A GIS approach for mapping the biogas potential from livestock manure and biogas site optimisation

***Abstract*—Biogas produced through the process of anaerobic digestion can utilise a wide range of different feedstocks and is considered a renewable energy source. The EU Commission has recognised the role of AD in achieving circular economy goals and set the biogas and digestate production as recycling in the hierarchy of waste-to-energy operations. This work presents a Geographic Information System (GIS) based approach used for mapping of the biogas potential, derived from manure generated in livestock farms. In accordance with the calculated and mapped potential, optimal locations of biogas plants were determined, and the shortest transport routes were determined by using the GIS tool. The presented method was tested at the case study of five Croatian counties.**

I. INTRODUCTION

The expansion of biogas production, as well as the high prices of natural gas, promotes the need for the assessment of the energy potential of biomass, which is available for biogas production and not in competition with the other purposes. The large span of different biomass sources can be used as a feedstock. However, most of the biogas plants use maize silage to the greatest extent as the feedstock for biogas production. As maize silage requires agricultural land for production, its utilization for biogas production brings in competition with food and feed production. Besides this negative economic and social impact, the use of agricultural land for bioenergy production has caused concerns over the negative environmental impact due to direct and indirect land change. Direct land-use change refers to changing from one type of land use to a bioenergy plantation [1], while indirect land-use change indicates shifting agricultural production to previously non-cropland such as forests and grasslands [2]. Thus, materials that have been regarded as waste are becoming more interesting for consideration, and their use is receiving increasing policy support from the European Union [3]. Manure utilization for biogas production is additionally supported in Directive 2018/2001, which defines additional negative greenhouse gas emissions (GHG savings) due to emissions saved from raw manure management.

A sound knowledge base on the availability of residue potential has therefore been recognized as a necessary prerequisite for the success of the development of a bioeconomy [4]. The assessment of that potential at the high spatial resolution is a necessary precondition for the identification of the optimal location for biogas plant sites, techno-economic studies of biomass supply chains and supply risks management. There have been numerous studies on the assessment of the technical potential for biogas production. In the last years, the application of the GIS tools has been recognised as very useful for biomass potential mapping, as it can give valuable insights into the spatial distribution of the biomass potential and enables the performance of numerous spatial queries. In the work [5] GIS tool was used for assessing the potential of residues from agroforestry sources, while authors of work [6] have used it for the assessment of sustainable crop residue potentials. In the work [7] it has been demonstrated that the application of GIS tools enables assessment of biomass delivery cost. GIS tools were also used for biomass resource assessment in India [8], for which authors developed land use maps for the selected pilot regions.

The research questions in this work are defined as follows:

- How to use GIS tools in assessing the biogas potential of manure?
- How to define the optimal location of biogas plants, by using biogas potential as a weighted factor?
- How to define the shortest route between biogas plant and feedstock provided (farms)?

II. METHOD

As spatial factors play a key role in the process of site selection, the methodology was developed using the Geographical Information System (GIS) enabling to assess the spatial distribution of biogas potential, the optimal location of biogas site and assessment of the shortest route. The method used for this work can be divided into six steps, as depicted in Figure 1.

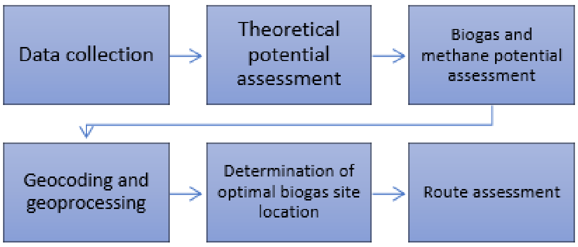

Figure 1 Steps of the method

A. *Data collection*

Data collection is the initial and essential step, as it determines to a great extent the accuracy of the obtained results. For this work, the following set of data was required:

- Type of livestock;
- Livestock number;
- Farm coordinates or address.

Most of the above-mentioned data can be obtained from different livestock reports. However, for the farms included in the Open street map (OSM) database, it is possible to automatically export the data in a polygon or/and point layers, with the Quick OSM Plugin. To export the farms available in the OSM database, it should be written/selected in Quick OSM interface the following: key=place (or landuse), value=farm, and define the area for which this query will be performed. This Plugin is available in the QGIS Plugin repository.

B. Assessment of the theoretical potential from manure

The theoretical potential of manure is calculated according to equation (1):

$$P_{th,liv} = N * MPH \qquad (1)$$

where $P_{th,liv}$ stands for the theoretical potential of manure, N for a number of heads of livestock (head) and MPH for manure per head ratio; a mass of the generated manure during one year (t/head). MPH factors for the considered livestock are presented in TABLE 1.

TABLE 1 MPH FACTORS FOR THE CONSIDERED LIVESTOCK

	Cattle	Pig	Horse	Poultry	Sheep
MPH (t/head)	12.3 [9]	1.2 [9]	8.5 [10]	0.095 [9]	0.4 [9]

C. Assessment of methane potential

Biogas potential of the considered feedstocks is based on theoretical potential of fresh feedstocks, specific biogas yield from fresh feedstock and methane content of biogas, according to equation (2):

$$E_{man} = P_{th,man} * y_{CH4} \qquad (2)$$

where E_{man} stands for a methane potential of manure (m^3) y_{com} for a specific methane yield of manure (m^3/t) and s_{CH_4} for a share of the methane contained in biogas (%). Specific methane yields of different types of manures are given in TABLE 2.

TABLE 2 SPECIFIC METHANE YIELD FROM DIFFERENT TYPES OF MANURE

	Cow manure	Horse manure	Pig manure	Poultry manure	Sheep manure
y_{CH4} (m^3/t)	22.1 [11]	28.56 [12]	18 [11]	70.8 [11]	62.1 [11]

D. Geocoding and geoprocessing

The economic feasibility of residues and by-product utilization is often constrained by the geographical distribution of the potential and the distance to potential biogas plants. This especially relates to farms, with a small amount of by-products and residues available for biogas production. The prior step to geoprocessing is geocoding, which is the process of converting addresses into geographic coordinates. Geoprocessing enables visualisation of sources of the biogas potential, distance determination between several points, density analysis etc. GIS tools are used for geospatial information processing (geoprocessing) and can be applied to a wide range of various problems. One of the main advantages provided by GIS tools is the possibility to link non-spatial attributes with spatial information. When using a GIS tool for spatial assessment of the biogas potential, in addition to the biogas potential, it is necessary to have coordinates of the farms, that can be obtained either through geocoding of addresses or through direct export of coordinates, that can be done through Quick OSM Plugin, as described in Data collection subsection.

E. Determination of optimal biogas site location

GIS tools enable assessment of the areas with high concertation of biogas potential. The prior step (Geocoding and geoprocessing) will result in a point vector layer, where each point represents one farm. The spatial and non-spatial information are used in defining the biogas plant location. Those biogas plant locations can be understood as the centralised processing sites, which use manure from nearby farms to produce biogas. When defining the biogas plant location, the objective is to maximise the biogas potential which can be utilised and to minimise the transportation distance. This task was performed in QGIS with the "Mean coordinate" spatial query, which provides the optimal location of the biogas site plant, in accordance with the weighted factor (in this case, biogas potential).

F. Route assessment

Route assessment can be done by using the "Shortest path" query in QGIS. This query allows automatic determination of the shortest distances between selected and optimal locations. To find the distance, it is necessary to have the following layers:

- -a layer containing existing roads in the observed area. They can be added to QGIS using the "QucikOSM" plugin.
- a layer containing farm;
- a layer containing the final destination (optimal biogas site location).

Those layers are used as input data for the "Shortest path" function which defines the road distance between farm and biogas site (optimal location). Once the transport distance is determined, industrial sites and farms up to 50 kilometres from potential biogas site are considered viable to provide their by-products and residues for biogas production, as higher distance would result in excessive GHG emissions.

III. RESULTS AND DISCUSSION

The presented method was tested and validated at the case study of five eastern Croatian counties: Virovitica-Podravina county, Osijek-Baranja county, Brod-Posavina county, Vukovar-Srijem county and Požega-Slavonia county. The selected counties have extensive livestock production. The methane potential of considered farms is presented in Figure 2.

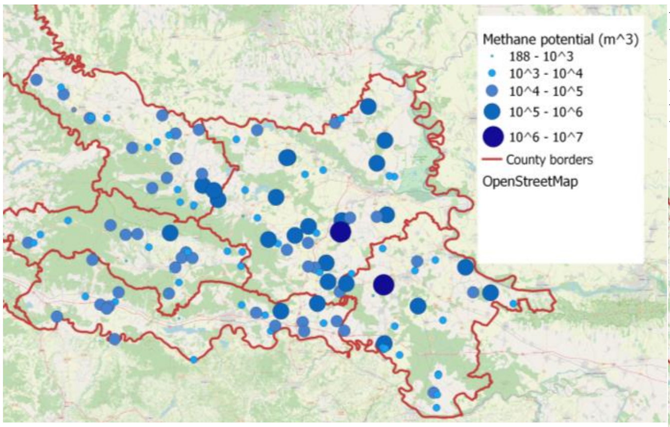

Figure 2 Methane potential of livestock farms

Methane potential of livestock farms, presented in Figure 2 is summarised for each considered county and presented in

TABLE 3 METHANE POTENTIAL IN THE CONSIDERED COUNTIES

County	Methane potential (m^3)
Osijek-Baranja county	6.983.240
Virovitica- Podravina county	837.988
Brod-Posavina county	977.653
Vukovar-Srijem county	2.234.636
Požega-Slavonia county	418.994
Total	**9.638.686**

Based on the biogas potential and locations of farms with the greatest biogas potential, the optimal location of the biogas site was determined with the "Mean coordination" query. Methane potential was used as a weighted factor. Optimal locations of biogas plants were defined for each considered county, as presented in Figure 3.

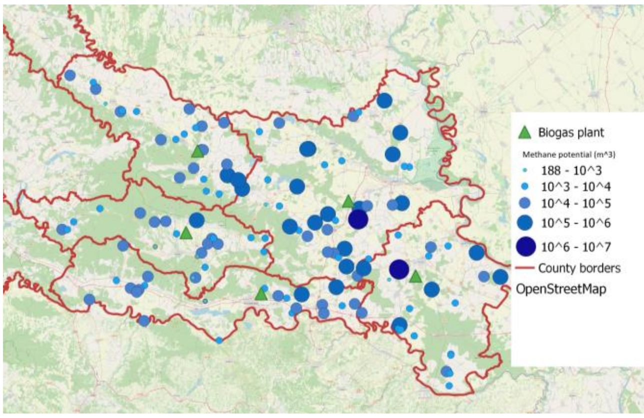

Figure 3 Methane potential and optimal biogas site location

It is clear from Figure 3 that optimal biogas sites are located closer to biogas plants with higher methane potential. Determination of optimal biogas site location leads to several benefits, such as lower transport cost and hence improves the economic viability of biogas plant, as well as decrease greenhouse gas emissions assigned to produced biogas.

In accordance with the optimal location, transport distance between farms and the optimal location of biogas plants was defined and calculated for each farm. Farms whose transport distance to biogas plants are up to 50 kilometres are considered eligible to provide feedstock for biogas production. The final results are presented in Figure 4.

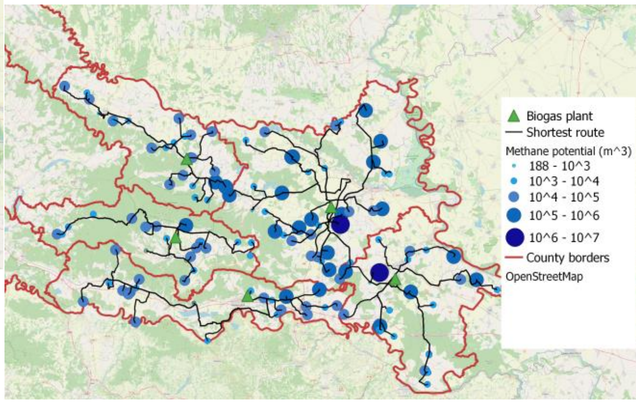

Figure 4 Shortest road route from farms to biogas sites

To determine the shortest road route presented in Figure 4, a line layer was used, that includes all roads available at the considered area.

IV. CONCLUSION

The GIS approach presented in this work exploits the spatial distribution of biogas potential from manure generated as a by-product of livestock production. The developed approach demonstrates how biogas potential, from livestock production, can be calculated and mapped with GIS tool, but also goes beyond the mapping, by enabling determination of optimal location for biogas site installation as well as shortest road distance from farms to determined biogas sites. The obtained biogas potential, calculated and mapped for five Croatian counties clearly indicate that manure has a significant potential for biogas production. More precisely, for five Croatian counties, it has been calculated that their methane potential equals 9.638.686 m^3, which provides a great untapped potential for increased production of renewable heat and electricity, but also a potential for production of biomethane, that can be used for substitution of natural gas in the natural gas grid. Optimal locations for biogas site installation, as well as transport distance between farms and biogas sites, were determined with the GIS tool (QGIS). By testing the approach and obtaining the results provided in this work, it can be concluded that a GIS tool provides several benefits in assessing biogas potential of manure, can be used for defining the optimal location of biogas plants, by using biogas potential as a weighted factor, and can very easily define the shortest route between biogas plant and feedstock provided (farms).

ACKNOWLEDGMENT

This work has been financially supported by the Croatian Science Foundation.

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