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Anaerobic digestion: a prime solution for water, energy and food nexus challenges

Ismail Haltas[a]*, James Suckling[b], Iain Soutar[c], Angela Druckman[b], Liz Varga[a]

[a]*Cranfield University, Cranfield, Beds MK43 0AL, UK*
[b]*University of Surrey, Guildford, Surrey, GU2 7XH, UK*
[c] *University of Exeter, Penryn Campus, Cornwall, TR10 9EZ, UK*

Abstract

We solve the problem of identifying one or more optimal patterns of anaerobic digestion (AD) installation across the UK, by considering existing installations, the current feedstock potential and the project growth of the potential via population, demography and urbanization. We test several scenarios for the level of adoption of the AD operations in the community under varying amounts of feedstock supply, which may arise from change in food waste or energy crops generation via other policies and incentives. For the most resilient scales of solutions, we demonstrate for the UK the net energy production (bio-gas and electricity) from AD (and so the avoided emissions from grid energy), the mass of bio-waste processed (and avoided land-fill), and the quantum of digestate produced (as a proxy for avoided irrigation and fertilizer production). In order to simulate the AD innovation within WEF nexus we use agent based modelling (ABM) owing to its bottom-up approach and capability of modelling complex systems with relatively low level data and information.

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Keywords: Nexus; water-energy-food; complexity; agent based model; case study; governance; technology

* Corresponding author. Tel.: +44-123-475-1122.
E-mail address: ismail.haltas@cranfield.ac.uk

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1. Introduction

1.1. WEF Nexus challenges

The water-energy-food (WEF) nexus is a contemporary framing of the challenges associated with a sectoral focus. These challenges arise because each sector has interdependencies with each other, the consequences of which are poorly understood, managed or exposed. Furthermore, the stresses created by the interdependencies result in major impacts on our global systems i.e. environment, economy, society, which can result in greater sectoral pressures.

Infrastructure systems provide products which are considered a public good: users have an expectation that water, energy and food is available, affordable, safe and secure. However the production of water, energy, and food is highly interdependent in a non-linear manner. Each product is reliant, directly or indirectly upon each other: they need each other. And the context of growing population growth, and in particular the rising expectations of the growing middle classes, are creating increased demand in each of the sectors, exacerbating interdependency stresses.

The consequent impacts of WEF nexus systems on our global systems are evidenced by legislation and regulation attempting to control carbon emissions, water abstraction and contamination, air pollution, and food insecurity, and in general to work toward United Nation Sustainable Development Goals. The core challenge for the global economy is to decouple economic growth from resource constraints [13] and more significantly to find strategies toward sustainable resource use [8].

1.2. Governance in the nexus

The lack of interconnectivity between water, food and energy systems is frequently framed as a governance issue, that is, a consequence of the lack of integrated organization, thinking and practice between systems [11]. Broadly defined, governance concerns how actors (i.e. the individuals, households, communities, firms, government departments, regulators and other organizations with interest or influence), their institutions (e.g. the norms, rules, conventions and values shaping the behavior of such actors) and their practices (i.e. the actions of actors, such as consumption behaviors or processes of policymaking) influence outcomes in systems. The articulation and appraisal of governance arrangements is thus of central importance in understanding the human factors shaping current WEF systems and their interconnections, as well as how future systems might be enabled and/or constrained [17].

One specific way in which governance affects outcomes at the nexus is by shaping processes of innovation and inertia within systems. Innovation comprises multiple actors, in multiple roles, interacting towards the development of solutions to address specific problems, while inertia is concerned with the role of actors in resisting such processes. Innovation is relevant to the nexus in terms of the development of both problems (i.e. the degree to which problems are framed as addressing single system objectives) and solutions (i.e. the impact of specific instances of innovation activity across systems). Taking an innovation-centric view of nexus issues can thus help to draw light the efficacy of both existing and future frameworks of governance in shaping processes of change.

1.3. The role of anaerobic digestion at the nexus

Anaerobic digestion (AD) is the decomposition of biodegradable matter by microbes in an oxygen-free environment. The principal outputs are biogas, which is composed primarily of methane and carbon dioxide, and nutrient rich digestate which is comprised of water and the remaining undigested solids. Digestate has the potential to be used as a fertilizer and the methane as an energy source, and both capable of replacing fossil fuel based energy sources. AD is often implemented in order to treat wastes and residues from the food supply chain and, when considering the environment, compares favorably with other disposal techniques such as composting [5] or landfilling [7], even if electricity production from methane captured from a sealed landfill is considered. The relative benefit of producing methane from AD increases with future decarbonisation of the UK electricity grid [22].

Anaerobic digestion has the potential to reduce the environmental impact of energy production through such displacement of fossil fuels [2]. Benefits have been observed not only to replace fossil fuels for heat, but also for electricity generation and transport fuel [21]. Since bio-gas can be stored, or upgraded for insertion into gas grid