Optimization of energy supply: 3d development for critical, wear-based insulatory components

Ivan Tkachuk [1]

Received: 2025-09-09
Accepted: 2025-10-15
DOI: https://doi.org/10.5281/zenodo.18120390

Abstract. The development of the energy sector, which is an indicator of successful economic development, requires the implementation of innovative advanced technological solutions. One such solution is 3D printing, which creates new opportunities for improving the energy equipment supply chain. The introduction of 3D printing not only reduces the financial and time resources required to manufacture critical and rapidly wearing insulation components, but also increases the flexibility and adaptability of production, allows for personalization of the process, and eliminates transportation constraints. Expanding the variety of materials and processes for 3D printing requires the development of industry standards for quality and certification. Other promising areas for improving the use of 3D printing in the energy equipment sector include attracting investment and establishing cooperation between stakeholders, actively using artificial intelligence and virtual reality, and optimizing institutional support.

Keywords: energy sector, energy equipment, supply chain, logistics, 3D printing.

[1] ORCID: https://orcid.org/0009-0003-8525-3452
Independent Researcher,
Master’s Degree in Electrical Power Engineering,
Yuriy Fedkovych Chernivtsi National University, Ukraine

Introduction

The pressing issue of rapid energy consumption and resource depletion necessitates the search for alternative ways to meet growing energy demands. 3D printing in the energy sector is an excellent way to revolutionize the processes used in the industry, including logistics. 3D printing provides the means for cleaner energy supply chains, improves the development process, and reduces costs.

This phenomenon has been studied by O. Vozisova et al. [1], A. Bazmi, G. Zahedi [2], and J. Song [3]. The authors focused their research efforts on the potential of additive manufacturing to stimulate alternative energy. Y. Jin, C. Gao [4], L. Wang et al. [5] analyzed the features of the practical use of 3D printing in the energy sector, while M. Harsasi, N. Minrohayati [6], B. de Sá et al. [7], A. Sasson, J. Johnson [8] proved that 3D printing transforms the supply chain from a linear model to a more flexible, sustainable, and decentralized one, which ultimately increases the operational efficiency of the energy sector. Specific aspects of supply chain optimization in the energy sector are addressed in publications by contemporary researchers M. Ryan et al. [9], N. Chan et al. [10], N. Rogers et al. [11], and S. Braziotis et al. [12].

Despite the considerable interest of scientists in the subject, certain aspects of the problem of improving the energy equipment supply chain remain understudied and require additional attention.

The purpose of the study is to conduct an in-depth analysis of the potential of 3D printing for critical, rapidly wearing insulation components in order to optimize the energy equipment supply chain.

Research Results

Today, 3D printing is positioned as an innovative approach to technological solutions in the energy sector, radically transforming both production processes and traditional supply chains. Additive manufacturing opens up new potential opportunities for improving the development, production, and logistics of energy equipment. In particular, among the main consequences of the introduction of 3D printing technology in the energy sector, it is necessary to note:

1) intensification of prototyping by developers using digital models, which opens up opportunities for faster testing and evaluation, with subsequent correction of product quality before mass production;

2) production of personalized products by adapting the digital model to specified parameters in the 3D printing process;

3) reduced need for large warehouse stocks due to the availability of manufacturing the necessary parts as needed;

4) the ability to localize production directly on site, saving delivery time, reducing logistics costs, and thereby optimizing supply chains;

5) integration of sustainable production principles, which implies environmental neutrality and waste reduction;

6) simplification of production processes by reducing the number of stages and the need for complex tools, which is especially important for the creation of complex components;

7) increased adaptability and flexibility of the production process, thanks to the ability to respond to demand dynamics, as well as the production of components as needed, in small quantities;

8) improvement of the supply chains themselves, which in the traditional format often involve stages and the presence of intermediaries, which significantly increases costs and complicates management processes – the use of 3D printing, allows production to be localized

and dependence on external suppliers to be minimized, which ultimately improves quality control and reduces the risks associated with logistics delays [7, 12].

It is evident that the implementation of 3D printing for the manufacture of fast-wearing and critically important insulation components will significantly reduce production complexity by reducing parts and processes, shortening order fulfillment times, reducing costs and waste through on-demand manufacturing and resource efficiency, leading to sustainability and flexibility by allowing components to be printed locally and quickly [4]. In particular, additive manufacturing is particularly effective in the manufacture of housings, insulators, fasteners, and other necessary elements, transforming the energy equipment supply chain from a linear model to a more flexible, decentralized, and sustainable one.

This area is actively developing and looks promising for the renewable energy sector, which benefits from the development of new, innovative products. The advantage of 3D printing in this area is rapid prototyping and reduced development time, allowing product managers and designers to test prototypes to verify the design before moving to full-scale production, make design changes, and conduct more tests in a shorter period of time [13]. The method also allows the creation of customized energy components tailored to specific requirements.

Additive manufacturing not only allows for easy product customization, but also enables the precise tuning of energy production systems for the easy creation of components with complex geometries [1, 11]. 3D printing offers advantages that reduce waste and increase the sustainability of the energy sector. It allows for precise control of material, reducing material waste and lowering raw material consumption [14]. In addition, recycled or biodegradable materials can be used in this method, reducing waste and increasing sustainability. Given that 3D printing facilitates localized production, this leads to reduced transportation costs and associated carbon dioxide emissions [10].

Although additive manufacturing has a number of advantages for the energy sector, there are also many limitations, including:

1) material limitations (many 3D printers can only work with plastics and low-strength materials, which can be problematic for the production of components that require heat-resistant or high-strength materials);

2) some parts require specific dimensional accuracy, surface roughness, and mechanical strength, and 3D printing may be incompatible with such materials [5];

3) relatively slow operation of 3D printers, which complicates the process of expanding production;

4) Limited capabilities of 3D printers in terms of size range, which complicates their use in the field of power equipment;

5) Contradictory use of plastic filament with environmental goals and sustainable production requirements;

6) High energy consumption of 3D printers.

Additive manufacturing has changed the perception of value, shifting it from the object to its design. However, ignoring intellectual property (IP) issues in 3D printing can lead to security problems for society. In addition, product quality can potentially be affected by the lack of universal standards and the high cost of high-performance machines [3,6].

The future prospects for the development of 3D printing technology are shaped by the following main vectors, which are determined by the needs of modern production and logistics systems:

- expanding the possibilities for using different materials for 3D printing, in particular ceramics, metals, and composites, which have unique properties and can be successfully used to manufacture various components of power equipment;

- development and implementation of technologies for 3D printing with several materials simultaneously, which makes it possible to solve the problem of manufacturing multi-component objects with different properties in a single operation;

- synergistic use of 3D printing technology with other innovative technological solutions, which potentially develops new opportunities for strengthening energy sustainability;

- using analytics and artificial intelligence algorithms to reduce the resource intensity of the 3D printing process;

- leveraging virtual and augmented reality capabilities to optimize prototyping processes;

- stimulating the investment process, as well as the exchange of experience and partnership interaction;

- encouraging greater stakeholder involvement in the production and use of energy equipment and joint financing projects, which will contribute to the accelerated spread of 3D printing in the industry;

- improving safety and quality levels through the development and implementation of unified standards and clear regulations.

Conclusions and prospects for further research. The introduction of 3D printing capabilities into the energy equipment sector is changing logistics parameters, optimizing aspects of resource provision, accuracy, efficiency, and speed. In particular, the technology allows for the localization of production of critical, fast-wearing insulation components, reducing costs and delivery times.

In the energy sector, the technological capabilities of 3D printing are transforming supply chains, making them more flexible, sustainable, and cost-effective. In particular, the main consequences include the ability to quickly test and evaluate products, with subsequent quality adjustments before mass production; the production of personalized products; a reduction in the need for large warehouse stocks; the integration of sustainable production principles; the simplification of production processes by reducing the number of stages and the need for complex tools; minimization of dependence on external suppliers, which improves quality control and reduces risks caused by logistics delays.

Promising scientific research in the field should be aimed at using 3D printing technology in the field of renewable energy sources to develop and implement sustainable energy solutions.

References

1. Vozisova, O., Eroshenko, S., Koksharova, E., Khalyasmaa, A., & Dmitriev, S. (2016, March). Application of 3D scanning and printing technologies in Electric power industry. In *2016 IEEE International Conference on Industrial Technology (ICIT)* (pp. 892-897). IEEE.

2. Bazmi, A. A., & Zahedi, G. (2011). Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—A review. Renewable and sustainable energy reviews, 15(8), 3480-3500. https://doi.org/10.1016/j.rser.2011.05.003

3. Song, J. (2025). Research on energy optimization space design of intelligent buildings based on generative AI technology and 3D modeling. *Microchemical Journal*, 218. https://doi.org/10.1016/j.microc.2025.115500

4. Jin, Y., & Gao, C. (2023). Hybrid optimization of green supply chain network and scheduling in distributed 3D printing intelligent factory. *Sustainability*, *15*(7), 5948. https://doi.org/10.3390/su15075948

5. Wang, L. W., Hung, C. C., & Hsieh, C. T. (2022). Security Strategy Optimization and Algorithm Based on 3D Economic Sustainable Supply Chain. *Scientific Programming*, *2022*(1), 9972658. https://doi.org/10.1155/2022/9972658

6. Harsasi, M., & Minrohayati, N. (2017). The impact of supply chain management practices on competitive advantage. *International Journal of Economic Policy in Emerging Economies*, *10*(3), 240-247. https://doi.org/10.1504/IJEPEE.2017.086623

7. de Sá, B. C., de Souza, E. H. D., Reis, L. P., & de Souza Dutra, M. D. (2022). Supply chain network design: a case study of the regional facilities analysis for a 3D printing company. *International Journal of Production Management and Engineering*, *10*(2), 211-223. https://doi.org/10.4995/ijpme.2022.17620

8. Sasson, A., & Johnson, J. C. (2016). The 3D printing order: variability, supercenters and supply chain reconfigurations. *International Journal of Physical Distribution & Logistics Management*, *46*(1), 82-94. https://doi.org/10.1108/IJPDLM-10-2015-0257

9. Ryan, M. J., Eyers, D. R., Potter, A. T., Purvis, L., & Gosling, J. (2017). 3D printing the future: scenarios for supply chains reviewed. *International Journal of Physical Distribution & Logistics Management*, *47*(10), 992-1014. https://doi.org/10.1108/IJPDLM-12-2016-0359

10. Chan, H. K., Griffin, J., Lim, J. J., Zeng, F., & Chiu, A. S. (2018). The impact of 3D Printing Technology on the supply chain: Manufacturing and legal perspectives. *International Journal of Production Economics*, *205*, 156-162. https://doi.org/10.1016/j.ijpe.2018.09.009

11. Rogers, H., Baricz, N., & Pawar, K. S. (2016). 3D printing services: classification, supply chain implications and research agenda. *International Journal of Physical Distribution & Logistics Management*, *46*(10), 886-907. https://doi.org/10.1108/IJPDLM-07-2016-0210

12. Braziotis, C., Rogers, H., & Jimo, A. (2019). 3D printing strategic deployment: the supply chain perspective. *Supply Chain Management: An International Journal*, *24*(3), 397-404. https://doi.org/10.1108/SCM-09-2017-0305

13. Budzik, G., Tomaszewski, K., & Soboń, A. (2022). Opportunities for the application of 3D printing in the critical infrastructure system. *Energies*, *15*(5), 1656. https://doi.org/10.3390/en15051656

14. Feldmann, C., & Pumpe, A. (2017). A holistic decision framework for 3D printing investments in global supply chains. *Transportation research procedia*, *25*, 677-694. https://doi.org/10.1016/j.trpro.2017.05.451