



# Transformers as blockchain assets: A transparent and circular model for the power equipment lifecycle



## ABSTRACT

This paper proposes a blockchain-based framework where transformers and their subcomponents are treated as digital assets with immutable histories. By adopting this model, stakeholders, including OEMs, utilities, EPC contractors, and refurbishers, can benefit from improved data integrity, enhanced traceability, and a significant leap toward sustainable, circular economy practices.

## KEYWORDS:

blockchain, transformers, asset management, lifecycle

# Demand is at the top, and most manufacturers could deliver transformers in at least 2 years on average

## 1. Introduction

The global power transformer market is undergoing a period of transformation driven by electrification demands, grid modernization, and decarbonization efforts [1]. Demand is at the top, and most manufacturers could deliver transformers in at least 2 years on average. One major shift is the rising popularity of refurbished transformers and modular procurement, particularly in regions facing material constraints, long lead times, or CAPEX limitations [2]. Simultaneously, rebranding strategies have become increasingly common: transformer manufacturers with limited manufacturing area and global distribu-

tors or OEMs frequently procure transformers from third-party manufacturers and rebrand them for use in turnkey projects. While this enables flexibility and price competitiveness, it also introduces a complex challenge: traceability. On the other hand, some companies are trying to use transformer manufacturers just as a manufacturer. Instead, the complete ordering process, starting with tendering design -> procurement -> final design -> manufacturing -> delivery, they are choosing a path in which the buyer makes the transformer design for the customer, and the manufacturer manufactures the product according to the customer's specifications and the buyer's

design. This is a new approach I learned at trade shows, where some skilled companies offer, and manufacturers with limited experience participate in larger units. 3 partners (manufacturer, buyer, and customer) for one transformer procurement.

In many cases, utilities and end users are left with limited visibility into the sub-components, origin, manufacturing standards, or maintenance records of transformers, especially when these units change hands or undergo refurbishment. Traditional asset management systems and ERPs are siloed and lack the granularity and reliability needed to track the full lifecycle of a transformer. These gaps expose stakeholders to financial, operational, and regulatory risks [3].

When a failure occurs, it is not always easy to see the full history of operation and maintenance. Customers are sometimes not very transparent with operating data, and manufacturers try to avoid in-guarantee costs. With transparent data, failure analysis could be done more quickly and transparently.

## 2. Digital Product Passport

Creating a Digital Product Passport (DPP) for a transformer is not a new concept. The European Union has already introduced the idea of digital

# The European Union has already introduced the idea of digital product passports as part of its Circular Economy Action Plan and the proposed Ecodesign for Sustainable Products Regulation

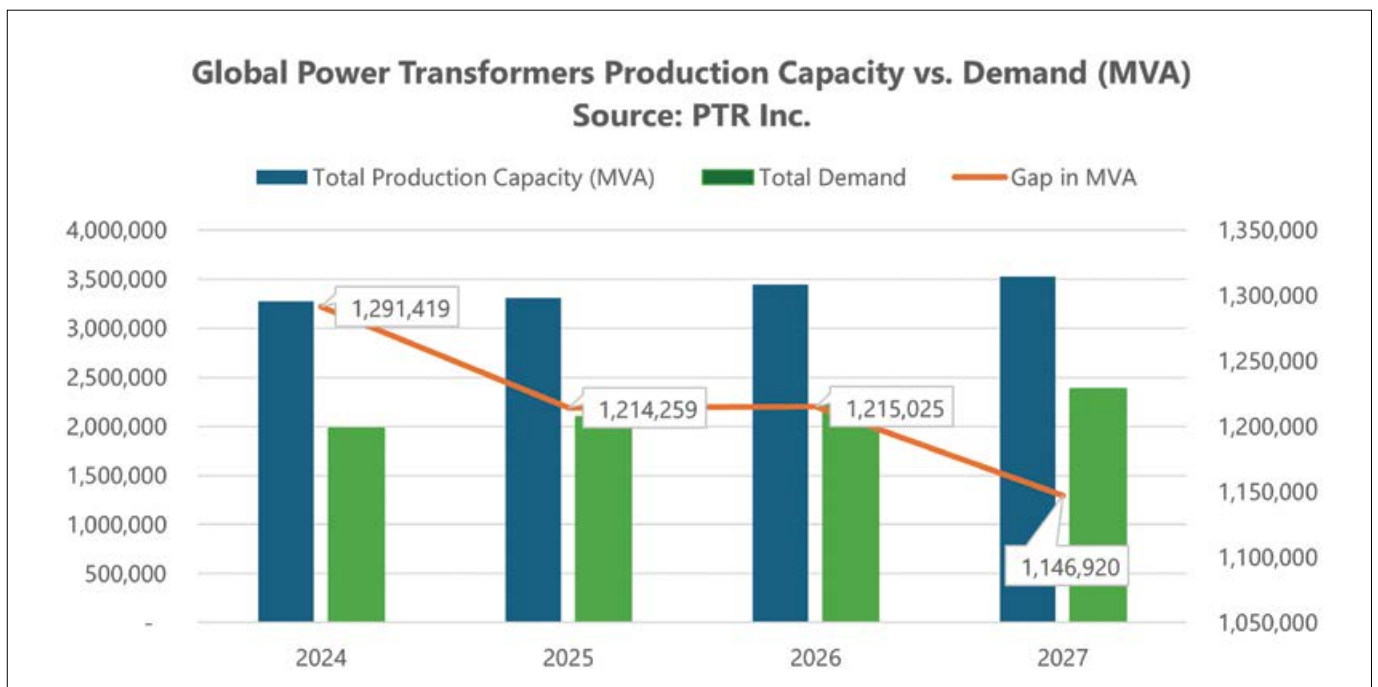


Figure 1. Power transformer demand and capacity [9]

product passports as part of its Circular Economy Action Plan and the proposed Ecodesign for Sustainable Products Regulation (ESPR) [4]. According to the ESPR framework, products will be required to carry digital passports that include information on the origin of materials, environmental performance, and compliance with sustainability standards [5]. However, in its current form, the DPP proposal emphasizes mainly environmental and sourcing data, such as the country of origin of raw materials or recyclability metrics, without incorporating detailed technical and operational information.

This limited scope presents a missed opportunity, especially for complex industrial assets like transformers, which have multi-decade lifespans, multiple ownership transfers, and often undergo refurbishment or upgrades. A more comprehensive DPP enriched with technical data (such as loading history, oil testing logs, component replacements, and fault records) would offer enormous value to utilities, OEMs, insurers, and second-hand buyers alike. For instance, countries like Germany and the Netherlands are already investing in pilot schemes under Horizon Europe and Digital Europe programs to explore DPP applications in complex electromechanical systems, but none currently include full transformer lifecycle data [1][5].

## Subcomponents, such as windings, bushings, conservators, and insulating oils, can be treated as nested digital objects, each contributing its data to the parent transformer's chain

Expanding the DPP concept with blockchain-backed technical data would enable the EU to lead globally in establishing transparent, accountable, and sustainable practices for power infrastructure assets, aligning with the goals of the European Green Deal, and supporting upcoming mandates in ESG disclosure.

### 3. Conceptual framework: Transformer as a blockchain asset

This paper introduces the concept of treating a transformer as a blockchain-based digital asset. Within this framework, each transformer is represented on a distributed ledger, and key lifecycle events (from manufacturing to end-of-life recycling) are logged as immutable transactions or blocks. Each block contains verified data contributed by authenticated stakeholders, creating a

comprehensive and transparent timeline of the transformer's history [5].

Subcomponents (such as windings, bushings, conservators, and insulating oils) can be treated as nested digital objects, each contributing its data to the parent transformer's chain. This structure mirrors real-world assembly processes and allows for granular traceability.

Stakeholders in this ecosystem include:

- Component and raw material suppliers
- Transformer OEMs and assemblers
- EPC firms and commissioning agents
- Utilities and asset managers
- Maintenance and repair contractors
- Refurbishment centers
- Secondary market buyers

Each stakeholder is authorized to write specific entries to the ledger, secured through digital signatures and permissioned access [6].

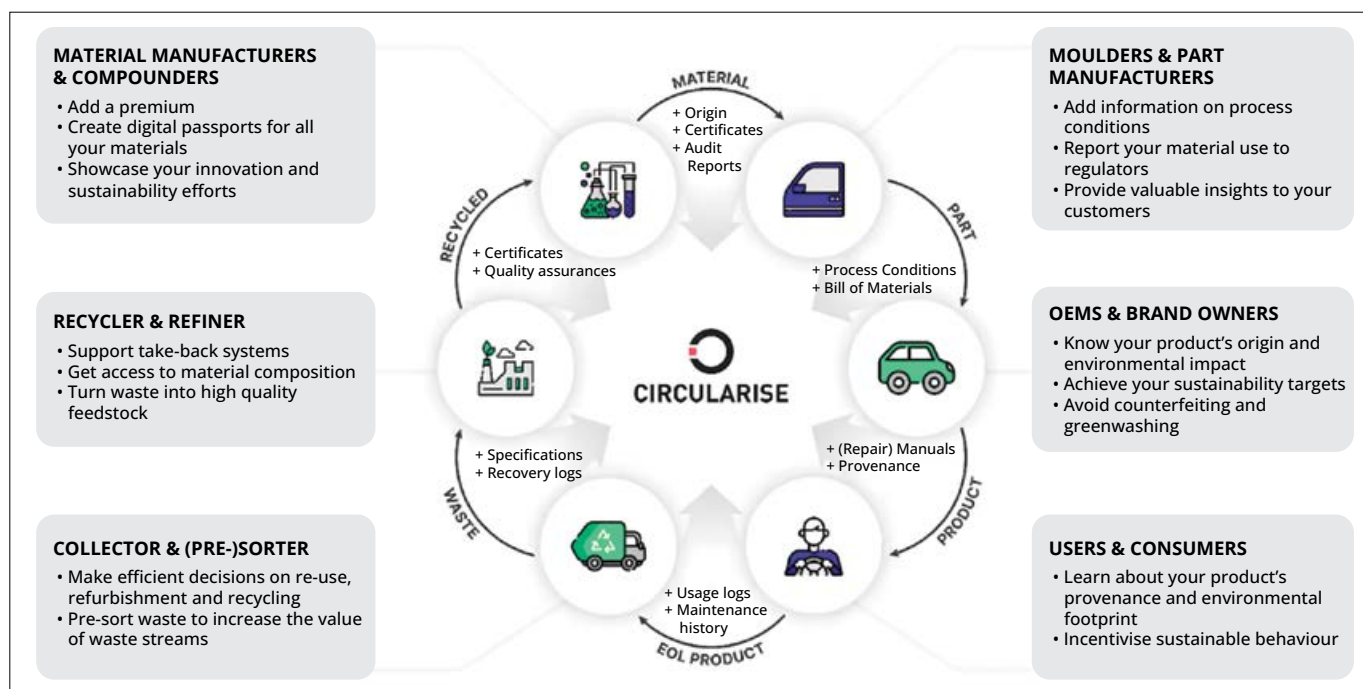


Figure 2. Digital Product Passport concept [10]

## Blockchain chain becomes the real digital passport of the transformer, ensuring that future buyers or operators have access to validated and comprehensive information

### 3.1 Lifecycle data and blockchain entries

The transformer's blockchain record evolves with its operational history. Below is a non-exhaustive list of entries:

- **Material procurement:** Certificates of origin, quality test results, and environmental compliance of raw materials (e.g., CRGO steel, copper, ester fluids). Production dates, serial numbers, used copper percentage, and steel technical data, such as loss test results (if done in independent laboratories, these results could add great value). Oil manufacturer data, test results, and all protection equipment data could be stored.
- **Component manufacturing:** Serial numbers, test certificates, and factory QA records for bushings, tap changers, sensors, and insulation systems. If the transformer manufacturer outsources some parts, this will also include another block. As an example, some manufacturers buy windings, tanks, or cores as ready-made sub-parts before final assembly. The blockchain will enable a great advantage by enabling the ability to see and monitor this process. Additionally, some orders can get cancelled after manufacturing, so reselling with data on how long the product was stored and under what conditions could provide useful data for a second buyer. Did the manufacturer store N<sub>2</sub> gas, or did they refill the unit with oil or dry products every 6 months? The second test results could be compared with the first test results, and any change could lead to a quick repair without the unit leaving the plant.
- **Assembly and Factory Acceptance Testing (FAT):** Final transformer configuration, rating plate details, FAT results, and factory location. Maybe including a drying schedule or the data of removed humidity during drying of the assembly could create good data for research purposes and for

failure analysis (if it happens). Did the winding wait a long time before the assembly started? This could lead to a close following of the manufacturing plan, good and transparent information for the customers at these tight schedules.

- **Delivery and site commissioning:** GPS-tagged installation site data, site test data, load parameters, initial DGA analysis, and as-built drawings could be stored as digital assets.
- **Ongoing maintenance:** Periodic test results, DGA trends, thermal monitoring data, and intervention logs [3]. Which service team measured what, how, and what decisions were made for the transformer? This will all help with a true assessment of the product. Was the maintenance done on time, as the manufacturer suggested? Oil filtration or replacement schedules, refilled units (possibly with esters) could be logged with minimum effort.
- **Refurbishment or upgrade:** Details of rewinding, insulation replacement, tank restoration, and post-repair testing [7], location of repair, and which parts are renewed - all this data will provide valuable information to monitor the performance of refurbishment or service companies.
- **Resale or relocation:** Updated asset valuation, remaining thermal life estimations, and operational history summary.

Further information could be stored digitally in blocks of the blockchain.

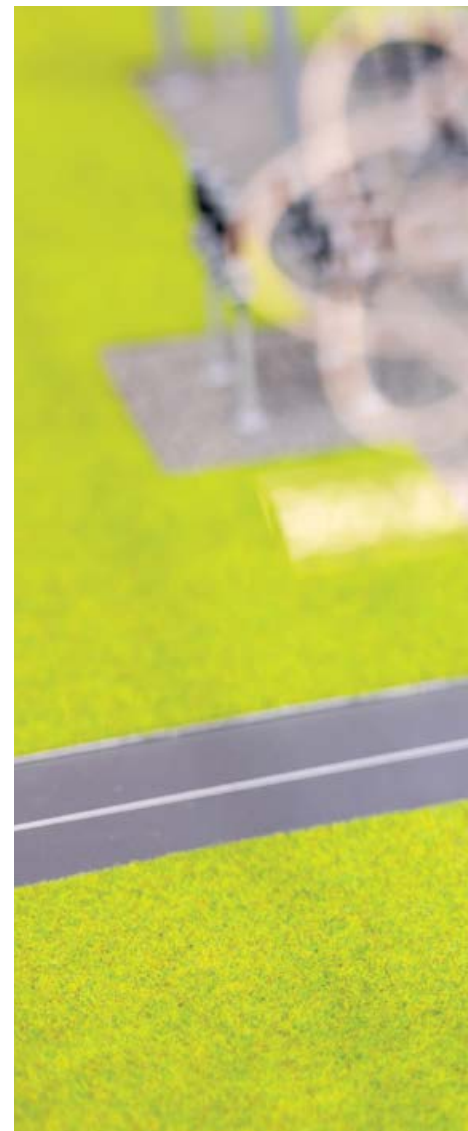
This blockchain chain becomes the real digital passport of the transformer, ensuring that future buyers or operators have access to validated and comprehensive information.

Also, storing all transformer data digitally will help the sustainability of the sector. Third-party FAT companies could log data into the system, and every feedback will create a real passport for the product.

### Value proposition

For transformer OEMs, blockchain registration allows them to enhance post-delivery service offerings and differentiate their products through transparency. Utilities gain the ability to make more informed decisions when procuring new or refurbished units, with verifiable insights into previous operating conditions and manufacturer practices.

Maintenance contractors and refurbishment centers benefit from real-time access to previous service logs and design documentation, streamlining repair operations. Finally, end users and regulators benefit from improved lifecycle documentation, essential for ESG reporting, warranty claims, and insurance validation [3][5].



Moreover, this system can prevent counterfeit equipment from circulating in the secondary market. When every transformer and its components are cryptographically registered and signed, any attempt to sell unauthorized or misrepresented equipment would be immediately detectable [5]. This will also protect a big brand's reputation and provide knowledge after reselling or repairing, so that they can follow up on their product.

Another topic to focus on could be the request for the same transformer. With blockchain data in hand, even without design, customers could request the same transformer very easily with all the data in their hands. This approach is suitable for spare part management too. Since the data for all equipment is in the customer's hands, they could go directly to the manufacturer and easily ask for

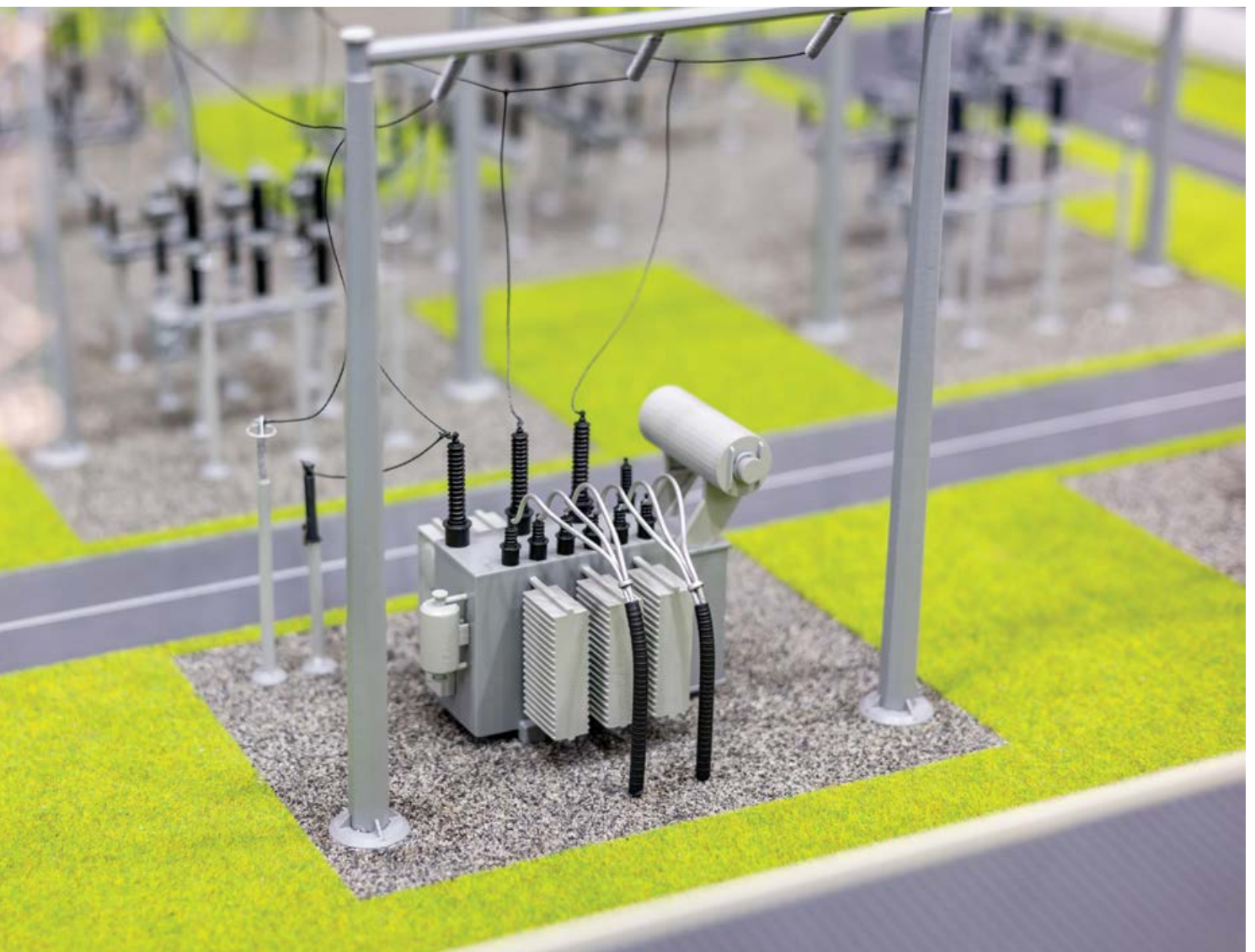
the same bushing or protection relay. To save customers from searching for manufacturers, contact details, or company information, it could possibly be added to the blockchain as data, too.

This will serve as a bridge between OEMs and customers, where, in many cases, OEMs don't have much information or data about how their equipment performs. They only know when there is a request for replacing parts or for failure. With blockchain data, they can get data

about the equipment lifecycle, or maybe they can request additional data during block creation. As an example, a fan manufacturer could know how long the fan operates, whether the maintenance of the fan is done in a period, or they could learn when the fan performance lowers, as well as the reason why.

Reference lists of OEMs and transformer manufacturers could be created in seconds. Since all data is in the blockchain system, customers could see which

## For transformer OEMs, blockchain registration allows them to enhance post-delivery service offerings and differentiate their products through transparency



### **Actual data (DGA reports, failures, etc.) could be stored on an off-chain database (also secure) or a decentralized file system, while only the hashed fingerprint is stored on the blockchain as the main solution**

transformers used a bushing or an ester oil for which unit. Good performance equipment will make its own reference in the long run, as transparent as it can be.

#### **Challenges and outlook**

From a technical perspective, implementing this blockchain framework would

require lightweight and scalable architectures, such as Hyperledger Fabric or Polygon, to ensure interoperability with existing systems [6]. Smart contracts could be used to automate warranty terms, initiate maintenance schedules, or trigger alerts for compliance events. The total guarantee of the unit could be split into a partial guarantee, as we

see for washing machines or fridges (as an example, we know there is a 10-year warranty for the engine of the fridge but 2 years only for the door), which can split the responsibility of the refurbishing center.

Integration with SCADA, Computerized Maintenance Management System (CMMS), and ERP systems would be essential for automatic data collection and synchronization. However, data privacy and commercial confidentiality must be carefully managed through permissioned access models and encryption protocols [5]. This could be solved via hybrid encryption systems, to make blockchain visible to some, with deadlines and software support. Permissioned blockchains and off-chain data



encryption make it possible to manage critical information for parties. Actual data (DGA reports, failures, etc.) could be stored on an off-chain database (also secure) or a decentralized file system, while only the hashed fingerprint is stored on the blockchain as the main solution. Attribute-Based Encryption (ABE) allows very fine-grained access. For instance, a person with the role tag "Field Engineer" can only access "Maintenance Logs" but not the design drawings. Please see Table 1 for an example of this topic.

A critical point for this suggestion is regulatory considerations. In the EU, GDPR and the EU Data Act could mandate open access to machine-generated data under certain contracts, which could

## In time, this model could evolve into an industry-wide digital registry, like Vehicle Identification Number (VIN) databases for automobiles, but an interactive and alive one

influence the access rights for OEMs and end users.

Governance is another critical factor. A consortium model involving OEMs, utilities, and independent auditors may be necessary to validate data entries and establish shared standards. Without unified commitment, blockchain entries

risk becoming inconsistent or incomplete [5][6].

The transformer blockchain model lays the foundation for several disruptive business models:

- **Transformer-as-a-service:** Leasing or pay-per-use models become viable

Table 1. Blockchain data access model

Partner	Example actions in a chain	Who can access	Encryption	Expiry
Raw Material Manufacturer (RMM)	Test reports, manufacturing data of raw materials, sustainability info	TM, O, RNO, FA, M, R	Off-chain	Can see own, rest N/A
Transformer Manufacturer (TM)	Transformer design, material data, FAT reports, sustainability info	O, CC, R, FA, RNO	Off-chain	Can see own, RMM, Outside Test, CC, FA data.
O, M, R, RNO optional.	Minimal maintenance compared t	Minimal maintenance compared t	Minimal maintenance compared t	Minimal maintenance compared t
Outside Test (Short-Circuit, etc.)	FAT test results	O, FA, RNO, TM, R	Off-chain	Can see own, rest N/A
Commissioning Company (CC)	Site data, GPS, Load Settings, erection, and commissioning log	O, M, FA, R, TM, RNO	Off-chain	Can see limited TM data
Cannot reach the chain after comm. completed	Used in gas-insulated switchgear (GIS) and transmission l	Used in gas-insulated switchgear (GIS) and transmission l	Used in gas-insulated switchgear (GIS) and transmission l	Used in gas-insulated switchgear (GIS) and transmission l
Operator (O)	Load data, failure information (alerts, trips)	TM, M, FA, R, RNO	On-chain	All data while the operator owns the product
Maintenance (M) *	DGA, oil change report, thermal scan	O, FA, RNO, TM, R	Off-chain	Just during the maintenance
Failure Analysis (FA) *	In case of failure, 3rd party inspector creates a report	O, TM, R, RNO	Off-chain	Until the claim is solved
Refurbishment (R) *	E.g., change of tank and radiators, sustainability info	TM, FA, RNO	Hybrid	Can see own, RMM, TM, Outside Test, CC, FA, M, O data.
Resale to New Operator * (RNO)	Load data, failure information (alerts, trips)	TM, FA, M, R	On-chain	All data while the operator owns the product

\* This could be a new partner or the same partner. The same scope of previous data could be adopted.

# In an era where asset transparency, sustainability, and digital transformation are critical, blockchain offers a disruptive yet practical path forward for the transformer industry

when operational performance is transparently logged.

- **Digital secondary marketplaces:** Verified and rated resale platforms for refurbished units could emerge, supported by blockchain-certified histories [5].
- **Circular economy enablement:** Real-time lifecycle data supports decisions around refurbishment, component recycling, or full asset repurposing [7].

In time, this model could evolve into an industry-wide digital registry, like Vehicle Identification Number (VIN) databases for automobiles, but an interactive and alive one. With clear ownership of histories, material declarations, and operating records, transformer assets will become safer, more valuable, and more sustainable [8].

Companies in the middle could create a value-based sales model to rent units or even suggest to companies that they upgrade their products when there is an opportunity in the market.

## Conclusion

In an era where asset transparency, sustainability, and digital transformation are critical, blockchain offers a disruptive yet practical path forward for the transformer industry. By redefining transformers as blockchain-registered digital assets, the sector can unlock new value streams, increase stakeholder trust, and support a truly circular economy model. The transformer of the future will not only be a physical object of copper and steel—it will be a data-rich, transparent, and traceable entity at the core of the energy transition [5].

## Bibliography

[1] IEA, “Electricity market report – update 2023 – analysis,” IEA, Jul. 2023. <https://www.iea.org/reports/electricity-market-report-update-2023>

[2] G. H. Gonzalez, “Distribution Grid Modernization and Loss Reduction Project,” Dec. 2015. Accessed: Jul. 17, 2025. [Online]. Available: <https://documents1.worldbank.org/curated/en/296731604639211819/pdf/Disclosure-Restructuring-Paper-Distribution-Grid-Modernization-and-Loss-Reduction-Project-P147277.pdf>

[3] “rameshthoomu”, “Welcome to Hyperledger Fabric’s Documentation,” Readthedocs.io, 2017. <https://fabric-estdocs.readthedocs.io/en/latest/> (accessed Jul. 17, 2025).

[4] IEA, “Electricity market report – update 2023 – analysis,” IEA, Jul. 2023.

[5] DNV, “Transformer Health and Risk Indexing Paper,” DNV, 2025. <https://www.dnv.com/publications/transformer-health-and-risk-indexing-paper-103199/> (accessed Jul. 17, 2025).

[6] World Economic Forum, “Inclusive Deployment of Blockchain for Supply Chains: Part 1 -Introduction,” 2019. Available: <https://www3.weforum.org/docs/>

[WEF\\_Introduction\\_to\\_Blockchain\\_for\\_Supply\\_Chains.pdf](#)

[7] D. M. Allan, “Asset Management Challenges in Ageing Power Systems,” Proceedings of 2005 International Symposium on Electrical Insulating Materials, 2005. (ISEIM 2005)., pp. 265–268 Vol. 1, Jan. 2005, doi: <https://doi.org/10.1109/iseim.2005.193395>.

[8] S. Ryder and M. Heinz, “Transformers and the Circular Economy,” 2023. Accessed: Jul. 17, 2025. [Online]. Available: <https://cigre.org.uk/web-cont1001/uploads/Transformers-and-the-Circular-Economy.pdf>

[9] H. Zaheer, “Power Transformers Supply-Demand Dynamics – Should You Still Invest in New Production Capacity expansions?,” Powersystems.technology, 2025. <https://www.powersystems.technology/community-hub/in-focus/power-transformers-supply-demand-dynamics-should-you-still-invest-in-new-production-capacity-expansions-transformer-technology-in-focus.html> (accessed Jul. 17, 2025).

[10] C. Stretton and Z. Buzeti, “Digital Product Passports (DPP): what, how, and why?,” www.circularise.com, Apr. 20, 2022. <https://www.circularise.com/blogs/digital-product-passports-dpp-what-how-and-why>



### Author



**A. Kerem Köseoğlu** ([www.linkedin.com/in/akkoseoglu](http://www.linkedin.com/in/akkoseoglu)), electrical engineer, started his PhD degree education in Cantabria University Transformer Institute, Spain, in 2021. He previously graduated from Istanbul Technical University in 2017 for MSc and 2009 for BSc. He has worked in the transformer industry for 14+ years in many roles, managed R&D, Marketing, Communications & Business Development divisions for a Forbes Top500 company. He has started and completed many Horizon EU, TUBITAK, or EPDK supported R&D Projects, representing the company and the nation. He received the “Most Innovative Person in Turkey – Refik Ureyen” award in 2018 from TTGV. Also, he is a CIGRE Türkiye VP, Head of NGN, and has been actively participating since the establishment of the national committee. He has many academic publications, especially on ester fluids. He is now working as a freelance consultant, helping the sector to develop and solve problems.