Response to Call for Evidence on an AI-enabled clean energy system

Institute of Materials, Minerals and Mining

The Institute of Materials, Minerals & Mining (IOM3) is a professional engineering, environmental and scientific institution, a registered charity and governed by a Royal Charter. IOM3 is the leading professional body for the global materials, minerals and mining community. We champion excellence and innovation to drive responsible and efficient use of the planet's resources. With around individual professional 13,000 members, IOM3 brings together expertise across the full materials cycle. This submission is informed by consultations with our members.

Investigation into the deployment of AI in critical infrastructure must, first and foremost, recognise AI as a highly material-intensive industry. While AI operates in the digital space, this technology is underpinned by a material supply chain that relies on the secure supply of finite resources. It is not possible to assess the opportunities, challenges and risks that AI presents for the UK's energy sector without considering the extensive material inputs required to build and operate AI infrastructure.

All key components of data centres, including semi-conductors and microchips, circuitry and wiring, data storage, and heat sinks, depend on an extensive array of raw and processed materials. While it is not feasible to provide an exhaustive list, key materials include boron, phosphorus and cobalt for semi-conductors; lithium, silicon and manganese for memory chips; copper, nickel and chromium for wiring[1]; and aluminium, beryllium and iron for cooling[2]. It is estimated that for each megawatt (MW) of capacity, a data centre embeds around 60-75 tonnes of minerals[3]. AI-enabled data centres are particularly material-intensive as they require more power, cooling and specialised equipment.

As demand for AI-enabled data centres increases, so too does the scale of the material resources consumed by the sector. Microsoft's 80 MW Chicago site used over 2000 tonnes of copper alone, when on-site and near-site power connections are included[4]. Moreover, large, multi-building sites can require over 200,000 tonnes of steel[5].

Many of the raw and processed materials feeding into AI supply chains are in high demand in other key industries, meaning governments will increasingly need to weigh ambitions in this

[1] https://www.sfa-oxford.com/knowledge-and-insights/critical-minerals-in-low-carbon-and-future-technologies/critical-minerals-in-artificial-intelligence/
[2] https://www.bgs.ac.uk/news/demand-for-data-centres-presents-challenges-and-opportunities-for-uk-critical-mineral-supply-chains/
[3] https://www.weforum.org/stories/manufacturing-and-value-chains/securing-data-centre-materials
[4] https://carboncredits.com/data-centers-copper-hunger-how-ai-is-driving-a-looming-supply-crunch/
[5] https://www.weforum.org/stories/manufacturing-and-value-chains/securing-data-centre-materials

sector against other national objectives[6]. Managing these competition pressures across the whole economy is a key reason why IOM3 has consistently called for a comprehensive materials strategy for the UK. As the pressure AI poses on global supply chains increases, it is vital that a proactive and sustainable approach to resource management is at the heart of policymaking in this area.

In line with this, key points in this submission include:

- In exploring the application of AI to the energy system, the government must consider the implications of this technology for the full clean energy supply chain, including materials discovery, design, maintenance, energy generation and distribution.
- The integration of digital twins and AI presents a key opportunity to maximise efficiencies and material sustainability in clean energy infrastructure, particularly wind.
- Increasing access to quality data and the standardisation of data storage across industry actors will be vital to the successful roll out of AI in the energy sector.
- Unlimited access to AI capacity cannot be taken for granted and the material supply chains on which AI infrastructure depends must be considered in assessing the risks and constraints of an AI-enabled energy system.
- The government must proactively and strategically plan the allocation of critical materials to domestic AI infrastructure versus other priority industries and this should be integrated into planning for the application of AI to the UK's energy system.
- Limitations in terms of both AI performance and the expansion of AI infrastructure highlight the need to ensure ongoing human involvement in all areas of the energy system.

Question 1: Where and how can AI add the most value in the energy system?

AI can add value across the full breadth of the clean energy supply chain, from accelerating the discovery of energy materials to maximising efficiencies in the distribution of renewable energy.

AI in the operation of clean energy infrastructure:

At the operational stage, AI can add economic and strategic input in the areas of grid infrastructure, transformer intelligence, grid stabilisation, and renewable integration. As power systems become decentralised and weather-dependent, AI could be employed to improve reliability, flexibility, and asset utilisation in the grid.

Traditional energy transformers are largely passive devices. AI could turn them into predictive, self-monitoring assets. AI can be used for predictive maintenance, remaining useful life estimation, early detection of insulation degradation, overheating, winding faults, and dynamic loading optimisation based on weather and demand forecasts. This would create business value by reducing unplanned outages, extending transformer lifetime, optimising maintenance spending, and deferring costly asset replacement.

[6] https://www.bgs.ac.uk/news/demand-for-data-centres-presents-challenges-and-opportunities-for-uk-critical-mineral-supply-chains/

Grid stabilisation and optimisation of grid layout present large strategic opportunities. Historically, grid operators managed predictable generation from coal, gas, and nuclear plants. Modern grids must balance solar variability, wind intermittency, electric vehicle charging, heat pumps, battery storage, and distributed generation. AI can process millions of data points in real time and make optimisation decisions far faster than human operators, provided the data is of sufficient quality. Useful applications could include optimising the call on the lowest cost generators to the grid in real time.

Capable AI can also assist with frequency stability by predicting frequency deviations before they occur and providing instructions to batteries, modifying the demand response, and feeding back to flexible generators. AI can predict demand overloads and reroute power flows before constraints emerge, as well as optimise voltage control.

One of the greatest challenges with renewables is uncertainty of supply and its frequency. AI significantly improves forecasting accuracy for solar and wind and operational planning. Successful deployment of AI could therefore result in less reserve generation being required, lower balancing costs, and higher renewable penetration.

Finally, the intra-day market process, including 30-minute scheduling, forecasting, and payment processes, is also a target for AI intervention, given the large volumes of existing and historic data and a relatively simple workflow suitable for automation.

AI in the efficient management of clean energy materials:

Be it through wind, solar, hydrogen, nuclear or CCUS, the decarbonisation of energy production is a materially intensive process, which raises new considerations in terms of material sourcing, performance, longevity and safety. AI can play a role in increasing efficiencies in these areas.

For example, digital twin technology, which involves high-fidelity geometric and material representations of real infrastructure[7], can be used to predict performance failures and make pre-emptive decisions on maintenance. Digital twins integrate real-time data from infrastructure with virtual models, using AI to make predictions and decisions[8].

Offshore wind turbines, due to their exposure to harsh environmental conditions and remote locations, can benefit in particular from digital twin technology[9]. For example, researchers at the University of Birmingham investigated the use of digital twins for wind towers in modular energy islands to develop a corrosion fatigue prediction model and construct a digital twins-based prognosis approach. This kind of analysis can feed into effective proactive maintenance, extending infrastructure lifespans[10], with AI integration supporting model robustness and the accuracy of physical behaviours simulation[11].

[7] https://www.imperial.ac.uk/news/257753/transforming-wind-energy-infrastructure-with-digital/
[8] https://research.tees.ac.uk/ws/portalfiles/portal/120700493/120573617.pdf
[9] https://dspace.lib.cranfield.ac.uk/server/api/core/bitstreams/18ab23c7-3741-40e7-baf9-cab65ec2805d/content
[10] https://gtr.ukri.org/projects?ref=EP/X022765/1#/tabOverview
[11] https://scindeks-clanci.ceon.rs/data/pdf/proc-0030/2024/proc-00302402053D.pdf

AI can also play a role in securing access to the raw and processed materials that are needed to construct renewable energy infrastructure. Advances in AI are accelerating the pace of energy materials discovery through self-driving laboratories that rapidly navigate vast chemical spaces and identify high-performance materials for commercialisation[12]. By increasing efficiencies and minimising commercial risk associated with exploration, AI can help improve the stability of critical supply chains in the renewable energy system.

Finally, AI can support more sustainable end-of-first-life management for clean energy infrastructure. AI-powered robotics are already playing a role in recovering critical materials from recycled electronic waste[13] across industries, with clear relevance for the high volumes of critical materials embodied in wind, solar, grid networks and energy storage[14]. In the wind sector specifically, AI has successfully been used to improve material recovery rates through high-precision sorting of complex composite materials in turbine blades[15]. Further investigation into the potential benefits of AI for promoting circularity in clean energy should form a key component of the government's policy agenda in this area.

Question 2: What are the UK's main strengths in applying AI in the energy system, and where may the UK have a competitive advantage over other countries?

The strongest competitive position for the UK is in applying AI to help operate a complex, renewable-rich energy system. The UK has a challenging power system with extremely high penetration of offshore wind, rapid growth of distributed renewables, electrification of transport and heating, increasing system balancing requirements and an island grid with limited interconnection compared with continental Europe. This means the UK is already solving problems that many countries will face in the future. The UK's offshore wind sector is already applying AI to turbine condition monitoring, predictive maintenance, fault detection, optimisation of wind farm performance, environmental monitoring and consenting. Expertise developed in Britain can become exportable, including on software, analytics and operational know-how.

The UK is unlikely to compete with China, South Korea, Japan, and Germany in transformer manufacturing volume for generating, transmission, and distribution assets. However, it could lead in transformer digital twins, fleet-health analytics, AI condition monitoring, dynamic asset rating, and network optimisation software. In this sense the UK could become a provider of knowledge as opposed to physical assets.

[12] https://www.sciencedirect.com/science/article/pii/S2666675826002560
[13] https://reboottechrecycling.com/the-next-wave-of-tech-recycling-ai-powered-urban-mining/
[14] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary
[15] https://www.bccresearch.com/market-research/artificial-intelligence-technology/ai-impact-on-wind-turbine-blade-recycling-market.html

Question 3: Do the 6 challenges set out above reflect the main barriers to safe and effective deployment? Which of these is most urgent to address?

The six challenges outlined in the call for evidence largely reflect the barriers to deployment at the use stage. In particular, data inadequacies present a major barrier to scaling even when good AI solutions already exist. The energy sector remains highly fragmented, with data sitting across network operators, generators, suppliers, asset owners, OEMs, aggregators, and EV charging operators. The data is often stored in different formats, subject to access restrictions, incomplete, poorly labelled or with different naming conventions, and not available in real time. AI performance is fundamentally limited by data quality and a sophisticated AI model trained on unsatisfactory data will often perform worse than a simple engineering model. It would therefore be wise to prioritise investment in common energy-data standards across transmission, distribution and generation, and create secure data-sharing infrastructure for energy-system participants.

In addition to barriers at the level of AI software performance, the material limitations on AI infrastructure is a key issue that is not captured by any of the challenges outlined. In the Initial Proposal for a National Policy Statement for Data Centres[16], the government has acknowledged that reliance on overseas AI-enabled data creates a strategic vulnerability to the UK's digital infrastructure. The government has estimated that to benefit from secure access to AI models locally, the UK will require 6 Gigawatts (GW) of AI data centre capacity by 2030[17], triple the current operating capacity of 2 GW[18].

As is highlighted above, AI infrastructure is extremely material-intensive and relies heavily on critical materials that are already facing a level of supply insecurity in the UK. For instance, AI is expected to drive up demand for gallium in the coming years, a material for which China accounts for 99% of global refined supply. Similarly, the supply of rare earth elements (REE), used in high performance magnets for cooling and drives, is heavily concentrated, with 90% of refined supply coming from the top three producing countries[19].

The challenge of implementing an AI-enabled energy system must therefore be contextualised within the broader demands of establishing resilient and sustainable access to AI infrastructure, including through building domestic capacity and working with international partners to ensure the security of materials supply chains on which such infrastructure relies. While issues associated with end use are a vital consideration, any ambition for the expansion of AI relies fundamentally on the physical building blocks of AI hardware. The responsible and secure management of the materials cycle, and in particular the use of critical materials, should

[16] https://assets.publishing.service.gov.uk/media/6ae37e6183b993d8d93eb7d4/draft-national-policy-statement-for-data-centres.pdf
[17] https://www.gov.uk/government/publications/data-centre-covenant/the-data-centre-covenant
[18] https://citp.ac.uk/publications/mapping-the-uks-data-centres-build-out-implications-for-digital-sovereignty
[19] https://www.bgs.ac.uk/news/demand-for-data-centres-presents-challenges-and-opportunities-for-uk-critical-mineral-supply-chains/

therefore be added to the government's list of challenges for consideration and be systemically integrated into decision making on the roll out of AI.

Question 4: For the most significant barriers identified, what specific constraints are limiting deployment (e.g. regulatory uncertainty, lack of data access, skills, integration challenges)?

In the immediate term, data access, quality and interoperability are among the largest constraints. The industry faces fragmented ownership of data which often resides with different organisations that have different commercial incentives and governance requirements. As such no single organisation may have the complete picture. A lack of common standards results in divergent asset-management platforms, naming conventions and telemetry, all of which makes AI integration slow and expensive. Further barriers include limited real-time accessibility, data quality issues and aging assets.

To address these constraints, it would be valuable to establish a common UK framework for asset data standards, operational data sharing and secure interoperability. Success in this area will require a change of industry culture and the fostering of cooperative relationships between organisations that may to some extent be competitors. Adoption will also require the roll out of education and training amongst industry actors to ensure there is a readiness among the workforce to apply AI where it is safe and valuable.

Another immediate constraint is a lack of regulatory clarity. There is value in applying AI to influence network operations, grid balancing, voltage control, asset dispatch, and protection decisions, however until regulation, governance and liability issues are resolved, many organisations will remain cautious, and AI will be confined to an advisory role. Existing standards were not designed for AI and many power-system governance frameworks were created for deterministic control systems, human decision-making, or rule-based automation. There is no clear approval pathway for deployment of AI in the sector, and utilities often do not know what evidence regulators require, what validation is needed, or how AI systems should be certified. The allocation of liability between the utility, network operator, software provider, or the AI developer is also currently unclear.

The UK could gain a competitive advantage by becoming one of the first countries to develop an energy-specific AI assurance framework covering grid operations, asset management, and safety-critical applications.

In the medium to long term, there is a risk that constraints could emerge in terms of access to AI infrastructure itself, due to geopolitical instability or supply chain disruptions. As is highlighted above, the UK is currently heavily dependent on overseas AI data centres, the expansion of which is reliant on access to large volumes of raw and processed materials. These supply chains, particularly for critical materials, are heavily geographically concentrated and are already under demand pressure from other key industries. The government must avoid a scenario where the UK becomes dependent on high levels of AI capacity to operate critical national infrastructure but lacks sovereign and secure access to necessary AI hardware.

Question 5: Where are current market, procurement or regulatory incentives failing to support AI deployment? In particular, where and why are promising applications struggling to move from pilot to full-scale deployment?

The UK does not suffer from a shortage of AI pilot trials, but from a shortage of mechanisms that convert successful pilots into operational deployments across regulated energy infrastructure. The "pilot-to-production gap" arises for several reasons:

- The benefits of AI deployment often accrue to one party, while the costs, risks and procurement hurdles fall on another.
- There is a lack of regulation or standards in place for AI deployment in the energy sector, making deployment risky for industry.
- Procurement models are poorly suited to AI, as traditional utility procurement favours established suppliers, fixed specifications, long qualification processes, and low technology risk. Many AI providers cannot satisfy current utility procurement requirements.
- High-value AI applications can appear less attractive than conventional investments with more immediately measurable returns.

Question 6: Which areas of the energy system should be priorities for government action to unlock near-term AI deployment?

For near-term deployment, the government should prioritise areas where the technology is already sufficiently mature, benefits can be realised relatively quickly, market failures are preventing adoption, and the UK has an identifiable competitive advantage. Grid data infrastructure and interoperability is the single biggest enabler. Many AI applications already work technically but cannot scale because energy-system data remains fragmented across network operators, generators, flexibility providers, EV operators, and asset owners. Government action should focus on common energy data standards, secure data-sharing frameworks, and open application programming interfaces (APIs) for operational and asset data.

Government priorities on the rollout of AI should also reflect the broader goal of transitioning to a sovereign clean energy system and aim to address associated challenges. As is noted above, the transition to clean energy is dependent on the responsible and secure management of the materials cycle. AI can be of value towards this end, from accelerating discovery of critical materials, improving material efficiencies in design and extending material longevity through predictive maintenance.

By considering the full clean energy supply chain, the government can maximise the value of AI for national resilience and growth, while also increasing efficiencies at the point of energy generation and distribution. It is therefore advisable that the application of AI to the sourcing, production and maintenance of clean energy materials is prioritised and comprehensively integrated into broader policy on an AI-enabled energy system.

Question 9: What are the most material risks arising from more autonomous and integrated AI deployment, how can these best be managed, and how do we stage autonomy safely?

In terms of the operation of integrated AI, risks emerge from large numbers of AI-enabled systems interacting autonomously across a tightly coupled physical, digital and market system, rather than single incorrect decisions. Future systems may contain thousands or millions of autonomous components. Each system may function correctly in isolation, but their interactions may create unexpected outcomes making system-level rather than application-level assurance essential. Autonomy must be introduced progressively within clearly defined safety boundaries.

In addition to potential challenges associated with AI performance, the government must also consider the risks arising from supply chains underpinning AI infrastructure. The UK is heavily reliant on data centres hosted overseas, leaving the UK exposed to disruptions associated with geopolitical instability[20]. Moreover, as the demand for AI accelerates globally, the expansion of data centre infrastructure both at home and abroad is dependent on access to critical materials, the supply chains for which are highly concentrated in the hands of a small number of producer countries, particularly China.

As such, when considering embedding AI into the energy system, it is vital to consider the limitations that may arise from supply constraints and disruptions. We cannot take ever-expanding AI capacity for granted or see access to this technology as somehow removed from material and resource constraints. The risks associated with supply chain disruptions are far more significant when AI is applied to critical national infrastructure on which households, businesses and vital service providers depend.

Limitations in terms of both AI performance and the expansion of AI infrastructure highlight the need to ensure ongoing human involvement in all areas of the energy system. The gradual loss of human skills, understanding and oversight would present a risk in cases where AI decision-making fails or where access to AI infrastructure is compromised. In increasing AI autonomy, the goal should not be to remove humans from the loop and human workforces must be available and ready to take control of decisions that are outsourced to AI when needed.

[20] https://assets.publishing.service.gov.uk/media/6ae1c5937fe45a08a4036e4e/draft-national-policy-statement-for-data-centres.pdf Government policy October 2026