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# Application of AI in big data analytics in the goal of energy transition: a comparative cost-effectiveness analysis of renewable energy sources versus fossil fuels

# Primena veštačke inteligencije u analizi velikih podataka u cilju energetske tranzicije: uporedna analiza isplativosti obnovljivih izvora energije u odnosu na fosilna goriva

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**Abstract:** The analytical processing of big data and AI technologies plays a key role in the energy transition, enabling more efficient utilization of renewable energy sources and the optimization of power systems. The utilization of alternative and renewable energy sources represents the only viable strategy that can ensure a successful energy transition, distancing us from outdated and environmentally harmful energy supply systems based on fossil fuels and high carbon emissions. With the support of artificial intelligence (AI) and big data technologies, this transition becomes more predictable, measurable, and feasible, enabling the anticipation of potential energy supply scenarios. This paper explores the application of AI and big data technologies, while a comparative analysis is employed to examine the use of alternative, renewable, and traditional energy sources within the context of the energy transition. Through a comparative analysis, the study examines the advantages, challenges, and production costs associated with alternative, renewable, and conventional energy sources. The findings underscore the potential of data-driven approaches to accelerate the energy transition while highlighting the economic and technological barriers that must be addressed to ensure a sustainable energy future.

**Keywords:** Carbon footprint, Sustainable energy, Energy transition, Big data, AI.

**Sažetak:** Analitička obrada velikih podataka i tehnologija veštačke inteligencije igra ključnu ulogu u energetskoj tranziciji, omogućavajući efikasnije korišćenje obnovljivih izvora energije i optimizaciju energetskih sistema. Korišćenje alternativnih i obnovljivih izvora energije predstavlja jedinu održivu strategiju koja može osigurati uspešnu energetsku tranziciju, distancirajući nas od zastarelih i ekološki štetnih sistema snabdevanja energijom zasnovanih na fosilnim gorivima i visokim emisijama ugljenika. Uz podršku veštačke inteligencije (VI) i tehnologija velikih podataka, ova tranzicija postaje predvidljivija, merljivija i izvodljivija, omogućavajući predviđanje potencijalnih scenarija snabdevanja energijom. Ovaj rad istražuje primenu tehnologija veštačke inteligencije i velikih podataka, dok se uporedna analiza koristi za ispitivanje upotrebe alternativnih, obnovljivih i tradicionalnih izvora energije u kontekstu energetske tranzicije. Kroz uporednu analizu, studija ispituje prednosti, izazove i troškove proizvodnje povezane s alternativnim, obnovljivim i konvencionalnim izvorima energije. Rezultati naglašavaju potencijal pristupa zasnovanih na podacima za ubrzanje energetske tranzicije, istovremeno ističući ekonomske i tehnološke barijere koje se moraju rešiti kako bi se osigurala održiva energetska budućnost.

**Ključne reči:** Ugljenični otisak, održiva energija, energetska tranzicija, veliki podaci, VI.

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## INTRODUCTION

The protection of the natural environment and the provision of sufficient energy will not be achievable without the use of advanced technologies such as big data and artificial intelligence (AI). The analytical processing of big data and AI technologies plays a key role in the energy transition, enabling more efficient utilization of renewable energy sources and the optimization of power systems. The use of big data technology is the key to the solution of multi-dimensional system problems, the improvement of operational efficiency, and the reduction of production costs. In addition, big data technology can also help users to analyze operating conditions and detect potential faults (Hong et al., 2023). The utilization of alternative and renewable energy sources represents the only viable strategy that can ensure a successful energy transition, distancing us from outdated and environmentally harmful energy supply systems based on fossil fuels and high carbon emissions.

With the support of artificial intelligence (AI) and big data technologies, this transition becomes more predictable, measurable, and feasible, enabling the anticipation of potential energy supply scenarios.

## 1. METHODOLOGY

The research was conducted through a comparative analysis of energy costs from various sources. Costs were presented using the Levelized Cost of Energy (LCOE) and Overnight Cost metrics for different sources - both renewable and conventional - using databases from the International Renewable Energy Agency (IRENA), Lazard, and the International Energy Agency (IEA).

## 2. MATERIALS AND METHODS

The energy sources included in the analysis are onshore wind, offshore wind, solar photovoltaics, and geothermal energy for renewable energy sources (RES), and natural gas, nuclear energy, and coal for conventional energy sources.

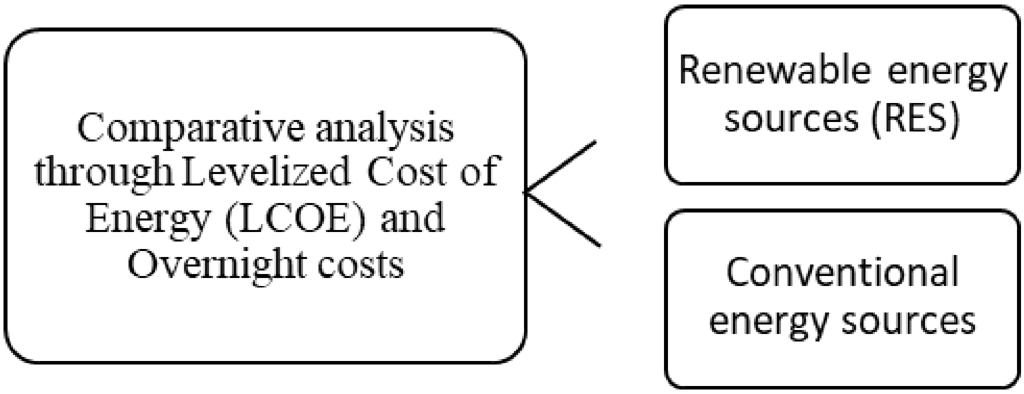


*Figure 1. Comparative analysis of energy costs*
*Source: Author's figure*

## 3. RESEARCH AND DISCUSSION

The comparative analysis of the Levelized Cost of Energy (LCOE) and overnight costs (as provided by Lazard, IRENA, and IEA) offers significant insights into the cost-effectiveness of both renewable energy sources (RES) and conventional energy sources.

Among the renewable energy sources analyzed, onshore wind stands out as the most cost-effective technology, with LCOE values ranging from 0.033 USD/kWh (IRENA) to 0.063 USD/kWh (Lazard). This places onshore wind as the leading renewable energy technology in terms of cost-effectiveness, making it an attractive option for large-scale energy production. In Serbia, where significant wind power capacity is already being developed, such as the Kovačica wind plant, onshore wind represents a critical component of the renewable energy transition.

Following closely in cost-effectiveness is solar photovoltaics (PV), with an LCOE ranging from 0.044 USD/kWh (IRENA) to 0.075 USD/kWh (Lazard). The declining cost of solar PV is a direct result of technological advancements and economies of scale, making it an increasingly viable option for sustainable energy production. With further investment in solar PV technologies, these costs are expected to continue decreasing, enhancing its competitiveness with onshore wind.

Offshore wind, with an LCOE ranging from 0.075 USD/kWh (IRENA) to 0.143 USD/kWh (Lazard), is still more expensive than onshore wind, yet remains an important technology, especially in coastal regions with high offshore wind potential. Despite its higher cost, offshore wind energy is expected to become more cost-competitive as turbine technologies improve and large-scale offshore wind farms continue to develop.

Among the renewable sources, geothermal energy stands out as the most expensive, with an LCOE ranging from 0.071 USD/kWh (IRENA) to 0.217 USD/kWh (Lazard). While geothermal provides reliable baseload power, its higher upfront costs and the need for specific geographical conditions make it less competitive compared to other renewables. Nevertheless, its long-term potential for stable energy production remains valuable, particularly in regions with significant geothermal resources.

When considering conventional energy sources, gas and nuclear still present higher LCOE compared to renewable sources, with values of 224 USD/kWh (gas) and 253 USD/kWh (nuclear), according to the IEA. However, these figures reflect the overnight costs of conventional plants, highlighting the significant capital expenditure involved in building these plants. Gas power plants, despite their relatively lower overnight costs (823 USD/kWe), face challenges related to fuel price volatility and carbon emissions, which reduce their cost-competitiveness in the long run. Nuclear power, with an overnight cost of 3606 USD/kWe, has the highest upfront capital requirements, making it less economically viable compared to renewable energy technologies. Additionally, nuclear plants face challenges related to regulatory approval, construction timelines, and waste disposal, further impacting their economic competitiveness.

*Levelized cost of energy comparative analysis coventional versus RES*

*Table 1. Levelized Cost of Energy Comparison (USD/MWh)*

| Source | Type of source | Min | Max | Mean |
|---|---|---|---|---|
| Onshore wind | RES | 27 | 73 | 63,5 |
| Offshore wind | RES | 74 | 139 | 143,5 |
| Solar Photovoltaics | RES | 29 | 92 | 75 |
| Geothermal | RES | 64 | 106 | 217 |
| Gas | Conventional | 110 | 228 | 224 |
| Nuclear | Conventional | 142 | 222 | 253 |
| Coal | Conventional | 69 | 168 | 153 |

Source: Author's systematization and calculation based on Lazard (2024) data

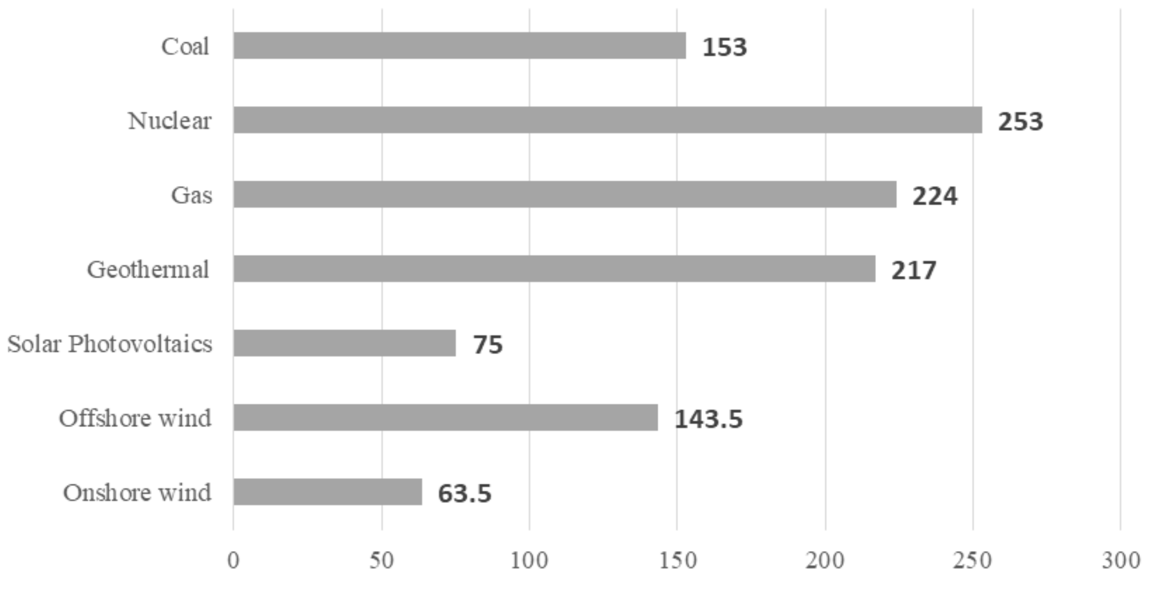


*Figure 2. LCOE by source of energy in USD/MWh*
*Source: Author's figure*

*Levelized cost of energy comparative analysis RES*

*Table 2. Total installed costs and Levelized Cost of Energy Comparison (USD/kWh)*

| Source | Total installed costs | LCOE |
|---|---|---|
| Onshore wind | 1160 | 0,033 |
| Offshore wind | 2800 | 0,075 |
| Solar Photovoltaics | 750 | 0,044 |
| Geothermal | 4589 | 0,071 |

Source: Author’s systematization based on IRENA (2023) data

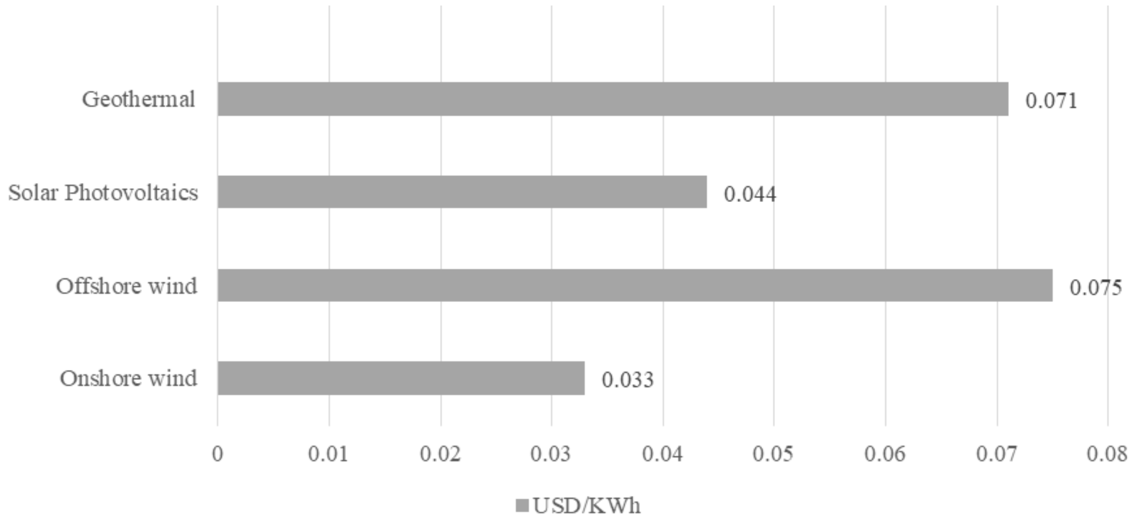


*Figure 3. LCOE by source of energy in USD/kWh*
*Source: Author’s figure*

*Overnight costs of energy comparative analysis coventional versus RES*

*Table 3. Overnight costs of Energy Comparison (USD/kWe)*

| Source | Type of source | Min | Max | Mean |
|---|---|---|---|---|
| Onshore wind | RES | 877 | 3022 | 1391 |
| Offshore wind | RES | 1721 | 4039 | 2876 |
| Solar Photovoltaics | RES | 534 | 2006 | 995 |
| Geothermal | RES | 3851 | 10959 | 6647 |
| Gas | Conventional | 254 | 1109 | 823 |
| Nuclear | Conventional | 2157 | 6920 | 3606 |
| Coal | Conventional | 800 | 4382 | 1897 |

Source: Author’s systematization based on IEA (2020) data

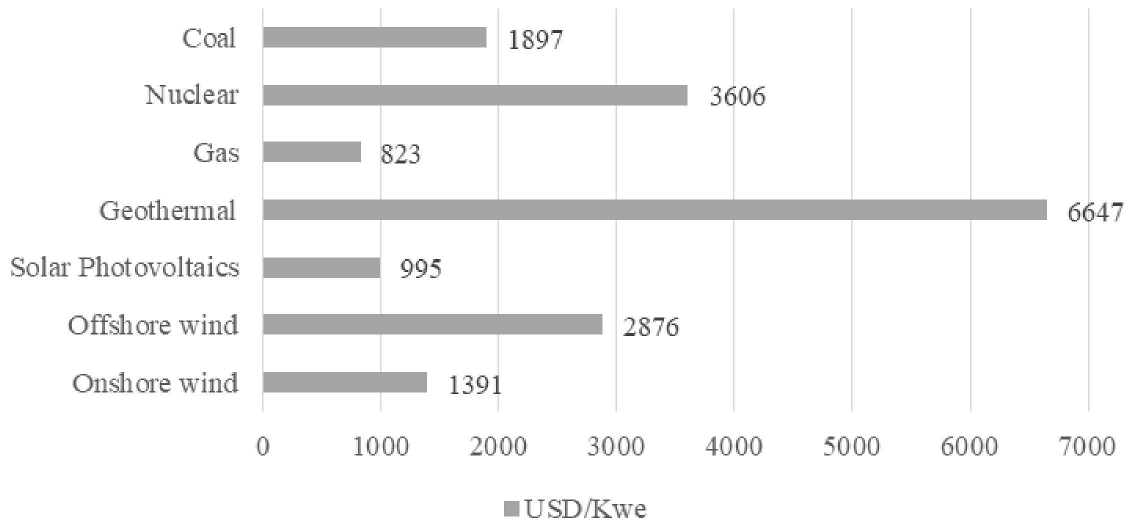


*Figure 4. Overnight costs by source of energy in USD/kWe*
*Source: Author's figure*

*Synthesis of Comparative LCOE Results for RES*

*Table 4. Summary of Results from Cross-Comparison of Renewable Energy Cost Data USD/kWh*

| **Source** | USD/kWh |
|---|---|
| Onshore wind | 0,048 |
| Offshore wind | 0,109 |
| Solar Photovoltaics | 0,059 |
| Geothermal | 0,144 |

Source: Author's calculation

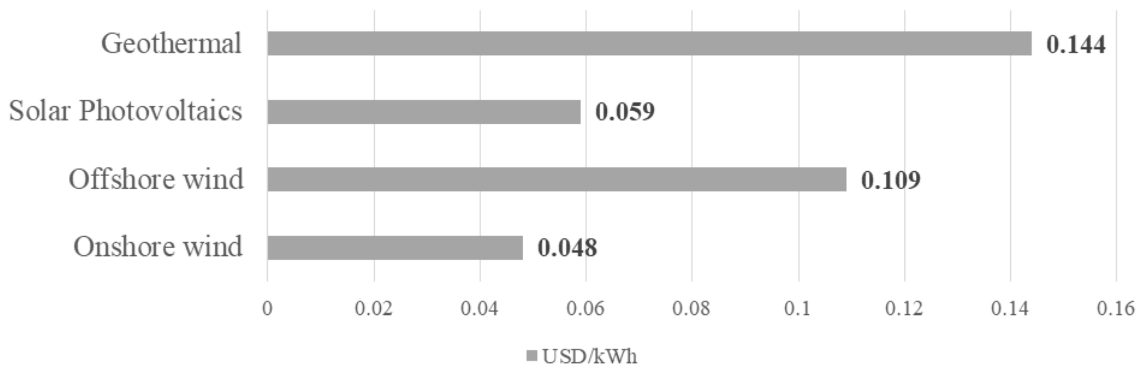


*Figure 5. Summary data of Cross-Comparison of Renewable Energy Cost Data USD/kWh*
*Source: Author's figure*

The differences between the LCOE values from Lazard and IRENA demonstrate the variations in assumptions and methodologies used in these reports. While Lazard tends to provide slightly higher LCOE values, especially for offshore wind and geothermal, IRENA's figures generally reflect lower costs, possibly due to different geographical assumptions or the inclusion of additional cost-reduction potential in emerging markets. These variations underscore the importance of using multiple sources of data to obtain a comprehensive understanding of the energy cost landscape.

Based on the comparative analysis of results according to LCOE, onshore wind is confirmed as the most cost-effective renewable energy technology among the sources analyzed, with a levelized cost of 0.048 USD/kWh.

Considering the high cost-effectiveness of these energy sources, which are being developed in Serbia (such as the significant wind power capacity at the Kovačica plant), the application and improvement of big data and AI technologies should be considered particularly in the context of cost-effective technologies. Following wind energy in terms of cost-effectiveness is solar PV – 0.059 USD/kWh, whose investment cost is significantly decreasing, while the cost of wind energy remains high.

In conclusion, renewable energy technologies - particularly onshore wind and solar PV - show great promise in providing cost-competitive solutions for global energy needs. As big data and artificial intelligence (AI) technologies continue to evolve, they can further optimize the performance, maintenance, and efficiency of renewable energy systems, potentially lowering the LCOE even more. The shift towards renewable energy is not only driven by environmental concerns but also by the growing recognition of its economic benefits, which are becoming increasingly clear as technologies continue to advance.

## CONCLUSION

The comparative analysis of the Levelized Cost of Energy (LCOE) and overnight investment costs for both renewable and conventional energy sources reveals a clear economic shift in favor of renewable technologies, particularly onshore wind and solar photovoltaics. These sources demonstrate significantly lower LCOE values compared to conventional fossil fuels, alongside a continued trend of decreasing investment costs due to technological advancements and increasing deployment.

Onshore wind, as the most cost-effective energy source in the analysis, highlights the growing maturity and financial viability of renewable energy technologies. Solar photovoltaics, following closely, benefits from continuous innovation and global scaling, further reinforcing the competitiveness of renewables in the global energy mix. In contrast, conventional sources such as natural gas and nuclear energy remain burdened with high LCOE values and substantial upfront capital costs, which pose considerable barriers to long-term sustainability and affordability.

In this context, the integration of AI and big data analytics presents a critical opportunity to enhance the efficiency, reliability, and cost-effectiveness of renewable energy systems. By enabling predictive maintenance, optimizing energy output, and improving grid integration, these technologies can further accelerate the energy transition and support the widespread adoption of clean energy sources.

This study underscores the importance of combining economic feasibility with technological innovation to ensure a successful and sustainable energy transition. As energy systems become more complex and data-intensive, the application of AI and big data analytics will not only support smarter decision-making but also unlock new potentials for cost reduction and performance optimization. Investing in these digital technologies, especially in the context of already cost-competitive renewable energy solutions, represents a strategic pathway toward achieving global decarbonization goals and ensuring long-term energy security.

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