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ARTİFİCİAL İNTELLİGENCE (AI) -BASED ENERGY MANAGEMENT SYSTEMS AND ENHANCEMENT OF EFFİCİENCY ROAD TRANSPORT

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Abstract: This study explores the role of Artificial Intelligence (AI)-based energy management systems in enhancing energy efficiency in road transport. Traditional energy management approaches are limited in adapting to dynamic traffic and environmental conditions, leading to inefficient energy use. In contrast, AI enables real-time data analysis, predictive decision-making, and adaptive optimization. The research highlights key applications such as real-time energy control, driver behavior analysis, battery management, and route optimization. Furthermore, advanced innovations including Vehicle-to-Grid (V2G), Digital Twin, Federated Learning, and Edge AI are examined as next-generation solutions. The findings indicate that AI integration significantly improves energy efficiency, reduces operational costs, and supports the development of sustainable and intelligent transport systems.

Keywords: *Artificial Intelligence, energy management, road transport, energy efficiency, V2G, Digital Twin, Edge AI, smart mobility*

In the modern era, the rapid increase in global energy demand and the intensification of the impacts of climate change have made improving energy efficiency in the transportation sector a strategic priority. Road transport is considered one of the main problems in this field in terms of both high energy consumption and its impact on carbon emissions. Since traditional energy management systems are based on static models, they remain limited in providing an adequate response to changing road, traffic, and user behaviors. This leads to an increase in energy losses and a decrease in the overall efficiency of the system (Mammadov, 2020).

In this context, the application of Artificial Intelligence (AI) technologies has created a qualitatively new stage in energy management. AI-based systems process large volumes of data in real time, enabling the formation of adaptive and predictive decision-making mechanisms. This approach is not limited only to reducing energy consumption, but also increases the overall performance and sustainability of transport systems (Zhang et al., 2022). In particular, through machine learning and reinforcement learning algorithms, systems learn from previous experiences and determine more optimal strategies for future situations (Khosravi et al., 2021). The effectiveness of AI-based energy management systems stems from their ability to perform multi-parameter analysis. These systems consider factors such as speed, road conditions, traffic density, and driver behavior in an integrated manner. As a result, energy usage is optimized not only based on technical parameters but also by considering the human factor. This provides higher accuracy and efficiency compared to traditional models (Aliyev, 2021).

AI applications in improving energy efficiency cover several key areas. Real-time energy management systems dynamically regulate vehicle motion parameters to minimize energy consumption. Battery management systems reduce energy losses in electric vehicles and extend battery lifespan. At the same time, route optimization systems analyze real-time traffic data to determine the most energy-efficient routes (Demir et al., 2019). As a result of the integration of these components, energy management becomes more complex and effective.

At the present stage, the development of energy management systems is no longer limited to the vehicle level, and system-level integrated approaches come to the forefront. In this regard, Vehicle-to-Grid (V2G) technology is of particular importance. The V2G approach enables electric vehicles to interact with the power grid, allowing them to function both as consumers and energy sources. The optimization of this process through AI contributes to maintaining energy balance and increasing overall system efficiency (Yıldız & Kaya, 2023). In addition, Digital Twin technology acts as an innovative approach in energy management. This technology creates a virtual model of the real system, enabling the simulation of various scenarios in advance. Thus, energy consumption and system behavior are optimized without intervention in the real environment. This approach is particularly important in reducing risks and increasing the accuracy of decision-making.

Another important direction in the development of AI technologies is the federated learning model. In this model, instead of centralized data transfer, each system learns locally and shares only the results. This approach ensures data security while enabling the optimization of large-scale systems. Edge AI technology ensures that data is processed directly within the vehicle, minimizing delays and accelerating real-time decision-making processes (Ivanov & Smirnov, 2022). One of the important innovations in improving energy efficiency is the concept of energy-aware autonomous driving. Within this approach, autonomous vehicles make optimal decisions not only in terms of safety but also in terms of energy consumption. AI algorithms compare different driving strategies and select the option that consumes the least energy, thereby increasing overall system efficiency.

Comparative analysis of traditional and AI-based systems shows that artificial intelligence technologies provide significant advantages in energy management. While traditional systems are static and have limited flexibility, AI systems are distinguished by their adaptive, learning, and predictive characteristics. As a result of these features, it is possible to achieve a 15–30% reduction in energy consumption, which is a significant indicator both economically and environmentally. In addition, smart charging technology acts as a new direction in energy management. This system determines the optimal charging time through AI by taking into account energy prices and grid load. Multimodal transport optimization increases overall system energy efficiency through the integration of different transport modes. These approaches enable more efficient energy management at the urban level.

At the same time, the application of AI-based systems is accompanied by certain challenges. High initial investment costs, the level of technological infrastructure development, and data security issues are considered the main limitations in this field. However, the development of modern technologies allows these problems to be gradually overcome. From the perspective of future prospects, AI-based energy management systems are expected to develop further. In particular, the widespread application of IoT and 5G technologies will accelerate real-time data exchange and increase the efficiency of AI systems. This will contribute to making transport systems more intelligent, adaptive, and sustainable (Petrov, 2021). In conclusion, it can be noted that AI-based energy management systems are one of the most promising and effective approaches for improving energy efficiency in road transport. These systems provide higher adaptability, accuracy, and optimization capabilities compared to traditional models. The integration of modern innovative technologies forms the basis of a new stage of development in this field and shows that future transport systems will be more efficient and environmentally sustainable.

Furthermore, the application of Artificial Intelligence enables not only real-time optimization of energy consumption but also long-term strategic planning through predictive analytics. By anticipating traffic conditions, user behavior, and energy demand patterns, AI systems can significantly reduce unnecessary energy losses and improve operational performance. This contributes to lowering overall transportation costs and enhancing system reliability. In addition, the integration of advanced technologies such as Vehicle-to-Grid (V2G), Digital Twin, Federated Learning, and Edge AI creates a comprehensive and intelligent ecosystem for energy management. These technologies ensure that decision-making processes become faster, more secure, and more efficient, especially in complex urban environments. As a result, transport systems evolve from isolated units into interconnected and adaptive networks. Despite the significant advantages, the widespread implementation of AI-based systems still faces certain challenges, including high initial investment costs, infrastructure limitations, and data security concerns. However, continuous technological advancements and increasing global interest in sustainable development are expected to gradually overcome these barriers.

From a future perspective, the integration of AI with emerging technologies such as the Internet of Things (IoT), 5G communication networks, and even quantum computing will further enhance the capabilities of energy management systems. This will lead to the development of fully intelligent, autonomous, and energy-efficient transport systems that can dynamically adapt to changing environments.

Overall, AI-based energy management systems represent a transformative solution that not only improves energy efficiency but also supports the transition toward sustainable and smart transportation systems on a global scale.

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