İSTANBUL TİCARET ÜNİVERSİTESİ
FEN BİLİMLERİ DERGİSİ

İstanbul Commerce University Journal of Science

http://dergipark.org.tr/ticaretfbd

Research Article / Araştırma Makalesi

SUSTAINABLE ENERGY SOLUTIONS FOR MOBILE NETWORK INFRASTRUCTURE

MOBİL AĞ ALTYAPISI İÇİN SÜRDÜRÜLEBİLİR ENERJİ ÇÖZÜMLERİ

Ahmet Mecid KAYA[1] **Şükrü OKUL**[2] **Özgür Can TURNA**[3]
Zeynep GÜRKAŞ AYDIN[4]

https://doi.org/10.55071/ticaretfbd.1675936

Corresponding Author (Sorumlu Yazar)
ozgurcan.turna@iuc.edu.tr

Received (Geliş Tarihi)
14.04.2025

Revised (Revizyon Tarihi)
27.04.2025

Accepted (Kabul Tarihi)
02.06.2025

Abstract

This article examines the importance and application possibilities of sustainable energy solutions in mobile network infrastructures. Reducing dependency on traditional energy sources provides environmental sustainability in the mobile communication sector while also providing long-term cost savings. The article discusses the integration of renewable energy sources, technologies that increase energy efficiency, and technological innovations in this field. In addition, economic and environmental benefits, challenges, and strategies to overcome these challenges are discussed. Finally, future research areas and application opportunities are evaluated, emphasizing the importance of sustainable solutions in energy management of mobile network infrastructures.

Keywords: Sustainable energy, mobile network ınfrastructure, renewable energy, energy efficiency, environmental sustainability, economic benefits.

Öz

Bu makale, mobil ağ altyapılarında sürdürülebilir enerji çözümlerinin önemini ve uygulama olanaklarını incelemektedir. Geleneksel enerji kaynaklarına bağımlılığın azaltılması, mobil iletişim sektöründe çevresel sürdürülebilirlik sağlarken aynı zamanda uzun vadeli maliyet tasarrufu sunmaktadır. Makalede, yenilenebilir enerji kaynaklarının entegrasyonu, enerji verimliliğini artıran teknolojiler ve bu alandaki teknolojik yenilikler ele alınmaktadır. Ayrıca, ekonomik ve çevresel faydalar, karşılaşılan zorluklar ve bu zorlukların üstesinden gelme stratejileri tartışılmaktadır. Son olarak, gelecekteki araştırma alanları ve uygulama fırsatları değerlendirilerek, mobil ağ altyapılarının enerji yönetiminde sürdürülebilir çözümlerin önemi vurgulanmaktadır.

Anahtar Kelimeler: Sürdürülebilir enerji, mobil ağ altyapısı, yenilenebilir enerji, enerji verimliliği, çevresel sürdürülebilirlik, ekonomik faydalar.

[1] Istanbul University-Cerrahpaşa, Faculty of Engineering, Computer Engineering, İstanbul, Türkiye. mecitkayaa@gmail.com.
[2] TÜBİTAK BİLGEM, Kocaeli, Türkiye. sukruokul@gmail.com.

[3] Istanbul University-Cerrahpaşa, Faculty of Engineering, Computer Engineering, İstanbul, Türkiye. ozgurcan.turna@iuc.edu.tr.

[4] Istanbul University-Cerrahpaşa, Faculty of Engineering, Computer Engineering, İstanbul, Türkiye. zeynepg@iuc.edu.tr.

1. INTRODUCTION

Mobile communication has become one of the basic communication tools of today's society. Mobile networks have accelerated information sharing between individuals and businesses and increased interaction on a global scale. However, this rapid development has also led to a significant increase in the energy demands of mobile network infrastructures. Mobile communication infrastructures worldwide consume a significant amount of energy, which causes serious concerns in terms of environmental impacts.

Mobile networks based on traditional energy sources not only increase energy costs, but also contribute to greenhouse gas emissions. Therefore, sustainable management of mobile network infrastructures is of great importance not only from an economic perspective but also from an environmental perspective. Sustainable energy solutions have the potential to reduce the environmental impacts of mobile networks by including the integration of renewable energy sources, increasing energy efficiency and technological innovations (Zhang et al., 2021).

This study aims to examine the current status, advantages and feasibility of sustainable energy solutions in mobile network infrastructures. It will also shed light on the challenges encountered and solution proposals for these challenges, and evaluate future research areas and application opportunities.

The organization of this article is as follows: In the second section, sustainable energy solutions are detailed, in the third section, technological developments and innovations are examined. In the fourth section, economic and environmental benefits are discussed, and in the fifth section, encountered challenges and solution proposals are discussed. In the sixth section, future research and application areas are listed, and in the seventh section, the obtained results are summarized and a general evaluation of the article is made.

2. SUSTAINABLE ENERGY SOLUTIONS

Sustainable energy solutions are of great importance to reduce the environmental impacts of mobile network infrastructures and optimize energy consumption. These solutions include areas such as the integration of renewable energy sources, energy efficiency enhancing technologies, and energy management systems.

2.1. Integration of Renewable Energy Sources

Renewable energy sources offer significant opportunities in meeting the energy needs of mobile networks. For example, the widespread use of solar energy systems stands out as an effective method for meeting the energy needs of mobile base stations. According to various studies, a solar panel can produce approximately 250 kWh of energy if it receives an average of 5-6 hours of sunlight per day. This can meet 30%-50% of the annual energy needs of many base stations (Shielden Channel, 2024) (Uz & Paksoy, 2018) (Louhi, 2008)

Wind energy is another important alternative source for mobile networks. Studies show that a wind turbine can produce more than approximately 500 kWh of energy per year under suitable wind conditions. Especially in rural areas, a large part of the energy needs of the mobile network infrastructure can be met by using mini wind turbines on buildings (Çelik et al., 2020).

2.2. Energy Efficiency Increasing Technologies

Various technologies need to be implemented to increase the energy efficiency of mobile networks. Energy efficiency enhancing systems and components can provide significant cost savings and environmental benefits. For example, it is estimated that energy savings of up to 30% can be achieved by upgrading existing base stations (GSMA, 2024).

LED lighting systems can consume 80% less energy than most traditional lighting systems. Replacing lighting needs in base stations with LED systems can provide significant energy savings (Turkish Electrical Engineers Association, n.d.).

At the same time, energy saving potential is increased by using energy management systems. Smart grid technologies reduce unnecessary energy expenditures by strictly monitoring consumption data and optimize the amount of energy actually needed. For example, in applications with smart energy management systems, a 10-20% reduction in energy consumption can be achieved (Dalia & Rasa, 2024).

2.3. Energy Management Systems

Energy management systems are critical for monitoring and managing the energy flow of mobile networks more effectively. These systems balance energy demand and production using data analytics and provide sustainable energy management. For example, AI-based energy management systems can analyze past data to make energy consumption estimates and thus enable more efficient use of energy resources.

As a result, sustainable energy solutions in mobile network infrastructures can be achieved with the integration of renewable energy sources, technical innovations that increase energy efficiency, and powerful energy management systems. These solutions reduce the environmental impact of the mobile communications sector and offer cost advantages to businesses. In the following sections, the integration of these solutions with technological developments and innovations will be examined in more detail.

3. TECHNOLOGICAL DEVELOPMENTS AND INNOVATION

The integration of mobile network infrastructures into sustainable energy solutions has gained significant momentum thanks to technological developments and innovative applications. In this section, we will examine the impacts of existing mobile communication technologies on energy efficiency and emerging innovations.

3.1. 5G and Energy Efficiency

5G technology increases the performance of mobile networks by offering higher speeds (up to approximately 10 Gbps) and lower latencies (below 1 ms). However, the impacts of 5G on energy consumption should be considered carefully. Studies show that the energy demand of 5G can increase by 20-30% compared to 4G. However, with 5G's small cell structure and more efficient spectrum usage, total energy efficiency can be increased by up to 30%. In particular, the beamforming technology offered by 5G optimizes energy consumption, ensuring that each cell serves only the necessary devices (Rapone et al., 2015), (Khafagy, 2019) (Lorincz et al., 2019) (Israr et al., 2021).

3.2. High-Efficiency Equipment and Infrastructures

New generation base stations have been developed to increase energy efficiency. For example, while current traditional base stations consume an average of 15 kWh (kilowatt-hours) of energy per day, new generation base stations provide energy savings equivalent to 40% (approximately 6 kWh) of this consumption. These small cell systems provide extended coverage with lower power consumption.

In addition, energy-saving cooling systems can provide 30-50% energy savings with new generation cooling systems integrated into data centers and base stations. Instead of traditional cooling systems, the use of liquid cooling or chilled air significantly reduces energy needs (Shielden Channel, 2024) (Uz & Paksoy, 2018) (GSMA, 2024) (Louhi, 2008) (Kwasinski & Kwasinski, 2015) (GSMA, 2020).

3.3. IoT and Smart Grid Integration

Internet of Things (IoT) applications play a critical role in improving the energy efficiency of mobile networks. IoT sensors monitor and analyze the energy consumption of base stations in real time. Studies show that IoT-based energy management systems can reduce energy consumption by 10-15%. Smart grids optimize energy demand using this data, while significant reductions in energy costs are also achieved (Israr et al., 2021) (Nataraju et al., 2023).

3.4. Innovative Battery Technologies

Energy storage systems are of critical importance for sustainable energy solutions. In particular, advanced battery technologies play an important role in ensuring power continuity in mobile networks. The 90% energy density of lithium-ion batteries makes them ideal for mobile applications. With developing technology, new generation solid-state batteries offer higher energy density (approximately 20-30% more) and shorter charging times, making energy management of mobile networks even more efficient (Park et al., 2021) (Redway Power, 2024), (Wikipedia, n.d.).

3.5. Artificial Intelligence and Data Analytics

Artificial intelligence applications are used to optimize energy consumption and improve energy management with data analytics. Artificial intelligence-based systems can analyze historical data to determine energy consumption patterns and make

recommendations to minimize waste. Studies have shown that such systems provide 15-20% savings in energy costs (Dalia & Rasa, 2024).

As a result, technological developments and innovations in mobile network infrastructures offer solutions to reduce energy consumption and ensure the integration of sustainable energy solutions. In the following sections, the economic and environmental advantages of these solutions will be discussed.

4. ECONOMICAL AND ENVIRONMENT

Adopting sustainable energy solutions in mobile network infrastructures brings not only environmental benefits but also economic advantages. This section will discuss the positive contributions of sustainable energy applications on both cost optimization and environmental impacts.

4.1. Cost Savings

Implementing sustainable energy solutions provides significant cost savings in the long term. With the integration of renewable energy sources, mobile networks can significantly reduce energy costs. For example, with the installation of solar energy systems, energy costs for base stations can be reduced by up to 40% (Aslanbaş et al., 2019).

In addition, the use of energy efficiency-enhancing technologies reduces operating costs. Considering that modern base stations consume 30-50% less energy than older systems, it is understood that energy savings offer both short-term and long-term cost advantages (GSMA, 2024).

4.2. Reducing Environmental Impacts

Sustainable energy solutions play a critical role in reducing the carbon footprint of the mobile communications sector. Mobile networks account for approximately 4% of total energy consumption worldwide. However, the adoption of renewable energy sources directly contributes to the reduction of greenhouse gas emissions. For example, the use of solar energy means that a 1 MW solar system can prevent the emission of an average of 1,500 tons of CO_2 per year (GSMA, 2020).

When mobile networks increase their energy efficiency, the environmental impacts are also significantly reduced. The use of advanced energy management systems and smart grids can reduce energy consumption by 15-20%. This minimizes the energy consumption of mobile networks and therefore their environmental impact (Trehan, 2012).

4.3. Energy Security and Sustainability

Another benefit of sustainable energy solutions is increased energy security. The integration of renewable energy sources reduces energy dependency by diversifying the energy supply. To be clear, reducing the dependency on fossil fuels provides greater resilience to fluctuations in energy prices. Renewable energy has the potential to

increase the energy security of mobile networks, especially when local resources are used (Nawaz & Zafar, 2013).

4.4. Impacts on Public Health

Adopting sustainable energy solutions not only provides economic and environmental benefits, but also contributes positively to public health. Renewable energy, which replaces fossil fuels, reduces air pollution and thus has material beneficial effects on public health. It is estimated that 4.2 million premature deaths can be prevented annually by preventing air pollution. This situation is extremely important in terms of the social responsibility of the mobile communications sector (Health and Environment Alliance, 2022)

As a result, sustainable energy solutions contribute to the achievement of sustainability goals by providing both economic savings and environmental benefits in mobile network infrastructures. The following sections will focus on the challenges encountered with these solutions and their proposed solutions.

5. CHALLENGES ENCOUNTERED AND SOLUTION SUGGESTIONS

There are various challenges when implementing sustainable energy solutions in mobile network infrastructures. This section will discuss the details of these challenges and proposed solution strategies.

5.1. High Initial Costs

One of the biggest obstacles to implementing sustainable energy solutions is the high initial costs. The installation of renewable energy systems (solar panels, wind turbines, etc.) requires a significant investment in the initial phase. For example, the installation costs of solar energy systems can range from $1,000 to $2,000 per kW depending on the system size. This can be a financial barrier, especially for small service providers (CW Enerji, 2024).

Solution Proposals: Government incentives and subsidies play an important role in the expansion of renewable energy systems. In addition, emphasizing long-term cost savings can encourage service providers to switch to sustainable solutions. Energy cooperatives and joint ventures can also provide a solution to share the initial costs (Alsharif et al., 2021).

5.2. Technological Compatibility

Sustainable energy solutions may not be compatible with existing mobile infrastructures. The integration of new technologies may not work seamlessly with old systems, which may result in additional costs. In particular, the energy requirements of new generation technologies such as 5G create challenges for the modernization of existing systems (Zhao et al., 2023).

Solution Proposals: Mobile network infrastructures need to be re-evaluated and technological improvements need to be implemented in a planned manner. Innovative

test projects and pilot applications can be useful to evaluate the effects of new technologies.

5.3. Energy Storage Problems

The intermittent nature of renewable energy sources requires energy storage solutions. However, current battery technologies may not be as effective as desired due to high costs and limited energy density. For example, while lithium-ion batteries today have an energy density of approximately 150-250 Wh/kg, this value can increase to around 500 Wh/kg in more advanced solid-state batteries (Park et al., 2021).

Solution Proposals: Investing in research and development activities allows the development of more efficient and low-cost energy storage systems. In addition, demand-based energy management systems can help optimize energy demand.

5.4. Policy and Regulatory Uncertainties

Another factor that makes it difficult to adopt sustainable energy solutions is policy and regulatory uncertainties. Energy policies may change depending on market conditions and technological developments, which may affect service providers' decisions.

Solution Proposals: Governments need to develop stable and transparent policies for sustainable energy investments. Long-term energy strategies will help service providers better plan their investments. In addition, development and improvement of energy infrastructures should be targeted through public-private partnerships (Ansari & Han, 2014).

The challenges encountered constitute obstacles to the effective implementation of sustainable energy solutions. However, these challenges can be overcome with appropriate strategies and innovative solutions. Future research and application areas will be discussed in the following sections.

6. FUTURE RESEARCH AND APPLICATION AREAS

In order for mobile network infrastructures to achieve their sustainability goals, it is critical to explore various research and application areas in the future. This section will detail these areas and highlight potential development opportunities.

6.1. Smart Energy Management Systems

In the future, the development of smart energy management systems will support the sustainability goals of mobile networks. These systems use artificial intelligence and machine learning to optimize energy consumption and increase integration with renewable resources. For example, the development of systems that predict energy demand based on historical data with dynamic energy management can reduce energy waste by up to 20% (Dalia & Rasa, 2024).

6.2. Microgrid Systems

Microgrid systems will allow for increased local energy production and ensure energy independence of mobile networks. The use of local solar or wind energy sources will meet the energy needs of base stations and data centers, reducing energy costs (Zhu, 2023).

6.3. Zero Energy Buildings

As part of sustainable mobile network infrastructure, the development of zero energy buildings is gaining importance. These buildings are optimized in terms of energy efficiency and renewable energy production. Zero energy buildings can generate their own energy for mobile base stations and data centers, thus reducing the environmental impact of the network and enabling them to achieve zero carbon emissions. Future research should include construction processes and cost analyses for such buildings (GSMA, 2020).

6.4. Diversity in Energy Production

Increasing the diversity in the energy supply of mobile networks will be an important strategy for ensuring energy security. By integrating different energy sources such as solar, wind, and biomass, mobile networks can minimize environmental impacts by reducing fossil fuel dependency. For example, in projects with hybrid energy systems, energy costs can be reduced by 40%, while environmental benefits can be significantly increased (GSMA, 2024).

6.5. Innovation and Education Programs

It is necessary to raise awareness and develop expertise in society for the adoption of sustainable energy solutions. Innovation and education programs will enable knowledge sharing on energy efficiency for both mobile network administrators and users. Future education programs need to focus on sustainable energy technologies and applications (5G Americas, 2023).

6.6. Policy and Regulations

Strengthening policies and laws is a critical factor in supporting sustainable energy applications. Governments need to develop sound and long-term policies to promote renewable energy sources. Such regulations can encourage mobile network service providers to adopt sustainable solutions. For example, tax breaks and subsidies can increase renewable energy investments (Wand et al., 2023).

Future research and application areas have the potential to increase the effectiveness of sustainable energy solutions in mobile network infrastructures. Innovations in this area will contribute to reducing environmental impacts, achieving economic savings, and increasing energy security. The next section discusses the general conclusions and recommendations of this paper.

6. CONCLUSION

This article has comprehensively examined the importance, current status, technological developments, economic and environmental benefits, challenges and future research areas of sustainable energy solutions in mobile network infrastructures. The mobile communications sector is faced with rapidly increasing energy demands and environmental impacts. Therefore, the adoption of sustainable energy solutions is of critical importance for both the future of the sector and energy management worldwide.

Sustainable energy solutions are made possible by the integration of renewable energy sources, technologies that increase energy efficiency and the use of smart energy management systems. These solutions have the potential to reduce the energy costs of mobile networks by 30-50%. At the same time, they significantly reduce the carbon footprint of mobile networks by reducing environmental impacts.

However, challenges such as high initial costs, lack of technological compatibility and energy storage problems stand in the way of effective implementation of sustainable energy solutions. Research and development activities, policy support and innovative approaches are essential to overcome these obstacles.

Future research and application areas offer various opportunities for mobile network infrastructures to become more sustainable. Smart energy management systems, microgrids, innovative energy storage systems and sustainable building designs are strategies that should be considered in this area. In addition, public-private partnerships and increasing public awareness are critical for the dissemination of sustainable energy solutions.

As a result, the adoption of sustainable energy solutions in mobile network infrastructures will provide economic gains as well as environmental advantages and shape the future of the mobile communication sector. It is hoped that this study will be a guide for policy makers, researchers and industry professionals in the process of adopting sustainable energy solutions.

Authors' Contributions
The authors' contributions to the article are equal.

Conflict of Interest Statement
There is no conflict of interest among the authors.

Research and Publication Ethics Statement
Research and publication ethics were followed in the study.

REFERENCES

5G Americas. (2023). *Energy efficiency and sustainability in mobile communications networks*.

Alsharif, M. H., Albreem, M. A., Jahid, A., Raju, K., Uthansakul, P., Nebhen, J., Chandrasekaran, V., & Aly, A. A. (2021). Powering mobile networks with optimal green energy for sustainable development. *Computers, Materials and Continua, 69*(1), 661–677.

Ansari, N., & Han, T. (2014). Powering mobile networks with green energy. *IEEE Wireless Communications, 21*(1), 90–96.

Aslanbaş, S., Şahin, A. Ş., & Yakut, A. K. (2019). Photovoltaic system design to meet the power needs of the GSM base station. https://dergipark.org.tr/en/download/article-file/1154296

Çelik, İ., Yıldız, C., Şekkeli, M., & Hasırcı, H. Y. (2020). *1 kW rüzgâr türbini için enerji üretim ve gelir hesabı*. https://dergipark.org.tr/tr/download/article-file/1094366

CW Energy. (2024). *Setup and calculation*. https://cw-enerji.com/tr/cw-enerji-kutuphanesi/bir-eve-yetecek-gunes-paneli-fiyati-24

Dalia, V., & Rasa. (2024). AI-driven innovations in building energy management systems: A review of potential applications and energy savings. *Energies, 17*(17), 4277. https://doi.org/10.3390/en17174277

GSMA. (2020). *Renewable energy for mobile towers: Opportunities for low- and middle-income countries*.

GSMA. (2024). *Energy savings in base stations with KDDI*. https://www.gsma.com/solutions-and-impact/connectivity-for-good/external-affairs/climate-action/case-studies/energy-savings-in-base-stations-with-kddi

Health and Environment Alliance. (2022). *Health effects of air pollution*. https://www.env-health.org/wp-content/uploads/2022/03/Hava_Kirliligi_Bilgi_Notu.pdf

Israr, A., Yang, Q., Li, W., & Zomaya, A. Y. (2021). Renewable energy powered sustainable 5G network infrastructure: Opportunities, challenges and perspectives. *Journal of Network and Computer Applications, 175*, 102910.

Khafagy, M. G. (2019). Green mobile networks for 5G and beyond. *IEEE Access, 7*, 107270–107299. https://doi.org/10.1109/ACCESS.2019.2932422

Kwasinski, A., & Kwasinski, A. (2015). Increasing sustainability and resiliency of cellular network infrastructure by harvesting renewable energy. *IEEE Communications Magazine, 53*(4).

Lorincz, J., Capone, A., & Wu, J. (2019). Greener, energy-efficient and sustainable networks: State-of-the-art and new trends. *Sensors, 19*(22), 4864. https://doi.org/10.3390/s19224864

Louhi, J. T. (2008). Energy efficiency of modern cellular base stations. *INTELEC 07 - 29th International Telecommunications Energy Conference*.

Nataraju, A. B., Pradhan, D., & Jambli, S. S. (2023). Opportunities, challenges, and benefits of 5G-IoT toward sustainable development of green smart cities. *Proceedings of the 2023 International Conference on Intelligent Technologies (CONIT)*. https://doi.org/10.1109/CONIT59222.2023.10205780

Nawaz, M. K., & Zafar, S. (2013). Integration of renewable energy sources in smart grid: A review. *Nucleus, 50*(4), 311–327.

Park, K.-H., Jung, K.-J., & Ko, Y.-C. (2021). *Renewable energy-enabled cellular networks*. https://doi.org/10.36227/techrxiv.16550607.v1

Rapone, T. D., Sabella, D., & Fodrini, M. (2015). *Energy efficiency solutions for the mobile network evolution towards 5G: An operator perspective*. Wireless Access Innovation Telecom Italia.

Redway Power. (2024). *What are solid-state batteries and their implications in 2024?* https://www.redwaypower.com/tr/a-deep-dive-into-solid-state-batteries-and-their-implications-in-2024

Shielden Channel. (2024). *How much energy does a solar panel produce?* https://tr.shieldenchannel.com/blogs/solar-panels/how-much-energy-does-a-solar-panel-produce

Trehan, A. K. (2012). Energy conservation solutions for mobile networks. *Proceedings of the 2012 International Telecommunications Energy Conference (INTELEC)*. https://doi.org/10.1109/INTLEC.2012.6374493

Turkish Electrical Engineers Association. (n.d.). *LED aydınlatma sistemleri ve enerji verimliliği*. https://www.emo.org.tr/ekler/222831e7e323228_ek.pdf

Uz, E., & Paksoy, H. Ö. (2018). Development of phase changing material for increasing energy efficiency in telecommunication base stations. *Çukurova University Journal of Faculty of Engineering and Architecture, 35*(1).

Wang, C., Zhang, H., & Li, Y. (2023). *AI-driven energy optimization in 5G networks: Future directions*. Proceedings of the IEEE GreenTech Conference (pp. 45-50). IEEE. https://doi.org/10.1109/GreenTech50055.2023.00015

Wikipedia. (n.d.). *Solid-state battery*. https://en.wikipedia.org/wiki/Solid-state_battery

Zhang, Y., Wang, L., & Chen, X. (2021). Renewable energy integration in 5G networks: A sustainable approach to reducing carbon footprint. *Energy Reports, 7*, 3456-3468. https://doi.org/10.1016/j.egyr.2021.05.042

Zhao, N., Zhang, H., Yang, X., Yan, J., & You, F. (2023). Emerging information and communication technologies for smart energy systems and renewable transition. *Advances in Applied Energy, 9*, 100125.

Zhu, X. (2023). *Breaking the energy curve: Network energy consumption modeling and energy saving technologies*. Ericsson. https://www.ericsson.com/en/blog/2023/8/breaking-the-energy-curve