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European Green Deal Objective for Sustainable Agriculture: Opportunities and Challenges to Reduce Pesticide Use

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Abstract

Agriculture in the 21st century faces complex global challenges, including rising food demand, resource depletion, and climate change. These pressures, however, also create opportunities to foster sustainability, enhance resource efficiency, and reduce reliance on synthetic pesticides. In response, the European Union (EU) adopted the European Green Deal in 2019, aiming for climate neutrality by 2050. The Farm to Fork (F2F) strategy sets a specific target: reducing chemical pesticide usage and its related risks by half by 2030. This study aims to assess the overall situation in the EU and the Member States' contributions to achieving the F2F objective of reducing pesticide use as well as risks at the policy level. A novel methodological approach was developed to assess Member State performance using a set of EU-defined indicators – such as Harmonised Risk Indicators (HRI 1 and HRI 2), pesticide sales data from Eurostat and FAOSTAT – and to classify countries into contribution-based groups. Findings reveal progress at the EU level: pesticide sales have declined and HRI 1 has dropped, but HRI 2 has increased. Significant variation among Member States was observed, highlighting the need for tailored policy actions. The study provides an innovative framework and practical insights for policymakers and stakeholders working toward sustainable agricultural transitions in the EU.

Keywords:

European Green Deal;
Farm to Fork Strategy;
Pesticide Use; Reduction;
EU Member States;
Contribution.

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1- Introduction

In the 21st century, agriculture is facing significant challenges due to the increasing global demand for food, the decreasing arable land and water resources, and the growing impact of climate change [1]. However, these challenges also offer opportunities to develop and increase the sustainability of food systems by reducing environmental impacts and adapting to climate change [2]. This means making more efficient use of natural resources, transforming food supply chains, reducing dependence on synthetic fertilisers and pesticides, and moving towards climate-neutral and circular production systems [3]. Given the challenges, the agricultural sector is becoming one of the strategically important elements for food security, promoting sustainability, and mitigating climate change, which requires a complex and coordinated approach between policymakers, scientists, and farmers [4]. This comprehensive approach is essential to meet the global food demand, contribute to sustainable development, and tackle climate change challenges in agriculture [1, 2].

In December 2019, the European Commission presented the European Green Deal – an overarching strategic framework that sets ambitious targets for achieving climate neutrality within the EU by 2050, addressing the growing environmental and climate challenges in agriculture and food production through a complex and multifaceted approach [5, 6]. The European Green Deal defines ambitious goals for establishing a fair, healthy, and environmentally sustainable food system through the Farm to Fork (F2F) strategy, necessitating substantial transformations in agricultural practices.

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Achieving the objectives of the European Green Deal requires decisive action by all actors in the food supply chain, focusing on mitigating the negative impacts of climate change [5]. As highlighted by Boix-Fayos & de Vente (2023), moving from overarching policy objectives to the actual implementation of and transition toward greener agriculture in Europe – one that respects environmental sustainability, human rights, and social equity, including fair working conditions and access to food both within and beyond EU borders – remains a complex and multifaceted challenge. It necessitates cross-sectoral cooperation, while the policy instruments and implementation tools to support this transition are not yet fully defined or operationalised [7].

Geiger et al. (2010) concluded that decades of EU policies have significantly reduced the use of chemicals on arable land. However, pesticides threaten agriculture, wild plants and animal species [8]. Policymakers must address the issue of balancing the benefits of pesticides with their harmful effects on environmental quality and human health [9]. An honest assessment of the benefits of pesticides is necessary to debate their pros and cons. Pesticides have many benefits in pest control but also pose risks to human health and the environment [10]. Studies have highlighted a lack of knowledge about the diversity of pesticide types and their impacts [11] and the need for greater awareness of agricultural sustainability [12]. Since the 1980s, EU agricultural policy documents have emphasised the need for sustainable and environmentally friendly agricultural practices, and climate and environmental awareness has become increasingly important in farmers' daily lives as well as in policy documents, especially after the adoption of the European Green Deal in 2019 [13, 14]. However, in achieving these ambitious goals, significant economic, political and cultural challenges will be faced [15]. Socioeconomic factors remain challenging, including market inefficiencies and difficulties in convincing smallholder farmers to adopt alternative practices [16]. Strategies to address these challenges include respecting farmer autonomy, knowledge sharing, raising awareness, and promoting agroecology [17].

Achieving this goal is challenging due to the diversity of crop production systems and European geographical conditions [15]. Implementing plant diversity management at the landscape level can reduce the need for pesticides and improve biological control in nature conservation [17]. A case study from Greece revealed gaps in practitioners' knowledge and application of F2F strategies and digital technologies. This highlights the need for increased stakeholder awareness and collaboration to promote the adoption of sustainable practices [18]. However, several pathways have been identified, such as the revision of directives, applying climate and soil legislation, developing action plans, and adapting the Common Agricultural Policy (CAP). The main objective of the F2F strategy is to foster the transition to greener agriculture, setting targets to be achieved in several areas: reducing dependence on pesticides and fertilisers, limiting the use of antimicrobials, increasing organic farming areas, improving animal welfare, and preventing biodiversity loss. One of the F2F strategy's key objectives is mitigating the use of pesticides and the risks associated with them. This objective is structured around two primary targets: (1) a 50% reduction in the overall use and risk of chemical pesticides by 2030, and (2) a 50% reduction in the use of high-risk pesticides within the same timeframe [19].

Therefore, the present research aims to assess the overall situation in the EU and the Member States' contributions to achieving the European Green Deal F2F strategy`s objective of reducing pesticide use and risks at the policy level. The evaluation of the management practices in EU Member States is not the focus of this study. The novelty of the present research is based on the fact that the European Green Deal and the subordinate F2F strategy focus on transforming agriculture and the entire food system in an environmentally and human-friendly way; therefore, it is necessary to reduce the use of pesticides and their associated risks. However, some research studies have found that different pesticide use situations have historically occurred across EU Member States, determined by the level of agricultural intensification, crop yields, innovation, and technological advancements on farms [12, 17]. It is therefore important to assess the contributions of EU Member States in 2022 based on historical data and to analyse the potential developments up to 2027, as defined by the CAP Strategic Plans approved by the Member States, so that their policymakers and farmers understand the reality and they can coordinate corrective actions to achieve future goals.

The present paper is structured in four consecutive parts. The Literature Review gives an insight into the importance of the problem examined by analysing the opinions of scientists and policymakers on the positive and negative aspects of reducing pesticide use. The Research Methodology part explains the methodological framework created for the research and defines the tasks to be performed and the literature sources used. The Results and Discussion section includes empirical findings that reveal the situation in the sale of pesticides in the EU as well as an assessment of various risk factors, furthermore identifying the contributions of EU Member States towards achieving the objective of the F2F strategy – to reduce the use of and risks associated with pesticides by 2027 – and the actual implementation in 2022. The discussion is based on the findings of this study and the gaps identified in the current scientific and policy literature. The Conclusion and Recommendations summarise the main findings and, in the authors' opinion, explain how the European Commission, Member States' policymakers, and farmers could use the research results to develop a more sustainable, human, and environmentally friendly food system.

2- Literature Review

The F2F strategy`s target of reducing by 50 % the use and risk of chemical pesticides by 2030 and reducing by 50% the use of high-risk pesticides by 2030 is important because excessive or inappropriate use of pesticides can hurt soil, water, and biodiversity [19]. This is why the use of pesticides is critically discussed, and reducing the risks posed by pesticide usage to the environment and human health is a priority on the agenda for policymakers and the food industry [20]. Reducing the use of pesticides is one of the most important drivers of preserving the environment and human health [21], as all synthetic pesticides approved by the EU have potentially harmful effects on humans or ecosystems [22].

However, it should be noted that there are many significant reasons for the use of pesticides in farming, as they protect crops from pests and diseases, increase the quality of crops, reduce food losses after harvest, and ensure a decrease in production costs, thus contributing to more efficient production. The use of pesticides can contribute to the reduction of the area needed for food production because of higher yields, and above all, these factors contribute to the availability of food, as it is projected that the demand for food will increase by 50% in the next century [22, 23]. Therefore, scientists believe an in-depth analysis of crops, weeds, and herbicide usage is necessary to balance economic and environmental aspects [23].

Silva et al. (2022) believe that the F2F strategy`s objective of reducing pesticide use poses significant challenges. Strict restrictions, e.g., the authorisation of low-hazard substances or the shift to organic farming, 50% reduction in the use of pesticide meeting the target [22]. The introduction of various restrictions on the use of pesticides could lead to a decrease in the value of manufactured products by 47-55% compared with the level of 2021 [24]. Limiting the use of pesticides by 61% in Latvia could reduce farm profits by 41% without changing market prices, support, and costs [25]. Similar conclusions have been drawn by scientists Böcker et al. (2019) [20], Lechenet et al. (2017) [21], Bremmer et al. (2021) [26], Keulemans et al. (2019) [27]; therefore, these aspects might hinder the change in the behaviour of agricultural producers by shifting to alternative methods.

The use of low-risk biological pesticides has been promoted as a means to facilitate the transition to more environmentally and human-friendly farming. However, current risk assessment procedures for high-risk synthetic products complicate the process of approving lower-risk alternatives, hampering the substitution of toxic synthetic chemicals [28]. However, Klinnert et al. (2024) believe that landscape elements that support natural pest control can partially replace synthetic pesticides, thereby reducing yield differences by four percentage points and increasing farm incomes [29]. Hokkanen (2015) notes that despite scientific advances in integrated pest and disease management, farmers are lagging behind and need to consider more environmentally friendly farming practices [30].

The objective of a quantitative reduction in the use of pesticides (in this case – herbicides), focusing on parameters important for human health without an understanding of the ecotoxicological properties of the active substance, might lead to a significant increase in negative effects on non-target organisms and the environment, many of which are not immediately visible. These effects include damage to ecosystems; bee colony losses; soil contamination; food, ground, and drinking water contamination; and potential adverse health effects on applicators, pickers, and consumers [31-33]. In addition, a quantitative pesticide reduction target might also lead to a shift towards pesticides with lower doses but more toxic and persistent effects [30], thereby requiring a detailed and comprehensive assessment of the economic, productivity, and biodiversity impacts of various pesticide reduction scenarios [22].

Scientists point out that reducing pesticide use might also affect the achievement of the other objectives of the F2F strategy. Attributing greenhouse gas (GHG) emissions from pesticide production to the agricultural sector could raise public awareness and motivate farmers to use less pesticide-intensive technologies [34]. An assessment of the emissions from various agricultural raw materials and work operations found that spraying pesticides also affects emissions, e.g., 1-1.4 kg CO_2 eq. per hectare of crops, while emissions per kilogram of active substance are 6.3 kg CO_2 eq. for herbicides, 5.1 kg CO2 eq. for insecticides, and 3.9 kg CO2 eq. for fungicides [35]. A research study on GHG emissions from insecticide use on soybeans in the USA found that GHG emissions from the production and use of insecticides to control only one invasive soybean pest totalled 10.6 kg CO_2 eq. per hectare [36]. Pesticides can directly impact emissions from soil, as certain pesticides affect the activity of nitrogen-fixation bacteria in the soil and can thus contribute to an increase in emissions from the soil [37]. The impact of pesticide use (in this case – herbicides) on soil emissions is complex, as the ratio of crops to weeds changes, which creates an additional source of N from the destroyed weeds in the soil, affecting the soil temperature and humidity regime and consequently also the activity of soil bacteria, as well as the rate of gas diffusion and urease activity. Another research study found that using herbicides significantly increased CO_2 emissions from the soil and the uptake of soil CH_4, with no effect on N_2O emissions [38].

A research study on the amount of GHG emissions in China concluded that in 2018, mineral fertilisers accounted for the majority (61%) of the GHG emissions from agricultural raw materials, while pesticides accounted for 9% [39]. A research study based on analyses of policy scenarios has established that reducing the use of pesticides also leads to a significant reduction in the need for NPK mineral fertilisers and a positive side effect of reducing GHG emissions [25]. Although GHG emissions from pesticide use are lower than those from fertilisers, reducing pesticide use, especially for crops with high pesticide intensity, could also significantly reduce GHG emissions from agricultural production [34].

Some scientists also point out that an impact assessment of policy changes needs to be performed, and there is a pressing need to adapt pesticide risk assessment methodologies and align management incentives with the support of ecosystem service clusters. This may necessitate challenging trade-offs between agricultural productivity, environmental protection, and socio-economic objectives in specific contexts. The accumulated knowledge should be used to inform all stakeholders within the food value chain regarding policy decisions aimed at fostering a more balanced food production system [40, 41]. Furthermore, it is important to improve the consistency and accessibility of pesticide use data across the EU to support the design and evaluation of measures that promote sustainable agricultural practices while supporting food production and environmental health [42]. However, some scientists stress that the assessment of policy impacts related to pesticide regulation may be significantly constrained by the lack of clearly defined guidance concerning the specific actions required for implementation and the prioritisation of pesticide active substances. This ambiguity can lead to inconsistent policy application across member states, hinder the monitoring and evaluation of progress, and ultimately limit the effectiveness of strategies aimed at reducing the risks associated with pesticide use [22]. The objectives of the F2F strategy to be achieved by 2030 have been adopted for the EU as a whole [22, 25], yet this does not mean that they are defined in the same way in all Member States. The Member States had to perform several tasks in implementing the strategy, e.g., drawing up action plans for adapting the EU CAP, reviewing soil and climate-related legislation, incorporating directive requirements into national documents, etc. [7]. Achieving the EU common goals should, therefore, be indicated in the CAP National Strategic Plans for 2023-2027, which is analysed in the present research to identify a possibility for Member States to achieve the set goals [6]. Some researchers also agree that the CAP plays a unique role in supporting the objectives of the European Green Deal [6, 43, 44]. The European Commission also recognises that the CAP helps manage the transition to sustainable food systems and strengthens the efforts of European farmers to contribute to the EU's climate goals and environmental protection [45].

3- Research Methodology

To attain the research objective, a methodological framework was developed (Figure 1), and the following specific research tasks were established: 1) to analyse the overall status of pesticide use within the EU; 2) to assess the contributions of EU Member States towards achieving the pesticide reduction target defined by the F2F strategy.

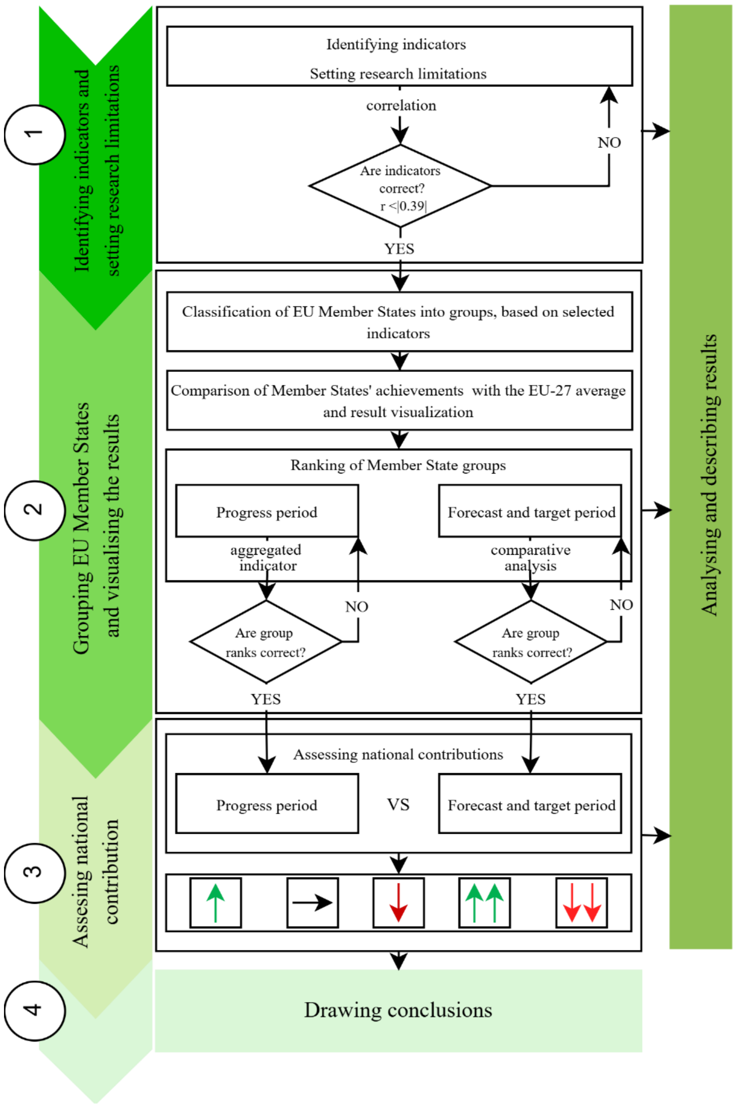


Figure 1. **Key Stages of the Research Methodology and the Intervention Logic of the Research Process and Its Core Components**

In the first stage, the research identified statistical indicators, selecting ones which show the target set by the F2F strategy and had available data. The research used the indicator "use of pesticides per unit of arable land area (kg/ha)" from the FAOSTAT database, as well as the Harmonised Risk Indicator 1 (HRI 1) available in the Eurostat database which allow Member States and the European Commission to: 1) track changes in the risks posed by pesticides over time; 2) assess the effectiveness of government policies and measures aimed at reducing the risks; 3) identify trends and create action plans for risk reduction. Since the indicator-based trends observed in previous years reflected only past trends and not current and future [46], the statistical indicators selected were complemented by a result indicator from the CAP National Strategic Plans for 2023-2027.

On 6 December 2021, the European Parliament and the Council of the EU adopted Regulation (EU) 2021/2115, which laid down the framework for assessing and tracking the impact of the CAP from 2023 to 2027 [47]. This revised results-focused approach introduces a set of harmonised contribution indicators for all EU Member States, including specific result indicators designed to measure progress toward established objectives. The CAP legislation includes 44 result indicators related to specific objectives. Not all 44 targets are included in each Member State's CAP Strategic Plan. The objectives consider needs and planned measures adopted at the national level [48]. For the objective set by the F2F strategy to reduce the use of and risks associated with pesticides, the sub-result indicator is R.24 "Sustainable and reduced use of pesticides", which shows the share of utilised agricultural area (UAA) under supported specific commitments which lead to a sustainable use of pesticides in order to reduce risks and impacts of pesticides, such as pesticides leakage [49]. The EU-27 average target value for this result indicator is 26.58% [50].

Using Microsoft Excel, the interrelationships of the indicators selected for the study were analysed using a correlation matrix to visualise the colour gradation method (Heat Map). This approach allowed us to illustrate the strength and direction of the correlation coefficients. Analysing the obtained data, it was concluded that the indicators can be used in further research since they are very weak (r: 0 – ±0.19) and have a weak correlation (r: ±0.20 – ±0.39) between them.

The region examined by the research covers 27 EU Member States: Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Czech Republic (CZ), Cyprus (CY), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), the Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Spain (ES) and Sweden (SE).

The contributions of EU Member States have been assessed for two periods: 1) the progress period (2018-2022) and 2) the forecast and target period (2022-2030).

In the second stage, EU Member States were classified into groups based on selected indicators. During the progress period, Member States were classified based on two differentiation indicators: 1) the use of pesticides per unit of arable land area (kg/ha) in 2022; 2) HRI 1 for 2022, which shows a change in pesticide use risks in 2022 compared with the average for the 2011-2013 baseline period.

To assess the contributions of EU Member States in the forecast period regarding the F2F strategy`s target of reduction by 50% in the use of chemical pesticides by 2030, the Member States were grouped based on two differentiation indicators: 1) HRI 1 for pesticides use (2011-2013 average = 100) in 2022 to measure the Member States' future potential, i.e. if HRI 1 > 50%, this means that the Member States are still on track to meet the target in the forecast and target period ahead; however, if HRI 1 < 50%, this means that the Member States have already met the F2F strategy`s targets in the progress period; 2) result indicator R.24 set by the CAP Strategic Plan of the relevant Member State for 2023-2027, which indicates current policies and future lines of action (Table 1).

Table 1. Correlation Matrix and Heat Map for the Indicators Used in the Study

Indicators	Use per area of cropland (2022) (kg/ha)	HRI 1 for pesticides (2022)	Targets for R.24 (2027) (%)
Use per area of cropland (2022) *(kg/ha)*	1		
HRI 1 for pesticides (2022)	-0.14	1	
Targets for R.24 (2027) *(%)*	-0.09	0.32	1

The indicator values achieved by EU Member States were compared with the EU-27 average, which allowed the Member States to be grouped into two groups based on each differentiation indicator: 1) above the EU average and 2) below the EU average. Thus, for both periods, Member States were classified into four groups. Based on the indicators, each group was assigned a group rank: a) Group 1 – the contributions of Member States were high compared with the EU average, i.e. the national contribution was superior (contribution opportunity); b) Group 2 – the contributions of Member States were average (contribution parity); c) Group 3 – the contributions of Member States were below average (limited contribution); d) Group 4 – the contributions of Member States were low (insufficient contribution).

A colour-coded visualisation allows Member States' achievements to be compared with the EU-27 average. It shows whether a given Member State's indicator value is higher, equal (± 15%), or lower than the EU average.

An aggregated indicator was also calculated for the progress period [51] to check whether the group ranks were assigned correctly. In order to ensure the comparison of different data and a uniform scale for analysis, the indicators used for the study were standardised using the zero unitarisation method [52]. Considering that the indicators selected for the study (pesticide use per unit of arable land area and HRI 1) are destimulants (variables that negatively affect the phenomenon under study) [52], the formula was used for standardisation (1):

$$z_{ij} = \frac{\max(x_{ij})_i - x_{ij}}{\max(x_{ij})_i - min\left(x_{i_j}\right)_i} \tag{1}$$

where z_{ij} is the normalised value of the j-th variable in the i-th country, x_{ij} is the initial value of the j-th variable in the i-th country, $\min(x_{ij})_i$ is the minimum value of x_{ij}, and $\max(x_{ij})_i$ is the maximum value of x_{ij}..

Since the normalised values are in the range [0-1], each country's average normalised value was calculated. Using the average normalised value calculated for each country, the average aggregated indicator for each group was calculated, which served as the basis for checking the group rank. The closer the aggregated indicator value was to 1, the higher the group rank was assigned.

Since the indicators used in the forecast and target period describe the future context, not the achieved level or past context, a comparative analysis combined with elements of the logically constructive method was used to check the assigned ranks rather than calculating an aggregated indicator.

In the third stage, the contributions of Member States during the progress period as well as the forecast and target period were compared to identify changes in national contributions: 1) whether the Member State's contribution improves; 2) whether the Member State's contribution deteriorates; 3) whether the Member State's contribution is stable; 4) whether the Member State's contribution significantly improves; 5) whether Member State's contribution deteriorates significantly.

In each stage, the research analysed the indicator values calculated and described the results, and at the end, the main conclusions and proposals were formulated.

The research used information and indicators from Eurostat [53-59], FAOSTAT [60], and the European Environment Agency [46], as well as reference values defined by the European Commission.

4- Results and Discussion

4-1- Characteristics of Pesticide Sales in the EU

The consumption of pesticides by agriculture could best be described by data on the actual use of active substances by farms or by application rates, yet this information is not available [42]. Currently, the EU uses data on pesticide sales [40] to indicate pesticide consumption by agriculture. Member States regularly provide the European Commission with pesticide statistics, and Eurostat publishes annual data on active substances in pesticides sold. The data show that sales of pesticides in the EU were relatively stable between 2011 and 2021, with total annual sales hovering around 350000 tonnes ± 6 % [41].

Figure 2 shows that in 2022, sales of pesticides in the EU decreased to approximately 322000 tonnes, the lowest level since the start of the data series in 2011. The decrease in 2022 was equivalent to 10 % compared to 2021 and was approximately 12 % lower than in 2011 [55]. In 2019, the amount of pesticides sold in the EU reached the second-lowest level since the start of the data series, with just over 333000 tonnes sold, which was 6% lower than in 2018; however, in the following two years, there was a moderate increase. This represents a further return to the medium-term annual average; therefore, decreasing pesticide sales in 2022 should be considered cautiously. The decrease in pesticide sales in 2022 of -10 % compared with 2021 could be partially explained by increased pesticide costs caused by the war in Ukraine and the resulting market volatility [57].

An analysis of trends within pesticide groups revealed that fungicides and herbicides were two large groups of pesticides that accounted for a significant share (on average 43% and 34%, respectively, during the period) of pesticides in the total. Their sales were relatively stable, with slight fluctuations in some years. Sales of the other pesticide groups were significantly lower but with relatively stable consumption during the period [61].

France, Spain, Germany, and Italy recorded the highest sales of pesticides in the EU in 2022 [59]. These Member States were also the main producers of agricultural products in the EU, both in terms of the share of agricultural land (52%) and the share of total EU arable land (49%) [59]. In contrast, Malta (0.03%), Luxembourg (0.04%), Estonia (0.24%), Slovenia (0.26%) recorded the lowest sales of pesticides in the EU in 2022 [59]; therefore, the national contribution in terms of reducing chemical pesticide use and associated risks by 50% was measured not based on the amount of pesticides sold in the market and therefore used in each Member State, but based on the use of pesticides per hectare of arable land area (kg/ha) (FAOSTAT data) [60]. It should also be noted that the Eurostat database for several EU Member States (BG, EE, LU, MT) [59] did not provide data on total sales of pesticides in 2011-2013; therefore, the research employed FAOSTAT data on pesticide use per arable land area.

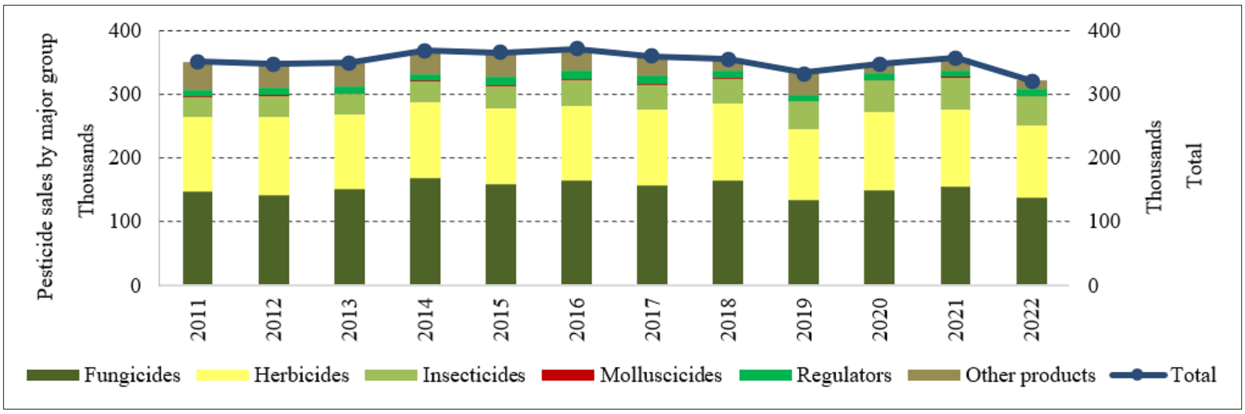


Figure 2. Pesticide Sales by Major Groups in the EU in 2011-2022, were Thousands of Tonnes [58]

Data for the FAO's pesticide use database are drawn from government surveys, and import and manufacturing data are reported annually to the FAO statistics division and made available on their database platform [62]. Many scientists have used the FAOSTAT database; e.g., A. Shattuck et al. (2023) examined the use of pesticide data [62], F.H.M. Tang et al. (2021) investigated the risks of ground, surface water, atmospheric water, and other pollution [63], and E.S. Bernhardt et al. (2017) examined global drivers of environmental change [64]. Some scientists point out that the most important benefits of pesticide use are higher agricultural yields, enhanced product homogeneity, and reduced agricultural labour and energy costs [30], while several scientists highlight the harmful effects of pesticide use on the environment and human health [22, 30-33].

To assess progress in sustainable pesticide use policies, two harmonised risk indicators are currently used in EU Member States and at the EU level: the HRI 1 and HRI 2 [31]. The European Commission published both indicators for the first time in 2019 for 2011-2017 [65]. HRI 1 is based on pesticide sales statistics, while HRI 2 is based on the number of issued emergency use authorisations for pesticides [66]. These indicators have been used to assess changes in pesticide use since the entry into force of Directive 2009/128/EC. The baseline value of the harmonised risk indicators is 100, corresponding to the average indicator for 2011-2013. The research has also used this baseline period (2011-2013), as data on the baseline of the average of three years 2015-2017 are not available for all EU Member States [67]. At the EU level, HRI 1 shows that the risk to human health and the environment from pesticides sold in the EU has decreased by 50% in 2022 compared to the baseline period 2011-2013 and by 11% compared to 2021. Moreover, this risk has decreased as the volume of pesticides sold has remained relatively constant. Hence, these data reflect a change in the characteristics of pesticides sold and used in the EU and indicate that overall sales of pesticides containing non-chemical active substances are increasing in the EU. This downward trend in the EU is mainly because sales of unapproved active substances (Group 4) are decreasing, which have a higher weight in the indicator calculation (Figure 3).

Indicator /Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
HRI 1	108	98	94	98	99	94	86	86	80	68	61	50
HRI 2	100	95	105	132	134	151	149	131	117	135	133	112

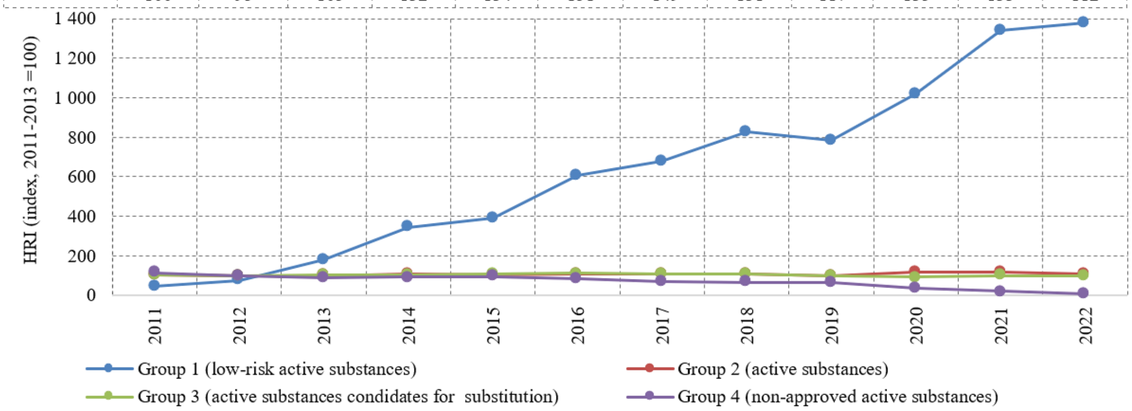


Figure 3. HRI 1 and HRI 2 (Index, 2011-2013 Average = 100) for the EU-27 by Group of Substances in 2011-2022 [58, 65, 67, 68]

HRI 2 shows that in 2022, the EU had a relatively high number of emergency use authorisations for pesticides, showing a 12% increase in value since the base period 2011-2013, but an 11% decrease compared to 2021. Although the last two years have seen a decrease in the amount of the most hazardous pesticides placed on the market, it points to the need to further reduce the risk by more fully implementing Directive 2009/128/EC and, in particular, by more widely implementing integrated pest management methods, including non-chemical pest and disease control methods [65, 69]. HRI 2 data are unavailable for all EU Member States, so this indicator was not included in the analysis [67]. The upward trend in HRI 2 indicates that the EU still lacks or is not using a sufficient range of preventive pest control tools that would reduce reliance on pesticides [70, 71].

It should be noted that neither of the two indicators introduced by the EU objectively shows how successfully a Member State is achieving the EU's goals regarding the sustainable use of pesticides, although they describe general changes in pesticide use.

It should be noted that pesticide sales and use rates are not identical. They are variables that depend on various factors, such as crop composition, agricultural practices, crop and input prices, and responses to changes in agricultural policy, which may include increased pesticide purchases and stockpiling. Furthermore, pesticide sales and use rates are not equivalent in risk and impact, as data on these processes do not reflect the properties of the pesticide's active substance used and its effects [72].

4-2-Evaluation of the Contributions of EU Member States to Achieving the Objective Defined in the F2F Strategy - to Reduce the Use of and Risks Associated with Pesticides

To assess the current contributions of EU Member States towards reducing chemical pesticide use and associated risks by 50% by 2030, the Member States were classified into four groups based on two differentiation indicators described in the research methodology (Figure 4).

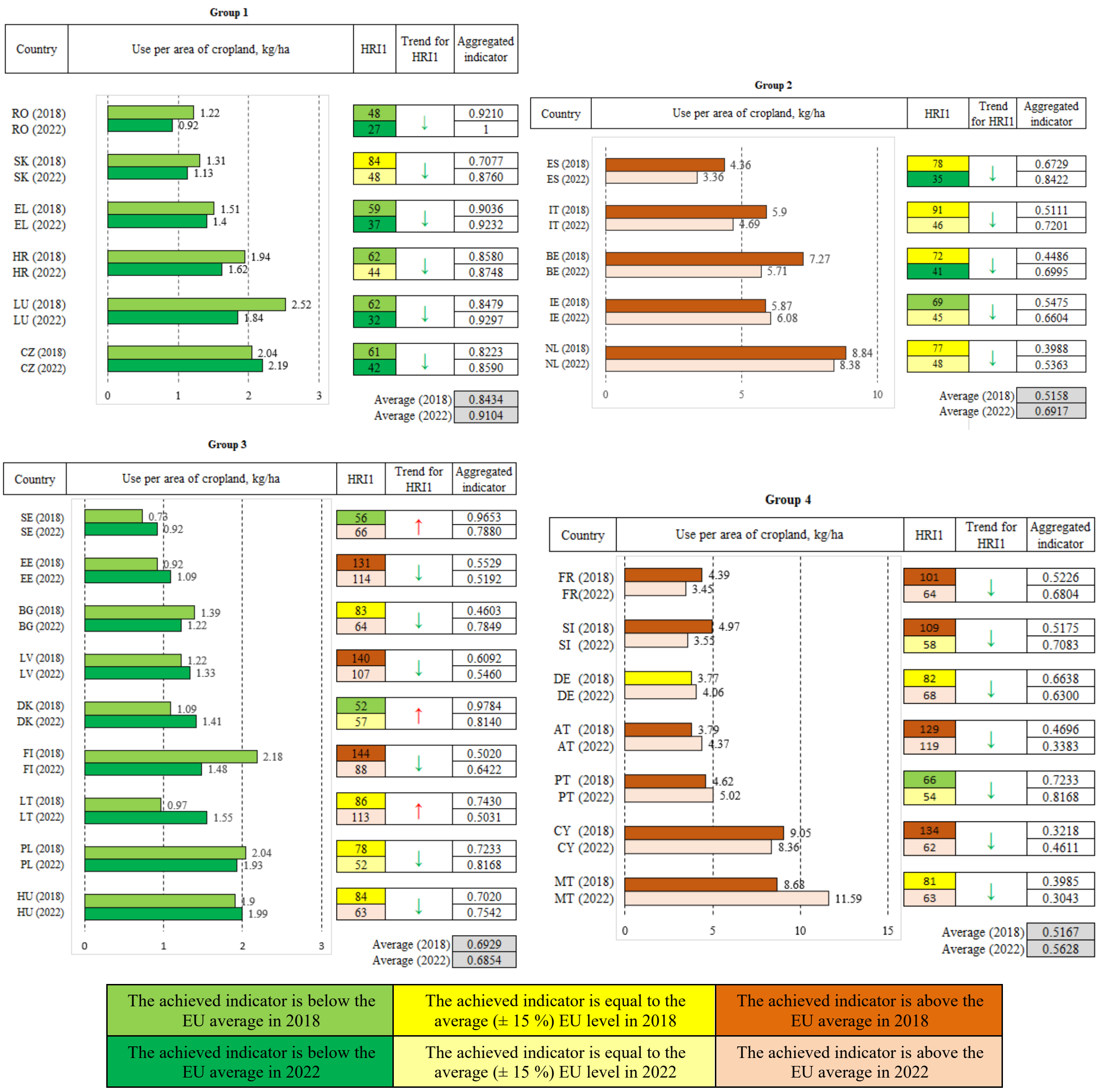


Figure 4. Classification of EU Member States by Pesticide Use per Unit of Arable Land Area (kg/ha) and HRI 1 in 2022 [56, 61]

The results of the analysis shown in Figure 4 show that Group 1 includes six EU Member States (RO, SK, EL, HR, LU, CZ), with pesticide use per hectare of arable land being below the EU-27 average (< 2.89 kg/ha) and ranging from 0.92 kg/ha (RO) to 2.19 kg/ha (CZ). In 2022, HRI 1 for Group 1 was below the EU average, i.e. below 50%, meaning that pesticide use and associated risks have decreased by more than 50% since the baseline period of 2011-2013. These Member States reached the target at the end of the progress period, i.e. in 2022. Based on the assumptions and research results, if compared with the EU average (± 15%), the values of HRI 1 achieved by Slovakia and Croatia in 2022 and Slovakia in 2018 were at the EU average.

Group 2 includes five EU Member States (ES, IT, BE, IE, NL), with pesticide use per hectare of arable land area exceeding the EU average (or > 2.89 kg/ha) and ranging from 3.36 kg/ha (EU) to 8.38 kg/ha (NL). However, HRI 1 for Group 2 in 2022 compared with the average in the baseline period of 2011-2013 was below 50%, which means that pesticide usage and associated risks have decreased by more than 50%. Based on the assumptions and research results, if compared with the EU average (± 15%), 2022 HRI 1 for three Member States (NL, IE, IT) was at the EU average. Only two Member States (ES, BE) classified in this group had an indicator below the EU average, i.e. the situation was better.

Group 3 includes nine EU Member States (PL, DK, HU, BG, SE, FI, LV, LT, EE), where pesticide use per hectare of arable land area was below the EU-27 average (< 2.89 kg/ha) and ranged from 0.92 kg/ha (SE) to 1.99 kg/ha (HU), while HRI 1 in 2022 was above the EU-27 average (> 50%). In the six Member States (PL, DK, HU, BG, SE, FI) belonging to Group 3, pesticide use and associated risks have decreased since the baseline period of 2011-2013, while in the Baltic States (LV, LT, EE) they have increased by 7 %, 13 % and 14 %, respectively; in Lithuania, Estonia and Latvia the amount of pesticides sold was very insignificant in absolute terms [55]. The authors' calculations showed that in all the three Baltic States, a change in the UAA in the period 2012-2022 was positive, meaning that the UAA increased by 7% in Latvia, 3.2% in Estonia and 2.4% in Lithuania, while in the other six Member States (PL, DK, HU, BG, SE, FI) a change in the UAA was negative – the areas have decreased, especially in Hungary (4.8%) [60]. If compared with the EU average (± 15%), in 2022, the values of HRI 1 for Poland and Denmark (52 and 57) were at the EU average, while in the other member States of this group – above the EU average, i.e. the situation was worse.

The aggregated indicators confirm and demonstrate that during the progress period, the contribution of countries in Group 1 is high (contribution opportunity), and the average aggregated indicator of the group is 0.9104. The contribution of countries in Group 2 is average (contribution parity), and the contribution of countries in Group 3 is below average (limited contribution). The calculated average aggregated indicators are 0.6917 and 0.6854, respectively for 2022 demonstrate that there are small differences between Groups 2 and 3; however, each group has its own advantages: Group 2 has a low HRI 1, and Group 3 has low pesticide use per hectare of arable land compared to the average EU-27 indicator. The contribution of countries in Group 4 is low (insufficient contribution).

Group 4 includes seven EU Member States (PT, SI, CY, MT, FR, DE, AT) where pesticide use per hectare of arable land area exceeded the EU average (> 2.89 kg/ha), and HRI 1 was more than 50% in 2022. The highest levels of pesticide use per hectare of arable land area were reported in Malta (11.59 kg/ha) and Cyprus (8.36 kg/ha). An analysis of the trends in the UAA in these two Member States showed that in Malta, the UAA decreased by 6.3 % between 2012 and 2022, while in Cyprus, there was an increase of 5.9 % [47]. In the six Member States from this group, pesticide usage and associated risks have decreased since the baseline period of 2011-2013, whereas in Austria, it has increased by 19 %. It should be noted that Austria and Germany had a large volume of inert gases, e.g., carbon dioxide or nitrogen, used to store agricultural products, which increased the total amount of pesticides sold there [42]. If compared with the EU average (± 15%), in 2022, the values of HRI 1 for Portugal and Slovenia could be aligned with the EU average (Figure 4).

To assess the contributions of EU Member States to achieving the F2F strategy`s target of reducing the use of chemical pesticides by 50% by 2030 in the forecast and target period, the Member States were grouped using two differentiation indicators:

1) HRI 1 for pesticide use (2011-2013 average = 100) in 2022. Based on this, the Member States were classified into two sub-groups: HRI 1 > 50%, which means that the Member States were still on track to achieve the target in the forecast and target period, and HRI 1 < 50%, meaning that the Member States have already achieved their F2F targets in the progress period;

2) result indicator R.24 – sustainable and reduced use of pesticide, % – set by the EU Member States' CAP Strategic Plans for 2023-2027 was compared with the EU-27 average (R.24=26.58%), which means that the EU Member States plan to dedicate 26.6% of the EU`s utilised agricultural area to sustainable management and reduced use of pesticides. Based on the indicators, the Member States were classified into four groups (Figure 5).

Group 1	HRI 1 for pesticides 2022 < 50 %				HRI 1 for pesticides 2022 > 50 %			Group 3
Targets for R.24 > 26.6%	*Member State*	*HRI 1*	*Targets for R.24, %*		*Member State*	*HRI 1*	*Targets for R.24, %*	Targets for R.24 > 26.6%
	LU	32	36.36		PT	54	29.09	
	EL	37	30.0		SI	58	40.24	
	BE (Wallonia)	41	27.21		CY	62	32.47	
	CZ	42	26.55		FR	64	61.4	
	IT	46	36.21		DE	68	33.75	
	SK	48	27.6		LV	107	34.82	
					EE	114	28.81	
					AT	119	44.78	
Group 2	**HRI 1 for pesticides 2022 < 50 %**				**HRI 1 for pesticides 2022 > 50 %**			**Group 4**
Targets for R.24 < 26.6%	*Member State*	*HRI 1*	*Targets for R.24, %*		*Member State*	*HRI 1*	*Targets for R.24, %*	Targets for R.24 < 26.6%
	RO	27	7.93		PL	52	9.43	
	ES	35	4.63		DK	57	17.27	
	BE (Flanders)	41	13.53		HU	63	23.94	
	HR	44	12.63		MT	63	11.42	
	IE	45	7.45		BG	64	18.09	
	NL	48	6.62		SE	66	14.54	
					FI	88	19.57	
					LT	113	20.99	

Better performance compared to the EU average	Similar to the EU average (±15%)	Worse performance compared to the EU average

Figure 5. Classification of EU Member States by HRI 1 in 2022 and Result Indicator R.24 set by the Member States' CAP Strategic Plans for 2023-2027 Compared with the EU-27 Average [56, 73]

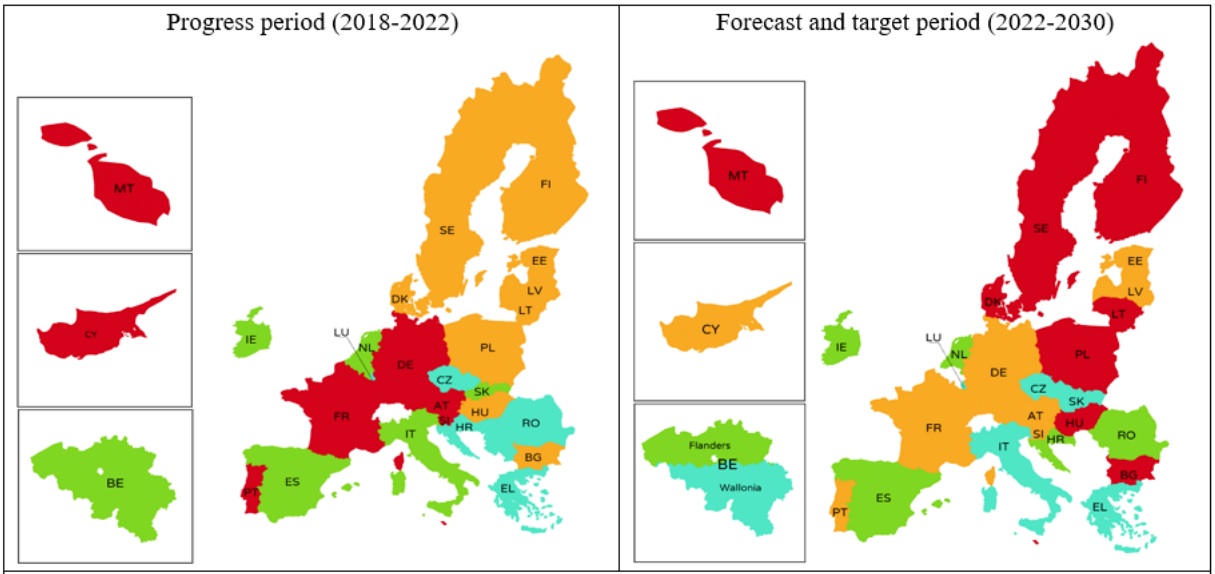
The results of the analysis presented in Figure 5 show that Group 1 includes six EU Member States (LU, EL, BE (Wallonia), CZ, IT, SK) that have already reached the target set by the F2F strategy (HRI 1 < 50%) and the result indicator set by the CAP Strategic Plan for 2023-2027, i.e. R.24 was above the EU-27 average (> 26.6%). An analysis of the national priorities concerning this indicator showed that four Member States (EL, CZ, IT and SK) have prioritised reducing the use of chemical pesticides and fostering integrated pest management (Figure 6). However, it is a medium priority for Luxembourg and the Wallonia region of Belgium [56]. A comparison of the national indicator values with the EU average (± 15%) revealed that only Luxembourg has achieved a level above the EU average in both indicators. When evaluating the indicators characterising the future context, the contribution capacity of countries in Group 1 in the forecast and target period is assessed as high (contribution opportunity).

Group 2 includes six EU Member States (RO, ES, BE (Flanders), HR, IE, NL) that have already reached the target (HRI 1 < 50%) during the progress period, while result indicator R.24 was below the EU-27 average (< 26.6%). Spain, the Netherlands, Ireland and Romania (< 8%) have set relatively low targets. An analysis of the national priorities for this target (Figure 6) showed that Romania, Spain and Croatia have prioritised the need to reduce the use of chemical pesticides and foster integrated pest management. However, the other EU Member States have stated in their CAP Strategic Plans that there is a lesser need to reduce the use of chemical pesticides and foster integrated pest management [56]. The performance of countries in Group 2 in the forecast and target period is assessed as average (performance parity).

Group 3 includes eight EU Member States (PT, SI, CY, FR, DE, LV, EE, AT) with HRI 1 > 50%, meaning that these Member States still must make efforts to achieve the target in the forecast and target period, while result indicator R.24 was above the EU-27 average (> 26.6%). Three Member States (FR, AT, SI) have set relatively high targets for R.24 (> 40%). However, four Member States (AT, EE, FR, CY) have given high priority in their CAP Strategic Plans for 2023-2027 to reduce the use of chemical pesticides and foster integrated pest management [56]. If the national indicators are compared with the EU average (± 15%), it could be concluded that the level achieved by Portugal in both indicators was equal to the EU average. When comparing the indicators characterising the future context with the EU-27 average indicators, the countries' contribution in Group 3 in the forecast and target period is assessed as limited or below average.

Group 4 includes eight EU Member States (PL, DK, HU, MT, BG, SE, FI, LT) with HRI 1 > 50%, meaning that these Member States still have to make efforts to achieve the target in the forecast and target period, while at the same time their targets for R.24 lacked ambition or R.24 was below the EU-27 average (< 26.6%). A relatively low target (9.43 %)

and a target priority have been set by Poland, with HRI 1 being 52. The other Member States have set R.24 above 10 % (UAA under commitments for sustainable and reduced use of pesticides), yet these Member States have HRI 1 above 55. If compared with the EU average (± 15%), the national indicator values for five Member States (MT, BG, SE, FI, LT) were below the EU average (Figure 5). The countries' performance in Group 4 is assessed as low (insufficient contribution). Figure 6 summarises EU Member States' contributions to reducing pesticide use and risks defined in the European Green Deal F2F strategy.



Colour legends:

Contribution opportunity (group 1)	Contribution parity (group 2)	Limited contribution (group 3)	Insufficient contribution (group 4)

EU Member States:

	AT	BE[1]	BE[2]	BG	HR	CY	CZ	DK	EE	FI	FR	DE	EL	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE
Trends	↑	→	↑	↓	↓	↑	→	↓	→	↓	↑	↑	→	↓	→	↑	→	↓	→	→	→	↓	↑	↓	→	↑	→	↓
Need to reduce chemicals and promote integrated pest management [56]	3	2.3	2	2.7	3	3	3	3	3	1	3	2.3	3	2.2	2	2.7	2	2	2	1.7	2.3	3	2.3	3	2.5	2.3	2.5	3

[1] BE- Flanders; [2] BE- Wallonia; ↑- contribution improves; ↓- contribution deteriorates; →-contribution is stable.

Figure 6. Assessment of the Contributions of EU Member States to Achieving the Objective Defined by the F2F Strategy: to Reduce the Use of and Risks Associated with Pesticides During the Progress Period, as well as in the Forecast and Target Period.

As shown in Figure 6, to achieve the F2F strategy`s objective of reducing the use of and risks associated with pesticides, the contribution tended to improve in eight Member States – Austria, Cyprus, France, Germany, Italy, Portugal and Slovenia – and one region of Belgium (Flanders), while it was stable in 10 Member States – the Czech Republic, Estonia, Greece, Ireland, Latvia, Luxembourg, Malta, the Netherlands, Romania and Spain – and one region of Belgium (Wallonia). In contrast, the other 9 Member States must improve significantly in the future.

An analysis of the trends in achieving the Green Deal objective of reducing the use of and risks associated with pesticides revealed that the contribution deteriorated mainly during the progress period in the Member States classified in Group 3 (BG, DK, FI, HU, LT, PL, SE), i.e. those with a limited contribution to achieving the target, as well as Croatia and Romania classified in Group 1. Result indicator R.24 lacked ambition in these Member States (R.24< 26.6%), even though six Member States (PL, RO, DK, BG, SE, HR) have given high priority to the need to reduce the use of chemical pesticides and foster integrated pest management, while the rest have indicated a lesser need to reduce the use of chemical pesticides and foster integrated pest management [56].

The aggregated data showed that the national contributions improved mainly during the progress period in the Member States classified in Group 4 (AT, CY, FR, DE, PT, SI), i.e. those with insufficient contributions to achieving the target, as well as Belgium (Wallonia) and Italy, which are part of Group 2. The data showed that result indicator R.24 set by these Member States was above the EU-27 average (R.24> 26.6%). Three Member States (FR, AT, SI) have set relatively high targets for R.24 (> 40%). However, four Member States (AT, FR, CY, IT) have given high priority in their CAP Strategic Plans to reduce the use of chemical pesticides and foster integrated pest management, while the rest have given medium priority to it [56].

The aggregated data indicate that the national contribution remained stable for the Member States classified in Groups 1 and 2 during both periods, i.e. those with superior (contribution opportunity) and medium (contribution parity) contributions to reducing pesticide use and pesticide risks.

The European Commission [56] gives "high" priority to clusters of needs with a priority value of 2.5-3. Clusters of needs with priority values of 1.5 to 2.4 are classified as "medium" priority, and those between 1 and 1.4 are classified as "low" priority. Clusters of needs with priority values below one are classified as having no priority (blank).

A critical challenge identified during the review of existing scientific literature is the scarcity of research specifically addressing the contributions of EU Member States toward the pesticide reduction targets outlined in the F2F Strategy. This gap partially stems from the novel methodological approach employed in this study, which was independently developed by the authors based on their accumulated research experience and applied here for the first time. The methodology includes an innovative dimension – particularly in selecting indicators to assess national contributions. While previous studies on pesticide use in agriculture predominantly utilised traditional metrics such as "total pesticide sales" (in tons) [74], "pesticide sales per hectare" (kg/ha) [75], and "fertiliser consumption per hectare" [76], the present study introduces newer indicators: HRI 1 and the result indicator R.24 from the EU member States CAP Strategic Plans. Both were established relatively recently – by the European Commission in 2019 and 2021, respectively – to enable consistent monitoring of progress towards pesticide reduction goals [77]. Furthermore, most existing literature focuses on retrospective evaluations, whereas this study adopts a dual temporal perspective, assessing historical trends and projected future contributions (forecast and target period). This methodological shift presents limitations when aligning the study's findings with earlier research.

In examining fiscal instruments, Blagoeva and Georgieva (2023) explored the concept of tax greening and concluded that there is no direct relationship between pesticide taxation and reduced pesticide usage [74]. The current study corroborates this conclusion. Across the EU, pesticide-related tax policies generally fall into two categories: (1) reduced Value-Added Tax (VAT) rates for agricultural inputs (including pesticides) and (2) specific pesticide taxes. Among these, reduced VAT rates are more widespread. For instance, Belgium, Spain, France, Italy, Cyprus, Portugal, and Slovenia all apply reduced VAT rates on pesticides. In this study, these countries are placed in Groups 2 and 4, characterised by pesticide use per hectare exceeding the EU average. In contrast, Germany and Austria (in Group 4 during the progress period) offer reduced VAT only on organic fertilisers. Meanwhile, Poland and Romania – belonging to Groups 3 and 1, respectively, where pesticide use is below the EU average – also apply reduced VAT to pesticides. Countries like Germany, Ireland, Luxembourg, and Latvia maintain standard VAT rates on pesticides [74], with their classification across different contribution groups reinforcing the lack of a consistent link between taxation and pesticide use intensity.

These results are consistent with research by Kasztelan and Nowak (2021), who evaluated green agricultural performance across 20 EU countries. Their results showed generally positive trends in pesticide use reduction during 2008-2017, evidenced by a high average standardised indicator value of 0.8446 [75]. Nevertheless, they noted that high pesticide use persisted in the Netherlands and Belgium, countries also classified in Group 2 (contribution parity) in the present study. Both continued to show the highest pesticide usage in their group in 2022, indicating persistent challenges despite broader EU sustainability goals.

Kasztelan & Nowak (2021) also reported favourable outcomes in countries such as Poland (Group 3), Czech Republic (Group 1), Hungary (Group 3), Slovenia (Group 4), and France (Group 4), most of which are categorised in this study as having limited or insufficient contributions to the F2F goals [75]. Meanwhile, Portugal, Austria, and Greece were identified as having high levels of green performance. This study classified Greece under Group 1 (contribution opportunity), whereas Portugal and Austria fall under Group 4 (insufficient contribution). Member States like Romania and Croatia – placed in Group 1 in this study – were not included by Kasztelan & Nowak (2021) [75]. Their analysis found that Slovakia and the Czech Republic exhibited medium-high green performance, and Luxembourg was assessed as medium-low [75].

A follow-up study by Nowak and Kasztelan (2022) [52] examined the green competitiveness of agriculture across EU Member States but did not include pesticide-related indicators. They emphasised that economic competitiveness in agriculture often does not correlate with environmental performance, arguing that more economically competitive systems exert more significant environmental pressure, while those with lower economic output may score higher environmentally [52]. In this study, Austria ranked highest in green competitiveness and the Netherlands lowest, whereas Spain led in economic competitiveness and Lithuania scored the lowest.

Further insights come from Jarosz-Angowska et al. (2022) [76], who assessed the overall competitiveness of the agricultural sector in all 27 EU Member States in 2004 and 2018. They included fertiliser consumption as a variable and concluded that overall agricultural competitiveness in the EU remained low in 2018. The most competitive countries were Romania, France, the Netherlands, and Denmark, while the least competitive were Finland, Portugal, and Cyprus. One of this study's key conclusions was that fertiliser use negatively impacted the competitiveness of agriculture, as evidenced by the low average standardised value of this indicator (0.1037). Notably, pesticide use was excluded from the competitiveness assessment, indicating a gap in the evaluation of inputs that affect both environmental sustainability and competitiveness within the agricultural sector.

In the report, Burtscher-Schaden (2022) [77] explains Austria's high HRI 1 score resulting from the intensive use of low-risk pesticides, especially those used in organic farming. Despite their lower toxicity, the HRI 1 methodology does not sufficiently differentiate between low- and high-risk substances, potentially overstating environmental risk and highlighting a limitation in current assessment frameworks [78].

Similarly, Nowak et al. (2019) did not include pesticide use or sales indicators in their sustainability assessment of EU agriculture [79]. Their findings identified Slovakia and the Czech Republic as highly sustainable, and the Netherlands, Belgium, Cyprus, and Malta were ranked among the countries with the lowest levels. This study categorises Cyprus and Malta in Group 4 (insufficient contribution) for the progress period. In both, pesticide use per hectare exceeds the EU average, with HRI 1 values in 2022 exceeding 50%. Cyprus's high pesticide usage is associated with its intensive horticulture and warm climate, which favours pest and disease proliferation [31, 80]. Malta's elevated usage is primarily linked to its limited land area, high concentration of vegetable production (over 90% of total output), and extensive use of fungicides [81].

A broader literature review across multiple agricultural dimensions consistently highlights the Czech Republic as a top contributor to sustainable farming practices. This aligns with the findings of this study, where the Czech Republic is consistently categorised in Group 1 (contribution opportunity) across all assessed periods. Conversely, the Netherlands and Cyprus are frequently cited as countries with low environmental contributions. In this study, the Netherlands is assigned to Group 2 (contribution parity), while Cyprus is in Group 4 in the progress period and Group 3 in the forecast and target period. The Netherlands' environmental performance is often explained by its highly competitive and intensive agricultural economy [76, 79], which tends to exert substantial environmental pressure [52]. Cyprus's position reflects the challenges inherent in its farming systems and climatic conditions that necessitate increased pesticide use [80].

This study was not primarily focused on the detailed assessment of farming practices within individual EU Member States. Still, instead of evaluating national contributions to pesticide reduction targets, it highlights several countries whose agricultural practices and regulatory frameworks warrant further examination in future research. Notably, the Czech Republic, Greece, Luxembourg, and Slovakia consistently exhibit contribution parity across both the progress and target periods. These countries may serve as valuable case studies for understanding effective national-level strategies, practices, and regulations aligned with the goals of the F2F Strategy.

5- Conclusions and Recommendations

In the EU, the main indicator for controlling pesticide use is information on pesticide sales. From 2011 to 2021, they were relatively stable at approximately 350000 tonnes per year, while in 2022, the sales decreased to 322000 tonnes, the lowest level since 2011. The decrease could be partially explained by the increased costs caused by the war in Ukraine and economic instability, as well as by the EU policies to limit the use of pesticides and promote sustainable agriculture.

The European Commission uses two Harmonised Risk Indicators to assess the impact of pesticides. HRI 1 measures the use of pesticides and the associated risks, and since the baseline period of 2011-2013, it has decreased by 50 % in 2022, while HRI 2 indicates the number of emergency authorisations, which has increased by 12 % over the analysis period. If the baseline period is 2015-2017, the use of and risks associated with chemical pesticides decreased overall by 46%, and the use of more hazardous pesticides by 25%. The indicators indicate the need for a policy framework to effectively monitor and mitigate the risks to human health and the environment from the use of pesticides.

To assess the contributions of EU Member States towards achieving the F2F strategy`s objective of reducing the use of chemical pesticides and associated risks by 50% by 2030 during the progress period, the Member States were grouped based on two indicators: pesticide use per hectare of arable land area and Harmonised Risk Indicator 1 in 2022. The calculations showed that the contributions of six EU Member States (RO, SK, EL, HR, LU, CZ) during the progress period can be rated as superior, i.e. a contribution opportunity. The contributions of the five Member States (ES, IT, BE, IE, NL) was average (contribution parity). Nine Member States (PL, DK, HU, BG, SE, FI, LV, LT, EE) made below-average or limited contributions. However, seven Member States (PT, SI, CY, MT, FR, DE, AT) had low or insufficient contributions during the progress period.

To assess the contributions of EU Member States towards reducing the use of chemical pesticides by 50% by 2030, the Member States were grouped using HRI 1 in 2022 and result indicator R.24 set by the CAP Strategic Plans for 2023-2027. Based on the methodology developed by the authors, it has been found that the contributions of five EU Member States (LU, EL, CZ, IT, SK) and the Wallonia region (BE) could be rated as superior in the forecast and target period. The contributions of five EU Member States (RO, ES, HR, IE, NL) and Flanders (BE) in the forecast and target period could be rated as average. The contributions of eight EU Member States (PT, SI, CY, FR, DE, LV, EE, AT) could be rated as limited in the forecast and target period, while the remaining eight EU Member States (PL, DK, HU, MT, BG, SE, FI, LT) could be rated as insufficient.

The research results indicate that in the Member States with limited contributions during the progress period (Group 3), the contributions will deteriorate during the forecast and target period, meaning that the national contributions are insufficient. In contrast, in the Member States underperforming in the progress period (Group 4), their contributions might improve if the objectives of the CAP Strategic Plans are achieved. In the Member States with a contribution opportunity and parity during the progress period (Groups 1 and 2), their contributions might also remain stable in the forecast and target period.

The present research assessed and classified the contributions of EU Member States, thereby making it possible to identify those that will have greater difficulty achieving the EU pesticide reduction targets by 2030 and will, therefore, need to adapt their future policies and actions to achieve the EU objectives set. The European Commission and EU Member State policymakers and farmers could use the research results to decide on the most appropriate farming practices towards a sustainable food system, thereby reducing and finding alternatives to pesticide use.

Future research should delve deeper into the national-level practices and regulatory instruments of countries exhibiting stable contribution parity, particularly the Czech Republic, Greece, Luxembourg, and Slovakia. A more detailed understanding of their institutional and agricultural systems could support designing more targeted and effective EU-wide strategies for achieving sustainable pesticide use and promoting environmentally resilient agriculture.

6- Declarations

6-1- Author Contributions

Conceptualization, A.M.; methodology, A.M.; software, A.M.; validation, I.P. and A.N.; formal analysis, A.M.; investigation, A.M. and I.P.; resources, A.N.; data curation, A.M.; writing–original draft preparation, A.M. and I.P.; writing–review and editing, A.M., I.P., and A.N., visualization, A.M.; supervision, A.N.; project administration, A.N.; funding acquisition, A.N. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6-3- Funding

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6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Not applicable.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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