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Editorial

The Role of Biogas and Biomethane as Renewable Gases in the Decarbonization Pathway to Zero Emissions

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1. Introduction

The production of biogas through the conversion of organic waste into energy and bio-products of added value has the potential to play a significant role in the transition towards a more sustainable and decarbonized energy system. This is particularly relevant for all sectors within modern societies, which are facing increasing pressure to reduce their greenhouse gas emissions. In this context, the use of biogas and biomethane as renewable energy sources can provide a viable and cost-effective solution for reducing the carbon footprint of our societies.

This Special Issue of *Energies*, entitled "Biogas Production-Converting Waste to Energy and Bio-Products of Added Value", brings together a collection of research papers that explore various aspects of biogas production, from the pretreatment of biomass to the upgrading of biogas into biomethane. The papers published in this issue provide valuable insights into the challenges and opportunities associated with the use of biogas and biomethane and contribute to our understanding of how these renewable energy sources can be effectively integrated.

2. Role of Renewable Gases

As stated above, biogas and biomethane have the potential to play a significant role in the decarbonization of different sectors. Renewable energy sources can help reduce greenhouse gas emissions by replacing fossil fuels, avoiding methane emissions from manure, producing green fertilizer that replaces carbon-intensive chemical fertilizers, storing carbon in soils, and capturing and storing carbon.

A review of biogas production and usage within the legislative framework across the globe shows that Europe has contributed to over 70% of the world's biogas generation in the past 10 years, representing 64 TWh [1]. A recent study on biogas policies and production development in Europe highlights significant differences in eight representative EU countries, their total biogas production, and the fundamental features of their biogas sectors. Germany has the highest total production (>1 $MWh_{\text{biogas production}}$/capita, year), exceeding the combined production of the other seven countries. Italy comes in second, with a production volume that is roughly one-fifth of Germany's. However, when population size is taken into account, the disparities are less pronounced. Denmark and the Czech Republic both have per capita biogas production rates that are more than half of Germany's. Sweden, Norway, and France have the lowest per capita production rates amongst the countries considered within the study [2].

Regarding the theoretical potential of biomethane production in the EU and UK by 2050, it is expected that this renewable gas will come from a diverse range of biomass feedstocks. Forest wood and residues are projected to be the most significant source, with a potential production of almost 500 TWh (>51 bcm). Intermediate crops are expected to contribute nearly 390 TWh (>39 bcm), while agricultural residues, manure, and green waste could provide about 200 TWh (>20 bcm), over 180 TWh (>18 bcm), and 165 TWh (>16 bcm),

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respectively. It is important to note that these estimates do not include energy crops, as the RED II Directive stipulates that biomass for sustainable biogas production should not compete with agricultural land used for food and feed production. In the past, nearly half of the newly installed biomethane plants between 2010 and 2015 were based on energy crops [3].

In addition to their potential for reducing greenhouse gas emissions, biogas and biomethane can also provide other environmental benefits. For example, the conversion of organic waste into biogas can provide a beneficial alternative disposal method for waste, reducing the environmental impact of waste management.

Overall, the use of biogas and biomethane can provide a cost-effective and scalable solution for reducing greenhouse gas emissions. However, there are also challenges associated with their adoption, such as the need for appropriate infrastructure and regulatory frameworks to support their use.

3. Short Review of the Contributions in this Special Issue

This Special Issue features a diverse range of contributions on the topic of biogas production. One notable study, conducted by Bedoić and colleagues, offers a comprehensive analysis of novel feedstocks for biogas production and their environmental impact, proposing a holistic and interdisciplinary approach for both the biogas production side and the utilization side [4]. Khadka and co-authors focus on the effect of substrate to inoculum ratios on biogas production from food waste, using the modified Gompertz model to predict the kinetics of anaerobic digestion [5]. Herman and colleagues investigate how waste composition affects the quality of biogas and digestate fertilizer, characterizing the biogas and digestate quality of anaerobically digested food waste from four diets and estimating the difference in biogas produced from co-digested food waste and brewery waste [6]. Hernández and co-authors present a techno-economic assessment of biogas treatment plants for the agro-industrial sector, optimizing the design and operation of these plants to reduce greenhouse gas emissions and improve the circular use of nitrogen [7]. Häner and colleagues explore the use of fixed-bed and expanded granular sludge bed reactors for the anaerobic digestion of pig slurry, aiming to increase efficiency by using reactors with biomass retention [8]. Mukawa and co-authors examine the energy potential of biogas from sewage sludge treated with thermal hydrolysis, providing detailed energy balance calculations and evaluating thermal energy demand coverage [9]. Rossi and colleagues aim to optimize biogas production through thermophilic dry anaerobic digestion, testing various operational strategies to reduce ammonia inhibition by altering feedstock composition [10]. Slepetiene and co-authors investigate changes in stable organic carbon in fluvisol treated with two types of anaerobic digestate, showing that digestate contributes to carbon accumulation and stabilization in soil [11]. Finally, Micoli and colleagues focus on the anaerobic digestion of olive mill wastewater in the presence of biochar, aiming to improve stability and efficiency by studying the addition of biochar to the digestion mixture [12].

4. Conclusions

The papers published in this Special Issue have made significant contributions to the field of biogas production. They have used geospatial analytic tools to identify novel feedstocks and analyzed the environmental impact of feedstock replacement and alternative biogas utilization pathways. Additionally, they have provided insights into the effect of substrate to inoculum ratios on the kinetics of biogas production and investigated the effect of waste composition on the quality of anaerobic digestion products. They have also employed techno-economic analysis to improve the performance of existing industrial anaerobic digestion plants and explored various operational strategies to optimize biogas production. These papers provide valuable insights into various aspects of biogas production, from feedstock availability to process optimization, and have implications for the integration of biogas technologies into the complex energy systems of modern societies.

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