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Environmental impacts of biogas deployment â€“ Part II: life cycle assessment of multiple production and utilization pathways

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Abstract

Energy security concerns and the need for mitigation of environmental impacts associated with energy generation from fossil fuels (e.g., greenhouse gas emissions), has accelerated the deployment of renewable fuels such as biogas. The objective of this study was to conduct an attributional Life Cycle Assessment (LCA) of multiple biogas production and utilization pathways in order to identify areas where further mitigation of potential environmental impacts could be realized to enhance environmental sustainability of biogas deployment. The LCA of pre-defined small (<500Â kW_{el}) and large-scale (â‰¥500Â kW_{el}) biogas systems was conducted in accordance with the ISO 14040 standards, using SimaPro 7.2 computer software. The functional unit was the anaerobic digestion of 1Â tonne of feedstock mixture to produce biogas with the digestate as process end product with multiple utilization options. The analyses

quantified the impacts of feedstock type (both single feedstock and co-digestion), biogas utilization pathways, and the digestate processing and handling unit processes. Analyses also considered the replacement of fossil fuels and chemical fertilizer with equivalent energy value of the biogas and nutrient content of the digestate, respectively.

The recorded variations in life-cycle impact categories for the scenarios compared indicated the importance of judicious selection of biogas pathways for environmental impact mitigation. The LCA and life-cycle energy analyses for single feedstock scenarios considered indicated that straw and corn silage as most efficient feedstocks for biogas. For example, straw mixture improved the environmental performance by almost 830% compared to the base scenario of cattle manure feedstock. This was mainly ascribed to the higher energy density, which exceeded the primary energy inputs for feedstock supply logistics. In order to minimize the environmental damage associated with feedstock type in all impact categories considered, and simultaneously maintain a positive energy balance, the analyses suggest that co-digestion of Municipal Solid Waste (MSW) with agricultural and food industry residues are most appropriate for both small and large-scale biogas plants; co-digestion of waste and residues accounted for just 1% of the estimated impacts on agricultural land occupation, compared to the co-digestion of predominantly energy crop feedstock, and also reduced the climate change impacts by up to 30%.

The results also indicated for the small-scale plants, the most promising pathway for sustainable biogas utilization would be in tri-generation; compared to electricity only generation in Combined Heat and Power (CHP), tri-generation could reduce the overall environmental impact by almost 200%. For the scenarios that included purification and upgrading biogas to biomethane for gas grid injection (arguably the most promising technology that could support rapid utilization expansion), it was noted that only the scenario with coupled small-scale CHP unit covering internal heat demands was capable of reducing the overall impact on fossil fuel depletion, compared to electricity generation alone. This was explained by the higher potential for fossil fuel substitution with biomethane, due to higher conversion efficiency (ca. 100%). It was also found that, the recovery of residual biogas from digestate storage reduced the environmental impacts of digestate management process by ca. tenfold, due to combined reduction of the potential biogas leakage to the atmosphere and subsequent use of the extra yield for energy generation.

Keywords

Life cycle impact assessment; Environmental sustainability; Environmental impact; Energy analysis; Biogas production; ReCiPe

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Martina Poeschl is a PhD student in the Charles Parsons Energy Research Programme of Science Foundation Ireland, University College Dublin. Her research area of interest is in biogas technology; specifically, feedstock-to-biogas conversion, optimization of AD systems and energy conversion, and environmental impact assessment and mitigation using LCA methodology.

Shane Ward is Professor of Biosystems Engineering, and Head of School of Agriculture, Food Science & Veterinary Medicine at University College Dublin. He was founder and director of Bioresources Research Centre (BRC) at the university, with responsibility for a large research group dealing with a variety of aspects of the agri-food and Bioresource industries. He was formerly Head of Production Research at the R&D Department of Bord na Mona (Irish Peat Board). Prof. Ward is Fellow of the Institution of Engineers of Ireland and has over 28 years of experience in research and technology

of Engineers of Ireland and has over 28 years of experience in research and technology development. He has established several research units some of which are in partnerships with industry. A former Chairperson of its Agri-Food Division of the Institution of Engineers of Ireland, he was responsible for the promotion and development of the agri-food and bioresource industry among professional engineers and the industry. He has had a strong track record in cooperation projects that include collaboration with industry. Prof. Ward has in excess of 150 peer-reviewed research publications, and has supervised in excess of 40 Masters and PhD students. His current research team comprises approximately 30 researchers (Masters, PhDs and Post-Doctoral fellows), working on a variety of bioresource projects.

Philip Owende is a senior research fellow in the Charles Parsons Energy Research Programme of Science Foundation Ireland, University College Dublin. His research area of interest is in biomass-to-energy systems covering energy feedstock production, pre-treatment standards, conversion technologies, and environmental impact assessment. Dr. Owende has published 40 scientific articles in peer-reviewed journals, over 30 international conference papers, and three book chapters.

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