings provide indeed a valuable lens to evaluate the technological innovations in the modern society, and their alignment with the net-zero principles.

They highlight how high-tech companies are leveraging their transformative capabilities to address environmental concerns.

They can be leveraged to develop and exploit new solutions to address the arising environmental concerns, especially considering the high-tech companies, with their global impact and their transformative technological capabilities.

This chapter specifically explores whether the opportunities identified in earlier sections are being translated into actual technological developments. It is structured into four main sections: Sectoral Analysis; Geographic Distribution; Temporal Evolution and Implications and Challenges.

The final objective is to provide a holistic insight into the state of innovation in sustainability and artificial intelligence across different sectors and perspectives, looking at possible future directions for environmentally responsible technological advancement.

6.4.1. Sectoral analysis

Patents | Sector of Application

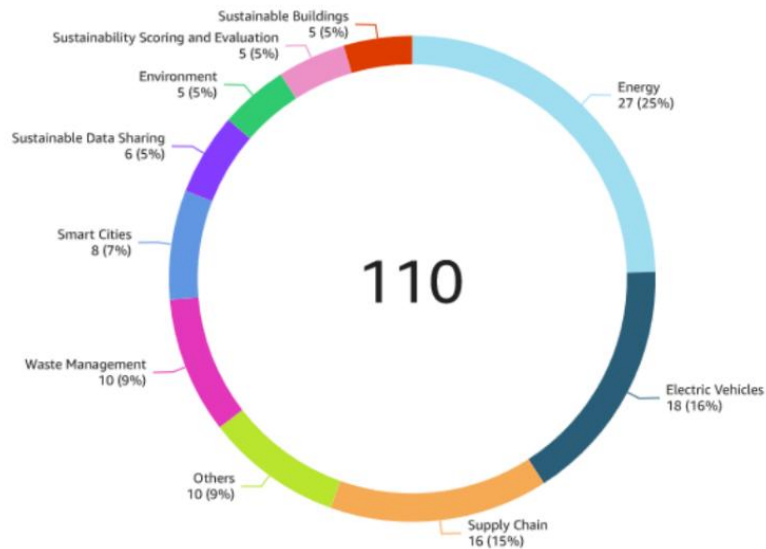


Figure 13 - Patents by Sector of Application

The analysis reveals a very diverse range of applications for AI-driven innovations in achieving sustainability.

The donut chart above (Figure 13) illustrates patents' distribution across various application domains, with a total of 110 different patents considered.

The primary sectors of application are:

1. Energy (24.5% of the total): with 27 patents addressing this sector. More in detail, the main sub-fields regard: energy efficiency and management, looking at optimization opportunities, also across the Supply Chains; Smart Grids and energy distribution, ensuring smart management of fluctuating energy demands and seeking opportunities for renewables integration into smart grids (i.e: photovoltaic cells' integration into smart grids); AI-enabled energy forecast and management.

2. Electric Vehicles (16.4% of the total): with 18 patents addressing this domain. Innovations focus on: Battery Management Systems (BMS) looking at AI-driven systems for monitoring, managing, and optimizing battery performance and health; Charging Infrastructure and Scheduling.

3. Supply Chain (14.5% of the total): with 16 patents addressing this sector. More in depth, the identified areas are: AI-driven optimization regarding risk management, frameworks for sustainable manufacturing, carbon emission monitoring systems in logistics, sustainable business practices' implementation and data transparency.

4. Waste Management (9.1% of the total): with 10 patents addressing this domain. Some innovations address physical solutions for an optimized waste collection, management and recover such as the smart trash bins integrated with AI and IoT. Others, instead, regard AI-powered systems which optimize collection schedules, improve energy conversions and recycling processes, and ultimately promote sustainable practices.

5. Smart Cities (7.3% of the total): with 8 patents addressing this sector. The predominant area here is the application of AI, IoT and ML capabilities to design and develop environmentally friendly smart cities, with solutions aiming at: sustainable energy solutions, data-driven solutions for urban planning and management; smarter infrastructures.

6. Sustainable Data Sharing (5.5% of the total): with 6 patents addressing this domain. AI-powered systems enable efficient and secure data sharing to support sustainability initiatives. Leveraging blockchain, AI and predictive analytics, these tools enhance transparent collaboration across relevant stakeholders, thus accelerating global sustainability efforts.

7. Sustainable Scoring and Evaluation Platforms (4.5% of the total): with 5 patents. These encompass AI-driven systems and tools which measure, analyze, optimize and track sustainability across organizations and stakeholders. Key applications are diverse: carbon footprint tracking, real time sustainability scoring and KPIs calculations, automated life cycle assessments.

8. Environmental Monitoring (4.5% of the total): with 5 patents. AI and IoT solutions integrated with drones are employed for real-time environmental monitoring, addressing challenges like biodiversity conservation, air and water quality analysis and disaster response procedures. By combining robust data collection and predictive analytics, these systems unlock fast and proactive decision-making and enhance the overall resilience of natural ecosystems.

9. Sustainable Buildings (4.5% of the total): with 5 patents addressing this sector. These AI-driven innovations focus on better energy efficiency, reducing carbon emissions, enhancing resource utilization in buildings and supporting sustainable building practices.

10. Others (9.1% of the total): with 10 patents encapsulating diverse other application domains from green project management to organizational flexibility and regulatory compliance. AI is leveraged to enhance agility, for sustainable resource management or fostering responsible consumption. This in turn provide double benefit to organizations: aligning activities with broader sustainable goals on one hand and promoting economic and environmental benefits on the other.

This analysis revealed how AI innovations for sustainability are manifesting and arising differently across high-tech domains. The highlighted trends showed the diversity of applications on one side (from energy to environmental monitoring or smart cities) and the growing strategic importance of data-driven technologies to unlock green outcomes in the future on the other.

Moreover, these findings also provide a wide view about how companies are positioning themselves for future competitiveness.

6.4.2. Geographic Distribution

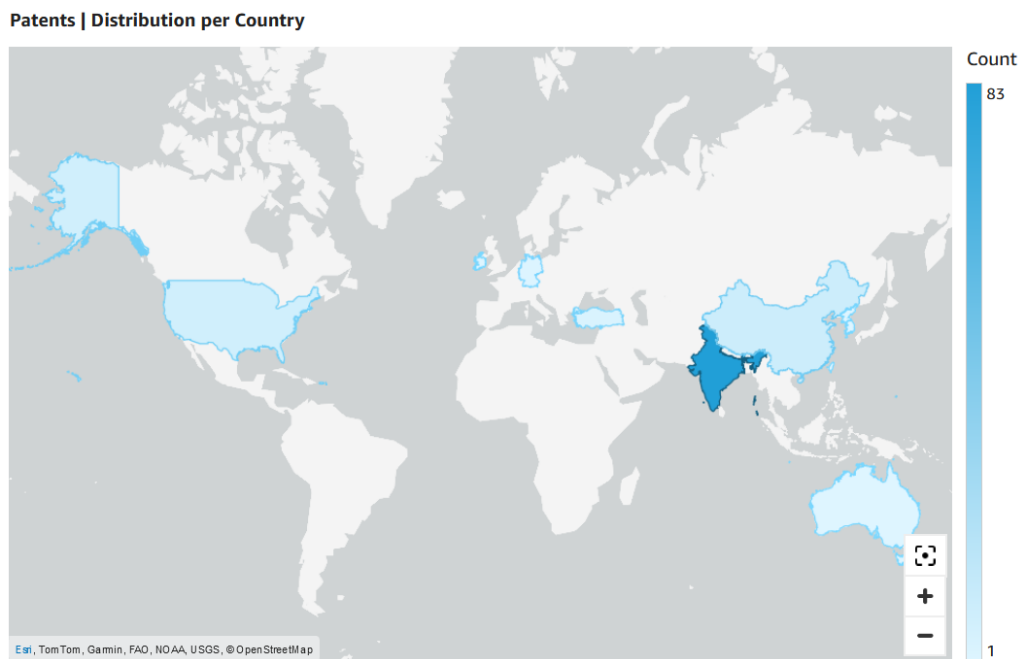


Figure 14 – Patents Distribution per Country, Heatmap

The geographic analysis considers the country of patents filing to the determine the locations highlighted in the above heatmap (Figure 14).

Table 11 reveals huge patent activity in India which seems to be the leader in innovation regarding the patents under analysis with more than 75% of the total patents analyzed (75.5%, 83 total patents), followed by China (8.2%, 9 patents), United States of America (6.4%, 7 patents) and smaller contributions from Turkey (2.7%, 3 patents), Germany (1.8%, 2 patents) and other countries.

Patents | Distribution per Country

Country	Count	Percentage
Australia	1	0.01
China	9	0.08
Germany	2	0.02
India	83	0.75
Ireland	1	0.01
Korea	1	0.01
Not specified	1	0.01
South Korea	1	0.01
Taiwan	1	0.01
Turkey	3	0.03
USA	7	0.06
	110	1

Table 11 - Patents Distribution per Country

India stands out as the biggest player as the country with a much growing tech industry ecosystem, with skilled workforce and relatively low cost of R&D, which furtherly contribute to innovations' spillovers. Moreover, the Indian government is pushing IP and patents generations through national initiatives such as 'Make in India' or 'Startup India', aiming at attracting Foreign Direct Investments (FDI), industrial investment and building a robust startup ecosystem (Startup India, 2024) (Make in India, 2024).

At the same time, this nation faces pressing environmental challenges like pollution, energy inefficiencies, resource scarcity. This may be reflected in the sector of applications of Indian high-tech innovations. Predominant areas, in fact, are the ones regarding electric vehicles (21,7%), energy (20,5%), supply chain (15,7%) and waste management (12,0%) as shown in

Patents | India Detail

Sector of Application	Count	Percentage
Electric Vehicles	18	0.22
Energy	17	0.21
Environment	5	0.06
Others	7	0.08
Smart Cities	8	0.1
Supply Chain	13	0.16
Sustainability Scoring and Evaluation	1	0.01
Sustainable Buildings	3	0.04
Sustainable Data Sharing	1	0.01
Waste Management	10	0.12
	83	1

Table 12 - Patents, India Detail

There are clearly global disparities as many countries are not investing and pursuing a significant innovation path. The reasons behind can be multifaceted: different governments and companies' priorities, inefficient use of policies as tool to push innovations towards greener directions, no funds to be invested or poor or nonexistent internet access for the population, especially in the African continent, where also basic technological infrastructure is often missing. This can trigger many discussions as "Special attention should be paid to implications of unequal data access that can result in digital poverty and hence increase inequalities instead of reducing the gap" (Mondejar et al., 2021).

There exist opportunities to foster global collaboration and knowledge-sharing, to address these gaps and efficiently tackle sustainability issues in a coordinated way, ensuring countries are not left behind.

This result is very meaningful as in the actual globalized world every participant should act proactively or be supported by others when needed, especially while tackling very urgent challenges such as the climate change, that poses very serious threats for everyone. Only through collective responsibility and support can AI-driven sustainability transitions succeed on a truly global scale.

6.4.3. Temporal Evolution

Patents | Year of Publication

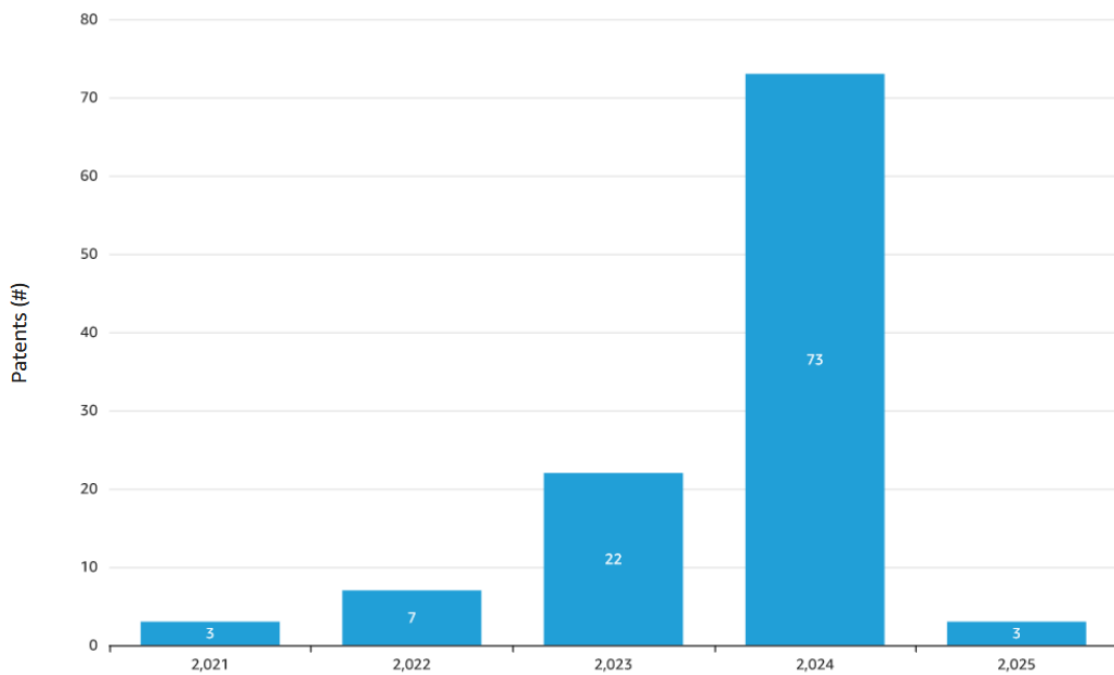


Figure 15 - Patents Temporal Evolution

The temporal analysis of patents publication shows a significant acceleration in AI sustainable innovations from 2021 to 2025, peaking in 2024. This particular year has been characterized by the release of 73 patents, which count for more than half (66,4%) of the entire dataset of 110 patents. This trend underscores a concentrated period of innovation in AI-driven sustainability and data management.

The number of patents steadily grew from 3 in 2021, to 7 in 2022, 22 in 2023 and 73 in 2024, a period of intense innovation driven by multiple factors.

Also 2025 sees 3 patents published and given the time of this analysis, this number will likely increase as the year unfolds and the technologies' development continues.

Looking ahead, maintaining this momentum in 2025 and beyond will require sustained investment in R&D, fostering collaboration across industries, and aligning innovation efforts with long-term sustainability objectives.

6.4.4. Implications and Challenges

This patent deep dive showed that Artificial Intelligence-driven innovations are indeed addressing the core challenges and needs highlighted in the primary data and company interviews' analysis, particularly in the supply chain domain. Key issues such as: limited visibility across multi-tier suppliers, poor data quality and lack of transparency which hinder compliance and sustainable strategies, opportunities to integrate GIS into SC to effectively stimulate green innovations. Also from the correlation analysis, companies should emphasize GIS integration across SC, which is where the true potential lies.

Moreover, there exist also specific patents that target Sustainable Data Sharing and Sustainable Evaluation and Scoring platform, meaning that actual pressing challenges faced by high-tech companies find a positive response in innovations, which are going in that precise direction.

This shows a proactive response to pressing business needs and reflects a growing alignment between technological advancements and environmental objectives.

On the other hand, these sectors are not seen as a central opportunity and priority compared to the energy one which dominates the landscape. High-tech companies can leverage their AI and data management tools and capabilities to furtherly innovate and unlock new possibilities in these domains, thus additionally contributing to a more sustainable future and accelerating the path towards sustainable outcomes.

This patent analysis is a good basis to understand the current scenario on AI-driven innovation for sustainability, but it should be viewed as a starting point.

First of all, continuous updates to include all latest patents in the initial dataset is needed. This ensures maximum coverage of the innovation landscape every time.

Another opportunity to enlarge the scope of this analysis is by going beyond the high-tech boundaries of this document, including other organizations' types and historical data from years ago as well, with the purpose of understanding trends and key areas that can drive significant sustainable improvements in the future years.

This analysis pointed out the relevant impact of India regarding innovations' publications, but this doesn't mean that other countries are not innovating.

Future studies should also dive deep in conducting more granular analysis for underrepresented regions, investigating possible blockers or mediating factors which are hindering innovation and AI adoption, thus arising possible point of attention regarding the path to a global net-zero agenda.

Ultimately, this patent analysis offers a foundation for understanding the current innovation landscape at the intersection of AI and sustainability. It delivers actionable insights for companies and researchers alike, pointing to both current achievements and emerging opportunities. With continued research and global collaboration, these technologies can play a pivotal role in supporting the net-zero transition.

The following chapter will conclude the entire thesis, wrapping up contents, insights, current opportunities and actual challenges.

7. Conclusion

AI is definitely a booming trend nowadays. Its impact can be already seen across countries, companies and fields and it's expected to grow exponentially in future years. This document emphasized its role within high-tech companies, focusing on the sustainability opportunities and threats that can arise.

On one side AI is a value adder resource for green purposes: rapid and effective data management enhances efficiency across energy, ecodesign, infrastructures and along the supply chain, abating carbon emissions in concrete applications.

Another additional aspect pertains to the indirect effects that AI has on high-tech companies, in particular in reducing cognitive biases in decision-making and enabling a robust and data-driven environmental governance. High-tech companies can improve green innovation and align their high-level strategies with decarbonization goals, even in turbulent environments. AI accelerates sustainability and enhances high-tech organizations' adaptability, thus enabling them to stay competitive while pursuing environmental goals, such as SDGs.

On the other hand, concerns and challenges are part of this technological transformation. First of all, the energy consumption of AI, which threatens sustainability. Implementation costs and disparities are another blocker to an effective AI implementation and limit its overall effectiveness. Moreover, ethical concerns regarding data security and privacy are arising. Policies can mitigate these downsides, pushing innovations and green AI adoption or by protecting data integrity, as the EU AI Act. Leaders, people, digital capabilities and a holistic data driven culture complement the scenario, contributing to the effective usage and leverage of AI for greener outcomes.

Looking ahead, Sustainable Agentic AI is a powerful future opportunity to furtherly pushing the boundaries for a greener future. Future AI research and applications should focus on this, always noticing its potential drawbacks.

Primary data from seven main high-tech companies showed current efforts put into the integration of GIS to enhance sustainability within the high-tech organizations. In particular, while firms are effectively tracking internal environmental performance, they struggle in having a successful GIS adoption within the supply chain.

Many gaps remain in this context, such as supply chain transparency and data sharing, which are currently blocking the effectiveness of sustainable practices in these companies. Later, the analysis of the interviews confirmed outlined challenges as supplier management and data sharing, thus contributing to weaken ESG compliance.

Patents analysis provided a comprehensive overview of current AI innovations, highlighting the sectors where they are most prevalent, such as energy, electric vehicles, and supply chain applications. In particular, some of the advancements are going towards the needs and gaps seen in the primary data analysis, such as the ones regarding Sustainable Data Sharing and Sustainable Scoring and Evaluation Platforms.

Patents' geographic distribution and temporal evolution provided more details, showing that India is by far the key player in AI progresses. Patents' publication showed an exponential trend from 2021 to 2024, remarking the huge attention to AI topic and advancements nowadays and possibly forecasting a similar growing trend for 2025.

7.1. Study Limitations and Implications

This study is set towards high-tech companies' landscape, but this considers just a portion of the possible actors towards a green future. Small and Medium Businesses (SMBs) can be huge players in accelerating climate change as they represent the vast majority of businesses in certain areas or countries (such as Italy or Spain). Being able to understand how these entities can embrace digital transformation and effectively use AI to mitigate their emissions or lower down their environmental burden is critical to ensure a huge and future push towards sustainability.

Another limitation lies in the data source leveraged in this analysis. A larger and more diversified dataset would unveil additional stronger insights, delivering a more robust statistical analysis and broader results' generalizability.

Additionally, patents are the pulse of the current innovations and future analysis must always capture the latest publications.

Longitudinal analysis of historical patent data would offer deeper insights into how technological development is progressing and in which areas and countries in the world.

7.2. Future Opportunities and Challenges

This report provides an integrated view about current AI applications and advancements for sustainability. It opens the door for future considerations regarding the correct usage of this powerful technology, especially considering the actual constraints and challenges.

Future research should deep-dive and empirically validate the proposed framework through studies and industry case applications, selecting different high-tech companies across multiple sectors.

This would help validate whether the framework fully captures the interplay between AI and sustainability or whether integrations and further development are needed. Such analysis will support organizations in operationalizing and developing AI within their structure in a concrete and sustainable way.

Agentic AI is a powerful opportunity but still a complex frontier. It needs more study to understand how it can be practically implemented in sustainability strategies and organizations, while ensuring a real-world adoption. AWS is currently heavily pushing on Agentic AI development and adoption, so in the future ad hoc case studies can contribute to gain knowledge from experts, which can be in turn applied and deployed in green realms. At the same time, due diligence and governance frameworks must evolve to address new arising concerns and to protect data integrity of all relevant people and stakeholders.

Moreover, Artificial Intelligence is currently transitioning from a being a tool leveraged by people to a possible future teammate. A central question remains: How will the relationship between AI or AI agents and humans evolve?

There are considerations regarding the delegation of the decision making to a machine which must be done. Additionally, people may fear these huge AI advancements in such a short period of time. Very few companies are putting mechanisms and strategies in place to mitigate the outlined challenges (Mary Mesaglio, 2025), so further studies should investigate how firms can establish robust strategies to manage this radical shift and ensure AI adoption will be secure, inclusive, and aligned with both long-term societal and environmental values.

8. References

8.1. Bibliography

- Aftab, J., Abid, N., Sarwar, H., Amin, A., Abedini, M., & Veneziani, M. (2024). Does corporate social responsibility drive financial performance? Exploring the significance of green innovation, green dynamic capabilities, and perceived environmental volatility. *Corporate Social Responsibility and Environmental Management*, 31(3), 1634–1653. <https://doi.org/10.1002/csr.2654>
- Ahmad, T., Zhang, D., Huang, C., Zhang, H., Dai, N., Song, Y., & Chen, H. (2021). Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities. In *Journal of Cleaner Production* (Vol. 289). Elsevier Ltd. <https://doi.org/10.1016/j.jclepro.2021.125834>
- Alzoubi, Y. I., & Mishra, A. (2024). Green artificial intelligence initiatives: Potentials and challenges. *Journal of Cleaner Production*, 468. <https://doi.org/10.1016/j.jclepro.2024.143090>
- Bag, S., Pretorius, J. H. C., Gupta, S., & Dwivedi, Y. K. (2021). Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities. *Technological Forecasting and Social Change*, 163. <https://doi.org/10.1016/j.techfore.2020.120420>
- Bag, S., Yadav, G., Dhamija, P., & Kataria, K. K. (2021). Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: An empirical study. *Journal of Cleaner Production*, 281. <https://doi.org/10.1016/j.jclepro.2020.125233>
- Blog Post PDF Download Eco Plastics in Packaging Article.* (n.d.).
- Cadden, T., Dennehy, D., Mantymaki, M., & Treacy, R. (2022). Understanding the influential and mediating role of cultural enablers of AI integration to supply chain. *International Journal of Production Research*, 60(14), 4592–4620. <https://doi.org/10.1080/00207543.2021.1946614>
- Chatterjee, S., Chaudhuri, R., Kamble, S., Gupta, S., & Sivarajah, U. (2023). Adoption of Artificial Intelligence and Cutting-Edge Technologies for Production System Sustainability: A Moderator-Mediation Analysis. *Information Systems Frontiers*, 25(5), 1779–1794. <https://doi.org/10.1007/s10796-022-10317-x>
- Chen, A., Yang, T., Ma, J., & Lu, Y. (2023). Employees' learning behavior in the context of AI collaboration: a perspective on the job demand-control model. *Industrial*

- Management and Data Systems*, 123(8), 2169–2193.
<https://doi.org/10.1108/IMDS-04-2022-0221>
- Collins, C., Dennehy, D., Conboy, K., & Mikalef, P. (2021). Artificial intelligence in information systems research: A systematic literature review and research agenda. *International Journal of Information Management*, 60.
<https://doi.org/10.1016/j.ijinfomgt.2021.102383>
- De Smet, A., Gao, W., Henderson, K., & Hundertmark, T. (2021). *Organization and Sustainability Practices*.
- Del Río Castro, G., González Fernández, M. C., & Uruburu Colsa, Á. (2021). Unleashing the convergence amid digitalization and sustainability towards pursuing the Sustainable Development Goals (SDGs): A holistic review. In *Journal of Cleaner Production* (Vol. 280). Elsevier Ltd. <https://doi.org/10.1016/j.jclepro.2020.122204>
- Di Vaio, A., Palladino, R., Hassan, R., & Escobar, O. (2020). Artificial intelligence and business models in the sustainable development goals perspective: A systematic literature review. *Journal of Business Research*, 121, 283–314.
<https://doi.org/10.1016/j.jbusres.2020.08.019>
- Díaz, A., Rowshankish, K., & Saleh, T. (n.d.). *Why data culture matters*.
- Felipe, C. M., Leidner, D. E., Roldán, J. L., & Leal-Rodríguez, A. L. (2020a). Impact of IS Capabilities on Firm Performance: The Roles of Organizational Agility and Industry Technology Intensity. *Decision Sciences*, 51(3), 575–619.
<https://doi.org/10.1111/dec.12379>
- Felipe, C. M., Leidner, D. E., Roldán, J. L., & Leal-Rodríguez, A. L. (2020b). Impact of IS Capabilities on Firm Performance: The Roles of Organizational Agility and Industry Technology Intensity. *Decision Sciences*, 51(3), 575–619.
<https://doi.org/10.1111/dec.12379>
- Ferreira, J. J., Lopes, J. M., Gomes, S., & Rammal, H. G. (2023). Industry 4.0 implementation: Environmental and social sustainability in manufacturing multinational enterprises. *Journal of Cleaner Production*, 404.
<https://doi.org/10.1016/j.jclepro.2023.136841>
- Fosso Wamba, S. (2022). Impact of artificial intelligence assimilation on firm performance: The mediating effects of organizational agility and customer agility.

- International Journal of Information Management*, 67.
<https://doi.org/10.1016/j.ijinfomgt.2022.102544>
- Fosso Wamba, S., Queiroz, M. M., Pappas, I. O., & Sullivan, Y. (2024). Artificial Intelligence Capability and Firm Performance: A Sustainable Development Perspective by the Mediating Role of Data-Driven Culture. *Information Systems Frontiers*. <https://doi.org/10.1007/s10796-023-10460-z>
- Gao, Y. (2023). Unleashing the mechanism among environmental regulation, artificial intelligence, and global value chain leaps: a roadmap toward digital revolution and environmental sustainability. *Environmental Science and Pollution Research*, 30(10), 28107–28117. <https://doi.org/10.1007/s11356-022-23898-6>
- Ghafarirollahi, A., & Buehler, M. J. (2024). *SciAgents: Automating scientific discovery through multi-agent intelligent graph reasoning*. <https://doi.org/10.1002/adma.202413523>
- Himeur, Y., Ghanem, K., Alsalemi, A., Bensaali, F., & Amira, A. (2021). Artificial intelligence based anomaly detection of energy consumption in buildings: A review, current trends and new perspectives. In *Applied Energy* (Vol. 287). Elsevier Ltd. <https://doi.org/10.1016/j.apenergy.2021.116601>
- Jiang, H., He, B., Mubarik, M. S., & Shi, S. (2024). Role of supply chain digitalization and global supply chain in decarbonization of natural resources sector supply chain. *Journal of Environmental Management*, 370. <https://doi.org/10.1016/j.jenvman.2024.122689>
- Khan, A. N., Mehmood, K., & Ali, A. (2024). Maximizing CSR impact: Leveraging artificial intelligence and process optimization for sustainability performance management. *Corporate Social Responsibility and Environmental Management*. <https://doi.org/10.1002/csr.2832>
- Kwon, H. B., & Lee, J. (2019). Exploring the differential impact of environmental sustainability, operational efficiency, and corporate reputation on market valuation in high-tech-oriented firms. *International Journal of Production Economics*, 211, 1–14. <https://doi.org/10.1016/j.ijpe.2019.01.034>
- Lopes, J. M. M., Gomes, S., & Trancoso, T. (2024). Navigating the green maze: insights for businesses on consumer decision-making and the mediating role of their

- environmental concerns. *Sustainability Accounting, Management and Policy Journal*, 15(4), 861–883. <https://doi.org/10.1108/SAMPJ-07-2023-0492>
- Lu, H. T., Li, X., & Yuen, K. F. (2023). Digital transformation as an enabler of sustainability innovation and performance – Information processing and innovation ambidexterity perspectives. *Technological Forecasting and Social Change*, 196. <https://doi.org/10.1016/j.techfore.2023.122860>
- Mehmood, K., Kautish, P., Mangla, S. K., Ali, A., & Kazancoglu, Y. (2024). Navigating a net-zero economy future: Antecedents and consequences of net-zero economy-based green innovation. *Business Strategy and the Environment*, 33(5), 4175–4197. <https://doi.org/10.1002/bse.3685>
- Meng, X., Xu, S., & Zhang, J. (2022). How does industrial intelligence affect carbon intensity in China? Empirical analysis based on Chinese provincial panel data. *Journal of Cleaner Production*, 376. <https://doi.org/10.1016/j.jclepro.2022.134273>
- Mondejar, M. E., Avtar, R., Diaz, H. L. B., Dubey, R. K., Esteban, J., Gómez-Morales, A., Hallam, B., Mbungu, N. T., Okolo, C. C., Prasad, K. A., She, Q., & Garcia-Segura, S. (2021). Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet. In *Science of the Total Environment* (Vol. 794). Elsevier B.V. <https://doi.org/10.1016/j.scitotenv.2021.148539>
- Mousavi, S., Bossink, B., & van Vliet, M. (2019). Microfoundations of companies' dynamic capabilities for environmentally sustainable innovation: Case study insights from high-tech innovation in science-based companies. *Business Strategy and the Environment*, 28(2), 366–387. <https://doi.org/10.1002/bse.2255>
- Moyano-Fuentes, J., Maqueira-Marín, J. M., & Bruque-Cámara, S. (2018). Process innovation and environmental sustainability engagement: An application on technological firms. *Journal of Cleaner Production*, 171, 844–856. <https://doi.org/10.1016/j.jclepro.2017.10.067>
- MSCI ESG Research LLC. (2023).
- Nayal, K., Kumar, S., Raut, R. D., Queiroz, M. M., Priyadarshinee, P., & Narkhede, B. E. (2022). Supply chain firm performance in circular economy and digital era to achieve sustainable development goals. *Business Strategy and the Environment*, 31(3), 1058–1073. <https://doi.org/10.1002/bse.2935>

- Nishant, R., Kennedy, M., & Corbett, J. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. *International Journal of Information Management*, 53. <https://doi.org/10.1016/j.ijinfomgt.2020.102104>
- Odugbesan, J. A., Aghazadeh, S., Al Qaralleh, R. E., & Sogeke, O. S. (2023). Green talent management and employees' innovative work behavior: the roles of artificial intelligence and transformational leadership. *Journal of Knowledge Management*, 27(3), 696–716. <https://doi.org/10.1108/JKM-08-2021-0601>
- Ogbeibu, S., Emelifeonwu, J., Pereira, V., Oseghale, R., Gaskin, J., Sivarajah, U., & Gunasekaran, A. (2024). Demystifying the roles of organisational smart technology, artificial intelligence, robotics and algorithms capability: A strategy for green human resource management and environmental sustainability. *Business Strategy and the Environment*, 33(2), 369–388. <https://doi.org/10.1002/bse.3495>
- Ogbeibu, S., Jabbour, C. J. C., Gaskin, J., Senadjki, A., & Hughes, M. (2021). Leveraging STARA competencies and green creativity to boost green organisational innovative evidence: A praxis for sustainable development. *Business Strategy and the Environment*, 30(5), 2421–2440. <https://doi.org/10.1002/bse.2754>
- Ortiz-Avram, D., Ovcharova, N., & Engelmann, A. (2024). Dynamic capabilities for sustainability: Toward a typology based on dimensions of sustainability-oriented innovation and stakeholder integration. *Business Strategy and the Environment*, 33(4), 2969–3004. <https://doi.org/10.1002/bse.3630>
- Paparoidamis, N. G., Tran, T. T. H., Leonidou, L. C., & Zeriti, A. (2019). Being Innovative While Being Green: An Experimental Inquiry into How Consumers Respond to Eco-Innovative Product Designs. *Journal of Product Innovation Management*, 36(6), 824–847. <https://doi.org/10.1111/jpim.12509>
- Rasheed, M. Q., Yuhuan, Z., Haseeb, A., Ahmed, Z., & Saud, S. (2024). Asymmetric relationship between competitive industrial performance, renewable energy, industrialization, and carbon footprint: Does artificial intelligence matter for environmental sustainability? *Applied Energy*, 367. <https://doi.org/10.1016/j.apenergy.2024.123346>
- Riggs, R., Felipe, C. M., Roldán, J. L., & Real, J. C. (2024). Information systems capabilities value creation through circular economy practices in uncertain environments: A

- conditional mediation model. *Journal of Business Research*, 175. <https://doi.org/10.1016/j.jbusres.2024.114526>
- Rusch, M., Schöggel, J. P., & Baumgartner, R. J. (2023). Application of digital technologies for sustainable product management in a circular economy: A review. *Business Strategy and the Environment*, 32(3), 1159–1174. <https://doi.org/10.1002/bse.3099>
- Sanders, N. R., Boone, T., Ganeshan, R., & Wood, J. D. (2019). Sustainable Supply Chains in the Age of AI and Digitization: Research Challenges and Opportunities. In *Journal of Business Logistics* (Vol. 40, Issue 3, pp. 229–240). Wiley-Blackwell. <https://doi.org/10.1111/jbl.12224>
- Schmidt, J. L., Sehnem, S., & Spuldaro, J. D. (2024). Blockchain and the transition to the circular economy: A literature review. *Corporate Social Responsibility and Environmental Management*, 31(3), 2010–2032. <https://doi.org/10.1002/csr.2674>
- Schöggel, J. P., Rusch, M., Stumpf, L., & Baumgartner, R. J. (2023). Implementation of digital technologies for a circular economy and sustainability management in the manufacturing sector. *Sustainable Production and Consumption*, 35, 401–420. <https://doi.org/10.1016/j.spc.2022.11.012>
- Shankar, A., Behl, A., Pereira, V., Chavan, M., & Chirico, F. (2024). Exploring enablers and inhibitors of AI-enabled drones for manufacturing process audits: A mixed-method approach. *Business Strategy and the Environment*, 33(5), 3749–3768. <https://doi.org/10.1002/bse.3679>
- Song, M., Fisher, R., & Kwoh, Y. (2019). Technological challenges of green innovation and sustainable resource management with large scale data. *Technological Forecasting and Social Change*, 144, 361–368. <https://doi.org/10.1016/j.techfore.2018.07.055>
- Tao, M. (2024). Digital brains, green gains: Artificial intelligence's path to sustainable transformation. *Journal of Environmental Management*, 370. <https://doi.org/10.1016/j.jenvman.2024.122679>
- Truby, J. (2020). Governing Artificial Intelligence to benefit the UN Sustainable Development Goals. *Sustainable Development*, 28(4), 946–959. <https://doi.org/10.1002/sd.2048>
- Tseng, M. L., Ha, H. M., Tran, T. P. T., Bui, T. D., Chen, C. C., & Lin, C. W. (2022). Building a data-driven circular supply chain hierarchical structure: Resource recovery

- implementation drives circular business strategy. *Business Strategy and the Environment*, 31(5), 2082–2106. <https://doi.org/10.1002/bse.3009>
- Venkatesh, V. G., Kang, K., Wang, B., Zhong, R. Y., & Zhang, A. (2020). System architecture for blockchain based transparency of supply chain social sustainability. *Robotics and Computer-Integrated Manufacturing*, 63. <https://doi.org/10.1016/j.rcim.2019.101896>
- Wang, Q., Zhang, F., Li, R., & Sun, J. (2024). Does artificial intelligence promote energy transition and curb carbon emissions? The role of trade openness. *Journal of Cleaner Production*, 447. <https://doi.org/10.1016/j.jclepro.2024.141298>
- Wang, X., Lin, X., & Shao, B. (2022). How does artificial intelligence create business agility? Evidence from chatbots. *International Journal of Information Management*, 66. <https://doi.org/10.1016/j.ijinfomgt.2022.102535>
- Wu, Y., Wu, Y., Cimen, H., Vasquez, J. C., & Guerrero, J. M. (2022). Towards collective energy Community: Potential roles of microgrid and blockchain to go beyond P2P energy trading. In *Applied Energy* (Vol. 314). Elsevier Ltd. <https://doi.org/10.1016/j.apenergy.2022.119003>
- Yigitcanlar, T., Desouza, K. C., Butler, L., & Roozkhosh, F. (2020). Contributions and risks of artificial intelligence (AI) in building smarter cities: Insights from a systematic review of the literature. In *Energies* (Vol. 13, Issue 6). MDPI AG. <https://doi.org/10.3390/en13061473>
- Zechiel, F., Blaurock, M., Weber, E., Büttgen, M., & Coussement, K. (2024). How tech companies advance sustainability through artificial intelligence: Developing and evaluating an AI x Sustainability strategy framework. *Industrial Marketing Management*, 119, 75–89. <https://doi.org/10.1016/j.indmarman.2024.03.010>
- Zuo, W., Li, Y., & Wang, Y. (2019). Research on the optimization of new energy vehicle industry research and development subsidy about generic technology based on the three-way decisions. *Journal of Cleaner Production*, 212, 46–55. <https://doi.org/10.1016/j.jclepro.2018.11.263>

8.2. Sitography

Amazon Web Services (2018). 3M Health Information Systems Case Study.

<https://aws.amazon.com/solutions/case-studies/3M-health-information-systems/>

Amazon Web Services (2021). Carbon Lighthouse Tackles CO₂ Emissions with Machine Learning on AWS. <https://aws.amazon.com/solutions/case-studies/carbon-lighthouse/>

Amazon Web Services (2023). Illumina Reduced Carbon Emissions by 89% and Lowered Data Storage Costs Using AWS. <https://aws.amazon.com/solutions/case-studies/illumina-carbon-emissions-case-study/>

Amazon Web Services (2023). Scaling Sustainability Solutions for Buildings Using AWS with BrainBox AI. <https://aws.amazon.com/solutions/case-studies/brainbox-ai-case-study/>

Amazon Web Services (AWS). (n.d.). Amazon Q – Generative AI Assistant.

<https://aws.amazon.com/q/>

Amazon Web Services. (n.d.). AWS Italia. <https://aws.amazon.com/it/>

Amazon. (n.d.) The Climate Pledge. <https://www.aboutamazon.eu/planet/the-climate-pledge>

Associazione Italiana di Ingegneria Gestionale (AIIG). (2022). Classificazione riviste AIIG 2022.

<https://www.ingegneriagestionale.it/classificazione-riviste-aiig-2022/>

Business Insider. (2025). What is DeepSeek? Get to know the Chinese startup that shocked the AI industry. <https://www.businessinsider.com/what-is-deepseek-r1-china-ai-2025-1>

Elsevier. (n.d.). Scopus. <https://www.elsevier.com/products/scopus>

European Commission. (n.d.). Green claims. https://environment.ec.europa.eu/topics/circular-economy/green-claims_en

European Commission. (n.d.). Regulatory framework on artificial intelligence. <https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai>

Financial Times. (2025). Amazon to spend \$100bn this year in AI drive. <https://www.ft.com/content/e5536a67-ed2d-4dfd-94a7-e9a518f4a73c>

Google. Google Patents. <https://patents.google.com/>

Government of India. (n.d.). About Startup India Initiative. <https://www.startupindia.gov.in/content/sih/en/about-startup-india-initiative.html>

Government of India. (n.d.). Make in India Initiative. <https://www.makeinindia.com/>

Harvard Business Review. (2024, December). What is agentic AI and how will it change work. <https://hbr.org/2024/12/what-is-agentic-ai-and-how-will-it-change-work>

Krause, C. (n.d.). UPS and Agentic AI: A case study in logistics innovation. Medium. <https://medium.com/@carsten.krause/ups-and-agentic-ai-a-case-study-in-logistics-innovationby-carsten-krause-ceo-chief-editor-9f9950868652>

McKinsey & Company. (n.d.). The Green IT revolution: A blueprint for CIOs to combat climate change. <https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-green-it-revolution-a-blueprint-for-cios-to-combat-climate-change#/>

New York Post. (2025). What is DeepSeek? All about China's latest AI model. <https://nypost.com/business/what-is-deepseek-all-about-chinas-latest-ai-model/>

NVIDIA. (n.d.). NVIDIA DRIVE powers next-generation transportation.

<https://nvidianews.nvidia.com/news/nvidia-drive-powers-next-generation-transportation>

Questel. Orbit Intelligence. <https://www.orbit.com/>

Shmueli, G., Bruce, P. C., Gedeck, P., & Patel, N. R. (n.d.). Prescriptive analytics: The final frontier for evidence-based decision making. InformIT.

https://www.informit.com/store/prescriptive-analytics-the-final-frontier-for-evidence-9780134387055?w_ptgrevartcl=Introduction+to+Business+Analytics+and+Decision-Making_2992600

Siemens. (2022). A smart square: Why Berlin's latest district is built twice.

<https://www.siemens.com/global/en/company/stories/infrastructure/2022/siemensstadt-a-smart-square.html>

The Guardian. (2025, January 17). Labour investment in AI isn't as clever as it thinks it is.

<https://www.theguardian.com/technology/2025/jan/17/labour-investment-in-ai-isnt-as-clever-as-it-thinks-it-is>

World Intellectual Property Organization (WIPO). PATENTSCOPE.

<https://patentscope.wipo.int/search/en/search.jsf>