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Lessons from spatial and environmental assessment of energy potentials for Anaerobic Digestion production systems applied to the Netherlands

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HIGHLIGHTS

- There is a substantial gap between bio-energy potential and net energy gain.
- For reaching production goals the green gas utilization pathway is preferable.
- Environmental sustainability favors the waste management pathway.
- Renewable energy production goals and environmental sustainability do not always align.
- There is a gap between top–down regulation and actual emission reduction and sustainability.

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ABSTRACT

Anaerobic digestion (AD) can play an important role in achieving the renewable energy goals set within the European Union. Within this article the focus is placed on reaching the Dutch local renewable production goal set for the year 2020 with locally available biomass waste flows, avoiding intensive farming and long transport distances of biomass and energy carriers. The bio-energy yields, efficiency and environmental sustainability are analyzed for five municipalities in the northern part of the Netherlands, using three utilization pathways: green gas production, combined heat and power, and waste management. Literature has indicated that there is sufficient bio-energy potential in local waste streams to reach the aforementioned goal. However, the average useful energy finally produced by the AD production pathway is significantly lower, often due to poor quality biomass and difficult harvesting conditions. Furthermore, of the potential bio-energy input in the three utilization pathways considered in this article, on average: 73% can be extracted as green gas; 57% as heat and power; and 44% as green gas in the waste management pathway. This demonstrates that the Dutch renewable production goal cannot be reached. The green gas utilization pathway is preferable for reaching production goals as it retains the highest amount of energy from the feedstock. However, environmental sustainability favors the waste management pathway as it has a higher overall efficiency, and lower emissions and environmental impacts. The main lessons drawn from the aforementioned are twofold: there is a substantial gap between bio-energy potential and net energy gain; there is also a gap between top–down regulation and actual emission reduction and sustainability. Therefore, a full life cycle-based understanding of the absolute energy and environmental impact of biogas production and utilization pathways is required to help governments to develop optimal policies serving a broad set of sustainable objectives. Well-founded ideas and decisions are needed on how best to utilize the limited biomass availability most effectively and sustainably in the near and far future, as biogas can play a supportive role for integrating other renewable sources into local decentralized energy systems as a flexible and storable energy source.

1. Introduction

The European Union has set high goals for renewable energy integration in the near future [1,2]. Within this context, Anaerobic Digestion (AD) can play an important role as it is capable of processing a multitude of biomass feedstocks, whilst producing both

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Nomenclature

AD	Anaerobic Digestion	GHG	Green House Gasses
CHP	combined heat and power	(P)EROI	Process Energy Returned on Invested
oDM	organic dry matter	GWP100	Global Warming Potential 100 year scale
FM	fresh matter	Pt	environmental impact in EcoPoint
PJ	peta joule (10^{15} J)	LCA	Life Cycle Analysis
GJ	giga joule (10^{9} J)	aLCA	Attributed Life Cycle Analysis
MJ	mega joule (10^{6} J)	$kgCO_2eq$	kilograms of carbon dioxide equivalent
Mg	mega gram (equivalent to metric tonne)	Nm^3	normal cubic meter (volume at 1 bar 0C)

energy in the form of biogas, and fertilizers in the form of digestate. Biogas can be seen as a renewable and flexible energy carrier which is storable and can be transformed into electricity, heat, or upgraded to green gas (biogas upgraded to natural gas quality) [3]. Digestate can be processed to produce quality fertilizers for use in agriculture [4]. AD has been successfully implemented in the treatment of several biomass feedstocks and is already established as a reliable technology in Europe [5]. In the year 2014 around 4% of the total energy supply within Europe was produced through biomass, and this is expected to grow significantly in the future [6]. However, the need for feedstocks will most likely also increase as a result, and the majority of the additional supply is expected will come from agricultural land [6]. Therefore, questions can be raised regarding the achievability, efficiency, and sustainability of the biogas production pathway when utilizing specially cultivated energy feedstocks and transporting them over longer distances. The choice of feedstocks, technologies, and the operational values of AD pathways (e.g. feedstock, transport, process) have a significant influence on the environmental impact [7–13], and the increased biomass use can claim valuable arable land for cultivation [6] and/or effect biodiversity [14].

Within the aforementioned context, focus could be placed on alternative feedstocks which: do not have other applications except as energy sources; do not have an extensive environmental impact; and, are locally available (e.g. manures, organic wastes, natural grasses, harvest remains) [13,15–19]. Studies have indicated that there is a sufficient amount of local waste feedstocks within the Netherlands to achieve the Dutch decentralized renewable goals of 40 PJ by 2020 [20]. One recent study concluded that locally available biomass waste streams can provide up to 66 PJ annually of energy within the Netherlands [21]. Other studies indicate: natural resources (e.g. roadside grass, natural grass reed) can provide around 12 PJ [22] to 13.5 PJ annually [23]; waste streams from agro-industry potentially hold another 14PJ annually [24]; overall, a range between 53 up to 94 PJ per year will be available by 2020 [25]. However, the aforementioned studies often ignore the energy required in the process of extracting energy from the biomass and the environmental impacts of the process. In order to make more reliable environmental assessments of biogas systems from feedstocks, specific local and regional conditions have to be included [7], which fit a unique geographic location with dispersed availability and quality of biomass. LCA studies on local implementation of AD focusing on single waste flows (e.g. food, vinasse, agro-food waste, municipal solid waste) have indicated environmental benefits over fossil resources [15–18,26,27]. However, the LCA studies do not focus on utilizing the multitude of locally available waste products for reaching decentralized renewable production goals. Additionally, the question could be raised, from an environmental perspective, whether to focus on quantity or quality of production: quantity, focusing on producing the largest amount of useful energy; or quality, achieving the highest efficiency or creating the biggest reduction of greenhouse gas emissions and environmental impacts. Currently, regulations in the Netherlands are mostly focused on quantity (e.g. the production of green gas, heat and electricity) [20].

Thus, research is still needed to assess the overall renewability, sustainability, and possible energy yields of biogas production pathways operating on locally available waste feedstocks. Understanding the local availability of biomass, the subsequent, related biogas production pathways, and the best sustainable practices can support decentralized renewable integration as AD can play an important role as a waste treatment system which also produces a flexible energy carrier. One indication can be whether the goal of the Dutch government is achievable and whether the focus should be placed merely on quantity or also on quality of energy production from an environmental sustainability perspective. This article aims to contribute to a proper assessment of the overall renewability, sustainability, and possible energy yields of biogas production pathways operating on locally available biomass waste flows. The goal will be affected by assessing and evaluating the local availability of organic waste materials within five municipalities in the northern part of the Netherlands. For these five locations, the following procedure is followed: first, the available biomass waste flows and bio-energy potentials are determined; second, the net energy yields from three biogas production and utilization pathways are calculated; third, the net average yield of the five municipalities are compared to the required yield to reach the Dutch goal of 40 PJ; and finally, the emissions and environmental impact are determined. Additionally, the effect of an increased percentage of manure in the feedstock for the digester is analyzed in terms of efficiency and environmental impacts. The lessons learned from the case study will be discussed in the conclusion.

2. Methods

The assessment of the complete biogas production pathway will be performed through the use of a method for calculating the sustainability of AD production pathways and the sustainability of feedstocks and process optimization (described in [13,28]) and Life Cycle Analysis (LCA). The LCA analysis is undertaken in accordance with European guidance and DIN EN ISO 14040 to 14044: 2006 [29]. The environmental impacts were obtained through the use of the SimaPro v8.0 (2013) utilizing the Eco Invent database v3.0 (2013) as endpoints.

2.1. System boundary

Dutch regulation states that at least 50% of the feedstock fed into the biogas production pathway must be composed of manure sources (e.g. cow, pig, chicken manure), while the remainder can be filled up by other biomass sources (e.g. harvest remains, roadside grass, or maize). Environmental impacts are taken into