# The impact of geographic direction on greenhouse gas emissions in the European agri-food processing industry

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***Abstract*— The research objective of this paper is to investigate the relationship between geographical direction and $CO_2$, $CH_4$ and $N_2O$ emissions in food processing, considering the four geographical regions defined by FAO. A one-way ANOVA variance was used to achieve the research objective. However, as all assumptions of the ANOVA model were not met, the nonparametric Kruskal-Wallis test was used. The analysis conducted allows us to conclude that western Europe has the highest emissions in all three greenhouse gas categories. The joint analysis indicates that GHG emissions in agri-food processing are strongly regionally dependent. No significant differences were observed in only five cases: eastern and southern region (CO2 and N2O), eastern and western region (CH4), southern and northern region (CH4), southern and western region (N2O). In order to reduce GHG emissions in agri-food processing, it is recommended to implement differentiated policies adapted to the specific characteristics of the regions.**

**Keywords— industry, FAO, analysis of variance, agriculture**

## I. INTRODUCTION

Agriculture is one of the main contributors to global climate change. It is the largest emitter of methane (CH4) and nitrous oxide (N2O), mainly through animal husbandry and intensive nitrogen fertilisation (Domínguez et al., 2016; Camanzi et al., 2017). Additionally, agriculture emits significant amounts of carbon dioxide (CO2), both through land use and land use changes (Blandford, Hassapoyannes, 2018). As a result, methane, nitrous oxide, and carbon dioxide are considered key greenhouse gases emitted by the agricultural sector, and their emissions are expected to increase in the coming decades due to growing populations and changes in diets (Smith et al., 2007).

It is important that measures to reduce GHG emissions in food systems are sustainable and do not inhibit food production growth, as global food security requires increased supply (Hasegawa et al., 2015). However, GHG emissions in the food sector vary between regions and depend on local circumstances such as processing technologies, regulations, and geographical specificities (Muller et al., 2018). This is largely due to production directions, i.e., the variation between unit emissions from livestock and crop production (Rojas-Downing et al., 2017) and the overall level of agricultural production intensity. Regionally appropriate improved agricultural practices can reduce the amount of greenhouse gases entering the atmosphere (Scialabba, Muller-Lindenlauf, 2010).

Agri-food processing, a key part of the food supply chain, also contributes to GHG emissions, especially at the so-called food processing stage. What is lacking in previous work is an examination of the relationships that exist between European regions and the level of greenhouse gases in this processing stage, using analysis of variance. Therefore, this article attempts to investigate the relationship between geographic direction and the amount of CO2, CH4 and N2O emissions in food processing, taking into account the four geographical regions defined by the FAO: North, South, East, and West. In addition, the results obtained are intended to indicate how the geographical direction of Europe influences the volume of greenhouse gas emissions considered.

The FAO classification, based on geographical, climatic, and socioeconomic criteria, is a tool to compare global emission trends in a standardised manner. Environmental performance in food systems should be an important component of climate policy (Frank et al., 2017), and individual emission reduction strategies tailored to the specifics of a region can play a key role in achieving global climate goals (Forster et al., 2018). The European Union, faced with limited resources of conventional energy sources and their destructive impact on environmental well-being, is forced to seek alternative solutions (Firlej,

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Stanuch, 2023).

The research conducted will answer the following research questions:

1) Which regions of Europe have the highest and lowest greenhouse gas emissions in food processing?
2) Does the region of Europe have an impact on emissions?
3) Are there regions in Europe with similar emissions?

It was decided to verify the following hypotheses:

H1: the distribution of $CO_2$, $CH_4$ and $N_2O$ emissions in agri-food processing in each geographical direction is the same (the geographic direction does not significantly affect the achieved $CO_2$, $CH_4$ and $N_2O$ emissions in agri-food processing);

H2: the distribution of $CO_2$, $CH_4$ and $N_2O$ emissions in agro-food processing in each geographical direction is different (the geographical direction significantly influences the achieved $CO_2$, $CH_4$ and $N_2O$ emissions in agro-food processing).

The article is structured in several integral parts. The first part presents a literature search for studies covering GHG emissions in the agricultural sector. The next section presents the research methods. This is followed by a presentation of the research results and discussion. The last part of the article illustrates the final conclusions.

## II. LITERATURE REVIEW

The agri-food industry is responsible for a significant proportion of global greenhouse gas (GHG) emissions, including carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). The sector is estimated to contribute around 21-37% of global GHG emissions, with the majority of emissions coming from agricultural crops, animal husbandry, and food processing and distribution processes (Vermeulen et al., 2012; IPCC, 2019). These emissions originate from energy use, digestion processes, and emissions from organic waste management, including wastewater (WRI 2014). Steffen et al. (2018) warn of the risk of reaching climate tipping points, indicating that the agri-food sector, including processing, requires a rapid transformation towards more sustainable practices to avoid further climate damage.

In the context of agriculture and food production, methane ($CH_4$) is produced primarily by raising ruminants such as cattle, while nitrous oxide ($N_2O$) comes from soil fertilisation, particularly where nitrogen fertilisers are used (Caro et al., 2017; Carlsson-Kanyama, Gonzalez, 2007). Carbon dioxide ($CO_2$), although less directly related to agricultural processes themselves, is released in large quantities as a result of the burning of fossil fuels during the transportation, processing, and storage of products (Bienkowski et al., 2015). There is growing concern about the ecological footprint of livestock production (Delgado et al., 1999; Smil, 2002; Steinfeld et al., 2010). Research results related to increasing demand for animal products (Reay et al. 2012; Bustamante et al. 2012) predict that $CH_4$ emissions could increase by 31% between 1990 and 2030 and $N_2O$ emissions from manure management could increase by 20% (Valin et al., 2013). Herrero et al. (2016) highlight that the livestock sector has significant potential for emission reductions, and the adoption of local, sustainable processing practices could significantly reduce GHG emissions in different regions.

Processing includes activities related to raw material handling, processing, packaging, and food storage, each of which can generate significant amounts of GHG emissions (Heller, Keoleian, 2003). Food transport is a significant source of GHG emissions, and its dependence on fossil fuels can increase GHG emissions from food systems by around 8% (Sims et al., 2015). On the contrary, Flammini et al. (2024) indicate that cold chains (from transport to storage) have a significant impact on total GHG emissions in agri-food systems.

Comparative studies point to the crucial importance of the energy efficiency of processing and technology choice (Pimentel, Pimentel, 2003). In contrast, Vermeulen et al. (2012) highlight that post-production stages, including processing, are a significant source of emissions in regions with developed food industries, requiring a geographically differentiated approach to reduce these emissions. A similar view is taken by Tubiello et al. (2021), who in their study pointed out the crucial importance of actions tailored to regional emission profiles in order to effectively manage their reductions. Garnett's (2011) research indicates that significant emission reduction opportunities in Europe are in the processing sector. The author - like Rosenzweig et al. (2020) - suggests the need for a regional approach to emissions reductions, especially as processing in Europe generates more emissions than in other regions. There are several solutions to effectively address this challenge. These include reducing the gap between potential and actual yields (known as closing the yield gap), increasing crop productivity by implementing modern technologies and intensifying research, reducing food losses, changing eating habits, and developing aquaculture. Springmann et al. (2018) identify opportunities for emissions reductions in food systems, highlighting the impact of local dietary patterns and differences in processing infrastructure on emissions. Technological innovations in processing can significantly reduce GHG emissions in food systems, especially in regions with high production of processed foods, such as Europe and North America (Poore, Nemecek, 2018; Benton et al., 2021). The authors also recommend changes in consumer behaviour to complement reduction efforts. However, it is crucial that all these actions are elements of an integrated and comprehensive global strategy that balances environmental needs with food security (Godfray et al., 2010). At the same time as the need to increase food production, efforts should be made to significantly reduce its climate impact and increase the resilience of the food sector to future environmental change (Smith et al., 2008).

Geography plays an important role in the GHG emissions associated with agri-food processing. Climatic conditions, natural resource availability, energy infrastructure, and technologies used in food processing vary from region to region, which can significantly affect emissions (Burney et al., 2010; Weiss et al., 2015). In regions with colder climates, such as northern Europe, more energy is needed to heat processing plants and store food, increasing $CO_2$ emissions. On the contrary, in southern regions, where higher temperatures prevail, other factors such as water consumption and organic waste management can lead to higher methane ($CH_4$) and $N_2O$ emissions. Eastern regions of the world, characterised by an increasing demand for food products, may have greater problems with large-scale processing, generating high levels of emissions (Odegard et al., 2016).

## III. MATERIAL AND RESEARCH METHODS

The data used in the research were taken from the FAOSTAT database from section „Emissions from pre and post agricultural production". This section covers the greenhouse gas (GHG) emissions, and related activity data, generated from pre- and post-agriculture production stages of the agri-food systems. The study period was taken from 2001 to 2021.

The studies conducted focus on $CO_2$, $CH_4$, and $N_2O$ emissions in the Food Processing stage. The four regions identified by the FAO were used to illustrate the geographical direction. The following geographical regions were distinguished:

- Eastern Europe (E), comprising the following countries: Belarus, Bulgaria, Czechia, Hungary, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia, Ukraine;
- Northern Europe (N), comprising the following countries: Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom of Great Britain and Northern, Ireland;
- Southern Europe (S), comprising the following countries: Albania, Bosnia and Herzegovina, Croatia, Greece, Italy, Malta, Montenegro, North Macedonia, Portugal, Serbia, Slovenia, Spain;
- Western Europe (W), comprising the following countries: Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland.

An ANOVA analysis of variance was used to achieve the stated research objective. This technique assesses whether there are statistically significant differences between mean values in several populations. ANOVA is a data analysis method that tests measurable observations that depend on one or more factors, while helping to determine whether these factors can explain differences between mean scores in the groups analysed. ANOVA tests the hypothesis of equality of means, viz:

$H_0: m_1=m_2= \ldots = m_k$

$H_1: m_i \neq m_j$ for certain $i \neq j$ (1)

The test statistic in the ANOVA method makes it possible to determine how much of the total variability in the data is due to the factor under study and how much is due to random fluctuations. The statistic has an F distribution with $k$-1 and $n$-$k$ degrees of freedom, where $k$ is the number of levels of the factor under study and $n$ is the sample size. The use of ANOVA requires several key assumptions to be met:

- independence of the random variables in the populations (groups) under consideration,
- measurability of the analysed variables,
- normality of the distribution of the variables in each population (group),
- homogeneity of variance between populations (groups).

The normality of the data distribution was tested using the Shapiro-Wilk test, which poses two opposing statistical hypotheses. The null hypothesis assumes that the data distribution is consistent with a normal distribution, while the alternative hypothesis indicates that it is not. As noted by Nor Aishah Ahad et al. (2011) and Prabhaker et al. (2019), the Shapiro-Wilk test has higher power to detect deviations from normality compared to other tests. The decision to reject the null hypothesis is made on the basis of the p-value - if the p-value is less than the accepted significance level (5%), the nonnormality of the distribution of the analysed variable is assumed.

The homogeneity of the variance between the groups was verified using the Bartlett test, which compares the weighted arithmetic mean of the variance with the weighted geometric mean of the variance. The test is based on a statistic with an asymptotic distribution $\chi^2$, which makes it possible to assess whether variances in populations can be considered homogeneous.

If any of the assumptions of ANOVA were not met, the alternative nonparametric Kruskal-Wallis test was used. This test allows the data to be analysed under less restrictive assumptions and assesses the equality of mean ranks between groups, rather than mean values. Its interpretation is similar to the classic one-way ANOVA but adapted to situations where the data do not meet parametric requirements.

## IV. RESEARCH RESULTS

In the first stage of the study, the basic statistics of the dependent variables were analysed (Table 1). Western Europe stands out as the region with the highest emissions in all three GHG categories. The average emissions of $CO_2$, $CH_4$, and $N_2O$ are the highest, indicating that this region is the least efficient in terms of emissions reductions. Northern Europe consistently achieves the lowest emission values for all gases. Eastern Europe and Southern Europe occupy intermediate positions, with the East shows higher emissions for all gases than the South.

The kurtosis values are negative for all emission types in all regions, suggesting a flatter than normal distribution. Such a distribution means that most results cluster around the mean, with extreme values being less frequent. The skewness, on the other hand, is generally close to zero, indicating a symmetric distribution of emissions, although in some regions (e.g., Eastern Europe for $CH_4$) the skewness is higher, meaning that the distribution is slightly asymmetric and more results are on the side of higher values.

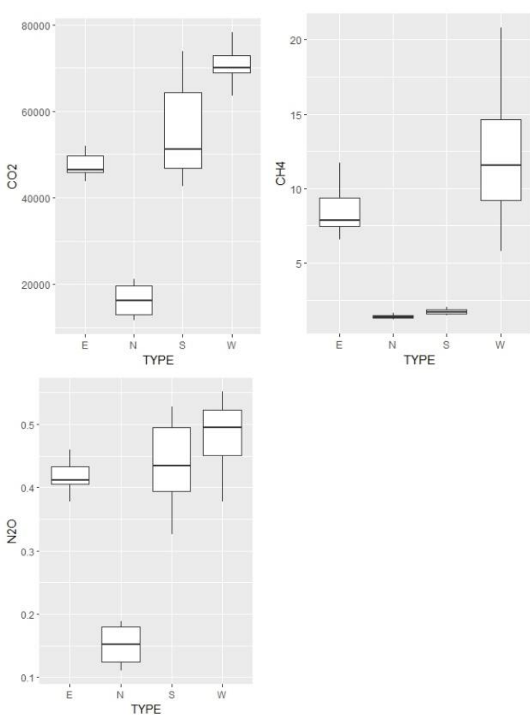
TABLE 1. BASIC DATA OF DEPENDENT VARIABLES IN INDIVIDUAL GROUPS

| Dependent variable: $CO_2$ (kt) | | | | | | |
|---|---|---|---|---|---|---|
| Types of geographical directions | Average | Median | Min | Max | Kurtosis | Skewness |
| E | 47382.29 | 46569.78 | 43746.41 | 52053.66 | -1.06 | 0.46 |
| N | 16390.28 | 16340.86 | 11721.11 | 21149.99 | -1.54 | 0.01 |
| S | 55284.34 | 51296.69 | 42701.34 | 73947.55 | -1.46 | 0.43 |
| W | 70697.94 | 70101.32 | 63641.31 | 78174.88 | -0.87 | 0.20 |
| **Dependent variable: $CH_4$ (kt)** | | | | | | |
| Types of geographical directions | Average | Median | Min | Max | Kurtosis | Skewness |
| E | 8.49 | 7.87 | 6.59 | 11.71 | -0.82 | 0.82 |
| N | 1.40 | 1.37 | 1.20 | 1.64 | -0.89 | 0.14 |
| S | 1.71 | 1.68 | 1.49 | 2.00 | -1.13 | 0.40 |
| W | 12.20 | 11.57 | 5.80 | 20.79 | -0.75 | 0.41 |
| **Dependent variable: $N_2O$ (kt)** | | | | | | |
| Types of geographical directions | Average | Median | Min | Max | Kurtosis | Skewness |
| E | 0.42 | 0.41 | 0.38 | 0.46 | -0.85 | 0.00 |
| N | 0.15 | 0.15 | 0.11 | 0.19 | -1.52 | 0.01 |
| S | 0.43 | 0.43 | 0.33 | 0.53 | -1.14 | 0.01 |
| W | 0.48 | 0.49 | 0.38 | 0.55 | -0.68 | 0.01 |

Source: own studies.

The mean values obtained of the individual variables allow for a preliminary rejection of the null hypothesis in most of the analysed cases. It should be noted that the obtained kurtosis and skewness indices suggest possible problems with the normality of the data distribution. Box plots were created to confirm the initial assumptions (Fig. 1).

FIGURE 1. BOX PLOTS SHOWING THE RELATIONSHIP BETWEEN GEOGRAPHICAL DIRECTION AND THE AMOUNT OF EMISSIONS OF INDIVIDUAL GREENHOUSE GASES




Source: own studies.

In the next step, the normality of the distribution of the variables in each population (group) was tested. The results of the Shapiro-Wilk test are presented in Table 2. The tests showed that the p-value was less than 5% in each group, indicating the absence of a normal distribution in each of the populations tested.

TABLE 2. RESULTS OF THE SHAPIRO-WILK TEST FOR INDIVIDUAL DEPENDENT VARIABLES

| | Dependent variable: $CO_2$ (kt) | | Dependent variable: $CH_4$ (kt) | | Dependent variable: $N_2O$ (kt) | |
|---|---|---|---|---|---|---|
| Types of geographical directions | W | p-value | W | p-value | W | p-value |
| E | 0.931 | 0.144 | 0.861 | 0.007 | 0.969 | 0.712 |
| N | 0.914 | 0.068 | 0.981 | 0.933 | 0.903 | 0.041 |
| S | 0.886 | 0.019 | 0.940 | 0.219 | 0.953 | 0.386 |
| W | 0.945 | 0.268 | 0.966 | 0.650 | 0.907 | 0.047 |

Source: own studies.

The homogeneity of the variance was verified using the Bartlett test and the results are shown in Table 3. Analysis indicates that there is no homogeneity of variance in any of the study groups, as confirmed by the p-values, which are less than 5% in all cases.

TABLE 3. BARTLETT TEST RESULTS FOR INDIVIDUAL DEPENDENT VARIABLES

| Dependent variable: $CO_2$ (kt) | |
|---|---|
| K-squared | p-value |
| 49.355 | 1.096e-10 |
| **Dependent variable: $CH_4$ (kt)** | |
| K-squared | p-value |
| 205.01 | < 2.2e-16 |
| **Dependent variable: $N_2O$ (kt)** | |
| K-squared | p-value |
| 24.480 | 1.983e-05 |

Source: own studies.

The Shapiro-Wilk and Bartlett tests showed that for each dependent variable, the assumptions required for the ANOVA test were not met. Therefore, a nonparametric Kruskal-Wallis test is warranted for further analysis. The results of the Kruskal-Wallis rank ANOVA test for each dependent variable are presented in Table 4.

TABLE 4. RESULTS OF THE KRUSKAL-WALLIS RANK ANOVA TEST FOR INDIVIDUAL DEPENDENT VARIABLES

| Dependent variable: $CO_2$ (kt) | |
|---|---|
| Chi-squared | p-value |
| 67.220 | 1.681e-14 |
| **Dependent variable: $CH_4$ (kt)** | |
| Chi-squared | p-value |
| 71.633 | 1.908e-15 |
| **Dependent variable: $CH_4$ (kt)** | |
| Chi-squared | p-value |
| 55.910 | 4.391e-12 |

Source: own studies.

Based on the obtained p values, which are less than the significance level of 5%, it is possible to reject the individual hypotheses that indicate that the distribution of $CO_2$, $CH_4$, and $N_2O$ emission volumes in agri-food processing in each geographical direction is the same in favour of the alternative hypothesis that at least two geographical directions differ in terms of $CO_2$, $CH_4$, and $N_2O$ emission volumes in agri-food processing. This makes it possible to conclude that the geographical directions significantly differentiate the level of dependent variables adopted for the study.

To determine the reasons for the significant differentiation between the geographical direction and the values of the individual variables, a multiple comparison test was applied (Table 5).

TABLE 5. DUNN TEST RESULTS WITH BONFERRONI CORRECTION

| Dependent variable: $CO_2$ (kt) | | | |
|---|---|---|---|
| Types of geographical directions | E | N | S |
| N | 0.001* | | |
| S | 0.422 | 0.000* | |
| W | 0.000* | 0.000* | 0.009* |
| Dependent variable: $CH_4$ (kt) | | | |
| Types of geographical directions | E | N | S |
| N | 0.000* | | |
| S | 0.002* | 0.031 | |
| W | 0.281 | 0.000* | 0.000* |
| Dependent variable: $N_2O$ (kt) | | | |
| Types of geographical directions | E | N | S |
| N | 0.001* | | |
| S | 1.000 | 0.000* | |
| W | 0.009* | 0.000* | 0.131 |
| *1 - statistically significant differences | | | |

Source: own studies.

The results obtained from the Dunn test with Bonferroni correction indicate that, for the $CO_2$ variable, there are significant differences in $CO_2$ between North and East Europe, North and West Europe and North and South Europe. Southern Europe differs significantly from Western Europe, but not from Eastern Europe. On the contrary, East and West Europe differ significantly, suggesting that these directions have different $CO_2$ emission profiles.

In addition, there are significant differences in $CH_4$ emissions between North Europe and East Europe, South Europe and East Europe, and West and North and South Europe. The East and West of Europe and South and North of Europe directions do not differ significantly, indicating that $CH_4$ emissions are similar in these regions.

When analysing $N_2O$ emissions, it should be noted that there are significant differences between North Europe and East Europe and between North and West and South Europe. On the contrary, Southern Europe is not significantly different from Eastern Europe and Western Europe, but Eastern and Western Europe are significantly different.

The results obtained are in line with the general trends observed in the literature. The analysed data show a clear variation in agricultural GHG emissions, with differences between North, East, West, and South Europe. Studies by Bauer et al. (2016), Giannadaki et al. (2018) and Ciais et al. (2010) confirm that $CO_2$, $CH_4$ and $N_2O$ emissions in Europe are highly variable and that the intensity of agriculture in different regions has a significant impact on these emissions. Countries with intensive agricultural systems, such as Germany, France, the UK, and Spain, have higher GHG emissions, including $CO_2$. Freibauer (2003) reached similar conclusions, who noted in his study that the highest agricultural $CO_2$ emissions occurred in the Netherlands and Belgium, slightly lower in some regions of France, Germany, Spain, Italy, as well as Denmark and Switzerland, and the lowest in the Mediterranean basin and northern countries. Northern European countries, such as Sweden and Finland, or Mediterranean countries (Italy, Spain, Portugal, Greece) show relatively lower $N_2O$ emissions (Boeckx, 2001). At the same time, the studies carried out confirm the conclusions presented by Odegard et al. (2016), who indicate that the eastern regions are characterised by relatively high GHG emissions. The increased demand for agricultural products and the growing intensification of production in these areas lead to higher emissions, especially in the agricultural processing sector.

## V. CONCLUSIONS

The analysis carried out concludes that western Europe has the highest emissions in all three greenhouse gas categories. At the same time, it is characterised by the highest variability of emissions, indicating that processing in this region is the most volatile. All types of emissions are relatively low in the northern region, while having the least variability between minimum and maximum values. Southern and eastern Europe occupy intermediate positions, but eastern Europe shows greater variability and higher emission values than the southern region.

The joint analysis indicates that GHG emissions from agri-food processing are strongly regionally dependent. The hypothesis that the distribution of $CO_2$, $CH_4$ and $N_2O$ emissions in agri-food processing is the same in each geographical direction was verified negatively. No significant differences were observed in only five cases: eastern and southern region ($CO_2$ and $N_2O$), eastern and western region ($CH_4$), southern and northern region ($CH_4$), southern and western region ($N_2O$). The existence of significant differences between the different geographic directions may be useful to further analyse the impact of these differences on agri-food processing. To reduce GHG emissions in agrifood processing, the implementation of differentiated policies tailored to the specific characteristics of the regions is recommended. Investments in low-carbon technologies such as renewable energy sources, heat recovery systems, and precision agriculture are key. The development of biotechnology and digitalisation can help to monitor emissions and optimise processes. It is also important to provide financial support to companies and training to support human resources to raise awareness and implement new technological solutions. Future research should focus on further understanding these differences and developing effective strategies to reduce GHG emissions in agriculture.

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