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COMMENTARY

Carbon credits monetary value for anaerobic digestion systems and energy policy implication in the UK

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Anaerobic digestion (AD) of organic materials is recognized as an efficient method for reducing greenhouse gas emissions, particularly when coupled with carbon capture and storage. While life cycle assessment (LCA) has been widely used to assess the environmental sustainability of AD systems, economic aspects have received less attention. Recent research has explored the financial benefits, including revenue from greenhouse gas (GHG) emissions reduction (carbon credits). However, the practical implications of participating in carbon trading and maximising financial benefits in real AD projects remains a challenge. To participate effectively, AD systems must become verified carbon offset schemes. This requires adherence to specific carbon offset standards. Achieving certification requires demonstrating effective GHG emissions reduction across various process stages. Implementing carbon capture and storage in AD systems is seen as a cost-effective way to achieve negative emissions. However, challenges may arise due to collateral CO_2 or GHG emissions and other factors that could offset the desired negative emissions. While AD projects offer potential for negative emissions, an in-depth analysis of associated GHG emissions is crucial. AD system operators must understand specific carbon offset standards and work closely with verification bodies to navigate the complex process of participating in a carbon trading system. Clear guidelines and support for achieving carbon offset certification can facilitate broader participation in carbon trading schemes. Highlighting the benefit of carbon credits monetary value for AD systems can drive policy decisions that support sustainable energy use and supply.

Increasing global interest in deploying renewable energy has arisen due to concerns about environmental sustainability, mitigating climate change, and reducing dependence on fossil fuel. Organic waste, in particular, has gained significant attention because of its abundance and its potential to aid in climate change mitigation and sustainable waste management. Consequently, it can contribute to nearly all sustainable development goals, offering potential advantages for the environment as well as economic and social development.

In this context, the production of biogas through the AD of organic materials is widely acknowledged as a well-established and efficient method for mitigating GHG emissions. This recognition is primarily due to the reduction in environmental impacts associated with traditional waste management and the production of mineral fertilizers. As pointed out in the UK 2023 Biomass Strategy, biomethane will continue to play an important role in optimising the path to net zero and increasing energy security. The AD process, serving as a primary source of biomethane, is acknowledged as a form of recycling, contributing to the establishment of a more circular economy. As a result of these perceived benefits, the application of AD systems is currently experiencing growth in several European nations like Germany, Italy, and the UK. The growth in the number of AD plants is expected to continue in the future, extending the share of this technology in the future energy generation mix.

There are only a few studies that have assessed the economic aspects throughout the life cycle of AD systems. Most of the research in this area has concentrated on either cost-benefit analysis or techno-economic analysis. These analyses encompass metrics like net present value, payback period, and internal rate of return, and also account for the costs associated with electricity generation. Moreover, recent research conducted by Hamedani et al.,[1] Lovarelli et al.,[2] and Zhang and Xu[3] have considered the financial aspects of environmental effects, particularly GHG emission reduction (carbon credits) revenue, attempting to offer a more comprehensive perspective on the environmental and economic sustainability of AD systems.

While the above studies incorporate revenue aspects into their life cycle economic analysis of AD systems, the practical implementation of joining the carbon trading system and generating income from carbon credit trading in real AD projects remains somewhat ambiguous and warrants further exploration. Further elucidation is needed to clarify the practical steps and strategies necessary for UK AD projects to successfully participate in carbon trading and fully capitalize on the associated financial benefits.

CARBON CREDIT TRADING MARKETS

The carbon credit trading market, or carbon market, allows organizations and countries to buy and sell permits to emit greenhouse gases (GHGs), mainly CO_2. It helps mitigate climate change by reducing carbon emissions. There are two types of carbon markets:

Compliance Markets: Driven by government regulations, requiring participants to buy carbon credits to meet emissions targets.

Voluntary Markets: Organizations and individuals buy carbon credits to offset emissions and show environmental responsibility.

Carbon credits are linked to cap-and-trade systems, where governments set emission limits, and companies must buy credits if they exceed these limits. Carbon offsets are traded in voluntary markets and involve projects that remove GHGs from the atmosphere. Verified renewable energy projects can sell carbon offsets to companies aiming to reduce their carbon footprint. Compliance market participants can also buy offsets from voluntary markets to meet government targets.

POTENTIAL AND CHALLENGES FOR AN AD PROJECT TO BECOME A VERIFIED CARBON OFFSET SCHEMES

AD systems in the UK can become verified carbon offset schemes if they meet specific standards and certification programs. The UK has its own standards, like the Woodland Carbon Code and the Peatland Code, focusing on afforestation, reforestation, and peatland restoration.

For AD systems to be verified as carbon offsets in the UK, they must meet international standards like the Verified Carbon Standard (VCS) or the Gold Standard. The VCS, managed by Verra, assesses and certifies projects that reduce or remove GHG emissions. Certified projects receive Verified Carbon Units (VCUs), each representing one metric tonne of CO2-eq reduced or removed. These VCUs can be sold in the carbon market to fund further climate mitigation efforts. The Gold Standard is a non-profit certification body that sets standards for carbon offset projects, ensuring environmental integrity and sustainable development. It is managed by the Gold Standard Foundation, which includes experts in sustainable development, climate finance, and environmental science.

Key considerations for an AD system to potentially become a verified carbon offset scheme in the UK:[4,5]

1. Project Eligibility: Determine if the biogas project meets the eligibility criteria set by the chosen carbon offset standard. These criteria may include additionality (i.e. that the project's emissions reduction is additional to business as usual), permanence (ensuring emissions reduction is maintained over the long term), and various environmental and social considerations.

2. Standards Compliance: Ensure that the AD project aligns with the

specific requirements and guidelines of the chosen carbon offset standard (e.g., VCS or Gold Standard).

3. Emission reduction qualification: Ensuring the project can effectively reduce GHG emissions during its operation. Project developers are responsible for finding a suitable methodology for calculating the project's GHG emissions. If there is no suitable methodology, it may be necessary to develop a new one. Some challenges faced by project participants include the inability to find a suitable methodology. Even if they develop their own appropriate methodology, the documentation does not provide adequate guidance on the depth and breadth of the methodology that needs to be developed. In the calculation of determining carbon emissions reductions, details such as how to establish reference emission standards and considerations for the situation when carbon dioxide is sold as a product are still unclear for participants.

4. Monitoring and Reporting: Establish robust monitoring and reporting systems to track emissions reduction accurately. Independent auditors will verify these reductions periodically.

5. Additionality: Demonstrate that the AD project is additional to business as usual and would not have occurred without the financial support from carbon offset sales.

6. Independent Verification: Undergo independent verification of emissions reduction and project compliance with the chosen carbon offset standard. Independent auditors assess the project's documentation, methodologies, and reported data.

7. Co-benefits: Some carbon offset standards consider co-benefits, such as social and environmental benefits, in addition to emissions reductions.

8. Credit Issuance: After successful verification, carbon offset credits are issued. These credits can be sold or retired to offset emissions from other sources.

9. Fees and Finances: The costs associated with joining the carbon offset standards can vary depending on the type and scale of the project. For example, the cost of VCS, includes the account opening fee, a registration fee, a VCU issuance fee which depends on the amount of VCUs issued as shown in Table 1, methodology review fees, methodology compensation rebate, verification body annual fee, gap analysis fee and retroactive label fee. Moreover, participants also face other costs and uncertainties, such as monitoring costs and market volatility. The uncertainties related to the volatility of carbon markets, which can impact the financial returns from emissions reductions.

Studies show that AD systems reduce GHG emissions compared to fossil fuels and landfill disposal of food waste. This makes including revenue from emissions reductions in life cycle economic analysis viable. New AD systems must prove their ability to reduce GHG emissions to be verified as carbon offset projects, requiring accurate LCA calculations. Existing AD systems need upgrades to reduce emissions further for carbon credit certification. Most biogas project verifications occur in developing countries, where new AD plants significantly cut emissions. In developed countries, existing systems need technological upgrades to achieve additional reductions, making verification more challenging.

AD systems with carbon capture and storage are seen as cost-effective for achieving negative emissions by reducing atmospheric CO_2. The UK's 2023 Biogas Strategy highlights significant carbon savings from capturing biogenic CO_2 during biogas upgrading to biomethane. This CO2 can be stored or used in sectors like agri-food and construction. Achieving net zero by 2050 will require more negative emissions, with biomass playing a key role. The UK is developing a biomethane policy to address barriers to AD Biomethane Bioenergy carbon capture storage (BECCS), including CO_2 transport and storage.

For a process to be carbon negative, it must:

1. Remove CO_2 from the atmosphere.
2. Ensure permanent CO_2 storage.
3. Include all emissions in the balance.
4. Achieve net carbon removal with permanent storage exceeding total emissions.

Additional CO_2 emissions can arise from indirect land use changes, biomass harvesting and transport, biochar production, capture and storage inefficiencies, and using captured CO_2 in enhanced oil recovery. These factors can offset the negative emissions potential of AD systems with carbon capture and storage.

While AD projects have strong potential for negative emissions, detailed examination of GHG emissions at each stage could weaken this potential. AD system operators must understand the carbon offset standards they follow and work with certification bodies for guidance and verification.

Table 1. Cumulative VCU issuance from a project occurring within a calendar year.

# of VCUs issued	USD / VCU
1 - 10,000	USD 0.05
10,001 - 1,000,000	USD 0.14
1,000,001-2,000,000	USD 0.12
2,000,001-4,000,000	USD 0.105
4,000,001-6,000,000	USD 0.085
6,000,001-8,000,000	USD 0.06
8,000,001-10,000,000	USD 0.04
>10,000,000	USD 0.025

CONCLUSION AND POLICY IMPLICATIONS

AD systems can significantly reduce GHG emissions and support sustainable waste management. While life cycle assessments (LCA) highlight their environmental benefits, economic aspects like carbon credit revenue need more focus. Recent research shows financial benefits from carbon credits, but practical implementation in carbon trading is challenging. AD systems must meet national and international carbon offset standards to participate.

The UK has its own standards, such as the Woodland Carbon Code and Peatland Code, but AD systems often need to align with broader standards like VCS or GS. Key considerations include project eligibility, compliance, emissions reduction, monitoring, additionality, verification, co-benefits, and financial aspects. Costs vary by project type and scale.

New AD systems must demonstrate GHG reductions with accurate LCA calculations for verification. Existing systems need modifications to achieve additional reductions. Most biogas project verifications are in developing countries, where new AD plants significantly cut emissions. Developed countries face the challenge of upgrading existing systems for verification.

AD systems with carbon capture and storage (CCS) are seen as cost-effective for additional GHG reductions, but CCS implementation can add CO_2 emissions. Clear guidelines and support for carbon offset certification can boost participation in carbon trading, making AD projects more financially viable and encouraging investment in renewable energy. Understanding carbon offset certification helps policymakers design incentives for AD system adoption, crucial for advancing climate and energy policy.

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AUTHOR CONTRIBUTIONS

All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.