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LEVERAGING ARTIFICIAL INTELLIGENCE FOR ECONOMIC DEVELOPMENT: INNOVATIONS IN CIRCULAR ECONOMY AND WASTE REDUCTION STRATEGIES

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Abstract. *The integration of Artificial Intelligence (AI) into the circular economy offers transformative solutions to the global challenge of waste management. This article explores the role of AI-driven innovations in promoting waste reduction, resource optimization, and sustainability. Through case studies such as AMP Robotics in the U.S. and ZenRobotics in Finland, the study analyzes how AI enhances waste sorting, recycling efficiency, and product lifecycle management. The findings underscore that AI not only contributes to environmental sustainability but also promotes economic opportunities by optimizing resource loops and minimizing waste generation.*

Keywords: *artificial intelligence, circular economy, waste reduction, recycling, sustainability, smart sorting.*

SUN’IY INTELLEKTNI IQTISODIY RIVOJLANISH UCHUN QO‘LLASH: AYLANMA IQTISODIYOT VA CHIQINDILARNI KAMAYTIRISH STRATEGIYALARIDAGI INNOVATSIYALAR

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Annotatsiya. *Sun’iy intellekt (SI) texnologiyalarining aylanma iqtisodiyotga integratsiyasi global miqyosdagi chiqindilarni boshqarish muammosiga inqilobiy yechimlar taklif etadi. Ushbu maqolada chiqindilarni kamaytirish, resurslardan samarali foydalanish va barqarorlikni ta’minlashda SI asosidagi innovatsiyalarning o‘rni tahlil qilinadi. AQShdagi AMP Robotics va Finlyandiyadagi ZenRobotics kabi amaliy misollar orqali SI texnologiyalari chiqindilarni saralash, qayta ishlash samaradorligini oshirish va mahsulotning hayotiy siklini boshqarishdagi ahamiyati ko‘rsatilgan. Tadqiqot natijalari shuni ko‘rsatadiki, sun’iy intellekt atrof-muhit barqarorligiga hissa qo‘shish bilan birga iqtisodiy imkoniyatlarni ham yaratadi, resurs aylanishini optimallashtiradi va chiqindilar hosil bo‘lishini kamaytiradi.*

Kalit so‘zlar: *sun’iy intellekt, aylanma iqtisodiyot, chiqindilarni kamaytirish, qayta ishlash, barqarorlik, aqlli saralash.*

ИСПОЛЬЗОВАНИЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА ДЛЯ ЭКОНОМИЧЕСКОГО РАЗВИТИЯ: ИННОВАЦИИ В ЦИРКУЛЯРНОЙ ЭКОНОМИКЕ И СТРАТЕГИЯХ СНИЖЕНИЯ ОТХОДОВ

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Аннотация. *Интеграция искусственного интеллекта (ИИ) в модель циркулярной экономики предлагает прорывные решения для глобальной проблемы управления отходами. В статье рассматриваются ИИ-инновации, способствующие сокращению отходов, оптимизации ресурсов и устойчивому развитию. На примере AMP Robotics (США) и ZenRobotics (Финляндия) анализируется, как ИИ повышает эффективность сортировки отходов, переработки и управления жизненным циклом продукции. Полученные результаты подчеркивают, что ИИ не только способствует экологической устойчивости, но и открывает экономические возможности за счёт оптимизации циклов ресурсов и сокращения объёмов отходов.*

Ключевые слова: *искусственный интеллект, циркулярная экономика, сокращение отходов, переработка, устойчивость, умная сортировка.*

Introduction.

The global economy has long operated on a linear model of “take, make, dispose,” leading to enormous waste and environmental degradation. In response, the circular economy concept has emerged, aiming to close the loop by keeping products and materials in use for as long as possible. Artificial Intelligence (AI) is now playing a pivotal role in accelerating this transition. AI technologies can analyze data at unprecedented speeds and make intelligent decisions, enabling more efficient resource use and waste minimization. The world’s economy operates largely upon linear economic principles (Ellen MacArthur Foundation, 2020). A traditional linear economy follows the “take-make-waste” approach where the natural raw materials are extracted and then manufactured into products. These products are used for a certain period of time and eventually discarded as waste (Akter, Pranto, & other, 2022). This economic model encourages over- consumption of material resources, creates unsustainable waste management practices, and creates serious health, biodiversity, and climate problems (Ogunmakinde, Sher, & other, 2021; Elghaish & other, 2022). It is estimated that by 2060, the amount of material resources consumed worldwide will almost double from 90 gigatonnes in 2020 to 167 gigatonnes while the number of consumers will increase by three billion by 2030 (Roberts, & other, 2022). This over-consumption leads to higher demands for resource extraction which in turn increases the levels of greenhouse gas emissions from mining and extraction, worsening air quality and accelerating habitat destruction (Da Silva, Sehnem, 2022).

A solution to overcome the many negative aspects of the linear economy is called the circular economy (CE). CE is an economic system operating on the principles of restoration and aims at reduced material consumption and waste elimination while promising economic development (Stahel, MacArthur, 2019; Schneider, 2019). The European Union (EU) defines CE as “an economy in which the value of products, materials and resources is preserved for as long as feasible, by designing durable products that can be reused, repaired, and recycled”. This sees the replacement of the ‘end-of-life’ approach (Barteková, Börkey, 2022). Furthermore, in CE, the waste from one product is seen as a resource for another. This greatly reduces the value of consuming finite material resources (Ghoreishi, Happonen, 2020). CE is restorative and is regenerative by its design. It reduces natural resource depletion, negates waste production, and enables green and sustainable economic development (Macarthur, Cowes, 2019). The objectives of CE are similar to those of the Sustainable Development Goals (SDGs), such as

SDG 12, 13, 14, in the promotion of economic growth without depleting the earth's resources by 2030 (Kholikova, 2024).

Literature review.

The integration of artificial intelligence (AI) into economic development strategies, particularly within the framework of circular economy and waste reduction, has garnered significant attention in recent literature. According to Geissdoerfer et al. (2018), the circular economy aims to minimize waste and make the most of resources, and AI technologies can enhance these efforts by optimizing resource management and improving efficiency in production processes. In a study by Wastl et al. (2020), the authors highlighted how AI-driven analytics can facilitate better decision-making in waste management systems, leading to reduced landfill use and increased recycling rates.

In the context of Uzbekistan, research by Abdullayev et al. (2021) emphasizes the potential of AI in transforming traditional economic practices into more sustainable models that align with circular economy principles. They argue that local industries can leverage AI for predictive maintenance, which not only reduces waste but also extends the lifespan of machinery. Similarly, the work of Rakhimov et al. (2022) focuses on the application of AI in agricultural sectors, where precision farming techniques can minimize resource use and enhance productivity while reducing environmental impacts.

Furthermore, a review by Bocken et al. (2016) discusses how AI can support business model innovation within the circular economy, enabling companies to create value from waste materials. The authors contend that AI applications such as machine learning can identify new opportunities for recycling and resource recovery. In addition, research by Zhang et al. (2021) explores the role of AI in developing smart waste management systems that utilize IoT and big data analytics to optimize collection routes and improve recycling processes.

Moreover, studies by Kjaer et al. (2020) illustrate how AI can facilitate consumer engagement in waste reduction initiatives by providing personalized recommendations and feedback on sustainable practices. This aligns with the findings of Lee et al. (2022), who emphasize the importance of public awareness and participation in achieving circular economy goals. Overall, the literature indicates that leveraging AI for economic development through innovations in circular economy practices and waste reduction strategies holds considerable promise for enhancing sustainability and resource efficiency across various sectors.

Methods.

The study employs a qualitative case study method, analyzing secondary data from industry reports, company websites, peer-reviewed journals, and government publications. A comparative approach is used to evaluate the impact of AI applications across different sectors of the circular economy, particularly in waste management and recycling.

Results.

Digitalisation has been widely recognised as one of the most important ways to unlock the benefits of a more inclusive and sustainable economy (Zhou, 2021). Digitalisation is the use of digital technologies to enhance business processes by leveraging digital technologies and digitized data (Prioux, & other, 2023). Effective utilisation of digital technologies such as Big Data, Blockchain, the IoT, Cloud Computing, and Online Digital Platforms sometimes referred as I4.0 tech- nologies enable circularity in a number of ways. These technologies can create knowledge about the material composition of products, their origin and properties, their location, condition, and availability, as well as their respective manufacturing processes and condi- tions for maintenance, dismantling, and recycling (Chlingaryan, & other, 2018; Shumway, & other, 2000). Digitalisation is disrupting the parameters of the current economic system by transforming business processes, facilitating data-driven decisions, affecting consumer behaviour, and mitigating some environmental effects.

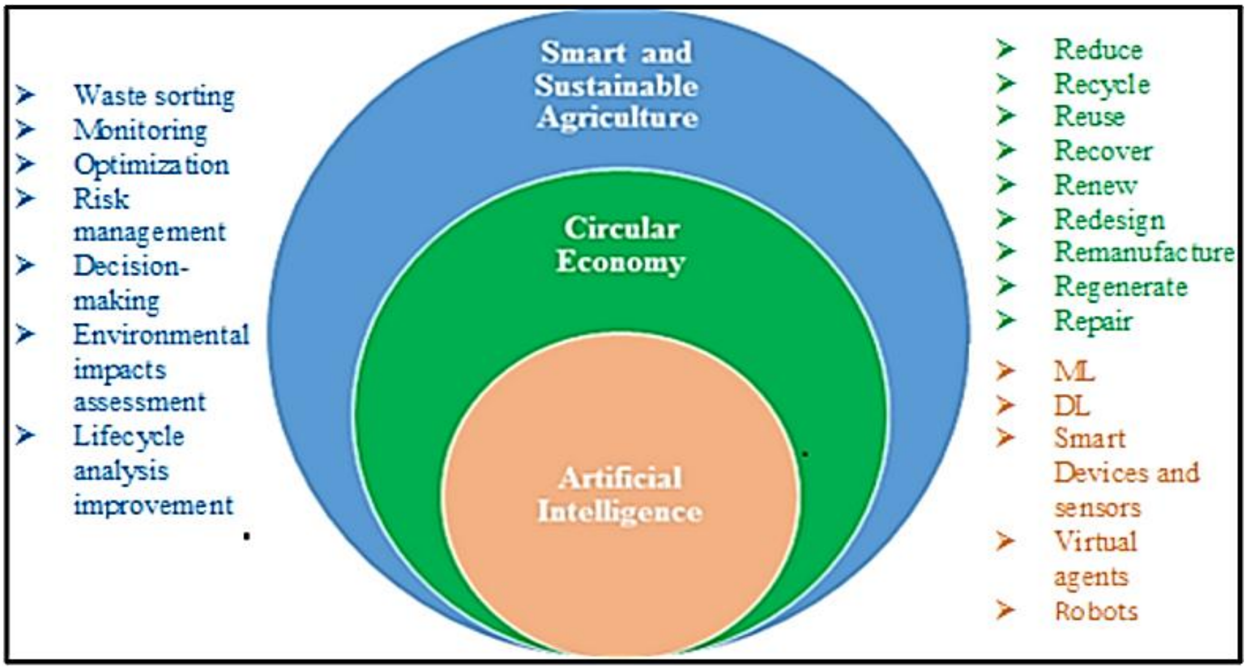

Figure 1. Artificial intelligence-driven circular economy for smart and sustainable agriculture

https://www.researchgate.net/figure/Artificial-intelligence-driven-circular-economy-for-smart-and-sustainable-agriculture_fig2_380788817

Circular economy puts a strong focus on innovative design to maintain the utility and value of products, components, and materials at all times (Makov, & other, 2020). Such designs can empower increased cycles of reuse, repair, and recycling of many products and their constituent materials. This is a difficult task. However, AI can be a helpful tool in enabling product designers to manage this complexity through iterative assisted design processes. These processes allow for rapid prototyping and testing, leading to better design outcomes in a shorter period of time (Kholikova, 2025). In this way, new products can be formed through circular design and these products can then be safely maintained and preserved in the economy for a longer period of time. As a result, the amount of resource extraction and waste production associated with excessive product development can be reduced substantially. AI can also help in predicting how materials change over time, such as their overall durability and potential toxicities (ZenRobotics, 2023). This type of information can help in advancing the reverse logistics and maintenance of products.

Machine learning (ML) is a branch of AI that provides computers with the ability to learn from data, analyse and draw inferences from complex data patterns, and make predictions with minimal human intervention (Kholikova, 2024). ML algorithms are provided with data and then through the use of statistical formulas, the algorithms are trained to derive results. This training process can be repeated and configured to improve the quality of derived results. ML algorithms can detect significant depen- dencies between the data features of real-time datasets and this ability can identify opportunities for circular solutions (Makov, & other, 2020). For example, ML approaches can be used to forecast the demand for a product as per consumer purchasing behaviour. Within agricultural settings, ML can be used to predict the right time to sow crops by using data related to the quality of the soil, weather, and possible future market conditions for the crop output.

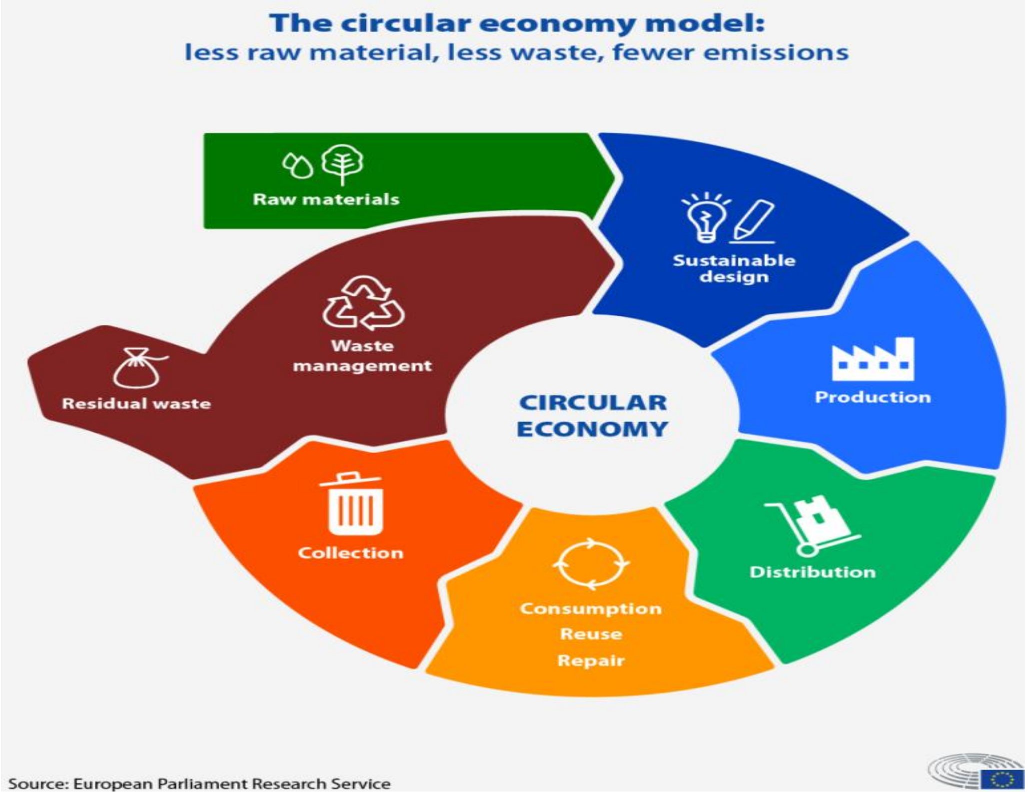

Figure 2. Circular economy model

Timeseries Analysis is an AI technique capable of working with variables evolving over time. This technique is very efficient in identifying specific trends in historical data in order to predict future events (Zhou, 2021). Methods include lines of Best Fit, Auto Regression, Moving Average, and more advanced Deep Learning (DL) models such as Long Short-Term Memory (LSTM). Applications can be found in predicting food demand based on consumption patterns to minimize food waste, predictive maintenance of equipment for reduced maintenance costs, and increasing the overall lifespan of equipment.

One of the most impactful applications of AI in the circular economy is automated waste sorting. Traditional sorting methods are labor-intensive, slow, and prone to human error. AI-enabled robots can rapidly identify and separate various waste types with high accuracy. AMP Robotics uses AI and computer vision to recognize different materials on recycling belts and sort them automatically. Its system, called Neuron, can distinguish between plastics, metals, and paper with over 90% accuracy. In Denver, Colorado, AMP's robots have increased the recovery rate of recyclables by up to 80% and reduced labor costs.ZenRobotics has developed AI-powered robotic arms that can sort construction and demolition waste. Their system uses machine learning algorithms and multispectral sensors to detect and pick up valuable materials from mixed waste. This has helped reduce landfill contributions by over 30% in some European recycling facilities (Akter, et all., 2022). AI is also used to predict waste generation patterns, allowing municipalities to optimize waste collection routes and schedules. EcoSmart uses AI algorithms to predict the fill level of waste bins using IoT sensors. This has enabled the city to reduce fuel consumption and greenhouse gas emissions by optimizing garbage truck routes, saving both environmental and financial resources (Schneider, 2019). AI is enhancing product design and manufacturing by suggesting more sustainable materials and predicting failure rates, extending product life and minimizing waste. Using AI-driven platforms, Dassault Systèmes allows manufacturers to simulate product lifecycles and environmental impacts, enabling the creation of longer-lasting, recyclable products. This design-for-sustainability approach is crucial for reducing waste (ZenRobotics, 2023).

Discussion.

AI significantly contributes to the circular economy by providing intelligent systems that reduce human error, increase efficiency, and lower costs. It not only improves the mechanical processes of waste management but also enhances strategic decision-making through predictive analytics. However, challenges remain. AI implementation requires significant investment, technical expertise, and data infrastructure. Moreover, ethical concerns around surveillance and data privacy need to be addressed. Nonetheless, the benefits of AI for sustainability outweigh the challenges when deployed responsibly (Kholikova, 2024).

The efficiency of AI-based systems to be trained and tailored for various CE approaches offers great potential. The major challenge is that in order to train and build intelligent AI models for CE, very large amounts of training data is usually required (Makov, Shepon, 2020). The lack of high-quality training data can be a potential hurdle in the effective utilisation of AI For CE. Training datasets may be difficult to generate and indeed to do so can be expensive. Collection and curation of training data can also take a great deal of time. In the absence of appropriate volumes of training data, one possible solution is to consider the usage of transfer learning. Transfer learning is a popular approach within deep learning applications. Transfer learning is a method where an already pre-trained existing AI model working for a particular task is reused and *transferred* for a new problem. AI-gathered knowledge from a high-quality existing dataset is then *transferred* to a new target application which is lacking in data, using the pre-trained existing AI model (Kholikova 2024).

To design efficient AI models for CE, an amount of data from various platforms is required to train and test the models in order to achieve circularity at a higher level. However, collection and analysis of such data could also pose various privacy, ethical, and legal risks. In many CE applications, particularly those related to consumer or customer behaviour, one finds that AI models are trained on the data generated by humans interacting with systems such as Internet applications, social media applications, and so on. These are heavily reliant on knowledge of the user's location (and associated geospatial data) and other personal characteristics. The use of these types of data streams introduces privacy considerations that are not easily solved (Schneider, 2019). For example, geospatial data about people makes it possible to connect or link those people to other types of user information including work, social, political affiliation, and other behavioural patterns, all of which represent highly confidential information (ZenRobotics, 2023). Furthermore, in terms of the analysis of such data, the inferences AI could make about an individual or group could also raise ethical issues.

Conclusion.

AI is a powerful enabler of the circular economy, offering innovative solutions to waste reduction and resource efficiency. From robotic sorting systems to predictive analytics and eco-design platforms, AI helps close the resource loop and drive sustainable economic development. Continued investment and cross-sector collaboration are essential to scale these innovations globally. A transformation from a linear to a circular economy is more important than ever and digitalisation can play a very critical role in this transformation (Kholikova, 2025). Over the past decade, the world has seen a significant industrial development using digital technologies. Stakeholders are considering incorporating AI into their businesses to attain economic growth along with substantial environmental benefits. AI can positively influence the development and the adoption of CEs worldwide.

However, gaps exist in the knowledge around how AI techniques can be practically applied in order to implement more circular business models and achieve CE ambitions across organisations. It is now of high importance to raise awareness about how AI can support CE so that governments, organisations, and sectors benefit from CE opportunities driven by AI. The range of tools available to develop AI software is expanding and becoming more user-friendly.

This is an important step towards more widespread consideration and adoption of AI as a digitalisation tool in practical real-world situations.

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