31 May – 5 June 2026
Bol, Brač Island, Croatia

Smart and resilient agriculture

Safety for future generations

2026

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Table of content

Plenary session

1 | Plant and Food Production

5 | Agribusiness and Smart Agriculture

ORIGINAL SCIENTIFIC PAPER

Spatial Patterns and Hotspots of Agricultural GHG Emissions at the Municipal Level in Slovenia

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Summary
The study quantifies methane (CH_4) emissions in Slovenia using a spatially bottom-up approach at the municipal level. Emissions are estimated based on grazing livestock data and emission factors for enteric fermentation and manure management. To enable spatial comparison, emissions are also expressed as emission intensity per selected unit and contextualised within EU-27 averages. The results reveal pronounced spatial heterogeneity. They improve understanding of the spatial distribution of CH_4 emissions, identify emission hotspots, and may support the identification of priority areas for climate policy implementation.

Keywords: methane emissions, emission hotspots, grazing livestock, spatial distribution

Introduction

Agriculture contributes significantly to non-CO_2 greenhouse gas emissions (GHG), primarily methane (CH_4) and nitrous oxide (N_2O). In agriculture, CH_4 is mainly linked to enteric fermentation and manure management in livestock, whereas N_2O emissions are associated mainly with manure management and agricultural soils, including fertilisation, atmospheric nitrogen deposition, leaching and runoff (Wójcik-Gront, 2020). In Slovenia, agriculture accounted for 10.6% of total national GHG in 2024, while CH_4 represented the largest share of agricultural emissions, with 59.7% originating from enteric fermentation and 11.7% from manure storage. Although N_2O is also part of the agricultural emission profile, this study focuses on CH_4 because of its dominant role in cattle production, which accounted for 68.6% of agricultural emissions (Climate Report, 2026). CH_4 is a short-lived climate pollutant with a perturbation lifetime of 11.8 ± 1.8 years (IPCC, 2021). In livestock production, CH_4 is generated through microbial processes. Emissions from manure storage depend on manure collection, storage duration, manure temperature and CH_4 capture (Beauchemin et al., 2022; Montes et al., 2013).

At the national level, CH_4 emissions from agriculture are linked to both direct and indirect technological, economic and socio-demographic factors that vary by region. Increased demand for livestock and crop products can lead to expanded production areas or higher livestock numbers, resulting in higher emissions (Liu et al., 2024; Hasan et al., 2025). In Slovenia, due to structural change, intensification is evident in the long-term increase in cattle numbers per farm and milk production per dairy cow, although these trends differ significantly between regions (Sadar et al., 2025).

Data on GHG emissions at the national level are reported in the Slovenian National Inventory Report (Mekinda Majaron et al., 2026). Although national GHG inventories provide the basis for emission monitoring, they do not capture within country variation in CH_4 emissions. A regional analysis can therefore provide insights into spatial variation in CH_4 emission intensity. This study aims to analyse spatial patterns and identify CH_4 emission hotspots at the municipal level in Slovenia, focusing on emissions from grazing livestock.

Material and Methods

To assess CH_4 emissions from grazing livestock at the regional level, a bottom-up approach was applied at the level of municipalities (NUTS 5). The analysis was based on the number of grazing livestock by individual categories and their spatial distribution in 2024.

For grazing livestock on regional level, an internal database developed within the national project was used (DSLFS, 2025). Compared to the official statistics of the Statistical Office of the Republic of Slovenia, it covers a broader range of holdings, as official statistics generally include farms above the threshold of 1 livestock unit (LSU). This improved grazing livestock coverage on local level.

The analysis included: three cattle categories (dairy cows, suckler cows, and other cattle), sheep, goats, and horses. These categories were selected based on their key contribution to CH_4 emissions from livestock production. According to data (Climate Report, 2026), grazing livestock accounted for 96.3% of total CH_4 emissions from livestock in 2024 (enteric fermentation and manure management), corresponding to 1,123.6 kt carbon dioxide equivalents (CO_2 eq) (Figure 1).

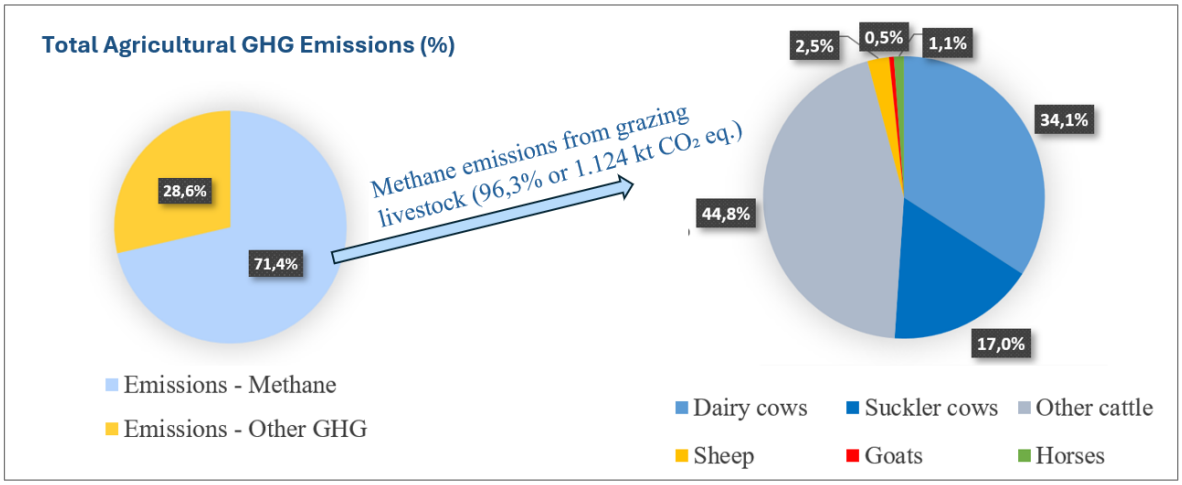

Figure 1: CH_4 emissions in Slovenia from grazing livestock, 2024 (%)

For CH_4 emission calculations, emission factors for 2024 were used (Slovenian National Inventory Report; Mekinda Majaron et al., 2026). Two separate emission factors were applied for each grazing livestock category: (i) CH_4 emissions from enteric fermentation (kg CH_4/head/year) and (ii) CH_4 emissions from manure management (kg CH_4/head/year). For dairy cows, a more detailed approach was applied by adjusting emission factors according to the average milk yield per feeding day at the municipal level. Municipality-specific coefficients linked to milk production productivity improved the accuracy of the estimates.

Based on the bottom-up approach used in this paper, we estimated that grazing livestock in Slovenia generated 1,140.4 kt CO_2 eq of CH_4 emissions in 2024. To convert CH_4 emissions into CO_2 equivalents, we used a global warming potential factor (GWP_{100}) of 28 (IPCC, 2014). The deviation from the nationally reported value was +1.5%, confirming the methodological consistency and reliability of the applied approach.

To improve comparability between municipalities, CH_4 emissions were analysed using two indicators of CH_4 intensity: (i) CH_4 emissions per hectare of utilised agricultural area (ha UAA) and (ii) CH_4 emissions per livestock unit (LSU) of grazing livestock.

To place the Slovenian results in a broader European context, average CH_4 emissions per unit were also calculated for the EU-27. Data on total CH_4 emissions were obtained from the European Environment Agency (EEA, 2026), while data on ha UAA and LSU of grazing livestock were sourced from Eurostat (Eurostat, 2026). Average CH_4 emission intensity in

Slovenia amounted to 2.4 t CO_2 eq per ha of UAA and 3.1 t CO_2 eq per LSU of grazing livestock. In the EU-27, average CH_4 emission intensity amounted to 1.5 t CO_2 eq per ha of UAA and 3.8 t CO_2 eq per LSU of grazing livestock.

Results and Discussion

The following section presents CH_4 emission intensity indicators (per ha of UAA in the Figure 2 left and per LSU in the Figure 2 right; classification legends are provided in Tables 1 and 2) based on a spatially explicit bottom-up analysis at the municipal level.

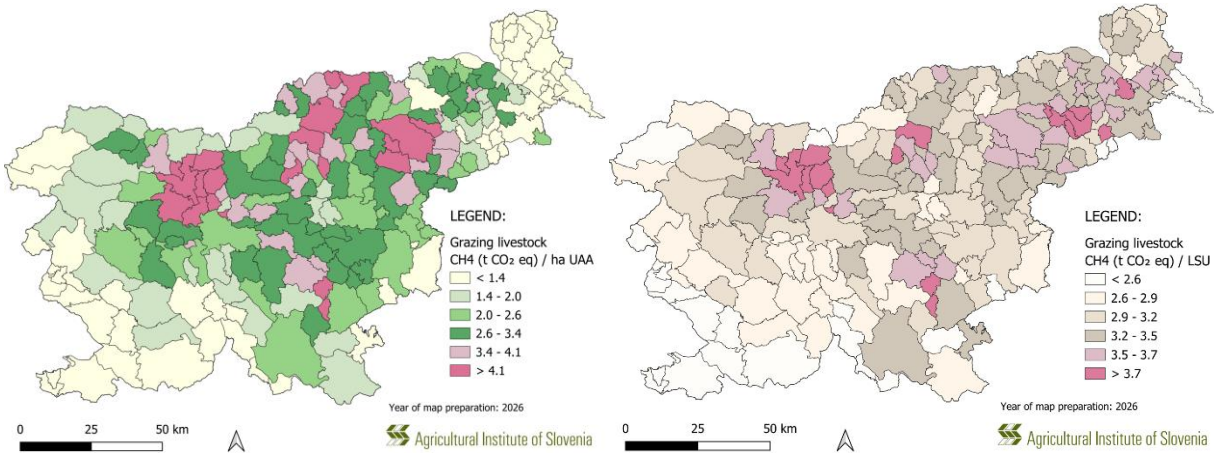

Figure 2: CH_4 emissions (tonnes CO_2 eq) per ha of UAA and per LSU

Spatial analysis of emission intensity per ha of UAA reveals three bigger clusters where emissions per unit significantly exceed both the Slovenian and EU-27 averages. These areas potentially indicate higher spatial pressure and may be suitable as case study regions for analysing CH_4 mitigation strategies in livestock systems. Overall, slightly more than 40% of municipalities fall within low emission intensity classes relative to both the Slovenian and EU-27 averages (Table 1).

Table 1: Grazing Livestock Emission Intensity Classes (per ha of UAA)

Class	Emission range (t CO_2 eq/ha UAA)	Description	Share of municipalities
Very low emission intensity	< 1.4	Below the Slovenian and EU-27 average	26.9%
Low emission intensity	1.4–2.0	Around the EU-27 average	16.5%
Moderate emission intensity	2.0–2.6	Around the Slovenian average and above the EU-27 average	14.6%
Elevated emission intensity	2.6–3.4	Above average (above the Slovenian and EU-27 average)	20.8%
Marginal emission hotspots	3.4–4.1	Noticeably above average (above the Slovenian and EU-27 average)	11.3%
Emission hotspots	> 4.1	Areas with concentrated emission pressures	9.9%

It is noteworthy that a substantial share of municipalities falls within higher emission classes compared to the EU average. However, interpretation of these results requires caution. Higher average CH_4 emissions per ha of UAA in Slovenia compared to the EU-27 are partly driven by the relatively smaller share of UAA in Slovenia (approximately 24% of national territory, compared to almost 40% in the EU-27). In simpler terms, the extent of agricultural land in Slovenia is considerably smaller than the EU-27 average, which increases emission intensity per unit of land.

In future analyses, comparisons should therefore preferably be made with structurally similar countries rather than EU-27 averages, as Slovenia's specific land-use structure leads to systematically higher emissions per unit of agricultural area.

In contrast to emission intensity per ha of UAA, CH_4 emission intensity per LSU reflects livestock system intensity and thus captures the scale of livestock production rather than land-based emission intensity. This indicator reveals a distinctly different spatial pattern. Nearly all municipalities fall into classes where emissions per LSU are below the European average (Table 2). This suggests that, despite the importance of livestock production in Slovenia, the scale and structural intensity of livestock systems remain comparatively lower than in the EU-27. Lower emissions per LSU in Slovenia are related to the particularly smaller average herd size (Slovenia: 9.1 LSU/holding; EU-27: 27.8 LSU/holding).

Table 2: Grazing Livestock Emission Intensity Classes (per LSU of Grazing Livestock)

Class	Emission range (t CO_2 eq/LSU)	Description	Share of municipalities
Very low emission intensity	< 2.6	Significantly below the Slovenian and EU-27 average	11.3%
Low emission intensity	2.6-2.9	Below the Slovenian and EU-27 average	16.5%
Moderate emission intensity	2.9-3.2	Around the Slovenian average and below the EU-27 average	25.5%
Elevated emission intensity	3.2-3.5	Slightly above the Slovenian average and below the EU-27 average	24.5%
Marginal emission hotspots	3.5-3.7	Above the Slovenian average and below the EU-27 average	13.7%
Emission hotspots	> 3.7	Areas with concentrated emission pressures	8.5%

Nevertheless, approximately 9% of municipalities exceed the Slovenian average and approach EU-27 levels. These cases require more detailed analysis, particularly in relation to natural conditions and farm structure. It is relevant to examine whether these areas correspond to more favourable agricultural regions (i.e. flat areas) which allow greater livestock concentration or correspond to areas with limited agricultural potential. However, a more detailed regional-scale analysis would be needed to better understand the underlying drivers of these patterns.

Measures to reduce CH_4 emissions differ between species and livestock categories, so future research should identify hotspots within each species or category to ensure measures are as targeted as possible. As total emissions at the regional level do not reflect actual livestock product output, further research should also examine emission intensity at the product level (meat or milk). Research should also investigate relationships between individual parameters at the regional level, for example, whether an area with low product-level intensity is characterised by high LSU-level intensity (so-called unrealized production potential), as different CH_4 intensity parameters provide insights from distinct perspectives. Finally, since political climate agreements, such as the Paris Agreement, focus on reducing additional global warming, further research should include temporal changes and use metrics that better capture the effects of emissions on temperature.

Conclusions

We identified spatial patterns of emission intensity and highlighted so-called emission hotspot areas. However, these results are not intended as a tool for "finger-pointing" at individual regions, but rather as an analytical basis for understanding structural differences in livestock emissions. In many cases, emission hotspot municipalities are located in areas dominated by less-favoured and permanent grassland regions, which play a key role in maintaining national food security through milk and meat supply and reduce the need for importing these products

(and the associated embodied emissions in imports), as Slovenia achieves a high level of self-sufficiency in these commodities.

The main added value of the results lies in providing spatial evidence on CH_4 emission distribution, improving understanding of regional emission patterns. Such insights can also support the identification of priority areas for climate policy interventions in the livestock sector and inform targeted mitigation strategies at the regional level.

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References

Beauchemin K. A., Ungerfeld E. M., Abdalla A. L., et al. (2022). Current enteric methane mitigation options. Journal of Dairy Science 105(12): 9297–9326. DOI: https://doi.org/10.3168/jds.2022-22091

Climate report on the state of agriculture in 2025. (2026). Ljubljana, Agricultural Institute of Slovenia, Ministry of Agriculture, Forestry and Food. (*Report in preparation*).

DSLFS. (2025). Development of Sustainable Livestock Farming in Slovenia (Razvoj trajnostne živinoreje v Sloveniji; Nacionalni projekt CRP V4-2402). Javna agencija za znanstvenoraziskovalno in inovacijsko dejavnost Republike Slovenije.

EEA. (2026). European environmental Agency. Greenhouse gas emissions inventory. https://climate-energy.eea.europa.eu/topics/climate-change-mitigation/greenhouse-gas-emissions-inventory/data

Eurostat. (2026). Agricultural statistics. https://ec.europa.eu/eurostat/data/database

Hasan S. S., Li Z., Zhang F. (2025). Exploring regional variations in agricultural greenhouse gas emissions: Insights from Bangladesh's districts. Geography and Sustainability 6(4). 100298. DOI: https://doi.org/10.1016/j.geosus.2025.100298

IPCC. (2014). Field C. B., et al. (eds.). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC. (2021). Masson-Delmotte V., et al. (eds.). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. DOI: https://doi.org/10.1017/9781009157896.

Liu G., Deng, X., Zhang F. (2024). The spatial and source heterogeneity of agricultural emissions highlight necessity of tailored regional mitigation strategies. Science of The Total Environment 914, 169917. DOI: https://doi.org/10.1016/j.scitotenv.2024.169917

Mekinda Majaron, T., Logar M., Šehić A., Mali B., Verbič J., et al. (2026). Slovenia's National Inventory Document 2026: GHG emissions inventories 1986–2024. Ljubljana, Ministry of the Environment, Climate and Energy, Slovenian Environment Agency.

Montes F., Meinen R., Dell C., Rotz A., Hristov A. N., et al. (2013). Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options1. Journal of Animal Science 91(11): 5070–5094. DOI: https://doi.org/10.2527/jas.2013-6584

Wójcik-Gront E. (2020). Analysis of sources and trends in agricultural GHG emissions from Annex I countries. Atmosphere 11(4): 392. DOI: https://doi.org/10.3390/atmos11040392

Sadar, M., Jeretina, J., Logar, B., Pečnik, Ž., et al. (2025). Dairy and Beef Recording database 2024. Agricultural Institute of Slovenia. https://www.govedo.si/wp-content/uploads/2025/07/POROCILO-2024_Kontrola_in_naslovnica.pdf

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