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A spatial analysis of biogas potential from manure in Europe

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ABSTRACT

Anaerobic digestion is increasingly used worldwide to generate energy from biogas, bringing significant economic and environmental benefits. In particular, in the European Union (EU), biogas can contribute significantly in several countries to reach the renewable energy targets. This study provides an assessment of the spatial distribution of the biogas potential of farm manure from livestock and poultry in Europe, which is a key issue for the location and economic performances of a bioenergy plant. Biogas estimates provided in this study are computed through a spatial analysis algorithm that uses data of livestock and poultry, manure production and collection, leading to the evaluation of the spatial distribution of biogas potential at 1 km spatial resolution. Following this analysis, the theoretical biogas potential of manure was estimated at 26 billion m^3 biomethane in Europe (23 billion m^3 biomethane in the EU) and the realistic biogas potential, counting on collectible manure, was assessed at 18 billion m^3 biomethane in Europe (16 billion m^3 biomethane in the EU). Several maps provide the suitable locations and capacity of manure-based biogas plants in two different scenarios. Between 13,866 and 19,482 biogas plants could be built in Europe, with a total installed capacity between 6144 MWe and 7145 MWe, and an average capacity between 315 kWe and 515 kWe.

1. Introduction

1.1. Renewable energy and bioenergy production

In 2007, the European Commission proposed an integrated *Energy and Climate Change* package on the EU's commitment to change: the *Energy policy for Europe* (COM(2007) 1 final) [1], and the *Limiting Global Climate Change to 2 °C - The way ahead for 2020 and beyond* (COM(2007) 2 final) [2]. This includes an EU commitment to achieve at least a 20% reduction of Greenhouse Gas (GHG) emissions by 2020 compared to 1990 levels and a mandatory EU target of 20% renewable energy.

The *Renewable Energy Directive* (RED) [3] on the promotion of renewable energy sources, requires the EU Member States (MS) to increase the share of renewable energy to 20% of gross final energy consumption and achieve a contribution of 10% of renewable energy in the energy used in transport by 2020. The MS have prepared National Renewable Energy Action Plans (NREAPs), which show detailed roadmaps and taken measures to reach the 2020 renewable energy targets and develop energy infrastructure [4].

The EU has adopted a new 2030 Framework (COM(2014) 15 final) [5] for climate and energy, including EU-wide targets and policy objectives for the period between 2020 and 2030. The key elements of this framework comprise a 40% reduction for domestic EU GHG emissions compared to 1990 levels, at least a 27% share of renewable energy consumption, and at least 27% energy savings compared with the business-as-usual scenario.

A bio-economy strategy (COM(2012) 60 final – page 2) [6] was set to develop an “innovative, resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes”. The bio-based economy plays a key role, as part of a green economy, to replace fossil fuels on a large scale, not only for energy applications but also for chemicals and materials applications.

The *Energy Roadmap 2050* (COM(2011) 112 final) [6] investigated possible pathways for a transition towards a decarbonisation of the energy system and the associated impacts, challenges and opportunities. In addition, it established long term goals to create a competitive low carbon economy and to reach 80–95% GHG emission reduction by 2050. As a consequence, the share of renewable energy could increase substantially in the EU between 55% and 75% of gross final energy consumption in this period.

The use of renewable energy in the gross final energy consumption

Abbreviations: AD, Anaerobic Digestion; CHP, Combined Heat and Power Plants; EU, European Union; GIS, Geographic Information System; GHG, Greenhouse Gas; MS, EU Member States; MSW, Municipal Solid Waste; NREAPs, Renewable Energy Action Plans

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has increased significantly in the EU from a share of 8.5% in 2005 to 14% in 2012. Significant development is expected for bioenergy, which would keep its major role in the EU energy mix until 2020 with a share above 60% of renewable energy. Overall, the share of bioenergy in the gross final energy consumption will increase from 5% in 2005 and 8.5% in 2012 to almost 12% in 2020.

The aggregated data from NREAPs shows that the use of biogas for electricity, heating and cooling, and biofuels in transport is estimated to increase in the EU from 71 PJ in 2005 and 264.9 PJ in 2012 to 433.5 PJ in 2020. This includes 189.5 PJ of heat, 63.4 TWh (230.1 PJ) of electricity and up to 13.9 PJ of biogas that could be used as a fuel in transport. Considering the energy conversion efficiencies (electricity in cogeneration or in electricity-only plants, heating, and fuels for transport), it is estimated that 25 billion m^3 of biomethane would be needed to reach this demand [4].

The installed bioenergy power capacity in the EU almost doubled, from 16 GW in 2005 to 29 GW in 2012, while the installed biogas capacity increased significantly since 2005, from 2665 MW in 2005 to reach 8339 MW in 2012. This is expected to further increase to 11232 MW in 2020. The biomass electricity generation is expected to expand from 69 TWh in 2005 to 233 TWh in 2020. The electricity generation from biogas has increased from 12.5 TWh in 2005 to 46.4 TWh in 2012, and this should further increase to 63.9 TWh in 2020. The share of biogas electricity of total biomass electricity generation is expected to increase from 18% in 2005 to 27% in 2020 [4].

A significant growth is expected to be registered by the use of biogas for heating and cooling, which has already increased from 26 PJ in 2005 to 94 PJ in 2012, and it could reach 189 PJ in 2020. The share of biogas in biomass heating should be expanded from 1% in 2005 to 5% in 2020. Biogas could also be used to some extent in the transport sector, with a contribution which is not detailed in the NREAP, but it could be estimated at maximum 13.9 PJ (about 1% of the biofuels expected to be used in transport in 2020) [4].

On the longer term, the installed capacity of bioenergy plants is expected to further rise in the EU from 44 GW in 2020 to 52 GW in 2030. In addition, the capacity can reach 87 GW in 2050 in the reference scenario of the Energy Roadmap 2050 (COM(2011) 885) [7], and between 106 and 163 GW in different decarbonisation scenarios. Similarly, the biomass electricity production is projected to reach 360 TWh in 2050 in the reference scenario and up to 460–494 TWh in 2050 in different decarbonisation scenarios. The contribution of biogas is expected to increase as well by 2050, but this development depends on the local availability of biogas feedstock [4].

1.2. Biogas as a sustainable fuel for heat, power and transport

The energy and climate change policies in the EU and the US, as well as the introduction of various support schemes for promoting the utilization of renewable resources, have encouraged the development of biogas plants for energy production. Biogas can be used for heat and electricity production as well as fuel in transport after prior purification and upgrading.

Biogas is produced in Anaerobic Digestion (AD) plants, wastewater treatment plants or recovered from landfill sites. In recent years, biogas production in AD plants has become one of the most attractive renewable energy sources worldwide.

The natural degradation of organic material by micro-organisms under anaerobic conditions leads to the production of biogas. It consists of 50–75% methane, 25–50% carbon dioxide (CO_2), water vapour (H_2O), and traces of oxygen (O_2), nitrogen (N_2) and hydrogen sulphide (H_2S) [8,9].

Biogas can be obtained from a wide range of diverse feedstocks: agricultural residues (livestock manure, crop residues), industrial residues (sewage sludge, food industry waste, slaughterhouse residues), energy crops, Municipal Solid Waste (MSW), etc. In the last decade, there has been a significant development in Europe towards the use energy crops (silage maize, grasses), industrial and municipal waste for biogas production [10].

Livestock manure is directly used as fertiliser in agriculture, which can cause environmental problems, such as odours, soil and water contamination and pollution. Moreover, natural degradation of manure leads to emissions of methane and carbon dioxide during storage [11,12]. Therefore, the use of this resource for energy generation brings various economic, environmental and climate benefits, such as displacing the use of fossil fuels and reducing GHG emissions released into the atmosphere by avoiding methane emissions during storage. It also contributes to mitigate odours associated with manure storage and removes pathogens [13].

Solid residues from anaerobic digestion (digestate) can still be used as fertiliser, just like manure, as it has the same content of nutrients. This brings additional economic benefits by reducing the use of chemical fertilizers in farms, reducing nutrient runoff and avoiding methane emissions [8,14].

Most of the modern AD plants provide electricity and heat generation (CHP plants). The heat generated can be used to meet the local heat demand (e.g. on farms or for external users), which can improve the overall efficiency of the plant. Biogas can be upgraded and injected into the natural gas network or use it in transport vehicles, with proper purification to remove trace gases such as CO_2, H_2S, and water [8–10,15].

Some existing estimations for the potential of biogas in Europe are based on statistical data on various feedstocks that might be available for biogas production. The technical potential of biogas in the EU was assessed by Deutsches Biomasseforschungszentrum (DBFZ) to be in the range of 151–246 billion Nm^3 biomethane from anaerobic digestion and bio-SNG produced via gasification. This estimation includes 66 billion Nm^3 from woody biomass (bio-SNG), 11 billion Nm^3 from herbaceous biomass, 48–143 billion Nm^3 from energy crops and 26 billion Nm^3 from wet biomass [16].

AEBIOM [17] estimated a potential in the EU at about 78 billion Nm^3 of biomethane, of which 58.9 billion Nm^3 derived from agriculture (27.2 billion Nm^3 from crops, 10 billion Nm^3 from straw, 20.5 billion Nm^3 from manure and 1.2 billion Nm^3 from landscape management), and 19 billion Nm^3 from waste (10.0 billion Nm^3 from MSW, 3.0 billion Nm^3 from industrial waste and 6.0 billion Nm^3 from sewage sludge). From this potential, 46 billion Nm^3 could be used until 2020.

While the information on the biogas potential at larger scale is needed (at national or European level), more detailed information on the spatial distribution is needed at local level, which considers all local specific conditions and constraints and are a key issue for the location and economic performances of a biogas plant.

1.3. The spatial distribution of biogas feedstock: a critical issue for its energy uses

A proper assessment of the biogas potential is the first step in assessing the feasibility of biogas-based power plants. The availability of the primary feedstock is essential in this process. Specifically, the availability of manure feedstock in a given area depends on the population of livestock and poultry and the density of farms, which could be either sparsely distributed or concentrated in small areas. Therefore, the information on the spatial distribution of livestock and poultry is crucial to assess the local availability of biogas feedstock.

Besides being a conditio sine qua non for plant establishment, a good knowledge of local availability of biogas feedstock resources and its spatial distribution is also important for assessing the economic viability of AD plants. In this context, economic parameters are multiple and might include, besides resources, specific considerations on the infrastructure for feedstock mobilization (e.g. roads or waterways) and final product distribution (e.g. gas networks for bio-methane injection, electricity grids and district heating networks). Furthermore, finding “suitable” locations for biogas plants is a key issue for sustainable