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MISSION BIOGAS

AD READY FOR TAKE OFF UNDER NEW NET ZERO STRATEGY

GET READY FOR THE AI BOOST

From fintech to farming, healthcare to energy, all corners of the economy are celebrating the boost to productivity secured through AI-driven efficiencies. Biogas production will be a big winner too, writes Angela Bywater.

Artificial intelligence (AI) and machine learning (ML) are technologies that have revolutionised how we interact with data and processes in various industries. In essence, they are tools or systems used to automate, enhance, and optimise processes across industries. AI refers to the simulation of human intelligence in machines, enabling them to perform tasks like decision-making, speech recognition and problem-solving. Siri, Alexa and ChatGPT are all examples of generative AI.

ML is a subset of AI. ML involves algorithms that allow systems to learn from data and improve their performance over time without human intervention or programming. Combined, these technologies are transforming all aspects of the economy from fintech to farming, healthcare to energy by improving efficiency, accuracy and adaptability.

Integration into Supervisory Control and Data Acquisition (SCADA) systems for anaerobic digesters is an obvious use for AI and ML. Traditionally, SCADA systems are used to monitor and control the operational parameters of anaerobic digesters, such as temperature, pressure and biogas output. The integration of AI and ML could greatly enhance the capabilities of these systems in a number of ways.

1. Predictive Maintenance AI and ML could be used to analyse data from sensors within the digester to predict when maintenance is required, reducing the risk of unexpected failures or breakdowns. By identifying patterns that indicate wear or degradation in system components, these technologies can help operators schedule maintenance proactively, avoiding costly and unexpected downtime. Conversely, AI can identify anomalies in the data that might indicate sensor malfunctions or unexpected system behaviours, alerting operators before minor issues escalate into larger problems.

2. Optimisation of Biogas Production Algorithms could be used to continuously analyse real-time data from the SCADA system to optimise digester performance. For instance, ML models are programmed to learn from historical data and adjust operational parameters (e.g., feedstock composition, retention time, temperature) to maximise biogas production while minimising waste.

3. Feedstock Management AI could help in the selection and management of feedstocks by predicting the most efficient combinations of organic waste materials for biogas production. Furthermore, these algorithms can factor in other considerations such as feedstock variability, environmental conditions, seasonal availability, cost and nutrient composition to suggest the best feedstock strategies, sensitive to local circumstances, including digestate offtake. The system could adjust control and inventory management strategies to ensure optimal performance without human intervention.

4. Process Stability and Control If the correct data is available, AI-driven SCADA systems could monitor the biological processes inside the digester and provide early warnings about potential process instability, such as acidification or accumulation of inhibitors. ML models can also help to understand and relate the complex biological interactions between microorganisms to performance and improve system predictability, allowing for stable and efficient biogas production.

5. Energy Management AI and ML models could be used to forecast energy demand and biogas production to optimise the balance between energy generation and consumption. By predicting future energy prices and demand, AI can help adjust operations to maximise profitability and/or to align with grid requirements.

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To be effective, these models require large amounts of robust and relevant data. Even where a SCADA system has collected large amounts of data, it might not cover all bases - there may not be information available to explain some data anomalies if the cause has not been previously experienced or modelled, for example, where a pump failed and needed repair or where the feedstock dregs of a silage clamp were used.

The complexities of AD's mixed microbial communities and their interaction with their environment – the engineering/biology interface - should not be underestimated. Although significant progress has been made in understanding these systems in recent years, there are still gaps in our knowledge. This includes the basic science, thorough life-cycle analysis, and how to optimise the technology for nutrient recycling, pollution control and renewable energy generation. AI and ML can help improve are understanding across the process.

Revolutionary Use of AI in Anaerobic Digesters

The "Artificial Intelligence Enabling Future Optimal Flexible Biogas Production for Net Zero (AI4AD)" project, funded by UK Research & Innovation AI for Net-Zero, aims to enhance the flexibility and profitability of AD systems for biogas production. The project's overarching goal is to accelerate the AD industry's contribution to the UK's Net Zero ambitions by leveraging AI to create a digitalised, data-driven system for biogas production.

Led by Dr Michael Short from the University of Surrey, this multi-disciplinary team consists of industry and academic partners, with expertise in AI, ML, life-cycle and techno-economic analysis, as well as biologists looking to understand the composition and function of these mixed microbial communities and the behaviour of AD systems under conditions which cannot be replicated at full-scale, such as temperature or mixing fluctuations, under- and over-feeding.

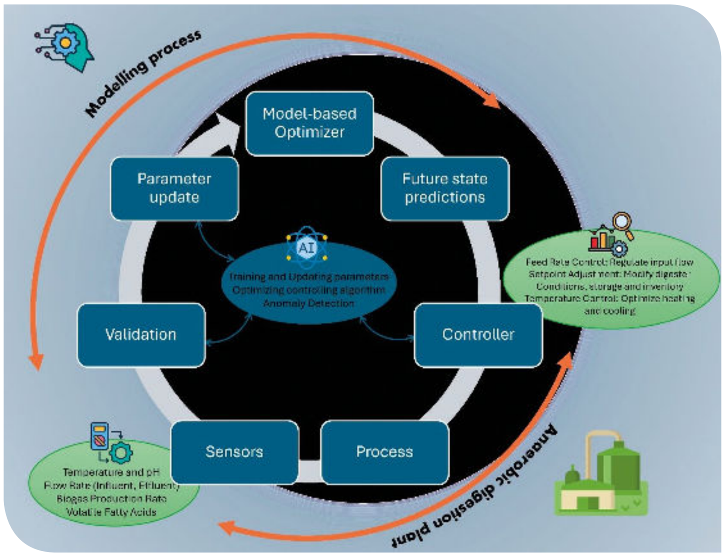
The use of AI and ML in understanding the biological systems within anaerobic digesters is groundbreaking because of the complexity of these systems. Anaerobic digestion relies on a diverse community of microorganisms to break down organic matter and produce biogas. The microbial populations within the digester are influenced by a wide range of factors, including temperature, pH, and feedstock composition. Traditionally, AD operators have used their hard-won experience to optimise these variables as far as possible, but these models can analyse and simultaneously optimise a far greater range of variables for optimal biogas production.

By employing AI and ML, researchers can model the intricate relationships between operating conditions and microbial behaviour in real time. This enables the prediction of how microbial populations will respond to changes in feedstock or environmental conditions, allowing for more precise control over the biogas production process. In this way AI-driven insights can optimise digestion processes, enhance biogas yields and reduce downtime due to system instability.

Future Improvements in AI for Mixed Microbial Systems

One area of potential improvement is the development of more advanced 'digital twins' that incorporate real-time genomic and metabolic data from microbial populations. A digital twin is a digital replica of a physical object, person, system, or process, contextualised in a digital version of its environment. Digital twins can help many kinds of organisations simulate real situations and their outcomes, ultimately allowing them to make better decisions.

As technologies for metagenomic and metabolomic analysis become more affordable and accessible, it will be possible to create digital twins that not only monitor system performance but also provide detailed insights into the functional roles of specific microbial species within the digester.



This diagram illustrates the integration of AI-driven optimisation and control in AD plants, showing a continuous feedback loop that monitors key parameters (like temperature, flow rate, and biogas production) and adjusts operations in real-time to enhance efficiency and stability.

Another area of future development is the incorporation of AI models that can learn and adapt over time. As more data is collected from operating AD plants, AI systems could use reinforcement learning techniques to continuously improve their performance, becoming more accurate at predicting that particular system's behaviour and identifying optimisation opportunities.

Finally, improvements in sensor technology can play a crucial role in advancing AI and ML for mixed microbial systems. More precise and reliable sensors could enable the collection of higher-quality data, allowing the models to make more informed decisions. These sensors could monitor not only traditional variables like temperature and pH but also the metabolic activity of specific microbial populations, providing a more comprehensive view of the system.

AI and ML in Optimising Anaerobic Digester Feedstock Supply Chains

Another key area where AI and ML can drive significant improvements in AD systems is feedstock supply chain optimisation. The cost and availability of high-quality waste feedstocks for AD are highly variable, depending on factors like seasonality and market prices. AI models can help operators forecast future feedstock availability and energy prices, enabling them to make more informed decisions about procurement.

By integrating these predictions with real-time data from the AD process, AI systems can optimise feedstock combinations to maximise biogas production while minimising costs. This could include switching to cheaper or more readily available feedstocks when high-quality materials are scarce, without sacrificing system performance. Moreover, AI-driven supply chain optimisation could help operators plan for future energy price fluctuations, allowing them to adjust their feedstock strategies to maintain profitability even as market conditions change.

Data collection and efficiency improvements enabled through AI methods can improve sustainability and allow real-time monitoring and potential control of these factors. Through incorporating not only economic indicators in the decision-making from these automated systems, we may be able to consider lifecycle assessment (LCA) indicators. AI-enabled optimisation techniques such as genetic algorithms are effective at multi-objective decision-making for these complex decisions.

AI4AD - A MULTI-DISCIPLINARY APPROACH

The AI4AD project is structured into several work packages (WPs), each examining a different facet of the AD process.

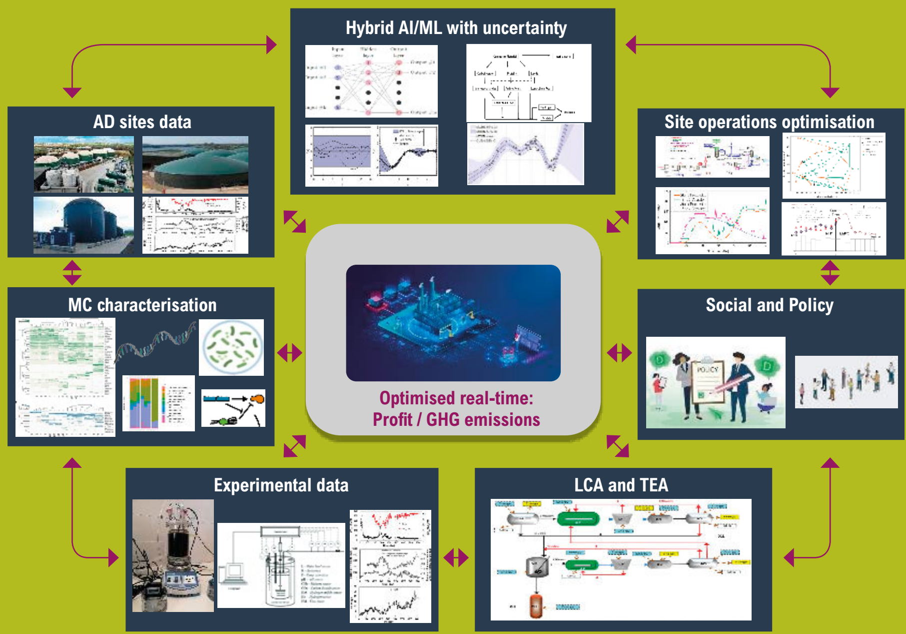
1. Whole-Site System Modelling for Real-Time Multi-Objective Optimisation and Negative Emissions Assessment - This work package focuses on the real-time optimisation of AD sites under uncertain conditions, with a multi-objective approach that balances economic, environmental, and operational goals. It also evaluates the life cycle costs (LCC) and greenhouse gas (GHG) savings, which are crucial for developing more sustainable and cost-effective biogas systems.

2. AI-Enabled Digital Twin of Anaerobic Biodigester - The second work package is dedicated to developing a hybrid machine learning-based digital twin for anaerobic biodigesters. A digital twin is a virtual representation of the physical system, allowing for real-time monitoring and predictive maintenance. This package also aims to optimise biodigester performance, improving biogas yields and system stability.

3. Experimental Programme and Microbiome Characterisation - This WP focuses on collecting and analysing industrial data from AD plants. This data is used to build comprehensive datasets on feedstock digestate and digestion processes. Additionally, it involves microbiome characterisation, a critical step in understanding how different microbial communities within the digester contribute to biogas production.

4. Integration, Validation, and Easy-to-Use Software Implementation - This package involves integrating models and data into an easy-to-use software platform, enabling real-time decision-making for AD operators. The software will simplify the complex process of managing an AD plant, allowing operators to make informed decisions on feedstock procurement and operational strategies.

5. Building a Community, Outreach, and Policy Dissemination - is focused on community outreach and policy advocacy. The goal is to foster a broader AI for Net-Zero community while ensuring the project's outcomes are accessible to policymakers, researchers, and industry stakeholders. This package is essential for ensuring the widespread adoption of the technologies developed during the project.



Digital Guides to Greater Efficiencies

While AI holds great promise for revolutionising the AD industry, several challenges arise when using AI models to understand perturbations within anaerobic digesters. One of the primary challenges is the inherent uncertainty in biological systems. The microbial communities within a digester are highly dynamic and can react unpredictably to changes in feedstock or operational conditions.

Building AI models that can accurately predict these responses is complex, as it requires vast amounts of relevant data and sophisticated algorithms to capture the non-linear interactions between variables.

Moreover, the slow dynamics of AD processes add another layer of complexity. Changes in feedstock composition or environmental conditions can take time to manifest in system outputs like biogas production. AI models must account for these delays to make accurate predictions, which can be challenging when real-time optimisation is required.

Finally, the risk-averse nature of AD operators poses a barrier to the widespread adoption of AI solutions. Many operators are hesitant to rely on AI models for decision-making or automated control, particularly when the consequences of errors could include costly system downtime or decreased biogas production. Making these models easier to understand and more transparent is crucial to enhancing trust and reliability.

The AI4AD project represents a significant step forward in the application of AI and ML to the AD industry. By developing advanced digital twins, real-time optimisation models, and supply chain management tools, the project aims to enhance the profitability and sustainability of biogas production in the UK. While challenges remain, particularly in modelling the complex and dynamic microbial communities within anaerobic digesters, the potential benefits of AI-driven optimisation are immense. As AI technologies continue to evolve, they will play an increasingly important role in driving the future of mixed microbial systems, paving the way for a more sustainable and resilient biogas industry.

The AI4AD team is led by Dr Michael Short and includes Prof Jhuma Sadhukhan, Prof Tao Chen, Dr Bing Guo, Dr Benaissa Dekhici, Dr Amin Zarei, Dr Duo Zhang, Rohit Murali, Meshkat Dolat, Mac-Anthony Nnorom and Ruosi Zhang (University of Surrey); Dr Yongqiang Liu, Tararag Pincam and Angela Bywater (University of Southampton); Dr Dongda Zhang, Dr Mengjia Zhu, and Oliver Pennington (University of Manchester) and Prof Jon McKechnie (University of Nottingham).