A Review of Geospatial Prediction and Modelling Approaches in Biogas Plant Suitability Assessment

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Abstract: The European Union and Croatia's energy policy aims to ensure accessible, safe, affordable, and competitive energy through significant technical, technological, and social changes in all sectors of the economy. New production capacities, such as biogas plants, can alleviate capacity shortages, increase system flexibility, and significantly improve the security of supply. Therefore, this paper provides an overview of the factors that affect the selection of a location for biogas plants. Geospatial biogas potential assessment is the first step in determining the feasibility of biogas plants. Several factors can contribute to the economic viability and sustainable production of biogas plants, while sufficient availability of feedstock, as well as cost-effective logistics related to transportation and fulfilment of institutional requirements, are essential. There are two geospatial state-of-the-art methods for land suitability determination: Geographic Information System (GIS)-based multicriteria analysis and machine learning regression. These studies were dominantly based on the GIS-based multicriteria analysis using the analytic hierarchy process (AHP), using distance rasters to supply sources, roads, and settlements as primary criteria. They also strongly considered land use, slope, and elevation for the determination of biogas plant suitability. However, three key gaps were noted in the current state-of-the-art approach: 1) crude geospatial modelling of biomass supply, which is required for biogas production using co-digestion, except for single crop; 2) the lack of geospatial modeling of soil contamination as criteria; and 3) the lack of independent validation of predicted biogas plant suitability.

Keywords: biogas plant site selection; Web of Science; GIS-based multicriteria analysis; Sustainable Development Goals of the United Nations.

1 Introduction

European Union and Croatia's energy policy aims to ensure accessible, safe, affordable, and competitive energy through significant technical, technological, and social changes in all sectors of the economy (Republic of Croatia 2020). Europe possesses an abundance of renewable energy sources, and its countries have emerged as leaders in deploying renewable technologies in recent years. With targets for renewable energy set for each nation in Europe and the European Green Deal aiming to make Europe the first climate-neutral continent by 2050, efforts are being made to make Europe's energy systems more sustainable (IRENA 2022). Significant investments in energy efficiency, renewable energy, new low-carbon technologies, and transportation and storage infrastructure will be needed to achieve these goals. Integration of the infrastructure of the gas and electricity industries must also be done more intelligently and closely (Morino et al. 2023). Renewable energy projects and new production capacities should utilize the latest technological advances to increase conversion efficiency and energy density, reducing space requirements and environmental impact across the European Union. Renewable energy projects should consider the socio-economic characteristics of the surrounding area while respecting national environmental goals, to contribute to the development of local communities (Republic of Croatia 2020).

Croatia's energy transition also promotes renewable energy sources, potentially reducing the country's dependence on energy imports. According to the Energy Development Strategy of Croatia until 2030 with a view to 2050, it was concluded that the energy production capacities are insufficient to meet the energy needs of the Croatian electricity system. New production capacities, such as biogas plants, can alleviate capacity shortages, increase system flexibility, and significantly improve the security of heat and electricity supply, along with transportation fuels (Scarlat et al. 2018, Republic of Croatia 2019). In addition, the Croatian Ministry of Agriculture signed the Bioeast Vision 2030 declaration in 2018, focusing on sustainable biomass production, circular processing ("zero waste"), agro-food systems, and diversification of the rural economy. Croatia's energy transition goals can be significantly achieved by actively managing agricultural land and organic waste from livestock production for biogas production (Republic of Croatia 2019).

Continental Croatia, comprising 13 counties, has high agricultural and industrial potential. In 2022, there were 41 operational biogas plants in 10 counties with an installed capacity of 53 MW. However, it is estimated that Croatia has the potential to generate up to 300 MW of biogas according to the Report on biogas plants from the database of the Environmental Pollution Register of the Republic of Croatia for the period 2017 – 2021 (Republic of Croatia, 2023). Biogas potential assessment is the first step in determining the feasibility and plant suitability of biogas plants.

The goal of this review was to present the state of scientific studies available in scientific database Web of Science in the period from 2010 to 2023 that deal with accessing suitable locations for generally all biofuel and specifically

biogas plants by using geospatial prediction and modelling approaches, and their interlinking with the Sustainable Development Goals of the United Nations (SDGs). Also, the goal was to identify SDGs that most often appear in these studies and thus stress their importance and presence in the biogas industry.

2 Materials and methods

To investigate the available scientific work that dealt with possible locations for the construction of any biofuel and specifically biogas plant locations, a search for information is performed using the scientific database Web of Science with the following search topic: "land suitability" OR "site selection", AND "biofuel plant" OR "biogas plant" for biofuel studies, and "biogas plant" for biogas studies published between 2010 and 2023. The criteria for selecting the information were defined by the year in which the manuscript was published. Additionally, the Sustainable Development Goals of the United Nations (SDGs) for filtered studies were analyzed based on their indexing in the Web of Science.

3 Results

The data on the number of papers indexed in the Web of Science since 2010 on the topic of land suitability or site selection and a biofuel and biogas plant is presented in Figure 1. Figure 2 represents the link between the biofuel and biogas plant suitability studies indexed in the Web of Science and SDGs.

The geographic distribution of biofuel and biogas plant suitability studies indexed in the Web of Science are presented in Figure 3, in which lighter colors indicate countries with a lesser number of biofuel and biogas plant suitability studies, whereas darker colors indicate countries with a larger number of biofuel and biogas plant suitability studies.

4 Discussion

The sustainable production of biogas plants and their economic viability can be attributed to various factors. Knowledge of the local availability of feedstock and its spatial distribution is important. Particularly, since different types of manures are usually the basic substrate for biogas production, the availability of manure is crucial. In a given area it depends on the population of livestock and poultry and the density of farms (Scarlat et al. 2018). Also, cost-effective logistics related to infrastructure, i.e. transportation and fulfillment of institutional requirements, are essential. Suitable infrastructure refers to road and rail networks, gas grids, and pipelines for transporting produced biogas from a biogas production facility to a distribution point or end-user (Feiz et al. 2022).

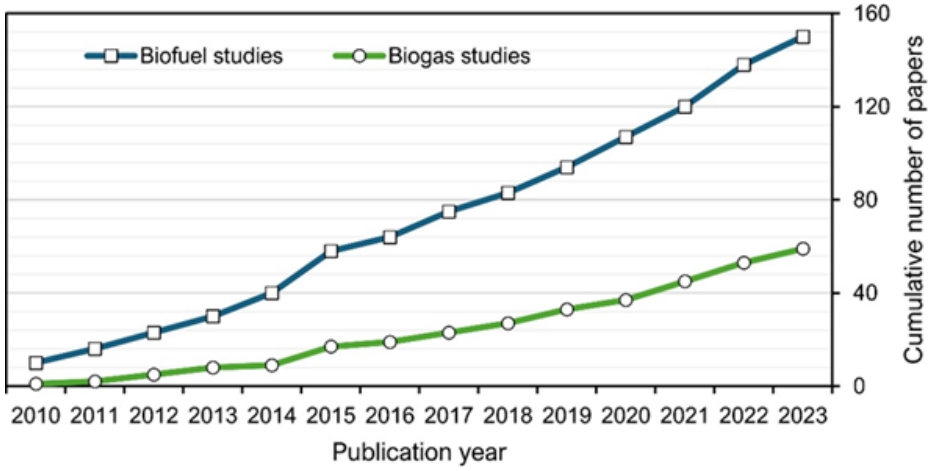

Figure 1. The cumulative number of papers indexed in the Web of Science since 2010 on the topic of ("land suitability" OR "site selection") AND: ("biofuel plant" OR "biogas plant") for biofuel studies; "biogas plant" for biogas studies.

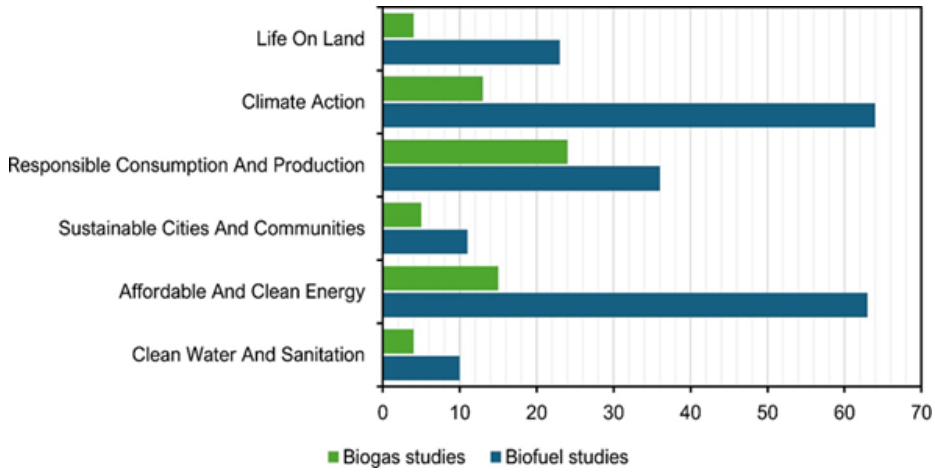

Figure 2. The SDGs of biofuel and biogas plant suitability studies indexed in the Web of Science.

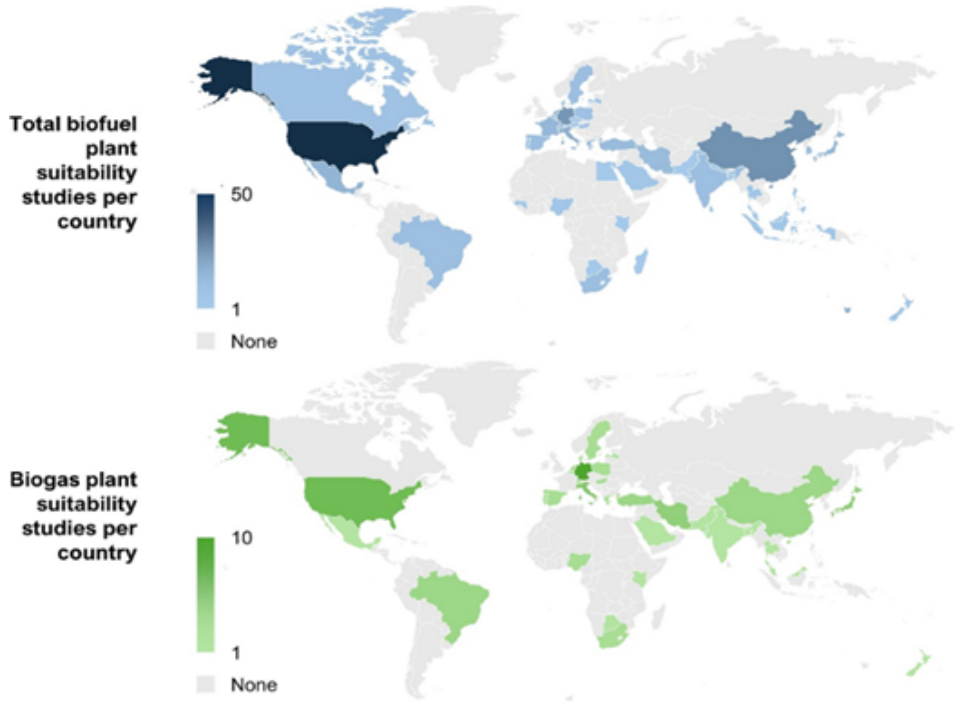

Figure 3. The geographic distribution of biofuel and biogas plant suitability studies indexed in the Web of Science.

Geographic Information System (GIS) has been used in several studies for biogas plant suitability determination across the world (Akther et al. 2018, Al-Ruzouq et al. 2021, Nantasaksiri et al. 2021, Soha and Hartmann 2022). These studies were dominantly based on the GIS-based multicriteria analysis using the Analytic Hierarchy Process (AHP), using distance rasters to supply sources, roads, and settlements as primary criteria. They also strongly considered land use, slope, and elevation to determine biogas plant suitability.

While GIS-based multicriteria analysis offers maximum flexibility in criteria selection and their weighting, thus being universally applicable in suitability studies, it is heavily relied on subjective expert knowledge and often lacks independent validation. To reduce the subjectivity effect, the Analytic Hierarchy Process (AHP) represents a state of the art for criteria weight calculation. This issue is completely resolved by the objective approach of machine learning regression for suitability prediction, which supports significantly more input covariates for prediction but requires reliable ground truth data (Radočaj and Jurišić 2022). The main reason for the prevalence of the GIS-based multicriteria analysis in comparison to machine learning regression for biogas plant suitability determination is the lack of straightforward ground truth data, which cannot be quantified to express the effectiveness of biogas production in a single indicator.

Regarding the scientific papers indexed in the database Web of Science, the year 2010 was chosen as the starting year, whereas the search ends with 2023. The results have shown that there have been only 150 biofuels and 59 biogas plant suitability studies published in that period (Figure 1), indicating that this is a niche scientific topic. However, their number steadily grew since 2010, with the record number of both biofuel and biogas plant suitability studies being indexed in 2022. A total of six SDGs were identified in the search of biofuel and biogas plant suitability studies indexed in the Web of Science (Figure 2), referring to life on land, climate action, responsible consumption and production, sustainable cities and communities, affordable and clean energy, and clean water and sanitation. The majority of the studies dealt with crucial global environmental issues related to climate action and affordable and clean energy. While a similar focus was present in more narrow biogas plant suitability studies, their dominant scope was on the responsible consumption and production goal, which is mandatory for reaching an independent energy policy.

The leading countries in the biofuel plant suitability research are the United States, China, and Germany (Figure 3). Moreover, it is notable that such research was dominantly focused on three global regions: North America, western Europe, and south-eastern Asia, with only a few studies indexed in the Web of Science outside these areas. The geographic distribution of specifically biogas plant suitability studies was further restricted, with Germany being the global leader in the number of research papers indexed in the Web of Science. This particular topic was even more prevalent in the European countries than more general biofuel plant suitability studies, with Italy being the third-ranked in this regard, slightly behind the United States.

5 Conclusions

To achieve sustainable development and energy and climate goals, policies that consider the synergies between various sectors, such as agriculture, rural development, and energy production, are necessary for fully utilizing the potential of biogas. GIS suitability assessment interconnects all these factors and enables the prediction of the spatial distribution of all resources important for selecting the biogas plant location. It is evident from the

literature that only a minor number of studies were published throughout the given period and the present state of scientific research on biofuel and biogas plant suitability is very restricted, even in regions that are global leaders in research, including North America, western Europe, and south-eastern Asia which brings the conclusion that GIS-based assessments are still insufficiently utilized in the scientific modelling related to the biofuel industry and the selection of locations for biofuel production plants. However, the number of published papers has an upward trend and because powerful GIS-based tools are becoming more available and influential, the authors strongly believe that in the future these tools will be increasingly applied for this purpose and that the number of published papers will continue this growing trend.

This observation strongly suggests the potential presence of major scientific gaps in this research topic, which should encourage scientists to address this issue in future studies and also in achieving energy independence and environmental sustainability, particularly for identified SDGs that most often appear in the database when searching for biofuel and biogas plant suitability studies.

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