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Chapter 2

Artificial intelligence, machine learning, and deep learning applications in smart and sustainable industry transformation

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Abstract: Continued integration of artificial intelligence (AI), machine learning (ML), and deep learning (DL) with modern, smart and sustainable industry domain provide a springboard to the Industry 4.0, Industry 5.0, and Society 5.0. These technologies revolutionize operational efficiency, sustainability, and innovation in many industries. Predictive maintenance scheduling powered by AI lowers downtime and reduces operation expenses. ML algorithms help effective demand forecasting and inventory management to make better use of available resources. Through the use of DL practices, robust quality control and defect identification for example are possible all due to the advancement in manufacturing product quality. In addition, AI-powered automation in manufacturing has the ability to scale and flex fuelling an agile industrial world. A smart grid with AI integration helps in bringing energy sustainability and efficiency by optimizing the energy distribution and pattern of consumption. AI and ML powered autonomous systems reinforce the systems that analyse data in real-time, that improve delivery performance and reduce carbon footprints in logistics and supply chain management. Moreover, the AI applications in the environmental monitoring, supports sustainability, which provides the actionable results in controlling the pollution and managing the resources. We see them working along with human individuals such as cobots which shows AI is supporting the human-centric design in Industry 5.0. The AI, ML and DL convergence has played a key role in the transformation towards the smart and sustainable industry and paved way for innovative as well as sustainable solution in the contemporary industrial scenario.

Keywords: Smart industry, Sustainable development, Artificial intelligence, Machine learning, Deep learning, Internet of things, Industry 5.0.

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2.1 Introduction

The recent technological progress in artificial intelligence (AI), machine learning (ML), and deep learning (DL) such as DL, fuelled the emergence of intelligent and green industry, over the years in several industrial sectors which helped to create sustainable industries (Rao et al., 2022; Rai et al., 2021; Drakaki, et al., 2022). These allow industries to boost efficiency, productivity and sustainability with unparalleled data processing, pattern recognition abilities, and decision-making capabilities (Rai et al., 2021; Lampropoulos, et al., 2023). With global economy under increasing pressure from environmental issues, resource scarcity, and the demand for more resilient systems, the adoption of AI, ML, and DL within industrial processes is an imperative prong of a broader strategy to align with the longer-term sustainability agenda (Lilhore et al., 2021; Ahmed, et al., 2022; Paramesha et al., 2024a). These industries are using AI-based solutions to enhance operations and reduce waste also improve system performance of their respective plants. An example of this is using ML algorithms for predictive maintenance that enables to predict when equipment is going to fail so we can fix it before it fails, thus reducing downtimes and extending machines life. AI techniques for manufacturing enable great precision in production processes, making for higher quality products and less wasted material (Bonada et al., 2020; Kumar et al., 2023). Moreover, DL models are used for quality assurance, to find faults with great precision in which only the best of best productions reaches the markets (Hernavs et al., 2018; Villalba-Díez et al., 2020; Paramesha et al., 2024b). The future of sustainability owes a lot to AI. It will also help in reducing carbon footprints as more industries have started implementing the AI-based energy management systems to monitor and control energy usage. The optimization of supply chains is an example of the kind of work ML algorithms can be involved in, which helps to make logistics more efficient and helps to reduce emissions (Gebhardt et al., 2022; Rane et al., 2024a). In addition, AI can help in developing high-end recycling processes and waste management systems, in turn, is merging industrial practices with environmental sustenance goals, well, let move to some more benefits.

The contributions of this research work:

1) A review provides a systematic analysis of AI, ML and DL integration into industrial applications from existing studies to extract trends, gaps, and future research directions.
2) Co-occurrence analysis based around commonly used keywords in the literature (core themes and concepts), to explain their relationships.
3) A comprehensive cluster analysis that classifies the research domains into these clusters helps in understanding the key areas where AI, ML, and DL are applied in smart and sustainable industries as well as in the emerging trends in them.

2.2 Methodology

The study adopts a structured method by including literature review in four phases, keyword analysis, co-occurrence analysis, and cluster analysis to map the integration and impact of AI, ML and DL in developing smart and sustainable industries. To identify the relevant literature published over the past decade, research articles, conference papers and reviews were collected from the databases IEEE Xplore, ScienceDirect, Springer Link and Google Scholar. Search strategy was conducted to identify the relevant major publications about AI/ML/DL for industrial applications (smart and sustainable industry types). To make better the search results, we improved search process with specific keywords; namely as "smart industry", "sustainable industry", "artificial intelligence", "machine learning", "deep learning", "Industry 4.0", "Industry 5.0"and "sustainability". For a better understanding of the present scenario, the literature review has been performed in order to identify the latest trends occurring in AI, ML and DL adoption within the industry as well as the technological breakthroughs associated with the same. To select those wards and concepts more often cited in the databases, a keyword analysis was done on the literature gathered. This was done by text mining techniques of extracting keywords from the abstracts and titles of the papers selected. The search terms and their frequency and the distribution of these searches were analysed to present the themes and trends identified. This analysis provided a quantitative foundation for highlighting the main areas and topics studied in the research field for smart and sustainable industries. During the analysis of keywords, co-occurrence analysis was performed to study different relationships between the various keywords/concepts identified in the co-occurrence of the keyword and concept. The method used was to build a co-occurrence matrix, which we can use to see how often different pairs of keywords show up together in the literature. Cluster analysis used to group the keywords and concepts into clusters. The study used statistical techniques like hierarchical clustering to cluster similar keywords by their co-occurrence patterns.

2.3 Results and discussions

Co-occurrence and cluster analysis of the keywords

The network diagram, reflecting the co-occurrence and clustering of keywords (Fig 2.1). The diagram visually represents which keywords are interrelated in terms of frequency of their co-occurrences in publications. In the diagram, keywords are divided into many groups by one colour. Thus, it is possible to determine that the most prominent term associated with many other keywords is “artificial intelligence.” Following it are such relevant terms as “deep learning,” “machine learning,” and “internet of things.” This fact emphasizes that AI is of the highest importance and contributes to diverse innovations. One of the key sub-groups is the blue one, where only the word “machine learning” is highlighted. The authors mention other accompanying terms such as “support vector machines,” “forecasting,” “machine learning models,” and “random forests.” One can assume that they all describe various types of machine learning methods and algorithms. This conclusion is based on the fact that these terms are closely associated with predictive analytics and making the right decision. Some of them include the use of the words “prediction” and “forecasting,” thus letting the reader presume that it is done to foresee future outcomes and tendencies in the industry.

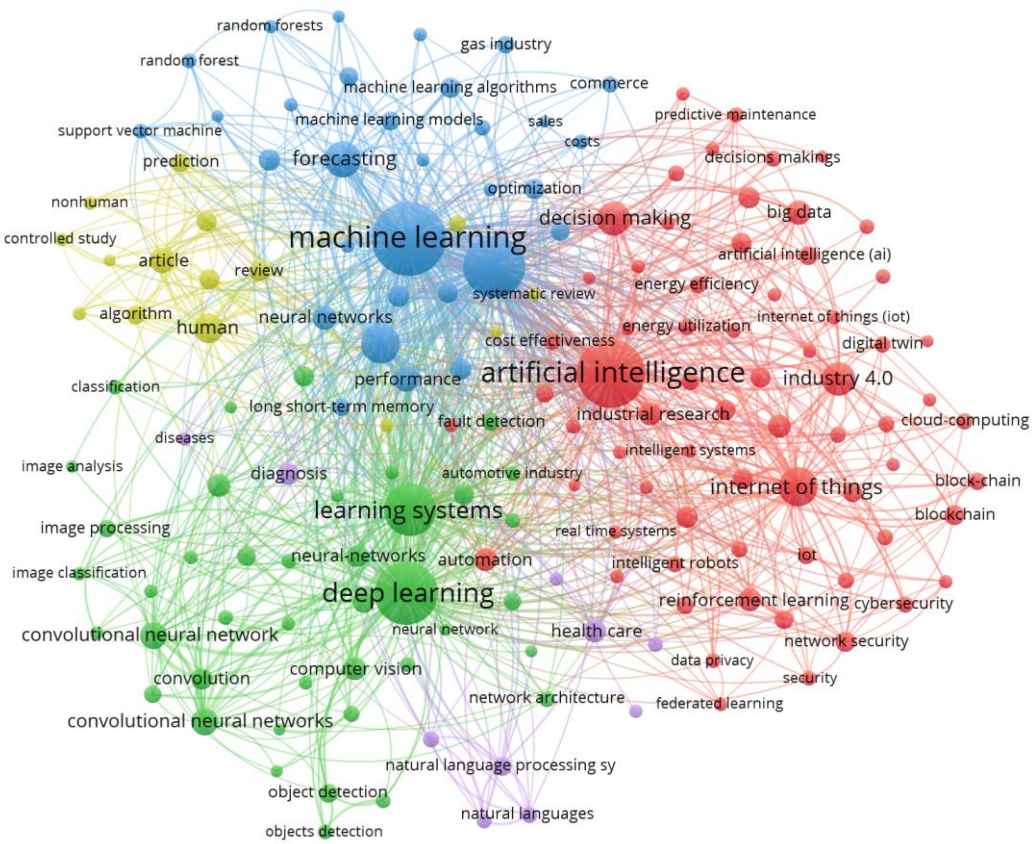

Fig. 2.1 Co-occurrence analysis of the keywords in literature

The “green cluster’s” deep learning, and learning systems’ concentration areas, are adjacent to the machine learning cluster. Words like “neural networks,” “convolutional neural network,” “computer vision,” “image processing,” and “object detection” are usually found in this cluster. In this case, we are observing the advanced learning methods and study their application in the task of recognizing patterns and pictures. In particular, this type stands out with a system in detail which makes it possible to collect and process an unfinished generated image as a visual input, since tasks of automation, monitoring, quality control in the production of intelligent manufacturing involves. An industry 4.0 Red cluster that is focused on the "internet of things," and "Industry 4.0," mainly puts a discussion of topics integrating AI, or machine learning and the "Internet of Things." Such Phrases as "big data," "cloud computing," "predictive maintenance," "energy efficiency," "digital twin," and "predictive maintenance" give a set of a large number of technologies managed to create an intelligent industrial system and unite them on a network level or "Industry 4.0," terms cloud computing and IoT, cyber-physical system integration, forming environmentally friendly industrial processes and smart factories. Among them all, digital twins, the digital content representation of the property, and predictive maintenance were particularly prominent due to the reduction of downtime and our ability to make operations as efficient as possible.

Examples of terms related to healthcare and medical diagnostics that are related to artificial intelligence and machine learning are "classification", "diagnosis", "algorithm", "diseases", and "image analysis". This type of cluster demonstrates the advantages of transdisciplinary AI technologies and how they can be beneficial for various branches, such as healthcare. In healthcare, image analysis and prediction algorithms may make a very impressive difference for providing patient care and improving the precision of diagnostics. Natural languages and natural language processing form another cluster of words and are related to the fact AI learns human language to some extent. The terms found in this cluster include "federated learning", "network architecture", "reinforcement learning", and "data privacy". This homogeneity of terms means that having advanced NLP in AI is a significant goal of researchers, and data should be private and secure while used in AI systems. Federated learning is of specific importance in this context because it allows train models in a decentralized manner with the data privacy being freeze-dried. The fact "security", "cybersecurity, "network security", and "data privacy" are used means that AI and IoT become more and more important for counteracting online threats. Business becomes more networking-oriented and relies upon data, so cybersecurity is important to protect the data and the integrity of the systems. The word "human" and concepts related to it, such as "systematic review", "cost-effectiveness", "performance", and "optimization" means everything related to using AI and machine learning technologies is human-centered. The terms mean that algorithms should be used based on trying to achieve the best human performance, optimize everything at low cost, and perform analyses to measure the effectiveness and significance of AI applications. It is important to make sure that all technological advancements do not oppose society but cater to human needs.

Applications of artificial intelligence, machine learning, and deep learning in smart and sustainable industry

Enhancing manufacturing processes

AI and ML are playing a central role in optimizing manufacturing processes (Zheng et al., 2021). ML algorithms help in offering predictive maintenance, which helps in determining potential equipment failure before they become one (Angelopoulos et al., 2019; Rai et al., 2021). This work is done by the algorithms that, analyzing the data obtained from the sensors built in the machinery, predict when a machine will fail and thus minimize the downtime and maintenance cost (Rai et al., 2021; Paramesha et al., 2024c). This proactive mindset not only increases operational efficiency but also increases equipment life, which helps sustainability by reducing waste. Another key use case is quality control driven by AI. DL-based vision systems are able to perform non-invasive inspections at superspeed, providing zero-defect inspections for applications where human inspectors might fail (Hernavs et al., 2018; Rane et al., 2024b). This decreases the chances of returns and rework, which leads to a lower introduction of products with a lower quality.

Smart energy management

In the energy sector as well AI, ML, and DL play a significant role in the management of smart grids (Mostafa et al., 2022; Mourtzis et al., 2022). These technologies provide live insights into actual energy usage patterns and the power grid can therefore adapt dynamically to the patterns in real time, making better supply to meet the demand. This will improve energy efficiency on every level from peak usage times these algorithms can predict and distribute the energy to create immense waste. AI also plays a key role in integrating renewable energy sources into the grid (Moreno et al., 2021; Mostafa et al., 2022; Paramesha et al., 2024d). AI systems can predict the supply of solar and wind energy by analysing historical data, as well as forecasting weather conditions. Ramping up and down wind and solar farms to follow such predictions is crucial for providing a consistent renewable energy supply to the grid, keeping fossil fuel resources untapped, promoting sustainability.

Advancing smart agriculture

AI and ML in agriculture are changing conventional farming into precision agriculture (Shaikh et al., 2022). Systems powered by AI to enhance precision in analysing soil health, monitoring crop conditions, and predicting output with high accuracy (Gera et al., 2022; Pallathadka et al., 2022). Drones, which have AI-powered cameras mounted on them, provide a constant and realtime update of the health of the crops and hence the farmers can take timely action such as only where it is needed by applying fertilizers or pesticides (Shaikh et al., 2022). This directed breeding not only improves the yield of the crops but also drastically decreases the use of chemicals, thereby promoting sustainable agricultural practices. Furthermore, agricultural AI also plays a role in optimizing irrigation systems. AI algorithms studying weather data and the moisture content of soil can help decide the precise amount of water a crop needs, saving water and ensuring its sustainable use. Table 2.1 shows the applications and techniques of artificial intelligence in smart and sustainable industry.

Intelligent Transportation Systems (ITS)

AI used to design intelligent transportation systems which are crucial for the development of modern smart and sustainable cities, contributes the most to sustainability (Akhmatova et al., 2022; Lom et al., 2016). More specifically, one of the most common uses of AI in ITS is the optimization of traffic flow (Gong, 2022; Rane et al., 2024c). Real-time data from traffic sensors and cameras are analyzed by AI algorithms in order to dynamically adjust traffic signals. This practice helps to reduce congestion and decrease emissions produced by vehicles due to idling. In addition, in logistics, AI is used for route optimization, helping delivery vehicles to switch to more efficient routes and reduce the consumption of fuel and generation of emissions. Finally, on a larger scale, AI helps to power autonomous vehicles, the development of which is based on DL algorithms. In turn, the use of AVs increases the safety of transportation and allows to decrease the number of vehicles, as human-related issues are one of the main causes of traffic accidents. Public transportation systems can also be AI-powered to help analyze data and optimize routes for each type of destination and users' schedule, thus, increasing their use and reducing the need for private transportation, which is one of the biggest sources of urban pollution.

Table 2.1. Applications and techniques of artificial intelligence in smart and sustainable industry

References	**Application Area**	**AI Techniques**	**ML Techniques**	**DL Techniques**	**Description**
Drakaki et al., (2022)	Predictive Maintenance	Expert systems, Anomaly detection	Regression analysis, Decision trees, Random forests	Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs)	Predicting equipment failures before they occur by analyzing sensor data and

					historical maintenance records.
Angelopoulos et al., (2019); Kotsiopoulos et al., (2021)	Quality Control and Inspection	Machine vision, Pattern recognition	Support Vector Machines (SVMs), Clustering algorithms	CNNs, Autoencoders	Automated inspection of products using image analysis to detect defects.
Bahrpeyma, & Reichelt, (2022); Mazzei, & Ramjattan, (2022)	Supply Chain Optimization	Intelligent agents, Decision support systems	Reinforcement learning, Optimization algorithms	Long Short-Term Memory (LSTM) networks, Deep Q-Networks (DQN)	Optimizing logistics, inventory management, and demand forecasting.
Ahsan et al., (2023); Guato Burgos et al., (2024); Khalil et al., (2021)	Energy Management	Smart grids, Energy consumption modeling	Time series forecasting, Ensemble methods	LSTM networks, Generative Adversarial Networks (GANs)	Monitoring and optimizing energy usage in manufacturing processes and buildings.
Bilal et al., (2019); Çınar et al., (2020)	Smart Manufacturing	Robotics, Process automation	Bayesian networks, K-Nearest Neighbors (KNN)	CNNs, RNNs	Automating manufacturing processes, enhancing robotics, and improving human-robot collaboration.
Tatipala et al., (2021); Bilal et al., (2019)	Product Design and Development	Generative design, Simulation	Genetic algorithms, Clustering	Variational Autoencoders (VAEs), GANs	Using AI to create innovative product designs and simulate

					performance under different conditions.
Oláh et al., (2020); Javaid et al., (2022)	Environmental Monitoring	Sensor networks, Environmental modeling	Regression analysis, Clustering	CNNs, RNNs	Monitoring air and water quality, predicting environmental changes, and managing resources.
Júnior et al., (2021); Savković et al., (2021)	Worker Safety and Training	Wearable technology, Safety analytics	Classification algorithms, Reinforcement learning	CNNs, RNNs	Monitoring worker health and safety, providing real-time feedback, and personalized training.
Khatter et al., (2021); Pereira et al., (2023)	Customer Service and Support	Chatbots, Virtual assistants	Natural Language Processing (NLP), Sentiment analysis	Transformer models, RNNs	Providing 24/7 customer support, handling inquiries, and resolving issues.
Mahmoodi et al., (2024); Grillo et al., (2022)	Sustainable Resource Management	Resource allocation algorithms, Optimization	Predictive analytics, Time series analysis	RNNs, Deep belief networks (DBNs)	Managing natural resources efficiently, optimizing usage, and minimizing waste.
Gera et al., (2022);	Smart Agriculture	Precision farming,	Decision trees, Random forests	CNNs, RNNs	Monitoring crop health,

Pallathadka et al., (2022); Shaikh et al., (2022)		Crop monitoring			optimizing irrigation, and improving yield prediction.
Motroniet et al., (2021); Nagy, & Lăzăroiu, (2022)	Autonomous Vehicles	Path planning, Sensor fusion	Reinforcement learning, Bayesian networks	CNNs, RNNs	Enabling self-driving cars to navigate, detect obstacles, and make decisions autonomously.
Kotsiopoulos et al., (2021)	Smart Grids	Load forecasting, Fault detection	Time series analysis, Clustering	LSTM networks, Autoencoders	Managing electricity distribution, detecting faults, and optimizing load balancing.
Paul et al., (2021); Popov et al., (2022)	Smart Healthcare	Medical imaging analysis, Diagnostics	Classification algorithms, Regression models	CNNs, RNNs	Analyzing medical images, predicting disease outbreaks, and personalizing treatment plans.
Kurniawan et al., (2023); Mohammadi et al., (2023)	Waste Management	Route optimization, Waste sorting	Clustering, Regression models	CNNs, RNNs	Optimizing waste collection routes, automating waste sorting, and predicting

					waste generation.
Elsisi et al., (2021); Rahimian et al., (2021)	Smart Buildings	HVAC optimization, Lighting control	Reinforcement learning, Time series forecasting	LSTM networks, Autoencoders	Managing heating, ventilation, air conditioning, and lighting systems for energy efficiency.
Li et al., (2021); Kaššaj, & Peráček, T. (2024)	Urban Planning	Traffic flow analysis, Land use optimization	Clustering, Regression models	CNNs, RNNs	Analyzing urban traffic patterns, optimizing land use, and planning infrastructure development.
Demertzis et al., (2020); Chang et al., (2022)	Fraud Detection	Anomaly detection, Risk assessment	Classification algorithms, Clustering	CNNs, RNNs	Identifying fraudulent transactions, assessing risks, and monitoring for suspicious activities.
Nia et al., (2021); Ahmad et al., (2022)	Renewable Energy Management	Energy forecasting, Resource allocation	Time series analysis, Regression models	LSTM networks, Autoencoders	Predicting renewable energy generation, optimizing resource allocation, and integrating with the grid.

Bruni, & Piccarozzi, (2022)	Smart Retail	Customer behaviour analysis, Inventory management	Clustering, Recommendation systems	CNNs, RNNs	Analyzing customer behavior, optimizing inventory, and personalizing shopping experiences.
Karabegović et al., (2019); Karabegović et al., (2020)	Industrial Automation	Process control, Robotics	Reinforcement learning, Decision trees	CNNs, RNNs	Automating industrial processes, controlling machinery, and enhancing robotics.
Tao et al., (2021); Jakubczak et al., (2021)	Financial Analytics	Algorithmic trading, Risk management	Regression models, Time series analysis	LSTM networks, GANs	Analyzing financial markets, predicting stock prices, and managing risks.

Smart buildings and infrastructure

AI and ML are technologies that can be used to manage buildings and infrastructure (Elsisi et al., 2021). Building management systems are monitoring and control systems that are used to manage and control mechanical and electrical equipment in a building. Building management systems can be used to monitor indoor climate, lighting, and energy use of buildings and give them a lot more ways to save money in everyday life (Elsisi et al., 2021; Rahimian et al., 2021). AI is being used with existing building management systems to address a number of challenges in energy management in buildings (Seraj et al., 2024). First of all, AI provides much better focus, ensuring that certain unoccupied areas of a room are not wasted when there is no one else there. In addition, AI can also be used in predictive analysis using data from similar sites. For example, predictive analytics can be used in construction by comparing current data with historical information on similar construction projects. This can help predict a potential delay, and activities that are likely to lead to a delay can be carried out, ensuring that the work is completed on time. In addition, using resources more efficiently. The main purpose of this use is the sustainability of the construction industry.

Sustainable supply chain management

Transparency, efficiency, and sustainability are the three attributes that AI, ML, DL, or all of them together bring to the supply chain management world (Bahrpeyma, & Reichelt, 2022; Paramesha et al., 2024e). By creating IT algorithms that can process large amounts of data, for instance, AI can help businesses optimize the process of managing their inventory. As a result, they can reduce spoilage or make sure that a shelf is never empty when a customer wants to buy something. For example, in the shipping industry, there are a lot of goods that can perish, and it is crucial to run the supply chain properly; otherwise, the goods will spoil, and the company will lose money. Predictive analytics allow making very precise predictions of future demand, so companies can plan their production and storage accordingly. On the one hand, they do not make too many products and have them sit on shelves. On the other hand, they do not run out of products to sell. Another technology is blockchain, which combined with AI can make the supply chain completely transparent (Esmaeilian et al., 2020; Mazzei, & Ramjattan, 2022). With the technology, every single transaction is recorded and cannot be deleted, which helps track everything and thus helps avoid fraud.

Environmental monitoring and conservation

AI and ML help monitor and protect the environment (Oláh et al., 2020). AI drones and satellites analyse photo and video camera data, determining deforestation rates, populations of different species, and so on. Optimized algorithms allow environmentalists to evaluate and detect the rapid changes in the environment and implement solutions in time (Oláh et al., 2020; Javaid et al., 2022). In addition, AI algorithms are able to assess the probability of the occurrence of a variety of fatal environmental events and adapt pre-emptive response actions. AI algorithms are also able to model the effects of climate change and predict future environmental impacts. ML models are needed to help develop effective strategies to combat the greenhouse effect, carbon footprints, and other environmental changes. In addition to carbon footprints, AI help monitor and collect non-recyclable items. Later, AI-powered robots and conveyors sort the collected waste, separating non-recyclable items from recyclable ones.

Promoting smart healthcare

Healthcare is a domain in which medical organizations can achieve significant improvements by using AI, ML, and DL-based technologies (Paul et al., 2021; Popov et al., 2022). Some examples of such improvements include better diagnostics, treatment, and care of the patients. Thus, AI algorithms can be used for analysing medical images with high precision, thereby enabling the detection of cancers and other diseases in their earliest stages. This helps improve the quality of patient care, since a timely diagnosis can be made and fewer patients will need to be treated with surgical methods. Additionally, personalized medicine uses AI to analyse the genome and determine the best course of treatment for the patient (Schlingensiepen et al., 2016; Popov et al., 2022). This approach guarantees that the selected treatment will be the best one and the side effects will be minimized, while the cost of the treatment may be decreased as well. AI-driven predictive analytics is used to optimize the operation of a hospital. They are applied to forecast the dates when a hospital is likely to have more or fewer patient admissions, as well as what resources will be required. This helps ensure that the hospital is operating efficiently and the patients receive the necessary care in a timely manner.

Smart retail and e-commerce

AI, ML, and DL are used in the retail and e-commerce sectors to help improve the overall customer experiences and optimize business operations (Bruni, & Piccarozzi, 2022). For example, AI-driven recommendation systems analyse customer behaviour and preferences, suggesting specific products that are most likely to be suitable for customers. Using DL algorithms, recommendation systems may adjust their suggestions, making their offers more personalized over time. This type of tool helps retain customers and attracts new ones, increasing sales through satisfaction with customer experience. Another example is AI-based chatbots and virtual assistants, which are used to automate the process of receiving feedback from customers and addressing the issues. The biggest advantage of AI-driven customer support services is that they are able to communicate with a vast number of customers simultaneously, reducing waiting times and consequently improving the experience. Finally, AI is also used to optimize pricing strategies by analysing market peculiarities, competitors' pricing, and customer demand (Ghosh et al., 2020). All this information may be processed in order to dynamically offer specific prices which maximize the revenue for a business and ensure competitiveness back.

Enhancing human resources management

Human resource management is benefiting from such advanced technologies as AI, ML, and DL that not only make it more effective but more efficient (Grillo et al., 2022). The process of HR is considered to be individual in a sense where the subjectivity of the recruiting process is considered to be the basis. Therefore, any insights generated and provided by AI are limited in the era of big data. The first area of AI application in HR is the recruitment process. The AI-powered system analyses resume, cover letters, and candidate profiles to identify who is the better fit for the open job position. It helps to save time, human resources, and leads to tougher results. Moreover, in a constantly changing labour market, the AI systems use ML algorithms to improve the matching every time and make it work even better. The second example is applied to the performance management of employees. AI can work with the data on the previous performance of employees and process them with the system of the company. It helps to draw the necessary conclusions for the employer and make some tangible information from the existing data. The manager can simply process this kind of data, see the trends, and make sure that the important decisions on promotions, training, and talent development are the most relevant. It is also considered to be useful since the AI-powered sentiment analysis program can analyse the comments of the employees or their communication with each other and measure their mood and morale.

Financial services

AI, ML, and DL contribute to the optimization of particular finance-related tasks in various ways (Jakubczak et al., 2021; Tao et al., 2021). For instance, one of the crucial functions in which they can help is fraud analysis. The algorithms of AI identify the patterns of account proceeding conditions, and in case a deviation from these patterns occurs, it helps to provide fraud detection in a timely manner. For example, financial institutions regularly identify a leakage of finance and react quickly. Besides, AI is used for credit risk assessment: a large amount of information is analysed to make a conclusion about a person's creditworthiness, including financial statements of the company or the person, market and economic indicators, and trends. Finally, AI-based robots, i.e., robo-advisors, assist in a customer providing advice on the details of making investments (Dhanabalan, & Sathish, 2018). Development in the sphere of ML allows selecting the best possible solution in a particular period of time.

Smart cities and urban planning

To begin with, AI, ML, and DL power the development of smart cities, which are cities where technology significantly improves the well-being of people (Kaššaj, & Peráček, T. 2024). For example, AI-based traffic management information systems reduce traffic congestion and pollution by adjusting city lights in real time based on sensor data from all the traffic lights in the city, traffic flow sensors, additional sensors, and cameras over the city roads. The function of the traffic management system to optimize and adjust the brightness of the city lights is connected with the activities of the traffic incident responder, which receives the information about the accident from the same data sources and decreases the flow of the traffic coming to the accident location. Moreover, for urban planning, on the one hand, AI, ML, and DL evaluate the data available for the city compared to the data for other cities by the same time, such as population growth, housing needs, and the impact on the environment (Li et al., 2021; Kaššaj, & Peráček, T. 2024). As a result, AI-based solutions develop a plan for the city's sustainable growth with efficient green systems for housing development and rapid transportation. On the other hand, AI applications in smart cities optimize the process of waste management by making a decision regarding a timely waste pick-up in locations where it is expected to fill up. As a result, the fuel consumption by the garbage truck drops, which means that the corresponding decrease in the emissions takes place.

Enhancing cybersecurity

To keep cybersecurity modern and cut off the majority of issues in real-time, AI, ML, and DL are employed (Lezzi et al., 2018; Culot et al., 2019). First of all, with the help of AI systems, it is possible to analyse network traffic. Given that such systems understand the way normal users perform their tasks and identify unusual behaviour and requests, it is a good opportunity to detect any problem that might have occurred. Next, DL is widely employed for this purpose, too, as systems employing DL techniques go on learning from the data they receive and become more efficient at spotting the threats. In addition to detecting threats, AI is instrumental in responding to incidents. There are some cases when an AI system can block a certain system or segment those devices that might have been attacked and successfully secure the attack's targets. Such systems can analyse reasons why a network attack might have occurred in the first place and offer methods of eliminating the threat (Culot et al., 2019). Another major aspect that is widely associated with AI is data privacy. AI can define the type of information that is used, how it is stored, and by whom it can be requested. In addition, with the help of AI systems, it is possible to spot any unusual tendency of how data is handled and respond to it, keeping in line with the newest rules of storing and distributing data.

Smart water management

Effective water management is essential for sustainability, and AI, ML, and DL are already used in various regions . First of all, AI-powered systems are used to monitor water consumption, detect leaks, and predict the need for maintenance in real-time. These solutions are developed to analyse the data retrieved from sensors integrated into the investigated water infrastructure, identify infeasibilities, and generate suggestions concerning the elimination of the problem to avoid water loss (Alabi et al., 2019; Saravanan et al., 2021). In addition, AI-driven prescriptive analytics can be adopted in resource management to predict water demand with regard to historical data and weather predictions to ensure this goal is achieved. These approaches minimize water waste, therefore, ensuring conservation (Saravanan et al., 2021).

Education

Technologies such as AI, ML, and DL have been applied in the field of education to personalize learning and streamline administrative processes (Coşkun et l., 2019; Mian et al., 2020). For instance, several AI-driven adaptive learning systems have been developed over the years that analyse data from student performance to adjust educational material to students' paces and styles of learning. Therefore, learning processes have become more personalized, which allows for achieving better results and preventing high dropout rates. In addition, AI helps analyse data related to students' involvement and performance to identify any shortages or other issues in the learning process (Mian et al., 2020). This feature also promotes sustainability as the resources of education are used more effectively. AI and its subset technologies simplify various administrative processes, such as scheduling, admissions, and grading, which allows educators to concentrate more on teaching, student care, and support.

Renewable energy optimization

Apart from the algorithms that allow controlling smart grids and integrating renewable energy sources, AI and ML are incorporated in the operation of renewable energy systems (Nia et al., 2021; Ahmad et al., 2022). For example, AI determines the optimal performance characteristics of solar panels and wind turbines, based on real-time data on the weather and the history of operating these devices. At the same time, in the field of renewable energy, AI-based predictive maintenance is particularly valuable, which causes renewable energy equipment to operate in optimal modes, which extends their service life and ensures maximum contribution to the safe generation of energy.

Construction safety

Construction is a field in which safety is a top concern, and AI, ML, and DL have brought improvements to the safety protocols and practices on construction sites (Júnior et al., 2021). For instance, AI-powered computer vision systems can monitor construction sites in real time and detect safety hazards or non-adherence to safety regulations. For example, they can detect unsafe behaviour, such as workers not wearing protective equipment, and send an alert to the site supervisor immediately. Predictive analytics used in construction can analyse historical data to detect hazardous patterns and predict potential incidents. In this way, construction companies can take preventative measures to improve safety performance and reduce the number of accidents.

Environmental risk assessment

AI, ML, DL are used in environmental risk assessment to predict and minimize the consequences of operation of industrial facilities (Oláh et al., 2020; Javaid et al., 2022). AI algorithms analyse data on the state of the environment, the operation of the enterprise, and the consequences of its work. For example, equipment condition data and production parameters allow to predict the likelihood of an oil spill or spill, plant seeds in oil production recommend the best safe solutions. As a result, the company will take preventive action and prevent environmental pollution. AI systems are also used to monitor the environment in real time (Javaid et al., 2022). Environmental monitoring systems based on AI track changes in air and water quality and toxic emissions are registered even before pollution occurs. As a result, the company reacts quickly, often the emissions do not reach the ecosystem.

Public safety and emergency response

Public safety and emergency response are now enhanced by AI, ML, and DL with the help of real-time data analysis and predictive insights (Longo et al., 2019; Reegu et al., 2020). For example, AI-based surveillance systems now monitor the public's performance in whichever type of public spaces to prevent any unusual activity and threats to the public. As soon as such threats appear, law enforcement officers can interfere and prevent the threats from being developed. In case of emergency, AI systems have learned to analyse all the possible sources of data. For example, it uses social media, sensors, emergency calls as well as other types of information to provide the situational understanding of what is happening and how the emergency situation can be managed. AI algorithms are also able to recognize patterns of natural disasters and predict further spread of them based on the weather and other relevant data (Reegu et al., 2020). For example, such technologies can now recognize fires, indicate these to the local departments, and predict the further spread of the fires hours before the fires actually spread. In addition, such systems can also help with communication. For example, there are AI communication platforms that help to deliver quickly comprehended information to the public upon any queries. Such platforms can work with natural language processing and process all the queries really fast as well as provide answers that are both effective and understandable.

Urban mobility

AI, ML and DL are changing urban mobility (Lom et al., 2016). Smart transportation networks are being developed with the help of AI-based ride-sharing platforms (Lom et al., 2016; Hamidi et al., 2017). They help to find the most appropriate ways or match riders with vehicles expeditiously optimizing the number of cars on the roads and decreasing emissions. AI is also involved in smart parking assistance in a way to help drivers find accessible parking lots more rapidly than they could do it by themselves. These systems are based on real-time and predictive analytics for parking utilization optimization. It is also possible to highlight the popularization of AI-managed electric scooters of bikes that can be observed in many cations and urban areas. The AI algorithm is also used for managing distribution and technical state of these vehicles, which should stay charged and in a ready condition in a necessary area. In general, these means of transportation are green and help to overcome excessive use of private cars.

2.4 Conclusions

Recent advancements in AI, ML, and DL have enabled huge progress in smarter and sustainable industries. They are revolutionizing a wide-range of industries leading to higher productivity, energy and resource optimization and predictive maintenance, all of which are driving sustainable efforts. For instance, the inclusion of AI and ML into manufacturing has enabled the deployment of smart factories where synoptic data analysis combined with automated decision-making capabilities can enhance product quality while reducing waste. Specifically, DL algorithms, including ones utilized in computer vision and natural language processing are transforming quality control and supply chain management by providing accurate defect identification and improving communication throughout the global supply chain. AI and ML play a big part in adjusting the renewable energy generation and distribution in the energy sector, assisting in the shift towards a low-carbon economy. AI-fueled smart grids manage energy demand resolve the big question of supply and demand in real time, as they simultaneously forecast utilization patterns to optimize the provision of energy with energy efficiency.

In addition, DL models have helped to improve autonomous systems in transportation and logistics, enabling the widespread use of electric and self-driving vehicles which decrease carbon emissions and enhance urban mobility. AI is all set to create a new revolution in the healthcare industry, such as for the creation of tailored medicines, increased diagnostic accuracy and for optimal treatment plans, thereby improving patient outcomes while reducing healthcare costs. Such technologies allow for exploratory data analyses across immense volumes of data to identify insights that support better decision-making and fuel improvements to medical research and development. The integration of AI, ML, and DL with the Internet of Things (IoT) and blockchain technologies, is also making industrial operations more transparent, secure and efficient. This convergence helps build smart cities which involve integration of systems and data-driven insights for sustainable urban development. Industries wishing to continue in a competitive and environmentally aware global market will have to embrace these developments.

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