

Emerging Electrical Engineering Technologies for the Energy Transition: A Taxonomy of Material Constraints and SDG Roadmap to 2030

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ABSTRACT

The transition to sustainable electrical engineering requires an understanding of technologies, their resource demands and their contributions to the United Nations Sustainable Development Goals. Wide bandgap power electronics, solid-state transformers, artificial intelligence-enabled grid management and renewable-energy conversion are changing electricity systems, but their deployment remains exposed to material shortages, supply-chain concentration and major interoperability barriers. This review develops a taxonomy that classifies emerging technologies by functional role, technological readiness, environmental footprint, scalability and material criticality. It then examines dependencies involving rare-earth elements, lithium, cobalt, copper and semiconductor substrates to reveal trade-offs that are often missed in technology-centred assessments. A sustainability framework connects technical performance with lifecycle impacts, supply risk, circularity and SDG alignment. The resulting roadmap identifies 2030 trajectories under conservative, baseline and accelerated policy scenarios. The analysis shows that efficiency and technological maturity alone cannot ensure sustainable deployment when reliability, material security, recycling capacity and social equity are overlooked. The review therefore proposes coordinated research priorities, industrial strategies and policy actions to support a resilient, low-carbon and equitable energy transition by 2030.

Keywords: Sustainable electrical engineering; Emerging energy technologies; Critical raw materials; Technology taxonomy; Sustainable Development Goals (SDGs).

INTRODUCTION

The energy transition is reshaping electricity systems globally while increasing the need for affordable and equitable access [1]. Technology assessment must consider environmental, economic and social lifecycle effects rather than efficiency alone [2]. Energy interventions can advance Sustainable Development Goals but may create trade-offs involving resources, infrastructure and climate mitigation [3]. Goal interactions mean progress in one area can constrain another [4]. Energy, industry, governance and resource management require coordinated transformation [5].

Transition benefits and burdens are unevenly distributed [6]. Low-carbon electricity systems require flexible generation, efficient conversion and bidirectional power flow [7]. As inverter-based resources replace synchronous generation, grid-forming converters become important for voltage regulation and frequency support [8]. Multiple near-optimal decarbonisation pathways exist, making resilience and resource availability important selection criteria [9].

Efficient motors reduce operating energy, but their sustainability depends on materials, manufacturing, maintenance and end-of-life management [10]. Photovoltaic deployment requires energy-intensive production and module recycling [11]. Premature equipment failure increases replacement demand, waste and downtime [12]. Carbon-accounting methods can alter reported electricity-generation emissions [13].

High renewable penetration requires forecasting, storage, transmission reinforcement and flexible demand [14] [15]. Silicon carbide converters can maintain high efficiency across wide voltage ranges [16], while gallium nitride devices enable compact high-frequency conversion [17]. Fast switching can introduce electromagnetic

interference [18], requiring mitigation [19]. Insulation behaviour [20] and component degradation affect converter reliability [21].

Solid-state transformers enable controlled voltage conversion and bidirectional power transfer [22] [23], while soft-switching designs can reduce losses [22]. Integrated storage improves flexibility but adds cost, complexity and material demand [24]. Motor architecture influences requirements for copper, electrical steel and permanent magnets [25]. Grid-forming control [8], renewable integration [8] and network stability [14] must be carefully evaluated together under conservative, baseline and accelerated policy scenarios.

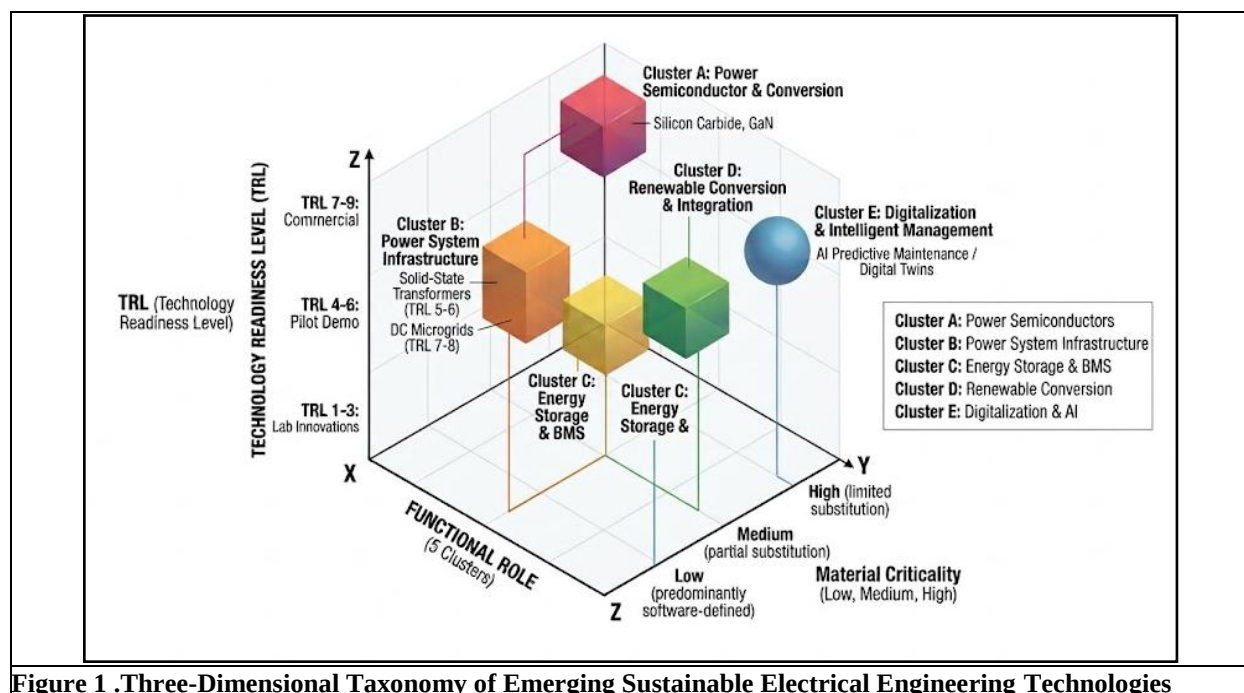
2. TAXONOMY AND CLASSIFICATION FRAMEWORK

The taxonomy compares emerging electrical technologies through functional role, technology readiness and material criticality [26] [27]. These dimensions connect performance with integration risk, maturity and resource dependence [26]. Cluster A covers power semiconductors and energy conversion, while Cluster B includes solid-state transformers, direct-current microgrids, transmission and grid-forming converters [26]. Converter stability depends on control behaviour, conditions and network impedance [8].

Cluster C comprises storage, battery management and converter interfaces [28] [29]. Cluster D covers renewable conversion and grid integration, where power-synchronisation control must remain stable as network characteristics change [28]. Photovoltaic inverters may experience oscillatory instability in weak grids [28], while frequency coupling affects admittance and stability modelling [30]. Cluster E includes artificial intelligence, digital twins, predictive maintenance and energy management [31]. Data-driven models can estimate system strength under changing renewable penetration [31]. Conventional indicators may become less representative in fully inverter-based systems [32]. Required grid-forming capacity depends on small-signal stability and converter interactions [32], while converter location affects multiconverter stability [32].

TRL 1–3 represents principles and laboratory concepts, TRL 4–6 covers validation and pilot demonstration, and TRL 7–9 indicates system demonstration or operational deployment [26]. Readiness must be judged at system level because mature components may retain integration, protection or stability limitations [33]. Established synchronisation methods support commercial distributed-generation systems [33], while coordinated high-voltage direct-current arrangements demonstrate advanced system integration [33].

High-criticality technologies face concentrated supply, limited substitution or immature recycling, while lower categories offer stronger availability or recovery pathways [34]. Reliability matters because premature replacement increases material demand [34]. Digital twins support condition assessment and predictive operation through links between physical equipment and simulation models [35]. Figure 1 positions each technology by cluster, readiness and material criticality, enabling comparison without assuming that maturity guarantees overall sustainability [35].



3. WIDE BANDGAP POWER ELECTRONICS AND ENERGY-EFFICIENT CONVERSION

Wide bandgap power electronics improve conversion efficiency and power density in renewable generation, transportation, industrial drives and data centres [36] [37]. Load-forecasting models can identify consumption patterns across time scales and support responsive energy management [36]. Electricity-price forecasting improves the scheduling of loads, storage and converter-interfaced resources [38]. Electric-vehicle charging adds variable demand that requires accurate forecasting [38], while demand response can coordinate charging with power-network conditions [38].

Artificial intelligence increases electricity demand through computation, cooling and infrastructure [39]. Its expansion may face supply-chain constraints involving semiconductors, data-centre equipment and energy availability [39]. Green-aware management can reduce data-centre consumption through workload allocation, cooling optimisation and power control [39]. Environmental performance still depends on location, electricity mix and operating conditions [40], while cooling can create substantial water demand [41].

Silicon carbide and gallium nitride devices have critical electric fields, faster switching and greater temperature capability than silicon devices [16] [42]. These characteristics enable higher frequencies, smaller passive components and lower conversion losses [16]. A reported four-phase interleaved SiC converter achieved over 98% efficiency in its tested operating range [16]. Gallium nitride devices support compact high-frequency conversion, although performance depends on dead time, control resolution and parasitic behaviour [17]. Multilevel gallium nitride converters can reduce device-voltage stress and waveform noise [18].

Fast switching can produce conducted and radiated electromagnetic emissions through high voltage and current slew rates [19] [43]. Frequency dithering can attenuate conducted emissions, although effectiveness depends on switching frequency and measurement bandwidth [19]. Insulation design must address charge accumulation and electric-field distortion [20]. Reliability assessment must consider thermal cycling, packaging stress, degradation and service life [21].

Rapid decarbonisation increases the importance of efficient converters across power, global transport and industry [44] [15]. Low-cost renewable electricity requires reliable conversion, storage and network integration [45]. High photovoltaic penetration can introduce voltage variation, reverse power flow, protection challenges and instability [46].

4. ADVANCED POWER SYSTEM ARCHITECTURES

Advanced power architectures integrate distributed generation, storage and power-electronic interfaces to maintain supply under renewable generation [47] [23]. Technologies differ in discharge duration, efficiency, response, lifespan and application [48].

Battery storage provides active-power support for renewable balancing, voltage regulation and frequency control [49] [37]. Economic viability depends on capital cost, cycling, electricity prices and grid services [50]. Battery-management systems coordinate cell balancing, protection and charge estimation [51]. Recycling retired electric-vehicle batteries can reduce primary extraction, but collection systems and chemistry influence environmental benefits [52]. Recycling processes differ in energy demand, recovery rate and output quality [53].

Hydrogen can complement batteries where seasonal balancing is required [54]. Electrolysers convert electricity into hydrogen, while fuel cells or turbines return stored energy to the system [54]. Conversion losses limit short-duration efficiency, but longer storage supports integrated electricity and industrial applications [54].

Data-centre demand reflects computing activity, cooling needs and efficiency [55]. Flexible scheduling, renewables and storage can enable demand response, although rapid growth may increase network loading [55]. Decentralised architectures can extend electricity access where grid expansion is difficult or uneconomic [56]. Swarm electrification enables households and small generators to exchange surplus electricity through interconnected local networks [57]. Photovoltaic mini-grids depend on demand estimation, affordable tariffs, maintenance and productive electricity use [58]. Hybrid renewable systems can improve continuity by combining complementary resources, storage and dispatchable backup [59].

Infrastructure decisions can distribute costs, employment and environmental burdens unevenly [60]. A just transition requires affordability, transparent governance, workforce development and community participation [60]. Deployment depends on minerals with geographically concentrated production [61]. Lithium-ion battery growth can create pressure when demand exceeds mining, refining and manufacturing expansion [62]. Under conservative, baseline and accelerated policy scenarios, architectures require progressively stronger storage, transmission, digital control and circular material flows [62].

5. ARTIFICIAL INTELLIGENCE AND DIGITALIZATION IN SUSTAINABLE ENERGY SYSTEMS

Digital planning must address strategic material supply risks that can restrict technology deployment [63]. Changing global technology shares alter requirements, making scenario-based assessment necessary [64]. Lifecycle digitalisation can improve reliable end-of-life traceability [65]. Photovoltaic recycling depends on module composition and recovery processes [65]. Battery recycling varies with chemistry and recovered-material

quality [66]. Logistics determine whether recovered products re-enter manufacturing chains [67], while automated sorting can improve mineral recovery [68].

Assessment supports second-life battery selection [69]. Electric-vehicle batteries require health, safety and performance screening before stationary use [69]. Outcomes depend on remaining life and repurposing cost [70]. Digital scheduling can coordinate electricity, electrolyser loading, storage and demand [71]. Assessment must include efficiency, infrastructure and electricity carbon intensity [72].

Digital monitoring supports converter system management [73] [74]. Power-electronic reliability depends on thermal stress, degradation and lifetime modelling [73]. Time-resolved accounting accurately determines whether electricity use matches carbon-free generation hourly [75].

Signal processing and machine learning support electrical diagnostics [76] [77] [78] [79] [80] [81] [82] [83] [84]. Periodogram analysis can localise harmonic sources in inverter loads [76]. Linear time-frequency distributions identify inverter-switch faults [85]. Multilevel inverter control can reduce torque ripple in direct-torque-controlled drives [86]. K-nearest-neighbour and naive Bayes models classify harmonic-source patterns [87]. Spectrogram and S-transform representations characterise power-quality disturbances [88]. Frequency and phase spectrograms identify dominant harmonics [89]. Short-time Fourier analysis supports inverter-switch fault classification [90], while logistic regression distinguishes periodogram-based harmonic-source signatures [91].

6. CRITICAL MATERIAL CONSTRAINTS AND SUPPLY CHAIN VULNERABILITIES

Multiphase machines combine windings, magnetic materials and converter hardware [92] [27], while direct-torque-control performance depends on machine and converter configuration [93]. Cascaded multilevel inverters require switches, capacitors and interconnections as voltage levels increase [94]. Hybrid wind-hydrogen systems add electrolysers, storage vessels and conversion equipment to renewable infrastructure [95]. Electrification may increase copper demand while mining capacity and development periods restrict supply expansion [96] [42]. Criticality assessment must consider production concentration, processing capacity, trade exposure, substitution and recycling [97]. Gallium is recovered as a by-product of aluminium and zinc production, limiting its response to gallium-nitride demand [98]. Lithium supply is affected by extraction technology, water requirements, concentration and project-development time [99]. Variable-speed drives reduce motor electricity use but require semiconductors, copper and components [100]. Silicon carbide and gallium nitride devices improve switching performance, efficiency and power density [101] [43]. Silicon-carbide defects can reduce yield and long-term reliability [102]. Direct-current microgrids require converters, protection, storage interfaces and communication infrastructure [103]. Solid-state transformers use semiconductor-rich multistage conversion, increasing reliance on power modules, magnetic components and control electronics [104]. Direct-torque-controlled drives depend on machine design, sensing and inverter capability [105]. Multilevel converters improve waveform quality and voltage sharing, but additional levels increase semiconductor count and control complexity [106]. Battery deployment creates vulnerabilities across mining, refining and cell manufacturing [62]. Recycling reduces primary extraction only when collection and recovery systems operate effectively [52]. Photovoltaic recycling can recover glass, aluminium and semiconductor materials from retired modules [65]. Under conservative, baseline and accelerated policy scenarios, material demand should be assessed against deployment rates, recycling capacity, substitution and diversified supply [61].

7. COMPARATIVE FRAMEWORK AND SUSTAINABILITY METRICS

A multidimensional framework is required because efficiency alone cannot represent the technical, environmental, material and social consequences of an electrical technology [2], [3]. The assessment therefore combines efficiency gain, power density, technology readiness level, environmental footprint, scalability, material criticality, supply risk and SDG alignment [5], [9]. Signal classification methods from electromyography offer a methodological comparison, not direct validation of electricity-network performance. [107]

Table 1 compares the five technology clusters using these common dimensions. Wide bandgap devices provide high efficiency and power density, although specialised substrates and manufacturing requirements create material and supply risks [16] [15], [98], [101]. Solid-state transformers offer controllable conversion and bidirectional operation, but their semiconductor-rich architecture remains less mature than conventional transformers [22], [104]. Direct-current microgrids can integrate distributed generation, storage and controllable loads while reducing unnecessary conversion stages [103]. Renewable-conversion technologies have strong deployment potential, although their scalability depends on grid integration and material availability [45], [61]. Artificial intelligence and digitalisation have relatively low direct material intensity, but their benefits depend on data quality, communication infrastructure and effective integration with physical assets [30], [35].

Table 1. Comparative Sustainability Assessment of Emerging Electrical Engineering Technologies

Technology Cluster	Efficiency Gain	Power Density	Material Criticality	Supply Risk	TRL	Environmental Footprint	Scalability	SDG Alignment
WBG Power Electronics	High	Very High	Medium	Medium	9–7	Low–Medium	High	13 ,12 ,9 ,7
Solid-State Transformers	Medium	High	Medium–High	Medium	7–5	Medium	Medium	12 ,9 ,7
DC Microgrids	Medium	Medium	Low–Medium	Low	8–6	Low	High	12 ,11 ,7 13
Renewable Conversion	High	Medium	High	High	9–8	Low	Very High	13 ,7
AI and Digitalization	Medium	N/A	Low	Low	8–6	Very Low	Very High	12 ,9

The comparison indicates that technical maturity does not automatically ensure low lifecycle impact or secure material supply [10], [97]. Environmental performance must include manufacturing, operation, replacement and end-of-life treatment rather than direct operating emissions alone [11], [13]. Reliability should also be assessed because premature failure increases material consumption, waste generation and system downtime [21], [73]. Medical-image processing provides an analogy for noise-aware feature extraction, not evidence of converter efficiency. [108]

Table 2 details the material intensity, substitution potential, recycling maturity and supply concentration associated with representative technologies. Permanent-magnet machines depend on rare-earth elements whose extraction and processing are geographically concentrated [25], [61]. Battery systems face comparable vulnerabilities involving lithium, nickel and cobalt [62]. Silicon carbide and gallium nitride devices use smaller material quantities, but limited substitution and specialised processing can still expose their supply chains to disruption [97], [98].

Table 2. Critical-Material Requirements and Supply-Chain Indicators

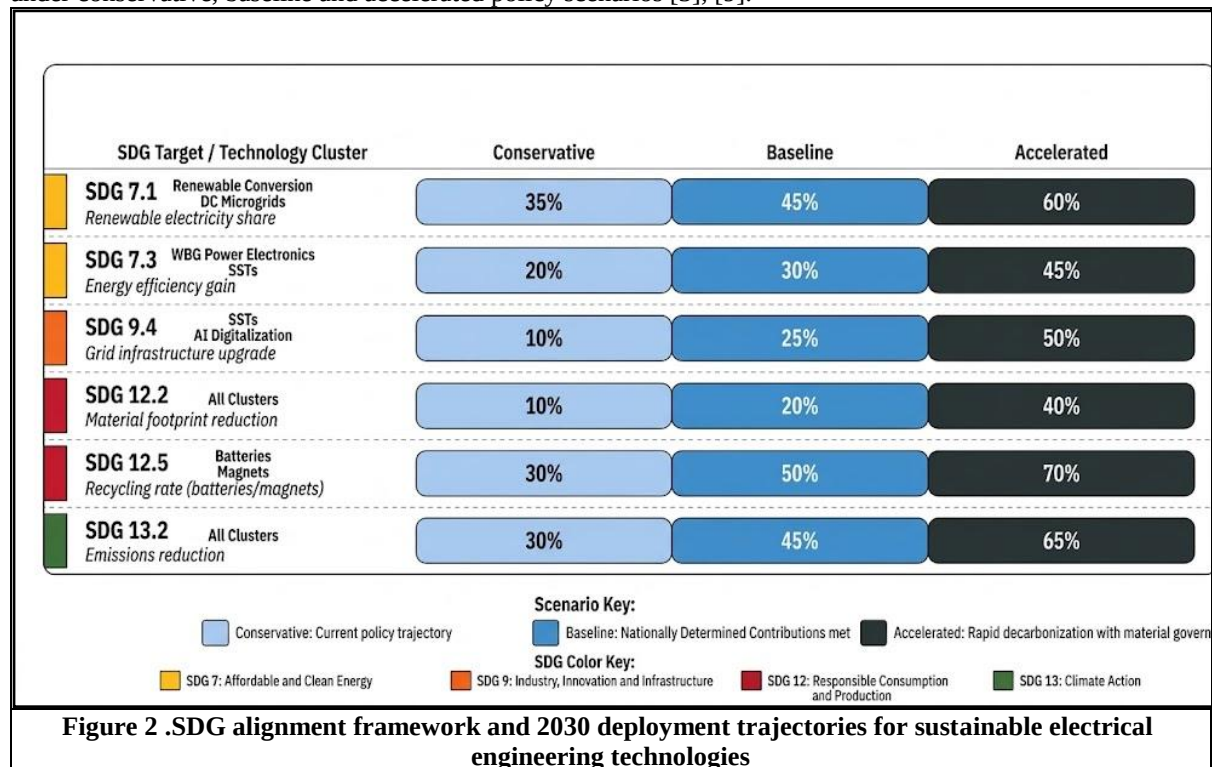
Technology	Critical Materials	kg per Unit	Substitution Potential	Recycling Maturity	Supply Concentration Risk
Direct-drive wind turbine (1 MW)	Nd, Pr, Dy, Tb	300–200	Medium	Low	Very High
EV permanent magnet motor	Nd, Pr, Dy	2.5–0.5	High	Low	High
NMC811 battery (1 kWh)	Li, Ni, Co	0.1 ,4.0 ,0.6	Medium	Medium	High
SiC traction inverter (100 kW)	SiC, Ga	0.02 ,0.05	Low	Very Low	Medium
GaN consumer charger (100 W)	Ga, Si	0.01 ,0.001	Low	Very Low	Medium

Under conservative, baseline and accelerated policy scenarios, the framework should be applied using different deployment rates, electricity mixes, recycling capacities and supply-chain assumptions [9], [96]. This scenario-based comparison identifies technologies that provide strong system benefits without shifting excessive environmental, material or social burdens elsewhere [3], [60].

8. SDG ROADMAP TO 2030 AND FUTURE TRAJECTORIES

The 2030 roadmap links technology deployment with affordable energy, resilient infrastructure, responsible production and climate action [1] [29], [3]. Because SDGs interact, technologies require combined technical,

environmental, economic and social assessment [4], [5]. Figure 2 maps technology clusters and SDG trajectories under conservative, baseline and accelerated policy scenarios [3], [9].



The conservative policy scenario prioritises renewables, silicon converters and network reinforcement [7], [45], [44]. Storage and grid-forming converters are introduced where variability or weak-grid conditions create needs [14], [26]. Material security focuses on procurement diversification and limited end-of-life recovery [61], [97]. The baseline policy scenario combines renewable deployment with storage, direct-current microgrids, grid-forming expansion, condition monitoring and solid-state-transformer demonstrations [24] [37], [34], [103], [104], [8], [32]. Battery reuse and recycling grow as retired assets accumulate [52], [69]. Artificial intelligence supports forecasting and system-strength assessment [30], [36], [38].

The accelerated policy scenario requires efficient conversion, flexible networks, long-duration storage and low-carbon hydrogen [47] [74], [54], [71]. Wide bandgap converters reduce losses and increase power density across transport, renewable and industrial applications [16], [17], [101]. Digital twins and predictive diagnostics support earlier fault detection and targeted maintenance [12], [35], [73]. Hourly accounting can align flexible demand with carbon-free generation [75].

Rapid deployment increases demand for copper, lithium, rare-earth elements and semiconductor materials [61] [80], [62], [96]. Recycling reduces primary extraction only when collection, recovery efficiency and secondary-material quality are adequate [52], [65], [68]. Policy must support material traceability, recycling infrastructure and diversified supply [6], [60], [97].

By 2030, progress should be measured through deployment, lifecycle emissions, reliability, material intensity, recycling, electricity access and SDG contributions [2], [3].

9. CONCLUSION

This review developed a taxonomy for evaluating electrical engineering technologies through readiness, lifecycle performance, material dependence, scalability and SDG contribution. The findings show that efficiency and maturity alone cannot guarantee sustainability. Wide bandgap converters, solid-state transformers, direct-current microgrids, storage and digital intelligence can strengthen low-carbon systems, but each introduces infrastructure, material and operational requirements.

Critical-material availability remains a constraint. Copper, lithium, rare-earth elements, gallium and semiconductor substrates may limit deployment when supply expansion, substitution and recycling lag. Circular design, collection, recovery and diversified supply chains are essential.

The roadmap distinguishes conservative, baseline and accelerated policy scenarios, allowing deployment speed, flexibility, recycling capacity and supply exposure to be compared across national conditions. Research should improve lifecycle data, material-flow estimates, reliability models and interoperable assessment methods.

Progress toward 2030 requires action among researchers, manufacturers, utilities and policymakers to deliver electricity, lower emissions, material use and equitable benefits while remaining adaptable to geopolitical change.

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REFERENCES

1. A. M. Minas et al., "Advancing Sustainable Development Goals through energy access: Lessons from the Global South," *Renew. Sustain. Energy Rev.*, vol. 199, Art. no. 114457, Jul. 2024, doi: 10.1016/j.rser.2024.114457.
2. A. Al-Kuwari, M. Kucukvar, N. C. Onat, H. Al-Yafei, and T. Al-Ansari, "Life cycle sustainability assessment of electricity production technologies: A structured review and future research perspectives," *Energy Strategy Rev.*, vol. 62, Art. no. 101939, Nov. 2025, doi: 10.1016/j.esr.2025.101939.
3. F. Fuso Nerini et al., "Mapping synergies and trade-offs between energy and the Sustainable Development Goals," *Nat. Energy*, vol. 3, no. 1, pp. 10–15, Jan. 2018, doi: 10.1038/s41560-017-0036-5.
4. P. Pradhan, L. Costa, D. Rybski, W. Lucht, and J. P. Kropp, "A systematic study of Sustainable Development Goal interactions," *Earth's Future*, vol. 5, no. 11, pp. 1169–1179, Nov. 2017, doi: 10.1002/2017EF000632.
5. J. D. Sachs et al., "Six transformations to achieve the Sustainable Development Goals," *Nat. Sustain.*, vol. 2, no. 9, pp. 805–814, Sep. 2019, doi: 10.1038/s41893-019-0352-9.
6. C. Sefa-Nyarko, "Ghana's National Energy Transition Framework: Domestic aspirations and mistrust in international relations complicate justice and equity," *Energy Res. Soc. Sci.*, vol. 110, Art. no. 103465, Apr. 2024, doi: 10.1016/j.erss.2024.103465.
7. M. J. B. Kabeyi and O. A. Olanrewaju, "Sustainable energy transition for renewable and low carbon grid electricity generation and supply," *Front. Energy Res.*, vol. 9, Art. no. 743114, Mar. 2022, doi: 10.3389/fenrg.2021.743114.
8. R. Rosso, X. Wang, M. Liserre, X. Lu, and S. Engelken, "Grid-forming converters: Control approaches, grid-synchronization, and future trends: A review," *IEEE Open J. Ind. Appl.*, vol. 2, pp. 93–109, 2021, doi: 10.1109/OJIA.2021.3074028.
9. F. Neumann and T. Brown, "The near-optimal feasible space of a renewable power system model," *Electr. Power Syst. Res.*, vol. 190, Art. no. 106690, Jan. 2021, doi: 10.1016/j.epsr.2020.106690.
10. D. F. de Souza, P. P. F. da Silva, I. L. Sauer, A. T. de Almeida, and H. Tatizawa, "Life cycle assessment of electric motors: A systematic literature review," *J. Clean. Prod.*, vol. 456, Art. no. 142366, Jun. 2024, doi: 10.1016/j.jclepro.2024.142366.
11. H. Cui et al., "Technoeconomic analysis of high-value, crystalline silicon photovoltaic module recycling processes," *Sol. Energy Mater. Sol. Cells*, vol. 238, Art. no. 111592, May 2022, doi: 10.1016/j.solmat.2022.111592.
12. T. Li, Q. Xu, K. Gao, Z. Yuan, J. Chen, and C. Li, "Review of insulation defect detection methods for a gas-insulated switchgear," *Energies*, vol. 19, no. 6, Art. no. 1491, Mar. 2026, doi: 10.3390/en19061491.
13. M. Bertolini, P. Dutillo, and F. Lisi, "Accounting carbon emissions from electricity generation: A review and comparison of emission factor-based methods," *Appl. Energy*, vol. 392, Art. no. 125992, Aug. 2025, doi: 10.1016/j.apenergy.2025.125992.
14. B. Kroposki et al., "Achieving a 100% renewable grid: Operating electric power systems with extremely high levels of variable renewable energy," *IEEE Power Energy Mag.*, vol. 15, no. 2, pp. 61–73, Mar./Apr. 2017, doi: 10.1109/MPE.2016.2637122.
15. A. Belsky, D. Glukhanich, T. Sutikno and M. H. Jopri, "Estimation of hourly solar irradiation on tilted surfaces," *Bull. Electr. Eng. Inform.*, vol. 12, no. 6, pp. 3202–3214, 2023, doi: 10.11591/eei.v12i6.6513.
16. S. Liu, G. Dong, T. Mishima, and C.-M. Lai, "Over 98% efficiency SiC-MOSFET based four-phase interleaved bidirectional DC–DC converter featuring wide-range voltage ratio," *IEEE Trans. Power Electron.*, vol. 39, no. 7, pp. 8436–8455, Jul. 2024, doi: 10.1109/TPEL.2024.3389052.
17. R. N. Tripathi, "Dead-time evaluation with switching frequency for GaN-based non-inverting buck–boost DC–DC converter using FPGA-based high-frequency control," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 12, no. 1, pp. 496–504, Feb. 2024, doi: 10.1109/JESTPE.2023.3344458.

18. V. Z. Lazarevic and M. Vasic, "High-frequency GaN-based ANPC three-level converter as a low-noise arbitrary PWL voltage generator," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 10, no. 5, pp. 5997–6008, Oct. 2022, doi: 10.1109/JESTPE.2022.3161421.
19. V. Pandey, K. Ghosh, and K. Hatua, "A frequency dithering technique to attenuate conducted electromagnetic emission of SiC MOSFET-based DC–DC converter," *IEEE Trans. Power Electron.*, vol. 41, no. 9, pp. 15242–15258, Sep. 2026, doi: 10.1109/TPEL.2026.3685809.
20. Y. Wang, Y. Xiong, Z. Wang, and W. Lu, "Characterization of space charge accumulations in alternative gas-to-liquid oil-immersed paper insulation under polarity reversal voltage scenarios," *Energies*, vol. 18, no. 12, Art. no. 3152, Jun. 2025, doi: 10.3390/en18123152.
21. H. Wang and F. Blaabjerg, "Power electronics reliability: State of the art and outlook," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 9, no. 6, pp. 6476–6493, Dec. 2021, doi: 10.1109/JESTPE.2020.3037161.
22. S. Rajendran and A. Q. Huang, "Design, analysis, and implementation of a 500-kVA hybrid solid-state transformer," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 13, no. 5, pp. 5734–5748, Oct. 2025, doi: 10.1109/JESTPE.2025.3593320.
23. A. F. N. Azam, A. Jidin, N. A. Ngatiman, M. H. Jopri, M. Manap, A. L. Herlino and N. F. Alias, "Current control of BLDC drives for EV application," in *Proc. IEEE 7th Int. Power Eng. Optim. Conf. (PEOCO)*, 2013, pp. 411–416, doi: 10.1109/PEOCO.2013.6564583.
24. L. Zheng et al., "Solid-state transformer and hybrid transformer with integrated energy storage in active distribution grids: Technical and economic comparison, dispatch, and control," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 10, no. 4, pp. 3771–3787, Aug. 2022, doi: 10.1109/JESTPE.2022.3144361.
25. A. T. de Almeida, F. J. T. E. Ferreira, and J. Fong, "Perspectives on electric motor market transformation for a net zero carbon economy," *Energies*, vol. 16, no. 3, Art. no. 1248, Jan. 2023, doi: 10.3390/en16031248.
26. F. Li and J. Ma, "Stability studies of grid-forming and grid-following inverter penetrated systems with different external power system models," *IEEE Trans. Power Del.*, vol. 39, no. 5, pp. 2580–2591, Oct. 2024, doi: 10.1109/TPWRD.2024.3407110.
27. L. R. L. V. Raj, A. Jidin, C. W. M. F. C. Wan, M. Zalani, K. A. Karim, W. Y. Goh and M. H. Jopri, "Improved performance of DTC of five-phase induction machines," in *Proc. IEEE 7th Int. Power Eng. Optim. Conf. (PEOCO)*, 2013, pp. 613–618, doi: 10.1109/PEOCO.2013.6564621.
28. E. Zhao et al., "Impedance characteristics investigation and oscillation stability analysis for two-stage PV inverter under weak grid condition," *Electr. Power Syst. Res.*, vol. 209, Art. no. 108053, Aug. 2022, doi: 10.1016/j.epsr.2022.108053.
29. M. H. Jopri, A. R. Abdullah, M. Manap, M. F. Habban and T. Sutikno, "An accurate classification method of harmonic signals in power distribution system by utilising S-transform," *TELKOMNIKA (Telecommun. Comput. Electron. Control)*, vol. 15, no. 1, pp. 62–70, 2017, doi: 10.12928/telkomnika.v15i1.3119.
30. M. O. Qays, I. Ahmad, D. Habibi, and M. A. S. Masoum, "Forecasting data-driven system strength level for inverter-based resources-integrated weak grid systems using multi-objective machine learning algorithms," *Electr. Power Syst. Res.*, vol. 238, Art. no. 111112, Jan. 2025, doi: 10.1016/j.epsr.2024.111112.
31. F. Ma, H. Xin, D. Wu, Y. Liu, and X. Chen, "Assessing small-signal grid strength of 100% inverter-based power systems," *IEEE Trans. Power Del.*, vol. 39, no. 5, pp. 2784–2796, Oct. 2024, doi: 10.1109/TPWRD.2024.3432582.
32. H. Xin, C. Liu, X. Chen, Y. Wang, E. Prieto-Araujo, and L. Huang, "How many grid-forming converters do we need? A perspective from small signal stability and power grid strength," *IEEE Trans. Power Syst.*, vol. 40, no. 1, pp. 623–635, Jan. 2025, doi: 10.1109/TPWRS.2024.3393877.
33. F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," *IEEE Trans. Ind. Electron.*, vol. 53, no. 5, pp. 1398–1409, Oct. 2006, doi: 10.1109/TIE.2006.881997.
34. P. Wegierek, D. Kostyla, and M. Lech, "Directions of development of diagnostic methods of vacuum medium-voltage switchgear," *Energies*, vol. 16, no. 5, Art. no. 2087, 2023, doi: 10.3390/en16052087.
35. F. Arrano-Vargas and G. Konstantinou, "Modular design and real-time simulators toward power system digital twins implementation," *IEEE Trans. Ind. Informat.*, vol. 19, no. 1, pp. 52–61, Jan. 2023, doi: 10.1109/TII.2022.3178713.
36. W. Yang et al., "A combined deep learning load forecasting model of single household resident user considering multi-time scale electricity consumption behavior," *Appl. Energy*, vol. 307, Art. no. 118197, Feb. 2022, doi: 10.1016/j.apenergy.2021.118197.
37. T. Sutikno, H. S. Purnama, A. Pamungkas, A. Fadlil, I. M. Alsofyani and M. H. Jopri, "Internet of things-based photovoltaics parameter monitoring system using NodeMCU ESP8266," *Int. J. Electr. Comput. Eng.*, vol. 11, no. 6, pp. 5578–5587, 2021, doi: 10.11591/ijece.v11i6.pp5578-5587.

38. L. Tschora, E. Pierre, M. Plantevit, and C. Robardet, "Electricity price forecasting on the day-ahead market using machine learning," *Appl. Energy*, vol. 313, Art. no. 118752, May 2022, doi: 10.1016/j.apenergy.2022.118752.
39. W. Lin, J. Lin, Z. Peng, H. Huang, W. Lin, and K. Li, "A systematic review of green-aware management techniques for sustainable data center," *Sustain. Comput. Informat. Syst.*, vol. 42, Art. no. 100989, Apr. 2024, doi: 10.1016/j.suscom.2024.100989.
40. M. A. B. Siddik, A. Shehabi, and L. Marston, "The environmental footprint of data centers in the United States," *Environ. Res. Lett.*, vol. 16, no. 6, Art. no. 064017, Jun. 2021, doi: 10.1088/1748-9326/abfba1.
41. D. Mytton, "Data centre water consumption," *npj Clean Water*, vol. 4, Art. no. 11, Feb. 2021, doi: 10.1038/s41545-021-00101-w.
42. A. R. Abdullah, N. Norddin, N. Q. Zainal Abidin, A. Aman and M. H. Jopri, "Leakage current analysis on polymeric and non-polymeric insulating materials using time-frequency distribution," in *Proc. IEEE Int. Conf. Power Energy (PECon)*, 2012, pp. 979–984, doi: 10.1109/PECon.2012.6450360.
43. A. R. Abdullah, N. S. Ahmad, N. Bahari, M. Manap, A. Jidin and M. H. Jopri, "Short-circuit switches fault analysis of voltage source inverter using spectrogram," in *Proc. Int. Conf. Electr. Mach. Syst. (ICEMS)*, 2013, pp. 1808–1813, doi: 10.1109/ICEMS.2013.6713294.
44. M. Victoria, E. Zeyen, and T. Brown, "Speed of technological transformations required in Europe to achieve different climate goals," *Joule*, vol. 6, no. 5, pp. 1066–1086, May 2022, doi: 10.1016/j.joule.2022.04.016.
45. D. Bogdanov et al., "Low-cost renewable electricity as the key driver of the global energy transition towards sustainability," *Energy*, vol. 227, Art. no. 120467, Jul. 2021, doi: 10.1016/j.energy.2021.120467.
46. O. Gandhi, D. S. Kumar, C. D. Rodriguez-Gallegos, and D. Srinivasan, "Review of power system impacts at high PV penetration," *Sol. Energy*, vol. 210, pp. 181–201, Nov. 2020, doi: 10.1016/j.solener.2020.06.097.
47. G. Strbac et al., "Opportunities for energy storage: Assessing whole-system economic benefits of energy storage in future electricity systems," *IEEE Power Energy Mag.*, vol. 17, no. 5, pp. 32–41, Sep./Oct. 2019, doi: 10.1109/MPE.2019.2920595.
48. [S. Koohi-Fayegh and M. A. Rosen, "A review of energy storage types, applications and recent developments," *J. Energy Storage*, vol. 27, Art. no. 101047, Feb. 2020, doi: 10.1016/j.est.2019.101047.
49. X. Hu, L. Xu, X. Lin, S. Dong, and M. G. Pecht, "Battery lifetime prognostics," *Joule*, vol. 4, no. 2, pp. 310–346, Feb. 2020, doi: 10.1016/j.joule.2019.11.018.
50. A. A. Kebede et al., "Techno-economic analysis of lithium-ion and lead-acid batteries in stationary energy storage application," *J. Energy Storage*, vol. 40, Art. no. 102748, Aug. 2021, doi: 10.1016/j.est.2021.102748.
51. M. A. Hannan et al., "Battery energy-storage system: A review of technologies, optimization objectives, constraints, approaches, and outstanding issues," *J. Energy Storage*, vol. 42, Art. no. 103023, Oct. 2021, doi: 10.1016/j.est.2021.103023.
52. G. Harper et al., "Recycling lithium-ion batteries from electric vehicles," *Nature*, vol. 575, no. 7781, pp. 75–86, Nov. 2019, doi: 10.1038/s41586-019-1682-5.
53. R. E. Ciez and J. F. Whitacre, "Examining different recycling processes for lithium-ion batteries," *Nat. Sustain.*, vol. 2, no. 2, pp. 148–156, Feb. 2019, doi: 10.1038/s41893-019-0222-5.
54. I. Staffell et al., "The role of hydrogen and fuel cells in the global energy system," *Energy Environ. Sci.*, vol. 12, no. 2, pp. 463–491, Feb. 2019, doi: 10.1039/C8EE01157E.
55. E. Masanet, A. Shehabi, N. Lei, S. Smith, and J. Koomey, "Recalibrating global data center energy-use estimates," *Science*, vol. 367, no. 6481, pp. 984–986, Feb. 2020, doi: 10.1126/science.aba3758.
56. D. Palit and A. Kumar, "Towards convergence of central grid and decentralised electricity solutions: Assessment of Indian rural electrification cases using a socio-technical framework," *Energy Sustain. Dev.*, vol. 71, pp. 27–53, Dec. 2022, doi: 10.1016/j.esd.2022.08.026.
57. I. Fuchs, S. Balderrama, S. Quoilin, P. Crespo del Granado, and J. Rajasekharan, "Swarm electrification: Harnessing surplus energy in off-grid solar home systems for universal electricity access," *Energy Sustain. Dev.*, vol. 77, Art. no. 101342, Dec. 2023, doi: 10.1016/j.esd.2023.101342.
58. Y. T. Wassie and E. O. Ahlgren, "Long-term optimal capacity expansion planning for an operating off-grid PV mini-grid in rural Africa under different demand and evolution scenarios," *Energy Sustain. Dev.*, vol. 76, Art. no. 101305, Oct. 2023, doi: 10.1016/j.esd.2023.101305.
59. A. A. B. Baloch, T. Ahmed, and R. Kaloi, "A comprehensive review of hybrid renewable energy systems for rural electrification," *Energy Rep.*, vol. 8, pp. 2616–2634, Nov. 2022, doi: 10.1016/j.egyr.2022.01.173.
60. A. Dahir, J. M. Bielicki, J. Jacquet, and H. T. K. Le, "Just transition to electric vehicles in disadvantaged communities: Integrating transportation, energy, environmental, and climate justice," *Energy Res. Soc. Sci.*, vol. 130, Art. no. 104449, Dec. 2025, doi: 10.1016/j.erss.2025.104449.
61. F. Montana et al., "Assessing critical raw materials and their supply risk in energy technologies: A literature review," *Energies*, vol. 18, no. 1, Art. no. 86, Jan. 2025, doi: 10.3390/en18010086.

62. R. Istrate et al., "Decarbonizing lithium-ion battery primary raw materials supply chain," *Joule*, vol. 8, no. 11, pp. 2992–3016, Nov. 2024, doi: 10.1016/j.joule.2024.10.003.
63. A. Y. Ku et al., "Grand challenges in anticipating and responding to critical materials supply risks," *Joule*, vol. 8, no. 5, pp. 1208–1223, May 2024, doi: 10.1016/j.joule.2024.03.001.
64. H. Dong, T. Zhang, Y. Geng, P. Wang, S. Zhang, and J. Sarkis, "Sub-technology market share strongly affects critical material constraints in power system transitions," *Nat. Commun.*, vol. 16, Art. no. 1255, Feb. 2025, doi: 10.1038/s41467-025-56592-5.
65. J. Wang, Y. Feng, and Y. He, "Insights for China from EU management of recycling end-of-life photovoltaic modules," *Sol. Energy*, vol. 273, Art. no. 112532, May 2024, doi: 10.1016/j.solener.2024.112532.
66. S. Vanderburgt, R. M. Santos, and Y. W. Chiang, "Is it worthwhile to recover lithium-ion battery electrolyte during lithium-ion battery recycling?" *Resour. Conserv. Recycl.*, vol. 189, Art. no. 106733, Feb. 2023, doi: 10.1016/j.resconrec.2022.106733.
67. E. Yoo, U. Lee, J. C. Kelly, and M. Wang, "Life-cycle analysis of battery metal recycling with lithium recovery from a spent lithium-ion battery," *Resour. Conserv. Recycl.*, vol. 196, Art. no. 107040, Sep. 2023, doi: 10.1016/j.resconrec.2023.107040.
68. D. Weigl and D. Young, "Impact of automated battery sorting for mineral recovery from lithium-ion battery recycling in the United States," *Resour. Conserv. Recycl.*, vol. 192, Art. no. 106936, May 2023, doi: 10.1016/j.resconrec.2023.106936.
69. A. H. Azad, F. F. Nia, A. Anvari-Moghaddam, and D. Flynn, "Second-life applications for retired electric vehicle batteries: Challenges, opportunities, and future directions," *J. Energy Storage*, vol. 151, Art. no. 120190, Mar. 2026, doi: 10.1016/j.est.2025.120190.
70. C. Hu, D. Li, W. Zhao, and H. Xi, "Deep reinforcement learning-based scheduling for integrated energy system utilizing retired electric vehicle battery energy storage," *J. Energy Storage*, vol. 97, Art. no. 112774, Sep. 2024, doi: 10.1016/j.est.2024.112774.
71. W. Ajeeb, R. Costa Neto, and P. Baptista, "Life cycle assessment of green hydrogen production through electrolysis: A literature review," *Sustain. Energy Technol. Assess.*, vol. 69, Art. no. 103923, Sep. 2024, doi: 10.1016/j.seta.2024.103923.
72. M. U. Hassan et al., "Recent progress of technologies for green hydrogen production via water electrolysis," *Int. J. Hydrogen Energy*, vol. 80, pp. 1–24, Aug. 2024, doi: 10.1016/j.ijhydene.2024.07.094.
73. S. Peyghami, P. Palensky, and F. Blaabjerg, "An overview on the reliability of modern power electronic based power systems," *IEEE Open J. Power Electron.*, vol. 1, pp. 34–50, 2020, doi: 10.1109/OJPEL.2020.2974875.
74. N. A. Abidullah, A. R. Abdullah, N. H. Shamsudin, N. H. T. H. Ahmad and M. H. Jopri, "Real-time power quality signals monitoring system," in *Proc. IEEE Student Conf. Research Development (SCORED)*, 2013, pp. 433–438, doi: 10.1109/SCORED.2013.7002626.
75. I. Riepin and T. Brown, "On the means, costs, and system-level impacts of 24/7 carbon-free energy procurement," *Energy Strategy Rev.*, vol. 54, Art. no. 101488, Jul. 2024, doi: 10.1016/j.esr.2024.101488.
76. M. H. Jopri, A. R. Abdullah, N. M. Kassim, M. Manap, N. A. Ngatiman and M. R. Yusoff, "Localization of multiple harmonic sources for inverter loads utilizing periodogram," *J. Telecommun. Electron. Comput. Eng.*, vol. 8, no. 2, pp. 87–91, 2016.
77. M. H. Jopri, A. R. Abdullah, T. Sutikno, M. Manap, M. R. Ab Ghani and M. R. Yusoff, "A critical review of time-frequency distribution analysis for detection and classification of harmonic signal in power distribution system," *Int. J. Electr. Comput. Eng.*, vol. 8, no. 6, pp. 4603–4618, 2018, doi: 10.11591/ijece.v8i6.pp4603-4618.
78. M. H. Jopri, A. R. Abdullah, T. Sutikno, M. Manap and M. R. Yusoff, "A utilisation of improved Gabor transform for harmonic signals detection and classification analysis," *Int. J. Electr. Comput. Eng.*, vol. 7, no. 1, pp. 21–28, 2017, doi: 10.11591/ijece.v7i1.pp21-28.
79. M. H. Jopri, A. R. Abdullah, M. Manap, T. Sutikno and M. R. Ab Ghani, "An identification of multiple harmonic sources in a distribution system by using spectrogram," *Bull. Electr. Eng. Inform.*, vol. 7, no. 2, pp. 244–256, 2018, doi: 10.11591/eei.v7i2.1188.
80. A. R. Abdullah, N. A. Abidullah, N. H. Shamsudin, N. H. H. Ahmad and M. H. Jopri, "Power quality signals classification system using time-frequency distribution," *Appl. Mech. Mater.*, vols. 494–495, pp. 1889–1894, 2014, doi: 10.4028/www.scientific.net/AMM.494-495.1889.
81. M. H. Jopri, A. R. Abdullah, M. Manap, M. R. Yusoff, T. Sutikno and M. F. Habban, "An improved detection and classification technique of harmonic signals in power distribution by utilizing spectrogram," *Int. J. Electr. Comput. Eng.*, vol. 7, no. 1, pp. 12–20, 2017, doi: 10.11591/ijece.v7i1.pp12-20.
82. N. H. T. H. Ahmad, A. R. Abdullah and M. H. Jopri, "Power quality signals detection using S-transform," in *Proc. IEEE 7th Int. Power Eng. Optim. Conf. (PEOCO)*, 2013, pp. 552–557, doi: 10.1109/PEOCO.2013.6564609.

83. N. A. Abidullah, A. R. Abdullah, A. Z. Sha'ameri, N. H. Shamsudin, N. H. H. Ahmad and M. H. Jopri, "Real-time power quality disturbances detection and classification system," *World Appl. Sci. J.*, vol. 32, no. 8, pp. 1637–1651, 2014, doi: 10.5829/idosi.wasj.2014.32.08.534.
84. A. R. Abdullah, G. Z. Peng, S. A. Ghani and M. H. Jopri, "A new vector draft method for harmonic source detection at point of common coupling," in *Proc. IEEE 8th Int. Power Eng. Optim. Conf. (PEOCO)*, 2014, pp. 110–114, doi: 10.1109/PEOCO.2014.6814409.
85. M. F. Habbani, M. Manap, A. R. Abdullah, M. H. Jopri and T. Sutikno, "An evaluation of linear time frequency distribution analysis for VSI switch faults identification," *Int. J. Power Electron. Drive Syst.*, vol. 8, no. 1, pp. 1–9, 2017, doi: 10.11591/ijpeds.v8.i1.pp1-9.
86. M. Z. R. Z. Ahmadi, A. Jidin, K. B. Jaffar, M. N. Othman, R. N. P. Nagarajan and M. H. Jopri, "Minimization of torque ripple utilizing by 3-L CHMI in DTC," in *Proc. IEEE 7th Int. Power Eng. Optim. Conf. (PEOCO)*, 2013, pp. 636–640, doi: 10.1109/PEOCO.2013.6564625.
87. M. H. Jopri, M. R. Ab Ghani, A. R. Abdullah, M. Manap, T. Sutikno and J. Too, "K-nearest neighbor and naïve Bayes based diagnostic analytic of harmonic source identification," *Bull. Electr. Eng. Inform.*, vol. 9, no. 6, pp. 2650–2657, 2020, doi: 10.11591/eei.v9i6.2685.
88. N. H. T. Ahmad, A. R. Abdullah, N. A. Abidullah and M. H. Jopri, "Analysis of power quality disturbances using spectrogram and S-transform," *Int. Rev. Electr. Eng.*, vol. 9, no. 3, pp. 611–619, 2014.
89. M. H. Jopri, N. A. Abidullah, G. Z. Peng and A. R. Abdullah, "A new two points method for identify dominant harmonic disturbance using frequency and phase spectrogram," *Int. Rev. Electr. Eng.*, vol. 9, no. 2, pp. 453–459, 2014.
90. M. Manap, S. Nikolovski, A. Skamyin, R. Karim, T. Sutikno and M. H. Jopri, "An analysis of voltage source inverter switches fault classification using short-time Fourier transform," *Int. J. Power Electron. Drive Syst.*, vol. 12, no. 4, pp. 2209–2220, 2021, doi: 10.11591/ijpeds.v12.i4.pp2209-2220.
91. M. Manap, M. H. Jopri, A. R. Abdullah, R. Karim, M. R. Yusoff and A. H. Azahar, "A verification of periodogram technique for harmonic source diagnostic analytic by using logistic regression," *TELKOMNIKA (Telecommun. Comput. Electron. Control)*, vol. 17, no. 1, pp. 497–507, 2019, doi: 10.12928/telkomnika.v17i1.10390.
92. L. R. L. V. Raj, A. Jidin, K. A. Karim, T. Sutikno, R. Sundram and M. H. Jopri, "Improved torque control performance of direct torque control for 5-phase induction machine," *Int. J. Power Electron. Drive Syst.*, vol. 3, no. 4, pp. 391–399, 2013, doi: 10.11591/ijpeds.v3i4.5249.
93. L. R. L. V. Raj, A. Jidin, Z. Ibrahim, K. A. Karim, M. A. Said and M. H. Jopri, "Optimal torque control performance of DTC of 5-phase induction machine," in *Proc. Int. Conf. Electr. Mach. Syst. (ICEMS)*, 2013, pp. 2094–2099, doi: 10.1109/ICEMS.2013.6713180.
94. R. Nair, A. Jidin, M. N. Othman, M. H. Jopri and M. Manap, "Comparison performance of 3-level and 5-level cascaded H-bridge multilevel inverter of DTC of induction machine," in *Proc. Int. Conf. Electr. Mach. Syst. (ICEMS)*, 2013, pp. 2100–2104, doi: 10.1109/ICEMS.2013.6713181.
95. Y. Shklyarskiy, I. Andreeva, T. Sutikno and M. H. Jopri, "Energy management in hybrid complexes based on wind generation and hydrogen storage," *Bull. Electr. Eng. Inform.*, vol. 13, no. 3, pp. 1483–1494, 2024, doi: 10.11591/eei.v13i3.6757.
96. J. Wang, S. Zheng, W. Liu, L. Chen, Z. Wen, and X. Li, "Prediction, evaluation and optimization of China's copper resource supply system under carbon constraints," *Sustain. Prod. Consum.*, vol. 39, pp. 285–300, Jul. 2023, doi: 10.1016/j.spc.2023.05.021.
97. V. Lundaev, A. A. Solomon, T. Le, A. Lohrmann, and C. Breyer, "Review of critical materials for the energy transition, an analysis of global resources and production databases and the state of material circularity," *Miner. Eng.*, vol. 203, Art. no. 108282, Nov. 2023, doi: 10.1016/j.mineng.2023.108282.
98. M. Frenzel, M. P. Ketris, T. Seifert, and J. Gutzmer, "On the current and future availability of gallium," *Resour. Policy*, vol. 47, pp. 38–50, Mar. 2016, doi: 10.1016/j.resourpol.2015.11.005.
99. V. Flexer, C. F. Baspineiro, and C. I. Galli, "Lithium recovery from brines: A vital raw material for green energies with a potential environmental impact in its mining and processing," *Sci. Total Environ.*, vol. 639, pp. 1188–1204, Oct. 2018, doi: 10.1016/j.scitotenv.2018.05.223.
100. R. Saidur, S. Mekhilef, M. B. Ali, A. Safari, and H. A. Mohammed, "Applications of variable speed drive in electrical motors energy savings," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 543–550, Jan. 2012, doi: 10.1016/j.rser.2011.08.020.
101. J. Millán, P. Godignon, X. Perpiñà, A. Pérez-Tomás, and J. Rebollo, "A survey of wide bandgap power semiconductor devices," *IEEE Trans. Power Electron.*, vol. 29, no. 5, pp. 2155–2163, May 2014, doi: 10.1109/TPEL.2013.2268900.
102. R. Yakimova, M. Syväjärvi, T. Iakimov, H. Jacobsson, A. Kakanakova-Georgieva, P. Råback, and E. Janzén, "Growth of silicon carbide: Process-related defects," *Appl. Surf. Sci.*, vol. 184, nos. 1–4, pp. 27–36, Dec. 2001, doi: 10.1016/S0169-4332(01)00472-X.

103. T. Dragičević, X. Lu, J. C. Vasquez, and J. M. Guerrero, "DC microgrids: Part I: A review of control strategies and stabilization techniques," *IEEE Trans. Power Electron.*, vol. 31, no. 7, pp. 4876–4891, Jul. 2016, doi: 10.1109/TPEL.2015.2478859.
104. X. She, A. Q. Huang, and R. Burgos, "Review of solid-state transformer technologies and their application in power distribution systems," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 1, no. 3, pp. 186–198, Sep. 2013, doi: 10.1109/JESTPE.2013.2277917.
105. R. H. Kumar, A. Iqbal, and N. C. Lenin, "Review of recent advancements of direct torque control in induction motor drives: A decade of progress," *IET Power Electron.*, vol. 11, no. 1, pp. 1–15, Jan. 2018, doi: 10.1049/iet-pel.2017.0252.
106. J. Rodríguez, J.-S. Lai, and F. Z. Peng, "Multilevel inverters: A survey of topologies, controls, and applications," *IEEE Trans. Ind. Electron.*, vol. 49, no. 4, pp. 724–738, Aug. 2002, doi: 10.1109/TIE.2002.801052.
107. T. N. S. Tengku Zawawi, A. R. Abdullah, M. H. Jopri, T. Sutikno, N. M. Saad and R. Sudirman, "A review of electromyography signal analysis techniques for musculoskeletal disorders," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 11, no. 3, pp. 1136–1146, 2018, doi: 10.11591/ijeecs.v11.i3.pp1136-1146.
108. N. H. Ali, A. R. Abdullah, N. M. Saad, A. S. Muda, T. Sutikno and M. H. Jopri, "Brain stroke computed tomography images analysis using image processing: A review," *IAES Int. J. Artif. Intell.*, vol. 10, no. 4, pp. 1048–1059, 2021, doi: 10.11591/ijai.v10.i4.pp1048-1059.