Smart Energy, Conscious Future: The Role of Artificial Intelligence in Energy Efficiency

Norbert Bozsik,[1] Ágnes Fűrész,[2]
András Szeberényi[3]

[1] Hungarian University of Agriculture and Life Sciences, Department of Economics and Natural Resource, Gödöllő, Hungary
bozsik.norbert@uni-mate.hu
[2] Hungarian University of Agriculture and Life Sciences, Doctoral School of Economic and Regional Sciences, Gödöllő, Hungary
fureszagi@gmail.com
[3] Budapest Metropolitan University, Institute of Marketing and Communication, Budapest, Hungary
aszeberenyi@metropolitan.hu

Artificial intelligence (AI) offers innovative tools to enhance energy efficiency and promote sustainable consumption. This study explores the role of AI in transforming energy use patterns and raising awareness, particularly in light of behavioral changes triggered by the 2021 energy crisis. Based on a quantitative online survey of over 400 Hungarian participants, the research examines how AI-supported systems—such as digital platforms and personalized feedback tools—can reduce fossil fuel dependence and support the adoption of renewable energy. The findings highlight AI's potential in promoting conscious energy behavior through targeted, low-cost, and scalable solutions.

DOI
https://doi.org/10.18690/um.epf.5.2025.47

ISBN
978-961-286-984-7

Keywords:
energy efficiency, consumer attitude, renewable energy, artificial intelligence, energy awareness

JEL:
D83, Q20, Q29

University of Maribor Press

1 Introduction

Energy efficiency and energy awareness have become critical issues both globally and societally, particularly in the context of sustainability goals and efforts to combat climate change. In recent years, the instability of energy markets, the volatility of fossil fuel prices, and concerns about energy security have highlighted the growing importance of energy-efficient solutions. The energy crisis that emerged in 2021 had a particularly significant impact on Hungary, where rising energy prices compelled a substantial portion of households to reconsider their consumption habits. As a result of the crisis, energy-conscious behavior rapidly became one of the most important adaptation mechanisms. Energy-saving practices – such as the modification of heating habits, the use of energy-efficient appliances, and the reduction of non-essential energy consumption – have gained widespread popularity among Hungarian households. Moreover, the energy crisis has underscored an inescapable reality: energy awareness is not merely an economic necessity but also a key driver for achieving climate protection objectives.

2 Literature Review

Energy efficiency and energy awareness are considered essential factors in promoting sustainable development, especially in the context of the energy crisis and climate change. The growing integration of artificial intelligence (AI) and machine learning (ML) technologies within the energy sector has created new opportunities for reducing energy consumption, improving demand-supply management, and encouraging energy-conscious behavior (Ukoba et al., 2024). The promotion of energy-efficient technologies and consumer practices not only contributes to the reduction of global carbon emissions but also alleviates the financial burden of rising energy costs on households and businesses (Gielen et al., 2019).

In Hungary, public energy awareness has shown significant progress in recent years; however, the widespread adoption of energy-conscious practices is still not a general norm (Szakály et al., 2021). Research indicates that regional and social disparities characterize energy awareness levels in Hungary. Although a large portion of the population acknowledges the importance of energy efficiency, the widespread diffusion of energy-conscious behaviors is still hindered by factors such as financial limitations, a lack of information, and skepticism toward modern technological

solutions. The 2021 energy crisis, marked by the drastic and volatile rise in energy prices, had a significant impact on consumer energy use habits (Gajdzik et al., 2023). Despite growing attention to energy-conscious mindsets and energy-efficient behaviors, numerous obstacles continue to impede their widespread adoption among the Hungarian population, including:

- *Entrenched consumption patterns:* A significant portion of the Hungarian population follows long-established energy consumption habits, many of which reflect energy-wasting behavior (Szakály et al., 2021). During periods of low energy prices – especially under the influence of public utility cost-cutting measures—there was no strong economic incentive for households to invest in energy efficiency or to modify their consumption habits (Gadenne et al., 2011).
- *Limited financial resources and living conditions:* The research highlights that one of the main barriers to energy efficiency is the lack of financing options (48.9%) and inadequate financial or living conditions (11.8%).
- *Lack of knowledge:* Some consumers are either unaware of their options (2.8%) or do not understand how and to what extent they could save energy at home (6.7%), nor how their individual decisions impact their own energy consumption and the environment. This is especially true in rural areas and among lower-income households, where environmental awareness and the importance of long-term savings are often less relevant due to financial constraints.
- *Financial barriers to energy efficiency investments:* The acquisition and installation of energy-efficient technologies – such as insulation, window replacement, or modern heating systems – represent significant financial burdens for many households (39.9%). Although the energy crisis has increased interest in such developments, a high proportion of the population still lacks the resources to undertake energy efficiency investments. Consequently, energy-saving efforts are often limited to daily consumption reductions (e.g., lowering heating or reducing lighting) rather than comprehensive technological upgrades (Remsei et al., 2024).
- *Cultural and perceptual barriers related to energy use:* Historically, energy has been perceived by much of the Hungarian population as a "basic service" with limited recognition of its intrinsic value. Some segments of the population have regarded utility services as a "necessary evil," resulting in weak

associations between energy efficiency and sustainability goals. Notably, 3.4% of respondents do not consider energy efficiency important at all, and 1.9% do not see the relevance of renewable energy systems.

In response to the 2021 energy crisis, a shift in perspective began to emerge within the Hungarian population, as broader segments of consumers recognized that energy awareness is no longer solely an environmental issue but also a tool for economic survival. The surge in energy prices led to growing interest in energy-saving solutions; however, the transformation of consumption patterns cannot yet be considered widespread (Szakály et al., 2021).

Today, energy awareness, energy efficiency, artificial intelligence (AI), and online communication have become closely intertwined components of sustainable energy management (Gielen et al., 2019). AI-based systems analyze consumption patterns in real time, optimize energy use, reduce waste, and simultaneously enhance user comfort (Iorgovan, 2024). AI enhances energy awareness by offering personalized feedback and identifying inefficient habits (Bennagi et al., 2024). Combined with digital communication, it serves as both a technological and behavioral tool, empowering consumers to adopt more sustainable energy practices (Rozite et al., 2023).

3 Materials and Methods

The study employed a quantitative methodology, using an online questionnaire via the Surveyplanet platform to examine the impact of the 2021 energy crisis on Hungarian households' attitudes toward renewable energy and energy awareness. The survey covered four thematic areas: knowledge, attitudes and perceptions, user experiences, and demographics. In total, 423 individuals participated, primarily private respondents open to renewable energy solutions. Data were collected through convenience sampling via social media and mailing lists. The sample was demographically diverse in terms of age (18–65+), gender (48% female, 52% male), and location (urban and rural). Despite its relevance, the study has limitations: the sample is not representative, the design is exploratory, and certain items may have caused ambiguity in whether respondents referred to personal or societal awareness. These factors limit generalizability and underscore the need for more robust, representative future research.

4 Results

The findings of this study provide important insights, as the identified consumer attitudes, behavioral patterns, areas of interest, and media consumption habits inform practical applications for artificial intelligence (AI) solutions. Respondents perceived 87.5% of the Hungarian population as not energy-conscious—a reflection of societal attitudes rather than self-assessment. This highlights notable potential for targeted awareness and behavior-change initiatives. By leveraging appropriate online platforms, a broader segment of consumers can be reached and educated regarding both energy efficiency and energy awareness. More than half of the respondents (66.6%) indicated that they seek information about renewable energy or energy efficiency through digital platforms. Social media platforms play a prominent role in daily life, with 21.5% of respondents primarily obtaining related information via social media. This considerable proportion represents a relevant target group not only in the domain of online communication but also within the context of energy efficiency. For instance, utility providers could achieve substantial progress through the development of a free, downloadable digital application targeting this digitally engaged 66.6%. Furthermore, 2.7% of respondents acknowledged that educational content provided by energy suppliers influences the spread of energy-efficient and renewable energy practices. Moreover, 76.5% believe that energy suppliers bear significant responsibility in promoting energy-conscious behavior among the population, thereby contributing to the broader adoption of energy efficiency.

The analysis of energy consumption patterns among private individuals revealed that Hungarian households primarily rely on natural gas (39.8%) and electricity (34.9%) to meet their energy needs. Additionally, 5.7% use heat pumps, 11.9% utilize wood, and 7.7% rely on other sources. This information is particularly relevant for this study, as it enables utility providers to offer more tailored and practical recommendations to consumers, thereby promoting energy efficiency based on a deeper understanding of household energy consumption habits. Notably, 39.9% of respondents reported being unable to afford energy-efficient systems, suggesting that this segment could benefit most from low-cost, digitally delivered solutions. Identifying both internal and external motivators (e.g., financial or psychological factors) would enable providers to further personalize their advice. A significant portion of respondents (48.9%) reported a lack of personal capital or inadequate financial circumstances to invest in energy-efficient systems. However, 65.3%

actively follow news and information related to renewable energy and energy awareness, while 55.3% have considered switching to a renewable energy source, making them a promising target audience for online campaigns promoting energy efficiency. While the surveyed group demonstrates an emerging commitment to energy-conscious and energy-efficient behaviors, their efforts remain in the early stages, constrained by limited financial means and basic energy-saving options currently available to them.

A substantial share of respondents (78.7%) reported engaging in energy-efficient practices in their daily lives, including the use of energy-saving appliances (28.5%), conscious energy consumption (32.7%), unplugging devices after use (17.5%), and the adoption of smart home technologies (7.8%). Furthermore, 9.2% reported using renewable energy sources to meet their energy needs. Only 0.7% of participants indicated that they do not make any effort to live an energy-conscious lifestyle.

5 Recommendations

Based on the identified behavioral patterns, attitudes, and consumer habits, the following AI-driven recommendations are proposed to enhance energy awareness and promote energy efficiency in practice:

- ***AI-based digital educational platform with targeted communication:*** Given that 87.5% of respondents perceive the Hungarian population as not energy-conscious and 66.6% rely on digital platforms for information, it is recommended to develop an AI-driven educational platform. This platform would segment target audiences based on interests, attitudes, and online media consumption patterns, offering personalized content while considering user motivation (e.g., cost savings, environmental protection, comfort).
- ***Intelligent mobile application offering personalized energy-saving tips:*** For the digitally active segment that remains less receptive to energy-efficient technologies (39.9%), an AI-based application could provide tailored recommendations based on users' energy sources (e.g., gas, electricity, heat pump). As digital engagement often reflects general media use rather than sustainability awareness, the app should combine personalized advice with educational content to encourage behavioral

change. Continuous consumption monitoring and gamification (e.g., challenges, rewards) could further support motivation (Kranz et al., 2010).

- ***AI-generated consumer motivation map for energy providers:*** As 76.5% of respondents emphasized the responsibility of energy providers in increasing energy awareness, AI could assist providers in developing detailed motivation maps. These maps would account for consumers' financial situations, energy habits, and attitudes, thereby facilitating the creation of customized services and supporting targeted incentive programs (e.g., leasing or installment plans for energy-efficient devices) (Li & Yuan, 2024).
- ***AI-driven, low-cost energy efficiency recommendation system*:** Given that 48.9% of respondents lack capital for the installation of energy-efficient systems, an AI-based recommendation engine could propose feasible, low-investment but effective energy-saving solutions tailored to individual financial, demographic, and housing conditions. The system would also calculate potential savings and payback periods (Dzwigol et al., 2024) and provide educational materials and step-by-step implementation guides.

Clarifying the operational principles of AI-based systems enhances the practical relevance of the proposed recommendations. These systems typically utilize user-generated and sensor-derived data – such as smart meter readings or appliance usage patterns – to identify inefficiencies and generate personalized feedback. Technologies like Google Nest and Tesla Powerwall exemplify how real-time optimization can improve both the effectiveness and user acceptance of such applications.

6 Conclusion

The results of this study confirm that the energy crisis has heightened energy awareness among the Hungarian population and increased interest in renewable energy sources. Among respondents, energy efficiency considerations and sustainable consumption practices have gained prominence, driven by rising energy prices and energy market instability. The findings also highlight the pivotal role of AI-based solutions and online communication channels in fostering energy awareness. The implementation of intelligent technologies can further support households and businesses in identifying and addressing energy-wasting behaviours

(Yussuf et al., 2024), positioning them as active participants in sustainability initiatives.

References

Abrahamse, W., & Steg, L. (2013). Social influence approaches to encourage resource conservation: A meta-analysis. *Global Environmental Change*, 23(6), 1773–1785. https://doi.org/10.1016/j.gloenvcha.2013.07.029

Balta-Ozkan, N., Amerighi, O., & Boteler, B. (2014). A comparison of consumer perceptions towards smart homes in the UK, Germany and Italy. *Energy Policy*, 74, 273–284. DOI: 10.1080/09537325.2014.975788

Bennagi, A., AlHousrya, O., Cotfas, D. T., & Cotfas, P. A. (2024). Comprehensive study of the artificial intelligence applied in renewable energy. Energy Strategy Reviews, 54, 101446. https://doi.org/10.1016/j.esr.2024.101446

Chmielewska, B., Chmielewski, Ł., & Remsei, S. (2024). CHANGES IN HOUSEHOLD INCOME AFTER POLAND'S ACCESSION TO THE EUROPEAN UNION. Economics & Sociology, 17(4), 295-314. DOI:10.14254/2071-789X.2024/17-4/16

Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency*, 1, 79–104. https://doi.org/10.1007/s12053-008-9009-7

Friege, J., & Chappin, É. J. L. (2014). Modelling decisions on energy-efficient renovations: A review. *Renewable and Sustainable Energy Reviews*, 39, 196–208. https://doi.org/10.1016/j.rser.2014.07.091

Gadenne, D., Sharma, B., Kerr, D., & Smith, T. (2011). The influence of consumers' environmental beliefs and attitudes on energy saving behaviours. *Energy Policy*, 39(12), 7684–7694. December 2011. Energy Policy 39 (12):7684-7694. DOI:10.1016/j.enpol.2011.09.002

Gajdzik, B., Jaciow, M., Wolniak, R., Wolny, R., & Grebski, W. W. (2023). Energy Behaviors of Prosumers in Example of Polish Households. Energies, 16(7), 3186. https://doi.org/10.3390/en16073186

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, 24, 38–50. https://doi.org/10.1016/j.esr.2019.01.006

Iorgovan, D. (2024). Artificial Intelligence and Renewable Energy Utilization. Proceedings of the ... International Conference on Business Excellence, 18(1), 2776–2783. DOI:10.2478/picbe-2024-0231

Rozite, V., Miller, J., & Oh, S. (2023). Why AI and energy are the new power couple. IEA. https://www.iea.org/commentaries/why-ai-and-energy-are-the-new-power-couple

Kranz, J., Gallenkamp, J., & Picot, A. (2010). Power to the people: applying gamification principles to demand-side management in the smart grid. *AMCIS 2010 Proceedings*.

Li, L., & Yuan, X. (2024). The influence of energy-saving information in online reviews on green home appliance purchase behavior based on machine learning. Energy and Buildings, 314, 114296. https://doi.org/10.1016/j.enbuild.2024.114296

Li, X., Li, S., Cao, J., & Spulbar, A. C. (2025). Does artificial intelligence improve energy efficiency? Evidence from provincial data in China. Energy Economics, 142, 108149. https://doi.org/10.1016/j.eneco.2024.108149

Henryk Dzwigol, Aleksy Kwilinski, Oleksii Lyulyov, & Tetyana Pimonenko. (2024). Digitalization and Energy in Attaining Sustainable Development: Impact on Energy Consumption, Energy Structure, and Energy Intensity. Energies, 17(5), 1213–1213. https://doi.org/10.3390/en17051213

Szakály, Z., Soós, M., & Berke, Sz. (2021). The level of energy consciousness among Hungarian consumers and its influencing factors. *Hungarian Journal of Marketing and Management*, 55(1), 3–15.

Szennay, Á., Szigeti, C., Beke, J., & Radácsi, L. (2021). Ecological Footprint as an Indicator of Corporate Environmental Performance—Empirical Evidence from Hungarian SMEs. Sustainability, 13(2), 1000. https://doi.org/10.3390/su13021000

Ukoba, K., Olatunji, K. O., Adeoye, E., Jen, T.-C., & Madyira, D. M. (2024). Optimizing renewable energy systems through artificial intelligence: Review and future prospects. Energy & Environment, 35(7). https://doi.org/10.1177/0958305x241256293

Yussuf, R. O., & Asfour, O. S. (2024). Applications of artificial intelligence for energy efficiency throughout the building lifecycle: An overview. Energy and Buildings, 305, 113903. https://doi.org/10.1016/j.enbuild.2024.113903