THE UTILIZATION OF ARTIFICAL INTELLIGENCE IN MEASURING, ACCOUNTING AND REPORTING FOR ECOSYSTEM SERVICES

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Abstract: *Artificial intelligence (AI) has become deeply integrated into daily life, enhancing decision-making efficiency and optimizing the use of personal and temporal resources. In response to rapidly evolving economic landscapes, industries across sectors are increasingly adopting AI tools to remain competitive and innovative. Heightened consumer demands and intensified competition drive businesses to operate at peak performance. Simultaneously, regulatory bodies are imposing stricter environmental guidelines, pushing companies toward sustainability. Given the growing concerns over resource scarcity and climate change, AI emerges as a pivotal tool for businesses to navigate these challenges. This paper examines the role of AI in enhancing the accounting, measurement, and reporting of ecosystem services, particularly within the scope of corporate environmental responsibility.*

Keywords: *artificial intelligence (AI), ecosystem accounting, sustainable reporting*

JEL classification: *Q55, Q56*

Introduction

The landscape of the sustainable economy is undergoing continuous evolution due to several influential factors: the growth of businesses and their environmental impact, the strengthening of legislative and regulatory requirements on how companies must measure, account for, and report environmental indicators, and more recently, the advancement of technology permeating nearly every aspect of daily and professional life. Employees are required to expand their knowledge by adopting new technologies, while companies must be open to investing in and implementing technologies that facilitate their business practices. The Fourth Industrial Revolution, a term popularized by economist Klaus Schwab, founder of the World Economic Forum, describes the rapid pace of technological advancement in the 21st century, bringing a new focus to ecosystem economy—artificial intelligence.

Description of the Problem

The reasons for considering the selected research topic as actual are as follows:

- **Increasing regulatory pressures:** Regulators worldwide are placing growing pressure on environmental protection and the adoption of transparent measurement and reporting practices. On January 5, 2023, the European Union's Corporate Sustainability Reporting Directive (CSRD) came into force. This directive "modernizes and strengthens the rules regarding social and environmental information that companies must report. A broader range of large companies, as well as small and medium-sized enterprises (SMEs) listed on the stock exchange, will now be required to report on sustainability. Additionally, some

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non-EU companies will also have to report if they generate revenues exceeding €150 million in the EU market." (European Commission, 2024). These new rules ensure that investors and other stakeholders have access to the necessary information to assess companies' impacts on people and the environment. Investors will also be able to evaluate financial risks and opportunities arising from climate change and other sustainability issues. Furthermore, reporting costs for companies will be reduced in the medium to long term through the harmonization of required disclosures. The first companies will need to apply the new rules for the financial year 2024, with reports published in 2025.

- **Artificial intelligence integration:** Artificial intelligence (AI) has become a daily component of the lives of individuals involved in the business environment. Whether a simple employee uses a search engine, an investor utilizes a return-on-investment calculation platform, or a company employs interactive visualization tools, it is evident that denying the importance of these tools is impossible. In most cases, they facilitate task execution and help align businesses with external requirements.

The overall aim of this paper is to investigate how the business sector is adapting to new sustainability challenges and to develop conclusions based on the studied materials regarding the optimal ways in which sustainability can be integrated into accounting and reporting processes with the support of artificial intelligence (AI). The research objectives are as follows:

- To review the specialized literature on artificial intelligence tools applied in business;
- To analyze how these tools can be integrated into companies' activities for the purpose of ecosystem accounting and reporting;
- To quantify the benefits and risks associated with the use of these tools.

Methodology and Data

To achieve an empirical analysis of the subject and to derive results as close to reality as possible, several research methods were employed:

- Axiomatic method – used in formulating the thesis;
- Induction and deduction – applied in the process of formulating and demonstrating the hypotheses presented in this report;
- Content analysis method – used for conducting an empirical review of the available specialized literature and collecting historical data;
- Comparison method – employed to differentiate information identified for two different yet comparable areas;
- Indirect observation – observing through available documentation the behaviors of the business sector regarding the adoption of business technologies of environmental impact in the accounting and reporting fields;

Results

The Importance of Artificial Intelligence in the Context of New Business Models

Artificial intelligence (AI) technologies have become indispensable tools in both everyday life and professional settings. Viewed through an optimistic lens, one can confidently state that AI assists in data collection, analysis, and visualization, effortlessly creating data syntheses, identifying patterns, and predicting future trends with unprecedented accuracy. The utility of AI is further validated by statistics regarding the market value of AI services, the rapid adoption of these technologies by organizations, and their impact on employee productivity.

According to Grand View Research, a market research and consulting firm, the global artificial intelligence industry is expected to generate revenues exceeding $1.8 trillion by 2030. Additionally, the industry is projected to experience a compound annual growth rate of 37.3% from 2024 to 2030 [Figure 1].

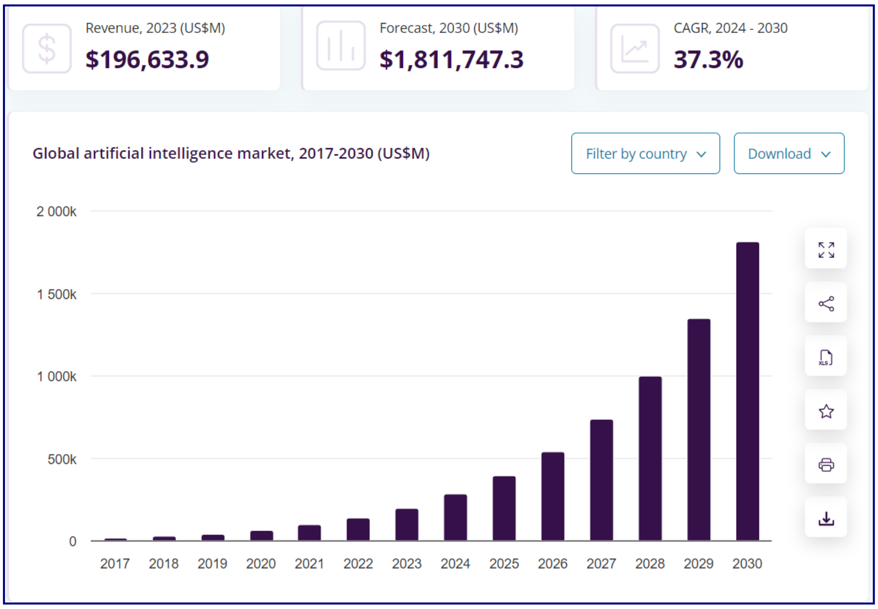

Figure 1: AI market evolution

Source: Grand View Research: Global Artificial Intelligence Market Size & Outlook

Regarding the adoption rate and the openness of individuals and organizations toward new AI tools, OpenAI reported that within less than a week of launching the widely known ChatGPT platform, it had amassed one million users, a figure that grew to 187.4 million monthly users by June 2024 (Similar Web, 2024). According to technology consultancy and research firm Gartner, Inc., surveys and studies conducted between 2015-2019 revealed a 270% increase in the percentage of businesses integrating AI technologies into their practices (Costello, 2019). Regarding employee productivity, AI could have a significant impact of 30%-40% over the coming years, as estimated by Big4 company PricewaterhouseCoopers in its "2024 AI Business Predictions" report (Pricewaterhousecoopers, 2024).

The statistics outlined above support not only the practicality and efficiency of AI but also its versatility. In this context, versatility refers to AI's capacity to continuously evolve and adapt to the needs of companies, market trends, consumer demands, and regulatory requirements. Due to its versatility, artificial intelligence is increasingly seen as a tool that can be seamlessly integrated into accounting and ecosystem reporting practices. While AI may currently represent a costly investment, primarily affordable for top-tier companies, the growing concern for environmental protection and the positive financial outcomes associated with sustainability innovations suggest that AI will become an indispensable asset for any successful business.

A responsible environmental economic behavior is indeed a crucial element that cannot be overlooked by any company aiming for financial and reputational success. To analyze this hypothesis, we have listed below five economic indicators that can be calibrated based on the level of environmental awareness exhibited by enterprises:

- **Revenue Growth Rate**: In 2023, the global consultancy firm McKinsey & Company published a study on 2,269 public companies, aiming to demonstrate that integrating environmental, social, and governance (ESG) priorities into growth strategies contributes to superior financial performance. The study found that "high-performing triple bottom-line companies (those rated highly on ESG scores, annualized revenue growth, and economic profit) grew their revenues at a median rate of 11% per year—1.4 percentage points higher than the median achieved by profitable companies with weaker ESG performance" (McKinsey & Company, 2023).
- **Profit Growth Rate**: Similar to the first indicator, a sustainable enterprise is expected to show a stable or upward trend in profitability. This is because businesses that focus on environmental awareness often implement energy-efficient practices, waste reduction measures, and sustainable supply chain management, all of which reduce operating costs and increase profitability.
- **Public Image Status**: An article published in the *Journal of Banking and Finance* titled "Corporate Social Responsibility (CSR) and Media Coverage" examines how the public, including investors, customers, and the media, focuses on CSR principles to encourage better economic outcomes: "For firms that demonstrate superior social responsibility and receive favorable media coverage, there is a significant interaction between social responsibility and media favorability, which enhances a firm's equity valuation" (Cahan, 2015).
- **Access to State Subsidies**: Environmental initiatives implemented by companies are often supported by external stakeholders, primarily governments. A prime example is the Greening of Small and Medium-Sized Enterprises (SMEs) Program funded by the Government of the Republic of Moldova and the European Union (EU) through the Organization for Entrepreneurship Development (ODA). The program was approved by Government Decision No. 592/2019 and is "implemented to create favorable conditions and support the business environment in transitioning from a consumption-based economic development model to one that applies greening principles and integrates green economy measures into the production processes of various national economic sectors". Through this project, applicants can receive continuous informational and consultative support, financial assistance in the form of grants up to MDL 500,000, and post-financing monitoring for 24 months from the date of grant transfer.
- **Risk Management Response Quality**: Proactive companies that acknowledge the influence of natural ecosystem factors on their financial performance can anticipate potential future risks and take steps to mitigate them or develop responses that balance the negative impact of these factors.

These indicators reflect the extent to which environmental awareness and responsible behavior can be aligned with economic performance and long-term business success.

Artificial Intelligence Tools for Measuring, Accounting, and Reporting Ecosystem Services

A catalyst that could drive companies to achieve favorable outcomes regarding the aforementioned indicators is the implementation of artificial intelligence tools. These tools would help draw a parallel between their financial viability and environmental behavior, particularly in the areas of measuring, accounting, and reporting ecosystem services. In this context, we have developed a diagram that classifies AI tools that would be useful for these three domains [Figure 2].

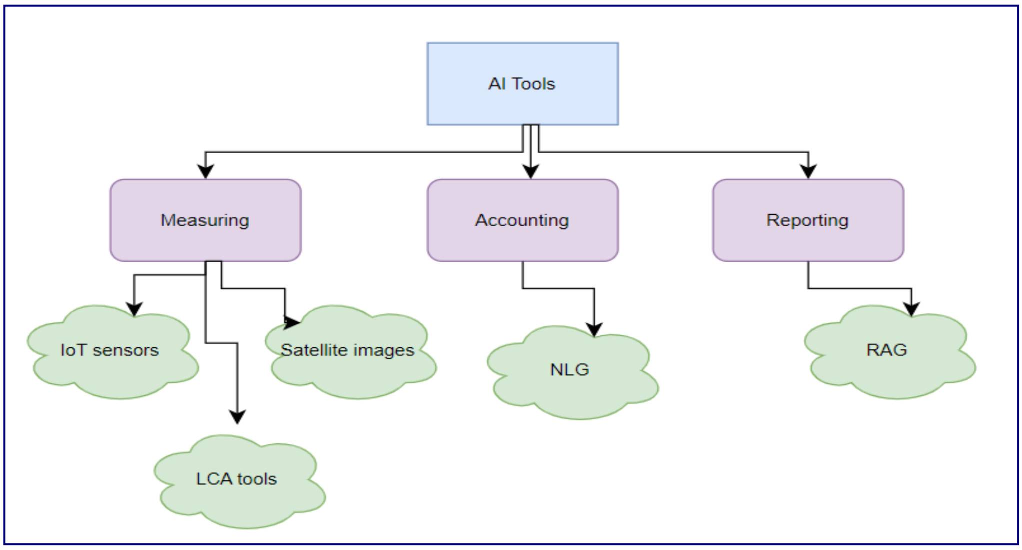

Figure 2: Useful AI tools for the processes of measuring, accounting and reporting ecosystem services

Source: Created by the author

Measuring ecosystem services refers to the quantification of the benefits that natural ecosystems provide to people and businesses, such as clean air, water, soil fertility, land areas, recreational opportunities, and more. This process involves assessing the economic, environmental, and social values of these services to better understand how ecosystems support human well-being and the economy. The importance of this process is highlighted by its role in helping decision-makers, businesses, and communities make informed choices regarding the use and conservation of resources. By recognizing both the tangible and intangible benefits of nature, it becomes possible to prioritize sustainable practices that protect biodiversity and mitigate the effects of climate change. For the "measurement" category, we identified three types of AI-based tools that enhance the efficiency and accuracy of measurements:

1. IoT Sensors (Internet of Things) - IoT sensors are devices that collect and transmit data from the physical environment to other systems via the internet. These sensors are essential components of the IoT ecosystem, enabling a wide range of applications by collecting real-time data related to various parameters such as temperature, humidity, light, motion, pressure, or even chemical composition. The data collected by these sensors are typically analyzed to trigger automated actions, remotely monitor systems, or provide insights for optimizing operations in industries like agriculture, manufacturing, and healthcare. IoT sensors are designed to be compact, energy-efficient, and capable of wireless communication. Currently, there are multiple protocols available for connecting to IoT systems, with functionality depending on data transmission rate, coverage range, and latency [Figure 3].

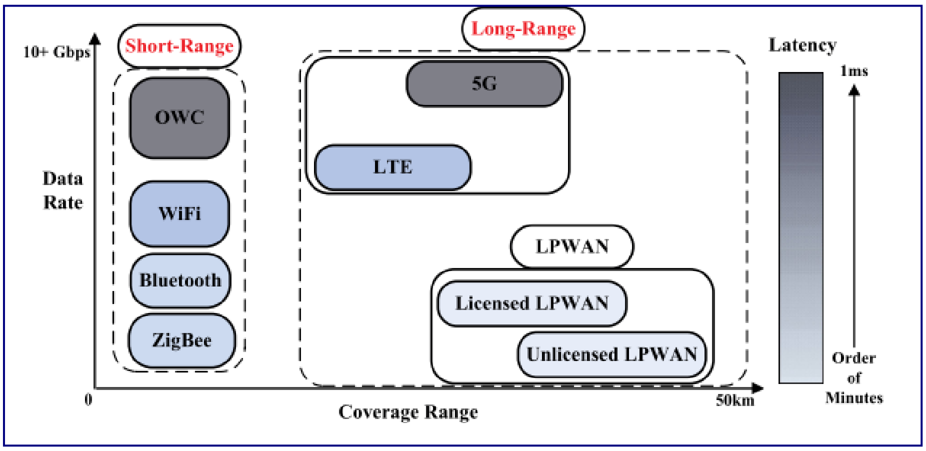

Figure 3: IoT connectivity protocols

Source: Ding, J., Nemati, M., et al., IoT Connectivity Technologies and Applications: A Survey

Currently, the largest share of IoT connections is achieved through Wi-Fi, accounting for 31%. In 2023, three-quarters of devices connected to Wi-Fi globally relied on the latest technologies - Wi-Fi 6 and Wi-Fi 6E - ensuring faster and more reliable wireless connectivity. The adoption of these technologies has made communication between IoT devices more efficient, leading to improved user experience and overall performance. Another 25% of devices use Bluetooth technology, while the remaining 21% rely on cellular technologies such as 4G or 5G. According to IoT Analytics, a global provider of statistical and strategic information on IoT, AI, and other revolutionary technologies, by the end of 2023, 16.6 billion devices were connected to IoT, representing a 15% increase compared to 2022. IoT Analytics projects this figure will grow by another 13%, reaching 18.8 billion devices by the end of 2024. Experts conclude, "This forecast is more modest than in 2023 due to cautious spending by businesses in response to inflation, high interest rates, ongoing chipset supply constraints, and geopolitical conflicts in Eastern Europe and the Middle East. Despite these macroeconomic factors, 51% of businesses adopting these technologies plan to increase their IoT budgets in 2024 (with 22% of companies expecting a budget increase of over 10% compared to 2023)" (Sinha, 2024).

IoT technology is multidimensional and can be applied across various sectors. For the purpose of this thesis, we have analyzed and exemplified four business sectors whose efficiency, productivity, and ability to manage natural resources are significantly improved through the use of these revolutionary tools: agriculture, forestry industry, heavy industries with significant impact on air quality.

o*Agriculture* – IoT has emerged as a transformative technology in agriculture, playing a vital role in protecting and conserving natural resources such as water, soil, and energy. Through real-time monitoring, data collection, and automation, IoT allows farmers to manage resources more efficiently, reducing waste and promoting sustainable practices. This technology is especially crucial as the agricultural sector faces increasing pressure to boost production while minimizing environmental impact in the context of climate change and resource depletion. One of the most important ways IoT contributes to natural resource conservation is through optimal water management. Water scarcity is a growing global concern, with agriculture accounting for approximately 70% of global freshwater use. According to Ayaz (2019), "IoT-based systems can significantly reduce water consumption by enabling precise control over irrigation, which directly contributes to water conservation efforts in agriculture" (Ayaz, 2019). These systems help prevent over-irrigation and reduce the depletion of water resources while ensuring crops receive the adequate amount of water for growth. Energy conservation is another area where IoT plays a crucial role in agriculture. Automated systems powered by IoT technology can help reduce energy consumption by optimizing the operation of machinery and equipment. For example, smart irrigation systems not only save water but also use energy more efficiently by scheduling irrigation during periods of lower energy demand. This helps farmers reduce their carbon footprint and operational costs. Soil quality protection is another area where IoT contributes to resource conservation. Poor soil management practices can lead to degradation, erosion, and loss of fertility. IoT sensors can monitor soil conditions in real-time, providing data on pH levels, nutrient content, and soil compaction. This allows farmers to apply fertilizers and soil amendments precisely, avoiding over-application that can lead to nutrient runoff and soil degradation. Additionally, IoT enhances resource efficiency through precision agriculture, which uses data to tailor farming practices to specific areas and ecosystems. This not only saves resources like water and fertilizers but also protects biodiversity. For instance, IoT drones equipped with sensors can map fields, identifying areas that need more or fewer resource inputs, thus avoiding excessive application of chemicals that could harm surrounding ecosystems. To illustrate the utility of these technologies in the context of measuring ecosystem services, we can refer to the data published by CropX – a leader in the sensor market and digital platforms used for collecting and interpreting sensor data. CropX is an agricultural technology company specializing in providing IoT-based solutions for precision agriculture. Their platform integrates advanced soil sensors, cloud-based data analytics, and machine learning to help farmers optimize water use, improve soil health, and increase crop productivity. The technology developed by CropX aims to enhance agricultural sustainability while simultaneously increasing the profitability of businesses. According to the company's latest sustainability report, with the help of the implemented technologies, CropX and its clients have managed to reduce water consumption by 25-50%, fertilizer use by 10-20%, fungicide use by 15-25%, greenhouse gas emissions by 9-13%, and energy costs by 10%. Additionally, CropX estimates that thanks to its technologies (especially those focused on irrigation), it is able to annually preserve an amount of water equivalent to the consumption needs of 2 million people (CropX Technologies, 2023).

○*Forestry* – The Internet of Things (IoT) is increasingly used in the forestry industry to help protect and conserve natural resources, playing a crucial role in sustainable forest management. Given the growing concerns about deforestation, forest degradation, and the impact of climate change, IoT technology offers innovative solutions for monitoring forest ecosystems, optimizing resource use, and preventing environmental damage. One of the primary ways IoT contributes to forest protection is through improved health monitoring. Sensors can be deployed across forested areas to track environmental factors such as soil moisture, temperature, and tree growth rates. These connected devices provide data that allows forest managers to detect early signs of diseases, pest infestations, or drought stress. Another significant application of IoT in forestry is the detection and prevention of wildfires. Wildfires are an increasing threat to forests, especially as climate change intensifies. IoT sensors can detect changes in temperature, smoke levels, and humidity, enabling early fire detection. These sensors are often connected to automated alert systems that notify forest managers or local authorities. IoT-based fire detection systems can drastically reduce response times and help prevent large-scale damage to forest ecosystems. This not only protects forest resources but also safeguards biodiversity and the communities that depend on these ecosystems. In addition to monitoring and optimizing forest health and resource management, IoT plays a critical role in tracking illegal activities such as logging and poaching. IoT devices equipped with GPS and motion sensors can be deployed to detect unauthorized access to protected forest areas. By reducing illegal deforestation and poaching, IoT helps conserve natural habitats. Such technologies also assist in understanding the carbon sequestration potential of forests. By measuring tree growth, soil carbon content, and atmospheric conditions, IoT devices provide accurate data on the amount of carbon a forest can capture and store. IoT-based carbon monitoring systems help quantify forests' carbon sequestration capacities, offering valuable data for climate change mitigation strategies. A notable example in this field is the American company Weyerhaeuser, which owns nearly 12.4 million acres of forestland in the U.S. and manages an additional 14 million acres of forests under long-term licenses in Canada. The company has been producing wood products for over a century. Alongside many other sustainable business practices, the use of IoT has enabled the company to recycle 98% of wood waste, plan to reduce greenhouse gas emissions by 42% by 2030 and eliminate the equivalent of 38 million metric tons of CO_2 from its forests and production processes (Weyerhaeuser, 2023).

○ *Heavy industries* – Integrating the Internet of Things (IoT) into heavy industries has become essential for protecting air quality and conserving natural resources. These industries, often associated with high levels of air pollution and environmental degradation, are now utilizing IoT technologies to minimize their ecological footprint, optimize energy use, and reduce emissions. One of the primary ways IoT helps maintain air quality is through Continuous Emissions Monitoring Systems (CEMS). These systems use IoT-connected sensors to monitor airborne pollutants such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter emitted from industrial processes. IoT sensors provide real-time data on emission levels, enabling companies to detect pollution spikes and take immediate corrective actions. Energy efficiency is closely tied to air quality conservation, as energy production often involves burning fossil fuels, which release large amounts of greenhouse gases. Smart grids and IoT-enabled sensors can monitor real-time energy consumption, identifying inefficiencies. By improving energy efficiency, heavy industries can minimize their reliance on fossil fuels. Additionally, IoT significantly contributes to controlling industrial dust and particulate matter, which are major contributors to air pollution. IoT integration in dust suppression systems provides real-time data on air quality, allowing for adaptive control of filtration processes that help reduce particulate emissions, protecting both workers and the environment. Smart air filtration and ventilation systems equipped with IoT sensors can detect airborne particles in factories or industrial sites and automatically adjust the filtration systems to capture and eliminate these particles. This technology is particularly valuable in sectors such as cement manufacturing and metal processing, where dust emissions can have significant health and environmental impacts. An example of a company that has successfully integrated IoT in its heavy industrial operations is Siemens. Focused on industrial automation, energy distribution, transportation, and healthcare technologies, Siemens has reported remarkable performance due to the development and implementation of IoT systems. In its 2023 sustainability report, Siemens highlighted that it achieved a high ranking in the Corporate Sustainability Assessment (CSA) from S&P Global, an annual evaluation of companies' sustainability practices focusing on both industry-specific and financially relevant sustainability criteria. In the fiscal year 2023, Siemens ranked second among its competitors in the Industrial Conglomerates category, with a score of 81/100. Additionally, EcoVadis, which assesses sustainability in global supply chains, awarded Siemens 77 points, placing the company in the top 1% of companies evaluated in the same industry (Siemens, 2023).

An important consideration in the adoption of technologies such as the Internet of Things (IoT) and high-speed internet connections is that, while they offer significant benefits, they also carry potential negative impacts—both for the environment and businesses. One of the primary concerns is security and privacy. IoT devices often collect vast amounts of personal and sensitive data. Without robust security measures, these devices are vulnerable to cyberattacks, which could lead to data breaches or unauthorized access. According to Statista - the German online platform specializing in data collection and visualization, the annual number of IoT malware attacks worldwide surged dramatically from 32.7 million in 2018 to 112.29 million in 2022.

Another challenge businesses face with IoT is the issue of interoperability and the increased complexity of maintenance. Many IoT devices, particularly those from different manufacturers, may not be compatible with one another, making it difficult to manage and integrate them effectively. Furthermore, as the number of connected devices grows, the management and upkeep of the network become more complicated. Organizations may struggle with monitoring device performance, troubleshooting issues, and ensuring timely updates, which can result in operational disruptions.

Perhaps the most significant downside of IoT and related technologies is their environmental impact. While some IoT devices are designed with energy efficiency in mind, the sheer volume of connected devices can lead to increased energy consumption—especially when considering widespread adoption in cities, homes, and businesses. Moreover, the mass production of IoT devices contributes to e-waste, particularly if the devices have short lifespans or are not properly recycled. As noted by the software development company ArtHaus, “the production of these devices sometimes includes rare earth metals. They may harm the environment and aren’t easy to acquire sustainably.”. Furthermore, the lack of awareness and education about the environmental effects of IoT devices among manufacturers and businesses exacerbates the issue.

Addressing these challenges requires a multifaceted approach, including the implementation of smart waste management solutions, the introduction of regulations on energy consumption and environmental pollution, and the self-education of entrepreneurs. By prioritizing sustainability and adopting best practices, both businesses and governments can mitigate the negative impacts of IoT technologies.

2.Life Cycle Assessment (LCA) Tools - Life Cycle Assessment (LCA) is a systematic methodology used to evaluate the environmental impact associated with all stages of a product’s life — from raw material extraction, through production, use, and disposal. By utilizing LCA tools, companies can better manage and account for natural resources and understand their environmental impact. This tool provides valuable insights that allow businesses to make informed decisions regarding sustainability initiatives. LCA comprises four main stages: goal and scope definition, inventory analysis, impact assessment, and interpretation [Figure 4].

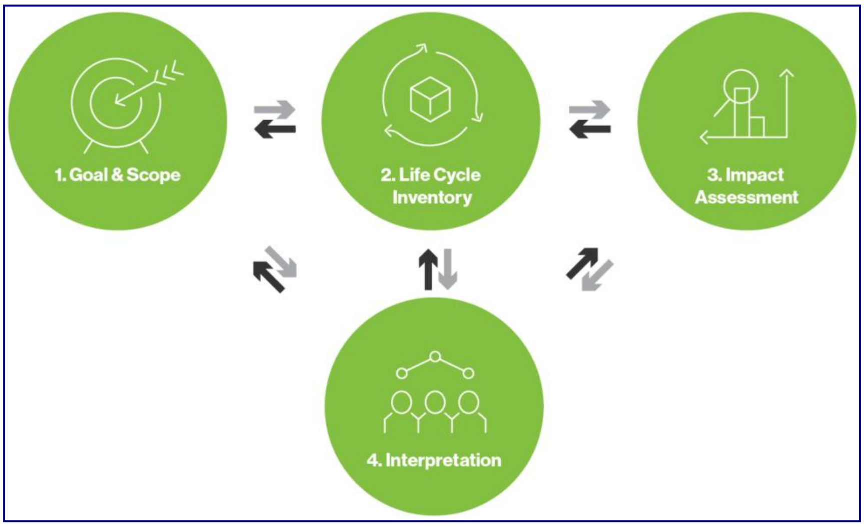

Figure 4: LCA analysis steps

Source: Golisano Institute for Sustainability, What is life cycle assessment (LCA)?

In the first stage, organizations establish the purpose of the assessment, the product system under study, and the boundaries of the analysis. The inventory analysis stage involves quantifying energy consumption, raw materials, emissions, and waste generated throughout the product's life cycle. The impact assessment translates this inventory data into environmental impacts, examining aspects such as greenhouse gas emissions, resource depletion, and ecological toxicity. Finally, the interpretation stage synthesizes the findings to provide actionable insights. By using LCA tools, companies can identify problem areas in processes where resource use is excessive or emissions are high. This information allows them to implement strategies to reduce resource consumption and mitigate environmental impacts. For example, businesses can evaluate alternative materials, optimize production processes, and design for recovery and recycling at the end of the life cycle, thus improving their sustainability profile (Kloppfer, 2016). Additionally, LCA helps meet regulatory requirements and increases transparency in environmental reporting, thereby fostering trust among stakeholders and consumers. LCA tools assist companies in accounting for natural resources by quantifying the environmental impacts of their product systems. For instance, by analyzing input resources at the start of the cycle, such as water, minerals, and energy, organizations can identify areas where they can reduce consumption or switch to more sustainable alternatives. Furthermore, LCA can highlight the benefits of recycling and material recovery, encouraging companies to adopt circular economy practices that minimize resource extraction and waste. Some notable examples of Life Cycle Assessment (LCA) tools developed and used internationally are: SimaPro, GaBi, OpenLCA, LCA Commons. A notable example of a company leveraging LCA for sustainability is Unilever, a multinational consumer goods company. Unilever has implemented LCA across various product lines to assess their environmental impacts and improve resource efficiency. The company uses LCA to evaluate factors such as packaging materials, ingredient sourcing, and product formulations. In 2010, Unilever launched its Sustainable Living Plan, aiming to halve its environmental footprint by 2030. As part of this initiative, Unilever conducted LCAs for several products to identify opportunities to reduce water and energy consumption. For example, their analysis showed that "in total, nearly 60% of Unilever's greenhouse gas emissions come from raw materials and ingredients purchased, and identifying alternatives to fossil fuel-based chemicals will be the biggest challenge in achieving sustainable goals by 2039." To get closer to these sustainable objectives, the company collaborates with supplier partners to drastically reduce the impact of Scope 3 emissions. The most recent example is the collaboration of its Indian subsidiary with leading chemical companies TFL and OCI to test the production of near-zero-emission synthetic soda ash—a key ingredient in laundry powder (Unilever, 2023).

3.Satellite images - Pixel technology has its origins in the 1960s, when American engineer Frederic C. Billingsley first introduced the term "pixel" to describe the elements of images scanned by space probes to the Moon and Mars (Peddie, 2021). At that time, digital image processing and interpretation routines were primarily developed for the Earth sciences community. However, more recently, the practice has expanded and become more accessible to various users such as social scientists, farmers, agricultural companies, local governments, urban developers, and others. It has been established that such data collections "have potential scientific value for studying interactions between the environment and humans, particularly changes in land cover and use" (Liverman, 1998). Satellite imagery has become a powerful tool for companies seeking to measure and account for ecosystem resources in a sustainable way. By providing high-resolution, real-time data on land use, vegetation cover, water resources, and environmental changes, satellite technology enables businesses to make informed decisions that support sustainability goals. There are numerous subdomains where satellite imaging tools can be used, including: Environmental monitoring:

Table 1

The subdomains in which satellite imaging can be used

Subdomain	Description
Monitoring land use and land cover	Satellite imagery allows for comprehensive monitoring of land-use changes over time. Companies can use this information to assess the impact of their operations on ecosystems. For example, agricultural companies can analyze the expansion of farmland and its effects on surrounding habitats. These data can inform land management practices, enabling organizations to minimize ecological disruption and optimize land use for sustainable productivity.
Assessing vegetation and biodiversity:	Satellite images can be used to monitor vegetation health and biodiversity. Remote sensing technologies capture spectral data that indicate plant health, species distribution, and ecosystem resilience. Companies involved in forestry or agriculture can assess the health of crops or forests, allowing them to implement timely interventions to improve productivity while conserving biodiversity (Turner, 2015).
Water resource management	Monitoring water bodies and surrounding ecosystems is crucial for the sustainable management of resources. Satellite imagery can track changes in water levels, assess water quality, and detect pollution events. This capability is particularly important for industries dependent on water, such as agriculture and manufacturing. By understanding water availability and quality, companies can implement practices that reduce water consumption and mitigate environmental impacts.
Estimating carbon footprint:	Satellite data can play a significant role in estimating greenhouse gas emissions and carbon sequestration potential. Remote sensing provides insights into land cover changes and biomass estimates, which are essential for calculating carbon stocks and understanding the carbon footprint of various operations. For example, energy companies can use satellite imagery to monitor reforestation efforts and calculate associated carbon offsets (Pettorelli, 2014).

Source: Created by the author

The opportunities to create such images are numerous, as the digital imaging and data analysis industries have significantly developed in recent years. One example would be the Sentinel Hub. The Sentinel mission encompasses a series of Earth observation satellites that collect various types of data, including images, for environmental monitoring, land management, and more. Sentinel-1, Sentinel-2, and Sentinel-3 are the main satellite missions within the Copernicus program, providing different types of data.

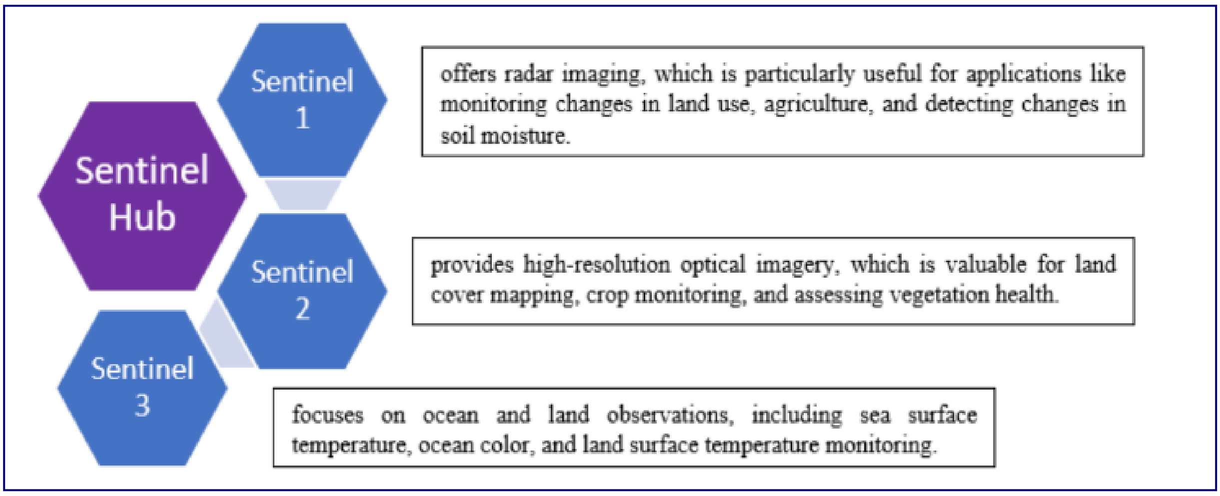

Figure 6: Copernicus satellite mission data

Source: Europe's eyes on Earth: the EU's Copernicus Programme

Accounting and **reporting** of ecosystem services involve introducing the measured data into the company's accounting systems and reports. Effective accounting and reporting help raise awareness about the importance of ecosystem services, promote sustainable practices, and support policies aimed at conserving natural resources for future generations. AI tools that are determined to aid businesses in the processes of ecosystem accounting and reporting are: Natural Language Generation (NLG) and Retrieval Augmented-Generation (RAG). Natural Language Generation (NLG) and Retrieval-Augmented Generation (RAG) are innovative technologies that can significantly enhance how companies account for natural resources and conduct sustainability reporting. As organizations face increasing pressure to demonstrate environmental responsibility, these tools facilitate the efficient processing of large datasets, generating clear narratives and improving communication with stakeholders. By utilizing NLG and RAG, companies can bolster their sustainability practices and provide transparent reporting on resource management. Some of the most common applications of NLG and RAG are:

- Automated Reporting: NLG automates the generation of sustainability reports, transforming complex data into easily readable text. Companies can use NLG to summarize resource consumption, emissions, and waste management practices in a structured format that complies with regulatory requirements. For instance, automated reporting helps organizations meet the demands of frameworks like the Global Reporting Initiative (GRI) and the Carbon Disclosure Project (CDP).
- Data Interpretation and Analysis: NLG can enhance data interpretation by generating insights from large datasets related to natural resource consumption. By translating data analysis into coherent narratives, organizations can identify trends, anomalies, and optimization opportunities. This understanding enables decision-makers to implement targeted strategies to improve resource use efficiency.
- Scenario Analysis: Companies can employ NLG to simulate various resource management scenarios, allowing them to understand the potential impacts of different strategies. NLG can generate narratives that explain the implications of adopting renewable energy sources or implementing waste reduction initiatives, helping organizations assess potential benefits and trade-offs.

The role of Retrieval-Augmented Generation (RAG) enhances NLG capabilities by integrating external knowledge sources into the narrative generation process. This hybrid approach combines generative models with retrieval mechanisms, enabling organizations to access updated information and contextual data from various databases.

- Contextualized Reporting: RAG can enhance sustainability reporting by integrating relevant data from multiple sources, including scientific studies, regulatory documents, and industry benchmarks. This ensures that reports are not only accurate but also rich in context.
- Enhanced Decision Support: By providing access to the latest information and research, RAG supports more informed decision-making. Companies can leverage this technology to identify best practices in sustainability, benchmark their performance against industry standards, and discover innovative solutions for resource management.
- Increased Transparency: The enhanced reporting capabilities promote transparency in resource management practices, positively influencing relationships with stakeholders and enhancing corporate reputation.

Conclusions

Artificial Intelligence (AI) tools, including machine learning algorithms, Natural Language Generation (NLG), and data-driven modeling, have proven essential for measuring, accounting for, and reporting ecosystem services. Ecosystem services refer to the benefits that humans derive from nature, such as clean air, water filtration, and carbon sequestration, and are recognized as critical for both environmental sustainability and economic growth. AI technologies offer innovative solutions to the challenges of quantifying and managing these services by automating data collection, improving resource accounting accuracy, and enhancing sustainability reporting quality. AI tools, such as satellite imagery, remote sensing, and machine learning algorithms, can process large-scale environmental data in real-time. This capability is particularly beneficial for monitoring complex and dynamic ecosystem processes, such as changes in forest cover, water quality, or biodiversity. AI enables more accurate and continuous monitoring of ecosystem services, which is essential for both conservation efforts and resource management. Additionally, AI tools enhance the quantification of ecosystem services by integrating multiple data streams and providing sophisticated predictive models. Machine learning algorithms can analyze historical data and environmental variables to estimate the value of ecosystem services, including carbon sequestration potential, pollination services, and water purification. These models provide reliable estimates of the economic and environmental benefits offered by ecosystems, which can inform decision-making for land use planning, resource allocation, and regulatory compliance. Moreover, AI can automate sustainability reporting through tools like NLG. By converting data into clear and coherent narratives, NLG allows organizations to produce accurate reports that comply with regulatory requirements and demonstrate transparency to stakeholders. These automated reports can track key performance indicators related to ecosystem services, such as greenhouse gas emission reductions or improvements in water quality, facilitating the communication of companies' environmental performance and their alignment with sustainability goals.

Despite their transformative potential, AI tools are not without limitations. One major limitation is the quality and availability of data. AI systems rely on large volumes of high-quality data to function effectively. In many regions, particularly in developing countries, there may be insufficient data on ecosystem services or inadequate technological infrastructure to support monitoring efforts. This can lead to gaps in AI models, reducing their accuracy and reliability. Addressing this issue requires investments in data collection infrastructure, especially in areas where ecosystems are most vulnerable. Another concern is algorithmic bias. AI systems can perpetuate or even amplify existing biases if trained on skewed or incomplete datasets. To mitigate this risk, implementing rigorous validation processes and combining AI results with human expertise is essential to ensure balanced and equitable decision-making. Interpretability and transparency also present challenges. AI models, especially deep learning algorithms, are often described as "black boxes" due to their complexity and lack of transparency. Stakeholders may struggle to understand how AI arrives at specific conclusions or predictions, making it difficult to trust the results. This lack of transparency can be problematic in sustainability reporting, where accountability is crucial. Lastly, ethical considerations must also be taken into account. The implementation of AI tools in managing ecosystem services raises questions about potential unintended consequences, such as job losses in industries reliant on manual environmental monitoring or the misuse of AI technologies to artificially enhance environmental outcomes (greenwashing). Companies must ensure that the adoption of AI aligns with ethical standards and contributes significantly to authentic sustainability outcomes. To overcome these challenges, a multifaceted approach is needed. First, improving data accessibility and quality is essential. Governments, companies, and NGOs should invest in developing open, high-quality environmental databases that can be used to train AI systems. Collaborations between academic institutions, industry, and public agencies can help fill data gaps. Second, ensuring algorithmic fairness and inclusivity is critical. This can be achieved by adopting diverse datasets that represent a wide range of ecosystems and integrating feedback from local stakeholders in data-scarce regions. Involving environmental scientists and experts in AI development can help address bias and equity issues. Finally, promoting transparency and accountability is crucial. Companies should prioritize the use of explainable AI models that allow stakeholders to understand how decisions are made. Additionally, AI outcomes should be validated by human experts to ensure accuracy and ethical compliance. Integrating human oversight into AI-based decision-making processes will not only enhance trust in technology but also lead to more responsible management of natural resources.

References

ArtHaus, IoT's Environmental Impact: Building a More Sustainable World, www.arthaus.mk , [Accessed January 25th, 2024]

Ayaz, M., Uddin, A., et al. (2019), Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk, In: IEEE Access, DOI: 10.1109/ACCESS.2019.2932609

Cahan, S., Chen, C., et al. (2015), Corporate social responsibility and media coverage, In: Journal of Banking & Finance, Vol. 59, ISSN 0378-4266

Costello, K. (2019), Gartner Survey Shows 37 Percent of Organizations Have Implemented AI in Some Form, Stamford, https://www.gartner.com, [Accessed August 31st, 2024]

CropX Technologies (2023), Inaugural Sustainability Report: Planet, People and Proesperity, https://cropx.com, [Accessed July 30th, 2024]

Ding, J., Nemati, M., et al. (2020), IoT Connectivity Technologies and Applications: A Survey, In: IEEE Access, DOI: 10.1109/ACCESS.2020.2985932

Europe's eyes on Earth: the EU's Copernicus Programme (2023), https://omcs.atlassian.net, [Accessed October 24th, 2023]

European Commission: Corporate Sustainability Reporting (2024), https://finance.ec.europa.eu, [Accessed September 10th, 2024]

Golisano Institute for Sustainability, What is life cycle assessment (LCA)? (2020), https://www.rit.edu, [Accessed September 10th, 2024]

Grand View Research: Global Artificial Intelligence Market Size & Outlook, https://www.grandviewresearch.com, [Accessed August 17th, 2024]

Hotărârea Guvernului Republicii Moldova cu privire la aprobarea Programului de Ecologizare a Întreprinderilor Mici și Mijlocii Nr 592 din 27.11.2019, In: Monitorul Oficial Nr. 360-366, 06-12-2019

Khan, W., Habib Ur Rehman, M. et al. (2020), Industrial Internet of Things: Recent Advances, Enabling Technologies, and Open Challenges, In: Computers & Electrical Engineering, Vol. 81, Nr. 2, DOI:10.1016/j.compeleceng.2019.106522

Kloppfer, W. (2016), The Hitch Hiker´s Guide to LCA - An orientation in LCA methodology and application, In: International Journal of Life Cycle Assessment - INT J LIFE CYCLE ASSESS, Vol. 11, DOI:10.1065/lca2006.02.008

Liverman, D., Moran, F. E., et.al. (1998), People and pixels. Linking Remote Sensing and Social Science., Washington D.C., ISBN 978-0-309-06408-8

McKinsey & Company (2023), The triple play: Growth, profit, and sustainability, https://www.mckinsey.com, [Accessed August 20th, 2024]

Organizația pentru Dezvoltarea Antreprenoriatului, Programul de Ecologizare a Întreprinderilor Mici și Mijlocii, https://www.oda.md , [Accessed August 20th, 2024]

Peddie, J. (2021), Tribute: the father of the pixel, https://www.jonpeddie.com, [Accessed October 15th, 2023]

Pettorelli, N., Laurence, W. F. (2014), et al., Satellite remote sensing for applied ecologists: opportunities and challenges, In: Journal of Applied Ecology, Vol. 51, Nr. 4, DOI:10.1111/1365-2664.12261

Pricewaterhousecoopers, 2024 AI Business Predictions, https://www.pwc.com, [Accessed August 18th, 2024]

Siemens, Sustainability Report 2023, https://assets.new.siemens.com, [Accessed September 5th 2024]

Similar Web: chat.openai.com Website Analysis for August 2024, https://www.similarweb.com, [Accessed September 15th, 2024]

Sinha, S. (2024), State of IoT 2024: Number of connected IoT devices growing 13% to 18.8 billion globally, https://iot-analytics.com, [Accessed September 16th, 2024]

Statista, Annual number of Internet of Things (IoT) malware attacks worldwide from 2018 to 2022, https://www.statista.com/, [Accessed January 25th, 2025]

Turner, W., Rondinini, C., et al. (2015), Free and open-access satellite data are key to biodiversity conservation, In: Biological Conservation, Vol. 182, ISSN 0006-3207

Unilever, Putting laundry and cleaning products on net zero emissions pathway, 19 Sep 2023, https://www.unilever.com.au, [Accessed August 19th, 2024]

Unilever, Sustainable Living Plan - 10th Year Assessment Report, https://www.unilever.com.tr, [Accessed August 19th, 2024]

Weyerhaeuser, 2023-2024 Sustainability Highlights, https://www.weyerhaeuser.com , [Accessed July 24th, 2024]