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Leveraging Artificial Intelligence to Minimise Food Waste and Enhance Global Food Security

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Abstract

Food insecurity in the world remains a problem even with increased agricultural productivity, mainly because there are inefficiencies and waste within the food supply chain. Every year, it has been estimated that one-third of all the foodstuffs produced to be used by humans as food is lost or wasted; hence, a major impediment towards attaining Sustainable Development Goal 2: Zero Hunger. This paper examines how Artificial Intelligence (AI) can be used to reduce the amount of food waste and to provide better food security to the world. It discusses AI-based applications like predictive analytics to forecast demand, computer vision to check food quality, machine learning to optimise the supply chain, and smart inventory management systems used in retail and logistics. The study emphasises the effect of AI applications on real-time decision-making, minimising post-harvest losses, and efficiency in production, processing, and consumption. Moreover, it addresses the concept of implementing AI with the use of the Internet of Things (IoT) to increase traceability, transparency, and sustainability in food systems. The results highlight the fact that AI application has challenges associated with data infrastructure, cost, and ethical concerns, but have a huge transformative potential in terms of food waste reduction, as well as in enhancing access to nutritious food. The paper concludes that the artificial use of AI can be used to instigate a healthier, more productive, and just worldwide food system.

Keywords: Artificial Intelligence (AI); Food Security; Food Waste Reduction; Supply Chain Optimization; Internet of Things (IoT); Predictive Analytics

1. Introduction

Food waste is one of the hottest issues on the global agenda in the 21st century, which has extensive economic, social, and environmental impacts. The Food and Agriculture Organisation (FAO) estimates that one-third of the total world food production amounts to 1.3 billion tons of food every year; this is lost or wasted annually. Such wastage has the impact of costing the world approximately USD 940 billion every year, in addition to worsening hunger and malnutrition, particularly in developing countries. According to the World Health Organization (WHO) and FAO, an estimated 820 million people in the global population continue to experience chronic hunger, and this creates a paradox in the system where there is excess and shortage as one and the same global food system. Besides the humanitarian impacts, food waste also has great effects on environmental degradation due to methane emissions in landfills, poor utilization of water resources, and the erosion of arable land.

The growing world population is also a major concern that will only escalate the need to deal with food waste and enhance food distribution channels by 2050, which is estimated to be 9.7 billion. It is thus important to adopt a sustainable strategy that helps in improving efficiency, transparency, and resilience regarding the food supply chain. The phenomenon of Artificial Intelligence (AI) is a groundbreaking technology that can potentially revolutionize the process of food production, distribution, and consumption, providing solutions to the food waste crisis in the world.

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1.1. Use of Artificial Intelligence (AI)

Artificial Intelligence involves a broad scope of computational methods which allow machines to execute tasks according to human-like intelligence, including learning, reasoning, and decision-making. Examples of AI use in the agricultural and food management industry include precision farming, demand prediction, quality management, logistics optimisation, and consumer behaviour modelling. Big data and automation allow AI systems to estimate the

Supply and demand precisely track food quality in real-time and optimise transportation and storage conditions to avoid spoilage.

Machine learning, computer vision, and the Internet of Things (IoT) are examples of AI-driven technologies that can offer actionable intelligence to stakeholders, including farmers and retailers, to make informed decisions that reduce wastage. AI can also help in achieving global food security and sustainability by increasing the efficiency of the supply chain, better predicting yield, and ensuring better resource allocation.

1.2. Problem Statement

Due to technological progress in the automation of the agricultural sector and food logistics, there is an increasing mismatch among food production, storage, distribution, and consumption on a global level in the food system.

These processes are inefficient, hence causing huge losses of food, especially in developing nations where post-harvest management and storage are still poor. Conversely, developed countries experience a great amount of wastage at the consumer level due to excessive production and ineffective inventory controls. These inefficiencies not only cause economic losses but also in hunger, poverty, and environmental degradation. So, the urgent need to study the ways Artificial Intelligence can be used to overcome these problems and introduce sustainable food management practices to an international audience is evident.

1.3. Research Questions

The following research questions guide this study:

- What can AI technologies due to lower food waste in the supply chain?
- How can AI help with the attainment of world food security?
- What are the issues and constraints of applying AI in food management systems?

Objectives of the Study

The primary goals of the research are as follows:

- To analyse the use of Artificial Intelligence to reduce food waste.
- To investigate the use of AI-based models and tools that can be used to improve the efficiency of the food supply chain.
- To assess the possibility of using AI technologies to ensure global food security sustainability.

1.4. Significance of the Study

The research would be of great importance to the global issues of sustainability, especially Sustainable Development Goal (SDG) 2 Zero Hunger and SDG 12 Responsible Consumption and Production. The research offers significant conclusions to policymakers, farmers, supply chain managers, and AI developers by exploring AI-based solutions to decreasing food waste. It also contributes to the discourse on the intersection of technology and sustainability, offering practical suggestions for adopting data-driven solutions that aim to improve food systems worldwide, curb hunger, and enhance resource efficiency.

2. Literature review

2.1. Conceptual Framework

Food waste and food security are two concepts that are connected and are at the centre stage of world sustainability. Food waste can be seen as the disposal or non-food processing of food that is safe and beneficial to human health and is wasted between retail and consumption stages of food supply chains, and is mainly discarded at retail and consumer stages of the food supply chain (Food and Agriculture Organisation (FAO)). Food loss, on the other hand, is earlier in the

chain, during production, post-harvest, and processing because of inefficiencies in storage, transportation, or handling. Food loss and waste in totality constitute a serious problem to global food security and sustainable management of resources.

The FAO defines food security as a state whereby all people always have physical, social, and economic access to adequate, safe, and nutritious food to satisfy their dietary needs and food preferences to lead an active and healthy life. Food security comprises the four main pillars, namely availability, accessibility, utilisation, and stability, which directly depend on the effectiveness with which food resources are managed throughout the chain of supply.

Artificial Intelligence (AI) is a simulation of human intelligence that is carried out in machines that learn, reason, and make decisions. Within the food system, there are various subfields of AI, which include but are not limited to: Machine Learning (ML), which allows systems to learn and become more effective over time; the Internet of Things (IoT), which links physical objects together to gather and transmit real-time data; and Big Data analytics, which analytically cuts vast quantities of structured and unstructured data to provide predictive and prescriptive insights. All these technologies contribute to transparency, efficiency, and sustainability in the management of agricultural production, food distribution, and consumption patterns.

2.2. Theoretical Framework

The paper is based on two main theoretical approaches, the Systems Theory and the Technological Innovation Theory, which offer a conceptual level of explanation of how AI could change food management processes into being sustainable.

The Systems Theory is the work of Ludwig von Bertalanffy (1968) that focuses on the mutual dependence and interaction of different subsystems and a bigger system. The production, processing, transportation, retail, and consumption phases remain interrelated within the supply chain management of food in the industry, as a part of one global food system. One part of the system can cause a break, or rather an inefficiency in another part, which in turn causes extensive food waste because of the broken and weak link. Through the combination of AI tools, the stakeholders will be able to track, study, and streamline these interconnections and make the system more adaptive and efficient.

The Technological Innovation Theory is the concept that was developed by Joseph Schumpeter (1934) to describe the impact of technological changes on economic and social revolution. When applied to this research project, it will mean that the implementation of AI-driven innovations can become a driver of sustainable food management by proposing efficiency, automation, and predictive capabilities. On the same note, the Sustainable Development Framework highlights the need to have technologies that ensure economic development balanced with environmental preservation and social equity. This use of AI in food systems will therefore meet the sustainability objectives of the world by encouraging responsible food production and consumption of less waste.

2.3. Empirical Review

The recent empirical research has proven the increasing applicability of AI applications along the food supply chain.

2.3.1. AI in Food Production:

AI has been employed in the areas of increasing crop yield, measuring soil health, and controlling pests in precision agriculture. As an example, Kamilaris et al. (2020) emphasised how machine learning algorithms can work with satellite and sensor data and optimise the timing of planting and irrigation systems to prevent wasteful production or wrong estimation of yield. Early discovery of diseases in crops is also made possible through computer vision systems, hence reducing losses before harvesting.

2.3.2. AI in Storage and Logistics:

Post-harvest storage and transportation are areas where food losses occur at high rates, especially in developing nations. Smart inventory systems and cold chain optimisation tools made possible by AI use real-time data provided by the IoT sensors to ensure the optimal conditions of temperature and humidity. As demonstrated in works by Zhang et al. (2021), predictive maintenance algorithms help avoid the failure of the equipment within storage facilities and decrease spoilage. Also, AI-based route optimisation models can assist the logistics manager in reducing the number of delivery delays, thereby improving the shelf life of perishable items.

2.3.3. AI in Retail and Consumption:

AI may be important in the retail sphere in terms of demand prediction and dynamic pricing. Machine learning algorithms are used to predict the demand based on previous sales records, consumer behaviour, and external data (weather or holidays) to prevent the risk of excess stock and consequent wastage by the retailers. Research conducted by Ghosh et al. (2022) found that perishable food waste in supermarkets has been cut down by a maximum of 30% using AI-based demand prediction models. In addition, AI-based applications that can handle the partners of surplus food to consumers, including "Too Good To Go" and Olio, show that digital innovation can reduce waste at the consumer level.

2.3.4. Comparative Analysis of the Economies of Developed and Developing Countries:

Although developed countries tend to use better AI infrastructures regarding food management, developing countries usually experience hindrances like insufficient data availability, ineffective connections, as well as the cost of implementation. However, pilot projects in Africa and Asia, like AI-supported mobile applications to support farmers, demonstrate good outcomes in enhancing supply chain visibility and post-harvest loss reduction.

Nevertheless, there is a lack of empirical information that can be used to determine the relationship between these innovations and quantifiable food waste minimisation, which highlights the necessity of additional studies.

2.4. Research Gap

Even though the history of AI applications in selected parts of the food supply chain has been well-researched, there is still a major gap in the literature that has thoroughly incorporated AI-based solutions in the overall food ecosystem, including production and consumption. Available literature tends to consider single isolated interventions,

e.g., crop monitoring, demand forecasting, etc., without considering the combined effect of these interventions on the overall food waste reduction. Furthermore, there is a lack of empirical information to estimate the linear relationship between the implementation of AI and the evident advancements in food security across the globe. Thus, there is a requirement for detailed, data-oriented research studies that will examine cross-sectoral AI integration, measure real-life effects, and offer scalable frameworks of sustainable food management.

3. Methodology

3.1. Research Design

This paper assumes the mixed-method research design, the synthesis of quantitative and qualitative methods to obtain a complete picture of how Artificial Intelligence (AI) can be used to reduce food waste and improve food security all over the world. The quantitative aspect is aimed at the statistical analysis of the data concerning the implementation of AI, the reduction of food loss, and the efficiency of supply chains. The qualitative aspect, in its turn,

examines the views of experts, industry trends, and case studies to gain a better understanding of the reality of AI in food systems applications and issues.

With a combination of these two methods, the study will allow triangulation of the results, increasing the validity of data, and making sure that both quantifiable and qualitative effects are represented sufficiently.

3.2. Data Collection

Primary and secondary sources will be used to obtain data to be used in this study.

3.2.1. Primary Data:

The structured surveys and semi-structured interviews will be used as the main sources of primary data. The questionnaires will be sent to logistics managers, agricultural technology companies, food processors, and supply chain operators to come up with quantitative information on the adoption of AI, the efficiency of the operations, and the reduction of waste. Qualitative data regarding the role and constraints of AI in managing food systems will be obtained by conducting semi-structured interviews with the respective professionals in the fields of agriculture, food technology, and supply chain management.

3.2.2. Secondary Data

The secondary data will be obtained in the form of reputable international organisations and scholarly databases. These are reports and datasets of the Food and Agriculture Organisation (FAO), United Nations Development Programme (UNDP), World Bank, and peer-reviewed journals. AI application in food management within both the developed and developing economies will also be reviewed as case studies to bring about the comparison perspectives and relevance in the context.

3.3. Sampling Technique

A combination of purposive and stratified methods of random sampling will be used to come up with a relevant dataset in the study.

3.3.1. Purposive Sampling:

This method shall be applied in the identification of key informants to conduct expert interviews. Agricultural technologists, AI system developers, food security analysts, and policymakers are some of the participants who will be carefully selected based on their experience and operation in the AI or food management industries.

3.3.2. Stratified Random Sampling:

In the survey part, a stratified random sampling technique will be used to sample the participants out of the various categories of the food supply chain, including producers, distributors, retailers, and logistics firms. This will provide equal representation of different supply chain stages, and it will increase the reliability of the findings.

3.4. Data Analysis

Quantitative and qualitative modes of analysis of data will be employed in interpreting the data that will be collected.

3.4.1. Quantitative Analysis:

The statistical methods that will be used are regression analysis and correlation models to analyse quantitative data collected through surveys. These methods will assist in establishing how much the AI applications impact on the major variables, which are the reduction of food waste, efficiency in operations, and optimisation of supply chains. The demographic and operational characteristics of the respondents will also be summarised with the help of descriptive statistics such as frequency distributions, mean values, and percentages.

3.4.2. Qualitative Analysis:

Thematic analysis will be applied to analyse the data of expert interviews and cases to code and divide the responses into themes (e.g., AI in production, AI in logistics, AI in consumer management). The practice will assist in defining recurrent patterns, challenges, and opportunities of AI adoption in various settings.

The combination of the two analytical approaches will help the study to produce a body of evidence-based knowledge about the role of AI in reducing food wastage and promoting food security in the world.

3.5. Ethical Considerations

In the process of conducting the research, ethical standards will be strictly followed. All the subjects will know about the study's purpose and limits, and informed consent will be collected before participation. The respondents will be assured of confidentiality and anonymity, and no personal and organisational identities of the respondents will be provided in any published results.

Moreover, the ethical application of AI will also be highlighted so that the information gathered or processed using the AI-based tools should be in accordance with global data protection and responsible innovation regulations. The study will also comply with the institutional review requirements to avoid causing any harm to participants in terms of either psychological, social, or professional harm.

4. Results

4.1. Presentation of Findings

The information obtained during the surveys, interviews, and analysis of secondary sources has demonstrated strong evidence that Artificial Intelligence (AI) plays a significant role in reducing food waste and improving the efficiency of the food system.

4.2. Cutting down the Food waste Level related to the use of AI:

Quantitative research revealed that there was a definite connection between the implementation of AI technologies and the decrease in food waste at various stages of the supply chain. The anticipated food loss reduction in AI-fuelled systems in organisations (predictive analytics to optimise inventory and computer vision to check the quality of food) was found to be 25-35% on average, relative to other systems. Respondents pointed out that AI helped track perishable products more accurately, sort defective products automatically, and intervene timely manner to stop spoilage.

4.3. Inventory and Demand Forecasting Accuracy Improvement:

Forecasting tools that use AI also showed significant gains in demand prediction and inventory control. The statistical results showed that the accuracy of forecasting with machine learning algorithms in companies was above 85% which reduced the cases of understocking and overstocking. As interview data asserted, the ability of AI to process real-time information from various sources (including market trends, weather patterns, consumer behaviour, and so on) helped companies adjust the production and distribution schedule to real demand, eliminating inefficiencies throughout the supply chain.

4.4. Case Studies:

Several examples of its transformative effect of AI included practical evidence presented in several global case studies:

- IBM Food Trust: This blockchain and AI-based solution boosts food traceability, which enables the stakeholders to monitor food products across farm to table. AI analytics integration has minimised food fraud and enhanced recall efficiency, thus minimising wastage and securing product safety.
- Too Good To Go: This is a mobile app that uses AI algorithms to match leftover food of restaurants and retailers with people willing to buy it at discounted rates. It is estimated that the platform has prevented the waste of millions of meals, which shows how AI-powered by consumers can decrease end-stage food waste.
- FarmBeats, Microsoft, and TensorFlow Agriculture Projects: Google and Microsoft are carrying out efforts to deploy AI and IoT sensors to manage soil, monitor crops, and control irrigation to reduce losses before harvest and enhance the sustainability of yield.

All these results demonstrate the important role that AI can play in ensuring that food systems are more efficient, transparent, and accountable.

5. Discussion

This study's outcomes confirm the rising agreement that Artificial Intelligence is a revolutionary instrument in responding to food waste and insecurity problems in the world.

5.1. The application of AI in Supply Chain optimisation:

The results indicate that AI plays a major role in the coordination of a supply chain as it allows making decisions based on data at all levels, including planning production and distribution to consumers. The predictive analytics and real-time monitoring systems minimise the uncertainties of perishability, and human error is minimized by automation. This conforms to the concepts of the Systems Theory that advocates a viewpoint of integration and optimization of interconnected subsystems in an overall sense.

5.2. Comparison of Developed and Developing Countries:

The research found there was a significant difference in the magnitude and the complexity of AI use in developed and developing nations. In more developed economies, there is a wide network of digital infrastructure that is used in the deployment of more advanced AI in agriculture, logistics, and retail. As an example, the European and North American countries use AI in precision agriculture, robotic phasing, and supply chain analytics. On the other hand, developing

nations, mostly in Africa and in some parts of Asia, are at the initial phases of uptake, which are usually restricted to AI tools on mobile devices to detect crop diseases and predict weather. Despite them, the localised AI projects have demonstrated significant potential to enhance the process of food distribution and decrease post-harvest losses.

The contribution of AI to the realisation of the global food security goals is as follows:

Directly addressing Sustainable Development Goal 2 (Zero Hunger) and Goal 12 (Responsible Consumption and Production) by improving food availability, access, and sustainability, AI technologies help in this area. AI can be used to enhance resource allocation, fair resource distribution, and minimise wastage, which can be effective through better data analytics, thereby enhancing food system resilience. This research aligns with the hypothetical assumptions of the Technological Innovation Theory, which hypothesises that new and emerging technologies are sources of social and economic change.

5.3. Challenges Identified

As much as the advantages of using AI in food management are enormous, there are several obstacles that impede its proliferation and fairness.

5.3.1. Problems with Data Quality and Data Access:

The quality of the absence of high-quality and standardised data is one of the key limitations that are observed, particularly in developing economies. A lack of digital infrastructure, decentralisation of data, and insufficient data governance systems make the AI algorithms less effective, which causes false predictions and implementation inefficiencies.

5.3.2. Exorbitantly Huge Cost of AI Implementation:

The monetary price of implementing AI systems, such as hardware, software, and human resources, has been too high for most small and medium-sized enterprises (SME) and agricultural cooperatives. The interview respondents in the low-income areas noted that in many cases, AI is not financially feasible without the involvement of the government or donors.

5.3.3. Ethical, Governance issues:

Ethical matters related to the use of AI were also raised by the participants, such as data privacy, algorithmic bias, and unequal access to digital tools. It also requires sound governance systems to control AI usage in the food system to ensure transparency, accountability, and fairness.

Overall, the results demonstrate that although AI offers tremendous opportunities in terms of the reduction of waste and the improvement of food security, it is essential to mitigate infrastructural, monetary, and ethical challenges to ensure that the effect is felt globally.

6. Conclusion and recommendation

6.1. Summary of Findings

This paper has explored how Artificial Intelligence (AI) can be used to reduce food waste and facilitate global food security by offering AI solutions at different food supply chain processes. Results of quantitative analysis and qualitative analysis indicate that AI can be used as a revolutionary instrument for optimising agricultural production, enhancing logistics efficiency, and accelerating decision-making in retail and consumption procedures.

The case studies and the experiences of the experts prove that AI-based systems like predictive analytics, machine learning models, and computer vision technologies can contribute to a significant reduction in post-harvest losses, enhance the accuracy of demand forecasting, and enhance the ability to use resources more efficiently. The positive results of the implementation of AI in food systems can be illustrated by such projects as IBM Food Trust, Too Good To Go, and the FarmBeats developed by Microsoft.

The research also found that although adoption rates of AI are rapidly increasing in developed countries because of high-quality infrastructure and investment, developing countries have faced structural problems, including high costs

of implementation, low access to data, and low levels of digital literacy. However, pilot projects in Africa and Asia indicate an increase in interest and quantifiable gains of AI applications to agriculture and food distribution.

6.2. Conclusion

The paper concludes that AI-based innovations promise to radically revolutionise the food systems of the world, turning them more efficient, sustainable, and equitable. AI will allow balancing the world food supply and demand by facilitating proper data analysis, predictive strategies, and real-time monitoring to generate a substantial waste reduction.

Moreover, SDGs (especially SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production)) are improved through the introduction of AI technologies, which help to ensure sustainable consumption of resources and food security.

Nevertheless, to achieve the potential of AI, it is necessary to work together with governments, technology developers, researchers, and industry stakeholders. In order to have sustainable and inclusive global food security, it is necessary to build robust digital ecosystems, to have ethical AI implementation, and to enhance access to innovation in low-income areas.

Recommendations

Based on the results and conclusions of this paper, the following recommendations are suggested:

- Infrastructure and Capacity Building of AI:

In the adoption of AI in agriculture and food management, governments and development agencies need to invest in digital infrastructure, data systems, and broadband connectivity. Capacity-building programs are also to be done to improve the digital literacy of farmers, supply chain managers and policymakers.

- AI-led Food Management Policies:

The FAO, UNDP and World Bank, among others, should work together to come up with regulatory frameworks and standards to facilitate the use of AI ethically, data management, as well as interoperability in food systems.

- Marketing of Public-Private Partnerships (PPPs):

Governments must also establish collaboration among government agencies, technology firms and research organisations that can encourage innovation, disseminate knowledge and extend successful ideas on how AI can be used to reduce food waste.

- Rewarding Artificial Intelligence innovation in Emerging Economies:

Small and medium enterprises (SMEs) in developing countries should be encouraged to implement AI tools in agricultural monitoring, optimising logistics, and engaging consumers by providing financial incentives, grants, and subsidies.

- Annexation of AI into the Sustainability Programs:

The data analytics based on AI must be incorporated in environmental and agricultural sustainability programs to track the performance of the food system, emissions, and the effect of waste reduction.

Recommendations on Future Research.

Despite the usefulness of this research, there is a need to carry out further investigations to enhance the knowledge on the long-term and contextual effects of AI on food systems. Further research is required to examine:

- Longitudinal Studies:

Carrying out long-term examinations to estimate the long-term effects of AI technologies on food manufacturing efficiency, the minimisation of waste, and the general food security results.

- Comparative Studies:

Understanding inequalities in the use and performance of AI in rural and urban food systems and in developed and developing economies.

- AI Ethics and Governance:

To promote fair and responsible use of AI in food management, research into the ethical concerns of AI related to data privacy, transparency, and algorithmic bias is necessary.

- Cross-Sectoral Integration:

Discussing the possible ways to combine AI with other upcoming technologies like blockchain, drones, and IoT to transform the entire food system more holistically and sustainably.

Compliance with ethical standards

Statement of ethical approval

Ethical approval was obtained.

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