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Emerging perspectives on environmental burden minimisation initiatives from anaerobic digestion technologies for community scale biomass valorisation

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ABSTRACT

This paper provides an extensive review of anaerobic digestion (AD) systems, with a specific focus on community scale digesters for urban applications, processing either municipal organic waste exclusively or as mix feed. Emphasis is placed on reducing the systems scale environmental impact of AD technologies, including pre- and post-treatment stages, alongside biogas production. Developments to-date in AD system research in Europe and in the Asia region have been compared, providing a comprehensive evaluation of current practice, elucidating the areas of further potentials.

The scope of this review is two-fold—one, covering AD technologies including a cohort of simple and integrated wet and dry systems, which can be operated as continuous flow designs in single- or multi-stages. Two, focusing more on practices in digestate handling that minimise environmental impacts arising from their storage and land application. From an environmental perspective, we note the following trends emerging in the literature for processing urban waste that need further exploitation: dry AD (60–85% moisture) is suitable for low organic loads, mainly owing to resource savings in terms of water usage; co-digestion has shown better buffering capability, especially for two-stage digestion of food-based feed stocks; separating the digestate into liquid/solid fractions is effective for handling post-digestion emissions, mainly for mitigating ammonia volatilisation to air and phosphate leaching to soil.

We report responses to a survey, conducted for this review, highlighting the contemporary issues and challenges—with particular focus on the operational, social and management issues from an Indian perspective. There is need for follow-up of running plants to ensure their environmental performance. Such initiatives will have to consider managing of pollution footprints from AD, alongside the current drive for its widespread implementation for two incentives: greenhouse gas mitigation and fossil-fuel independence.

Contents

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1. Introduction

1.1. Anaerobic digestion—An emerging model for community scale renewable energy sustainability

Mounting organic waste, produced mainly from ever-increasing human activities in confined urban settings globally, has put immense pressure on land and civic resources. As a consequence, modern infrastructure planning is increasingly yielding to development of inclusive, self-sustaining cities through adoption of a systems approach to integrated solid waste management—for both increased fuel security and better utilisation of waste [1,2]. A recent study [3] introduced the concept of a Biomass Energy Conversion Park, and conducted a techno-economic evaluation of potentials for an integrated system of conversion technologies, primarily focussing on anaerobic digestion (AD). Over the years, AD has emerged as a new model in biomass valorisation and in the European Union (EU), for example, it is attracting increasing levels of investment, primarily driven by current issues such as global warming, demand for renewable energy, landfill tax on organic waste, demand for organic fertiliser, high fossil fuel prices, pollution of the environment and legislation relating to the treatment and disposal of organic wastes [4]. Subscribing to this notion, life cycle assessment (LCA) of different waste disposal strategies for utilisation of the organic fraction of the MSW (OFMSW[1]) have shown AD as inducing significant resource savings [5] and being the most environmentally favourable solid waste management option in terms of both greenhouse gas (GHG) saving and environmental toxicity to the terrestrial and aquatic environments when compared to aerobic composting, incineration or landfilling [6–9]. Further, AD has additional attributes, making it worthy of promoting renewable energy sustainability when compared to other bioenergy conversion technologies—(a) it does not consume oxygen; (b) has lower nutrient requirements and; (c) it generates energy carrier (i.e. methane) through non-destructive means and enables reuse of the residual biomass in agriculture. Revenues for anaerobic digesters can come from energy (gas, heat, and electricity), tipping or service fees (landfill disposal offset), secondary products (digestate, liquid fertiliser, and feedstock for downstream processes), carbon offset credits, and government incentives (renewable energy tax credits and price supports).

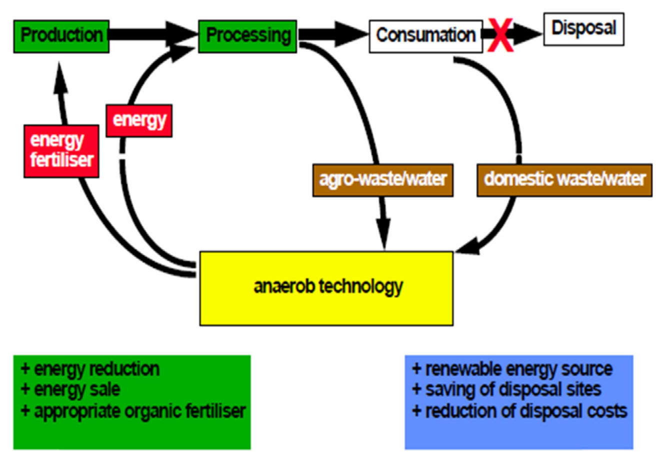

Fig. 1. Waste-to-resource conservation loop for anaerobic digestion (AD) technology. (Adapted from the European Anaerobic Digestion Network [12]).

AD of urban organic waste, typically comprising of OFMSW, waste oils and animal fat, energy crops and agricultural waste, manure and sewage sludge, has been reported to offer a positive valorisation pathway [10] with an overall positive balance (0.67 MJ primary exergy inputs from nature per MJ electricity if heat is used and 0.86 MJ primary exergy inputs from nature if heat is not used [5]. Bio energy from AD has been considered as a dominant future renewable energy source, providing a steady supply of heat and power all the year round (*quasi* base load for a thermal power station on a fossil grid). The methane produced can even be stored in gasometers, and can be pumped, after some further purification, into gas distribution systems as part of the renewable heat incentive[2] [11]. AD of bio-degradable organic residues (crop/animal/food) has been considered vital as a 'closed-nutrient cycle' system (i.e. where nutrients are not lost but re-utilised in the food cycle) along with recovery of bioenergy (Fig. 1) [12]. This is an economic edge of AD over conventional aerobic systems, currently in operation for processing biodegradable waste, thereby offering authorities a multi-purpose technology option for fulfilling a cluster of policy needs [4]. Besides, it has potential buy-ins from

[1] OFMSW is defined by the European Commission as "biodegradable park and garden waste, food and kitchen waste from household, restaurants, caterers and retail premises and comparable waste from food processing plants" [103].

[2] The Renewable Heat Incentive offers financial support for 20 years for biomethane injected into the gas grid at all scales, as well as heat produced from biogas plants with a thermal capacity up to 200 kW [11].