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Sustainable Farming: Insights from Data Clustering

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ABSTRACT
This study delves into the perceptions and practices of the agricultural community regarding eco-friendly technologies and air pollution through a detailed clustering analysis of survey data. The primary objective is to identify distinct groups within the agricultural sector based on their responses to various factors, including demographic information, types of crops grown, perceptions of air pollution, and attitudes toward sustainable practices. The analysis employs K-Means clustering to categorize respondents into three distinct clusters, each representing a unique combination of views and practices. The findings are visualized using scatter plots and box plots, offering a clear depiction of the variations and commonalities within each cluster. The study reveals significant diversity in the adoption and perception of eco-friendly practices in agriculture. Some groups demonstrate high satisfaction and effectiveness, indicating successful integration of sustainable methods, while others show skepticism and challenges, possibly due to economic constraints or lack of access to resources and knowledge. The economic interpretation of these clusters suggests that varying levels of resource availability, technological access, and knowledge dissemination influence differences in the adoption of sustainable practices. The study concludes with recommendations for targeted policy-making, educational initiatives, and resource allocation to support and enhance the adoption of eco-friendly practices across different segments of the agricultural community. This tailored approach can significantly contribute to the broader objective of promoting sustainable agriculture and environmental stewardship.

KEYWORDS: Economy, Economic Development, Sustainable Agriculture, Farming Systems, Data Clustering, Farmer Perception, Air Pollution, Emission

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Устойчивое сельское хозяйство: выводы из кластеризации данных

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АННОТАЦИЯ

В этом исследовании изучаются практические аспекты развития сельскохозяйственной отрасли в отношении экологически чистых технологий и загрязнения воздуха посредством использования кластерного анализа данных. Целью данного исследования является идентификация различных групп в аграрном секторе на основе их реакции на разнообразные факторы, которые включают в себя демографические данные, типы культивируемых культур, осведомленность о проблемах загрязнения воздуха, а также отношение к практикам устойчивого развития. Для анализа применяется метод кластеризации К-средних, который позволяет разделить участников исследования на три отдельные группы, представляющие собой уникальное сочетание взглядов и практик. Результаты исследования визуализируются с помощью точечных и столбчатых диаграмм, что обеспечивает наглядное представление о различиях и сходствах между кластерами. Данная визуализация позволяет наглядно увидеть, как различные кластеры располагаются относительно друг друга по ключевым параметрам исследования, выделяя тем самым уникальные характеристики каждой группы. Исследование выявило значительное разнообразие в принятии и восприятии экологически чистых практик в сельском хозяйстве. Некоторые группы демонстрируют высокую удовлетворенность и эффективность, что свидетельствует об успешной интеграции устойчивых методов, в то время как другие проявляют скептицизм и проблемы, возможно, из-за экономических ограничений или отсутствия доступа к ресурсам и знаниям. Экономическая интерпретация этих кластеров предполагает, что различные уровни доступности ресурсов и распространения знаний влияют на различия в принятии устойчивых практик. Исследование завершается серией рекомендаций, направленных на целенаправленное формирование политики, развитие образовательных инициатив и эффективное распределение ресурсов для расширения применения экологически безопасных методов в сельскохозяйственном секторе. Такой подход предлагает значительный потенциал по продвижению устойчивых практик в аграрной деятельности и сохранении природной среды.

КЛЮЧЕВЫЕ СЛОВА: экономика, экономический рост, устойчивое сельское хозяйство, сельскохозяйственные системы, кластеризация данных, восприятие фермерами, загрязнение воздуха, выбросы

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Introduction

Research into the impact of emissions on crop yields is essential because of its strategic importance for food security and the environment in the Republic of Kazakhstan. The country's unique climate conditions may amplify these impacts. With global climate change and the quest for sustainability, understanding the impact of emissions is essential to developing effective agricultural resource management strategies that balance food production and environmental protection.

Over the past two centuries, the global agricultural economy has undergone profound transformations driven by population shifts and economic changes. In 1800, a predominantly rural population engaged 75-80% in agriculture, contrasting sharply with the urbanized, diverse landscape of 2010, with a population exceeding 6.9 billion. Projecting agricultural production faces added intricacies due to the site-sensitive nature of biological processes and changing production geographies (Pardey et al., 2014).

Agriculture, a vital economic sector, plays a pivotal role in meeting the escalating demand for food, feed, and ornamental crops due to the rapidly increasing global population, which is predicted to reach 9.6 billion by 2050 (Tripathi et al., 2019). The challenge lies in enhancing agricultural efficiency while addressing environmental concerns and resource limitations. Although essential for optimal plant growth, the conventional use of chemical fertilizers has led to severe environmental consequences, such as groundwater pollution, soil degradation, and air pollution. With limited arable land and scarce water resources, the demand for efficient mineral fertilizers becomes imperative for sustainable agriculture and economic development.

As the world anticipates a need for 70 to 100% more food by 2050, there is a pressing requirement for a sustainable approach to agriculture that addresses the paradox of hunger coexisting with abundance. The ecological impact of agriculture, measured by indicators like Human Appropriation of Net Primary Productivity (HANPP) and Ecological Footprint, reveals a concerning trend of resource overshoot. With the projected population growth, there is an imminent need to reevaluate agricultural practices to ensure long-term sustainability and mitigate environmental consequences (Graham et al., 2001; Roux et al., 2020).

The agricultural sector in the Republic of Kazakhstan is a critical element of its economic and socio-cultural structure. With vast land resources comprising more than 75% of the country's territory, it has the potential for diversified development. Exporting grains, meat, and oilseeds is a significant source of income. Traditional communities, especially national minorities, are essential in shaping the agricultural structure. Introducing modern technologies and irrigation systems is becoming a critical factor in increasing productivity. The agricultural sector also provides energy through alternative sources such as biomass. Thus, the agricultural sector ensures food security and plays a strategic role in the sustainable development of the country's economy, society, and energy.

This article aims to identify the varying levels of adoption and satisfaction with eco-friendly practices in agriculture, influenced by economic factors such as resource availability, technology access, and knowledge dissemination. The study aims to provide insights for policymakers and stakeholders to design tailored interventions, financial incentives, and educational programs that promote sustainable agriculture practices across different economic contexts. By identifying the specific needs and constraints of distinct groups within the agricultural sector, the analysis guides the development of effective strategies to support a transition toward sustainable agriculture.

Research Methodology

The current study methodology is based on the research of Dessart et al. (2019), which emphasizes the importance of providing a qualitative approach for a more profound understanding of sustainable agriculture development challenges. The study examines levels of adoption of eco-friendly practices in agriculture and their impact on economic aspects such as access to resources and technology (Figure 1).

The research methodology encompasses identifying the respondent group, which includes agricultural workers, farmers, ecologists, and researchers. Google Forms is utilized as the data collection platform, providing ease in creating, managing, and analyzing surveys with the capability for automated response processing. The survey questions are divided into three blocks aimed at identifying the impact of emissions on crop yield, quantitatively assessing respondents' perceptions, and eliciting open comments and suggestions. The sample size comprises 100 respondents representing various regions and segments of agriculture in the Republic of Kazakhstan. Survey distribution is carried out through email, social networks, and web platforms. Data is processed in Google Sheets and MS Excel using statistical analysis and visualization. Control measures, such as periodic data checks and setting control questions, are implemented.

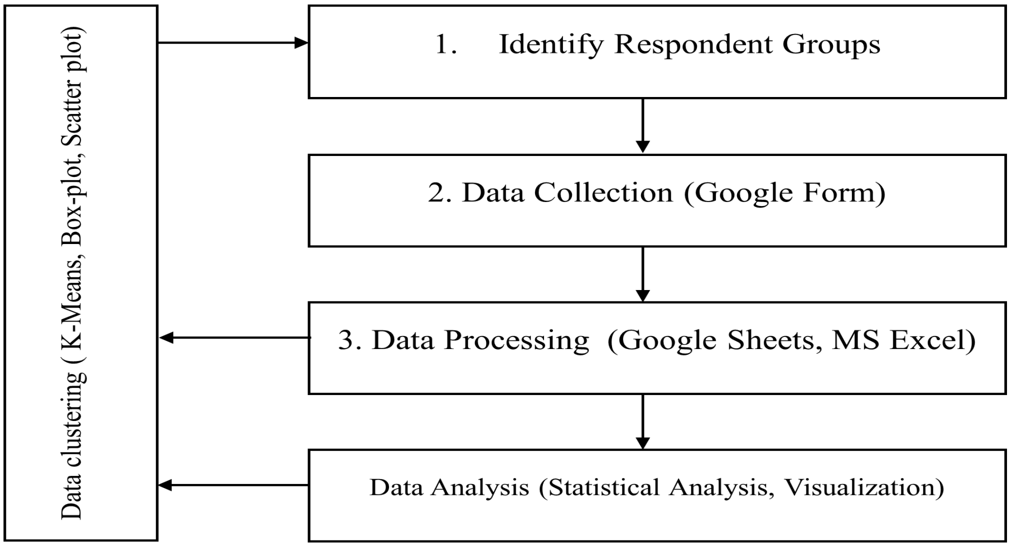


Figure 1 - Stages of research methodology

Note: compiled by the authors

Given the nature of the survey data, which includes demographic information, types of crops grown, perceptions of air pollution, and attitudes towards eco-friendly practices, clustering will be conducted to identify distinct groups of respondents based on these attributes. This can help in understanding if there are specific segments within the respondents that share common characteristics or opinions. For this purpose, K-Means Clustering and Box-plot Clustering will be used. K-Means is a popular method for partitioning data into K-distinct, non-overlapping subgroups.

Literature review

Sustainable agriculture has become a critical focus of contemporary debates, necessitating an exploration of factors influencing the adoption of sustainable farming practices. Sustainable agriculture is the ability to maintain productivity without compromising land resources. The existing literature emphasizes the multi-dimensional nature of sustainability, encompassing environmental, social, and economic aspects (Gebska et al.,2020). Farmers' awareness and knowledge of sustainable practices play a crucial role in their adoption, with potential benefits including food safety and increased profitability.

Velten et al. (2015) conducted a systematic review to understand the diverse definitions and perspectives on sustainable agriculture, aiming to identify areas of complementarity and concern between emerging definitions. They highlight the threats to agriculture, including climate change, biodiversity loss, land degradation, and resource depletion. The ambiguity in the concept of sustainable agriculture leads to diverse discourses and paradigms. Due to its complex and contested nature, they emphasize the challenge of arriving at a single, all-encompassing definition.

Qi et al. (2021) emphasized that the emergence of different and opposing paradigms of sustainable agriculture contributes to confusion. The influence of informal promoters, such as farmers' relatives and friends, in the adoption process was identified as crucial. This suggests the importance of social networks and trust in spreading eco-friendly agricultural practices. Ramborun et al. (2019) introduced the concept of Indigenous/Traditional Knowledge (ITK) as a crucial factor influencing farmers' resistance or adaptation to new changes. Despite being provided, climate change training does not always translate into modified cultural practices. Mistrust between farmers and extension officers, perceived training ineffectiveness, and farmers' confidence in their practices contribute to the reliance on ITK. Limited evidence exists regarding the impact of information sources on adopting conservation practices. Giovanopoulou et al. (2020) found that membership in professional cooperatives tends to discourage adoption. There may be complexities in the relationship between farmers and these cooperatives. While cooperatives are often seen as entities that can facilitate knowledge sharing and resource pooling, this study implies that there might be factors within professional cooperatives that act as barriers to adopting sustainable farming practices. Potential reasons for this could include conflicting interests within the cooperatives, divergent views on what constitutes sustainable agriculture, or perhaps the presence of institutional barriers that impede the implementation of new practices.

Therefore, innovative strategies are crucial. Gomiero et al. (2011) emphasized the historical evolution of agriculture, marked by the "green revolution," which significantly increased productivity but also led to environmental degradation and nutritional imbalances. Despite increased food production, a substantial portion of the global population still suffers from malnutrition, while the obesity epidemic coexists in developed nations. Moreover, intensifying agricultural practices contributes to food wastage, soil loss, water depletion, and biodiversity threats. Nanofertilizers, as explored by Zulfiqar et al. (2019), presented a promising option for sustainable agriculture. Nanotechnology applications offer controlled nutrient release, increased fertilizer use efficiency, and reduced environmental hazards. However, the adoption of nanofertilizers must be considered within the broader context of sustainable agriculture and the environmental impact of modern agricultural practices.

Despite the importance of adopting innovative strategies, farmers' desire to implement innovations plays a much more significant part. Farmer beliefs and values were portrayed as multifaceted and influential factors shaping environmental subsidies and payment decisions. These factors contribute to farmers' decisions to adopt sustainable practices, reflecting a diverse set of motivations and considerations in the context of agriculture and environmental stewardship: societal identity, social connectedness, responsibility for future generations, openness and societal attitudes, economic diversity and resilience, values associated with traditional modes of production, social recognition, and acknowledgment. It is important to note that these beliefs and values are interconnected, and individual farmers may prioritize different factors based on their unique perspectives and circumstances (Brown et al., 2022).

The key elements (regulatory frameworks, ecological conditions, customs, and traditions) identified by Serebrennikov et al. (2020) shape farmers' decisions regarding adopting sustainable farming practices in Europe. These factors are intricately linked to the farming environment's regulatory, cultural, and ecological dimensions. European agriculture is subject to a complex web of regulations and policies governing various farming practices. These regulations may include environmental standards, subsidies, and guidelines for sustainable agriculture. Farmers' decisions are influenced by compliance requirements, incentives, and penalties outlined in these regulations. For example, subsidies for adopting sustainable practices or restrictions on specific farming methods can significantly impact adoption behaviors. Farmers may be more inclined to adopt practices that align with cultural norms and values. They are likely to consider ecological factors such as soil fertility, climate suitability, and water availability when deciding to adopt specific agricultural practices. Practices well-suited to the local ecology are more likely to be adopted.

Dessart et al. (2019) explored the intricacies of farmers' decisions regarding adopting sustainable agricultural practices and classified behavioral factors as dispositional, social, and cognitive. Notably, social factors emerged as key influencers, with injunctive norms shaping farmers' choices based on societal expectations and peer influences.

In the works of Kazakh researchers, the authors focused on implementing government programs and analyzing current changes. Akimbekova and Nikitina (2020) and Kerimova and Kasenbayev (2021) emphasize the importance of introducing innovative technologies and improving the technical equipment of the industry to solve critical problems, including low labor productivity, insufficient product processing and weak implementation of scientific developments, as well as the need for efficient use of natural resources. Moreover, Aliyev (2020) identified changes in the land use structure. Namely, the transition from agricultural land to urbanized areas for the needs of housing construction, industry, and infrastructure facilities. For example, Siskimbayev et al. (2023) looked at various aspects, including livestock production, crop production, investment dynamics, export-import activities, and technological advances in the sector. They highlighted both the achievements and problems of the agricultural sector, focusing on the need to resolve issues regarding personnel, financing, technical equipment, and the introduction of technologies for sustainable development. Thus, there is a reduction in available land for agricultural production, which can have a negative impact on food security and requires adaptation of the agro-industrial sector through the introduction of innovative technologies and land management methods.

The literature review underscores the influence of farmer attitudes and beliefs as crucial factors. Positive attitudes toward environmental protection and sustainability are associated with a higher likelihood of adopting new methods, approaches, and modern farming practices. Conversely, economic attitudes that discourage adopting sustainable practices indicate the complexity of factors at play. Expanding on this, it becomes evident that understanding and addressing farmers' attitudes is paramount for successful interventions promoting sustainable agriculture. Policymakers and extension services need to consider these attitudinal factors when designing strategies, educational programs, and incentives to encourage adopting sustainable agriculture practices.

Results and Discussion

Analyzing emissions data, particularly from stationary sources, plays a crucial role in understanding a region's environmental and economic landscape. A comprehensive review of emissions data from 2005 to 2021 across various regions provides critical insights into the interplay between industrial activities, environmental policies, and their economic implications (Table 1). This longitudinal data is vital for policymakers, environmentalists, and economists to gauge the effectiveness of environmental regulations, understand the impact of industrial growth, and plan for sustainable economic development.

Table 1 - Emissions of pollutants into the atmosphere from stationary sources

Region	2005	2010	2015	2020	2021
The Republic of Kazakhstan	2 968,8	2 226,6	2 180,0	2 441,0	2 407,5
Akmola	44,0	72,9	85,6	77,2	77,3
Aktobe	168,2	125,3	134,3	135,1	137,4
Almaty	68,4	74,7	55,0	46,3	47,9
Atyrau	89,4	97,8	110,7	153,9	160,3
West Kazakhstan	76,4	58,1	42,4	30,8	26,0
Zhambyl	18,9	19,3	41,9	55,0	55,8
Karaganda	1 415,4	661,2	596,4	627,7	569,7
Kostanayskaya	100,4	114,5	91,6	123,4	137,9
Kyzylorda	40,0	29,0	30,1	28,3	29,2
Mangystau	63,5	68,6	72,5	72,5	75,2
South Kazakhstan	36,8	40,7	69,0	-	-
Pavlodar	556,8	572,5	552,9	723,0	736,1
North Kazakhstan	65,5	77,8	74,9	76,0	61,2
Turkestan	-	-	-	28,1	29,0
East Kazakhstan	165,7	147,0	127,1	127,2	128,1
Nur-Sultan	43,9	56,2	56,3	62,4	62,2
Almaty city	15,5	11,0	39,1	44,5	40,8
Shymkent	-	-	-	29,6	33,2

Note: compiled by authors based on the Bureau of National Statistics (2022)

The overall trend in emissions from stationary sources reveals a nuanced picture. Initially, emissions were notably decreased from 2005 to 2010 across the Republic, dropping from 2,968.8 thousand tons to 2,226.6 thousand tons. This decrease could be attributed to various factors, including implementing stricter environmental regulations, shifts in industrial practices towards more eco-friendly methods, or a general decline in certain types of industrial activity. However, the period from 2010 to 2021 saw a gradual increase in emissions, culminating in 2,407.5 thousand tons in 2021. This rise could suggest a rebound in industrial activities, potentially driven by economic growth, or it might reflect a lag in adopting newer, cleaner technologies.

Regionally, the data exhibits significant variations, indicative of Kazakhstan's diverse industrial and economic landscapes. For instance, the Karaganda region showed a remarkable reduction in emissions, halving from 1,415.4 thousand tons in 2005 to 569.7 thousand tons in 2021. This could indicate a successful transition to cleaner industrial processes or a shift in the region's economic base away from heavy industries. In contrast, regions like Pavlodar and Atyrau experienced an upward emission trend, particularly post-2015. This increase might be linked to the growth in energy-intensive industries, possibly driven by local economic development policies, or it might reflect inadequacies in environmental control measures.

Economically, these emission trends have far-reaching implications. Regions with decreasing emissions could move towards a more sustainable economic model, balancing industrial growth with environmental stewardship. While beneficial in the long term, this transition might present short-term economic challenges, including the need for investment in new technologies and potential shifts in employment patterns. On the other hand, regions with increasing emissions, while possibly experiencing economic growth, face the challenge of aligning their development with environmental sustainability goals. This necessitates investments in cleaner technologies, potential reforms in regulatory frameworks, and a proactive approach to managing industrial growth.

Further, an analysis of the survey is provided (Figure 2).

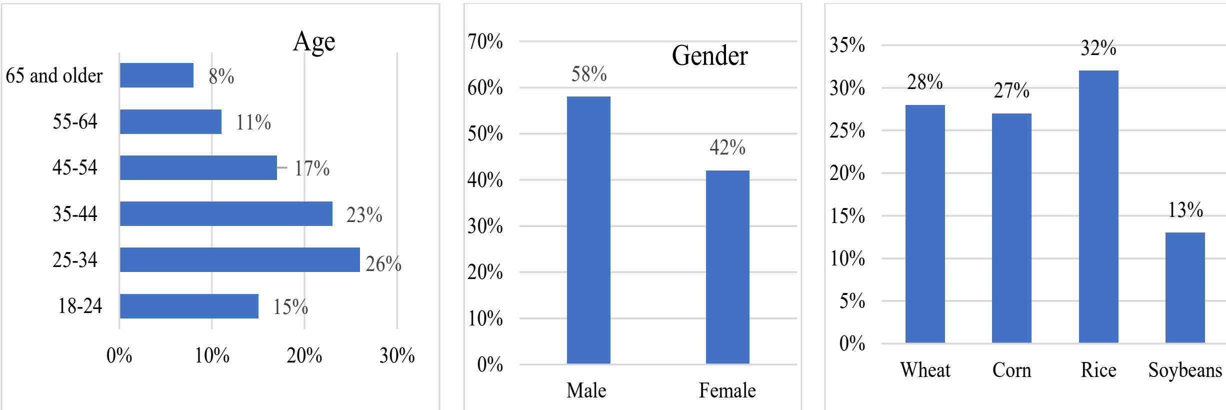
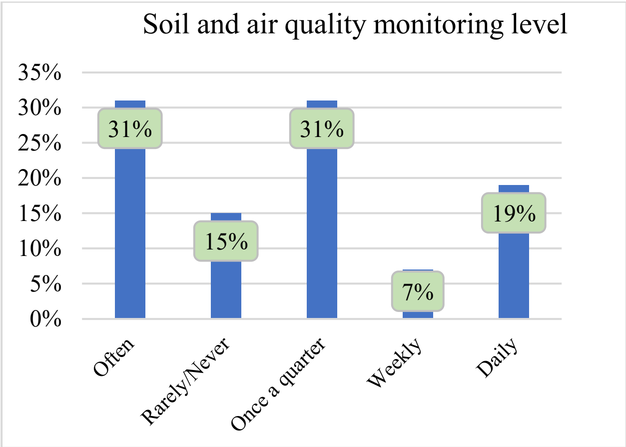


Figure 2 - Descriptive data

Note – compiled by the authors

The vast majority of respondents, namely 58%, were men, while women comprised 42%. This result may indicate male dominance among respondents in the group under consideration. The majority of respondents, namely 26%, were people aged 25 to 34 years. In second place were respondents aged 35 to 44, accounting for 23%. A noticeably smaller number of questionnaires were completed by people over 65, namely 8%. This data can provide essential insights into the age distribution of the audience, which is a significant factor when analyzing results and drawing conclusions. The high percentage of rice cultivation (32%) may indicate suitable conditions for the crop or high demand for it in the region. Wheat (28%) and corn (27%) have similar shares, which may indicate a crop rotation strategy or adaptation to different market demands. The low percentage of soybeans grown (13%) may indicate limitations such as climatic conditions or farmer preferences. It may also reflect market factors where demand for soybeans is limited. Next in Figure 3 are results on the impact of external factors.

Farmers demonstrate a variety of approaches to monitoring soil and air quality. A significant proportion undertakes regular monitoring, including daily, weekly, and monthly monitoring. Most prefer a systematic approach with an emphasis on quarterly monitoring. However, there is also a segment that rarely or never monitors, perhaps due to limited resources or a lack of awareness of the importance of this practice. The general trend points to a desire to understand and control the state of the agricultural environment. Based on the answers, more than half of the respondents, 62% to be exact, expressed the opinion “Yes”, believing that emissions have an impact on the yield of crops grown. This result indicates widespread agreement among respondents that there is a link between emissions and crop yields.



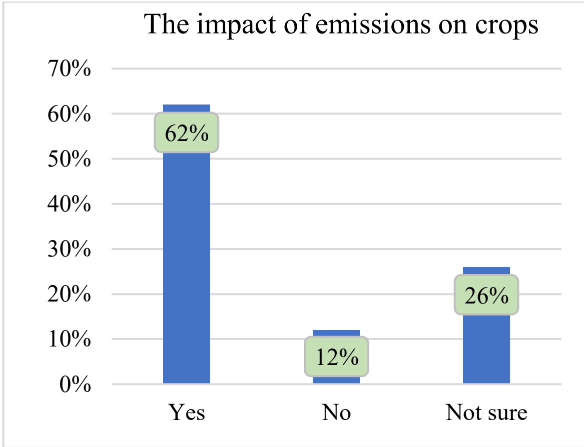
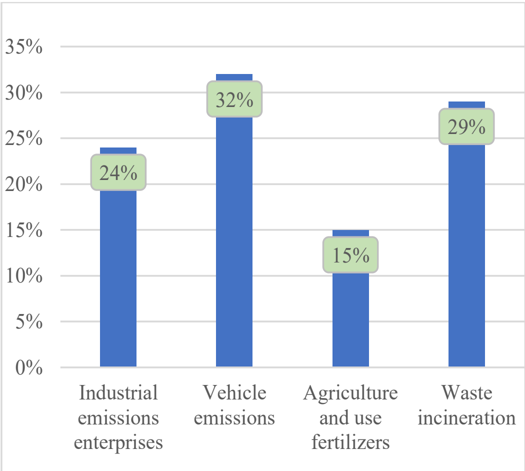


Figure 3 - Emissions monitoring

Note – compiled by the authors



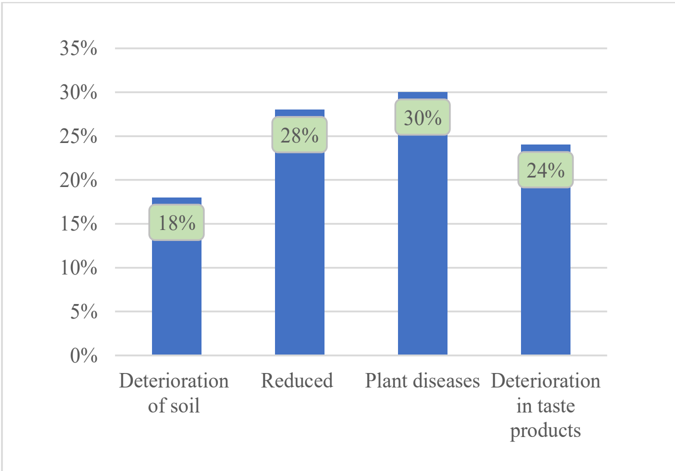
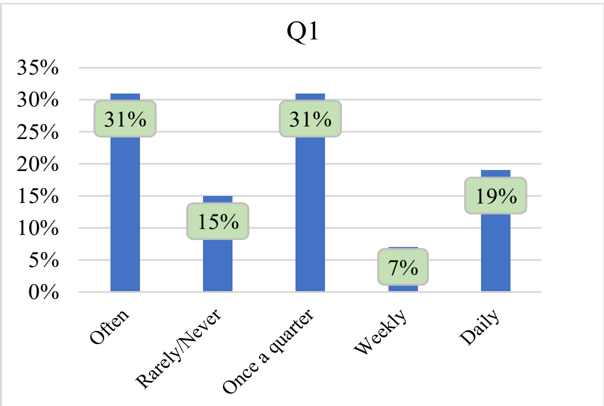


Figure 4 - Emissions issues affecting crops and types of air pollution

Note: compiled by the authors



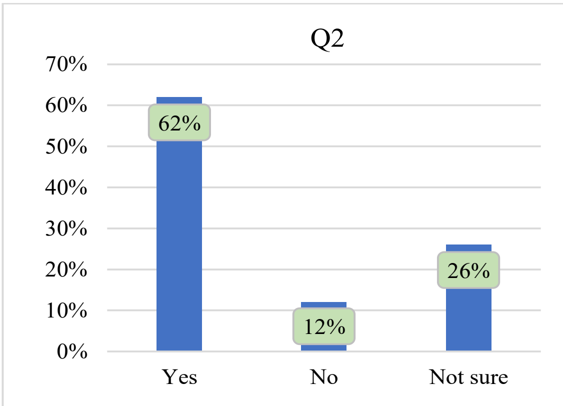


Figure 5 - Emissions monitoring

**Q1 - Soil and air quality monitoring level*
**Q2 - The impact of emissions on the yield of crops*

Note: compiled by the authors

Farmers demonstrate a variety of approaches to monitoring soil and air quality. A significant proportion undertake regular daily, weekly, and monthly monitoring. Most prefer a systematic approach with an emphasis on quarterly monitoring. However, there is also a segment that rarely or never monitors, perhaps due to limited resources or a lack of awareness of the importance of this practice. The general trend points to a desire to understand and control the state of the agricultural environment. Based on the answers, more than half of the respondents, 62% to be exact, expressed the opinion "Yes", believing that emissions have an impact on the yield of crops grown. This result indicates widespread agreement among respondents that there is a link between emissions and crop yields. Next are results related to emission issues and air pollution (Figure 6).

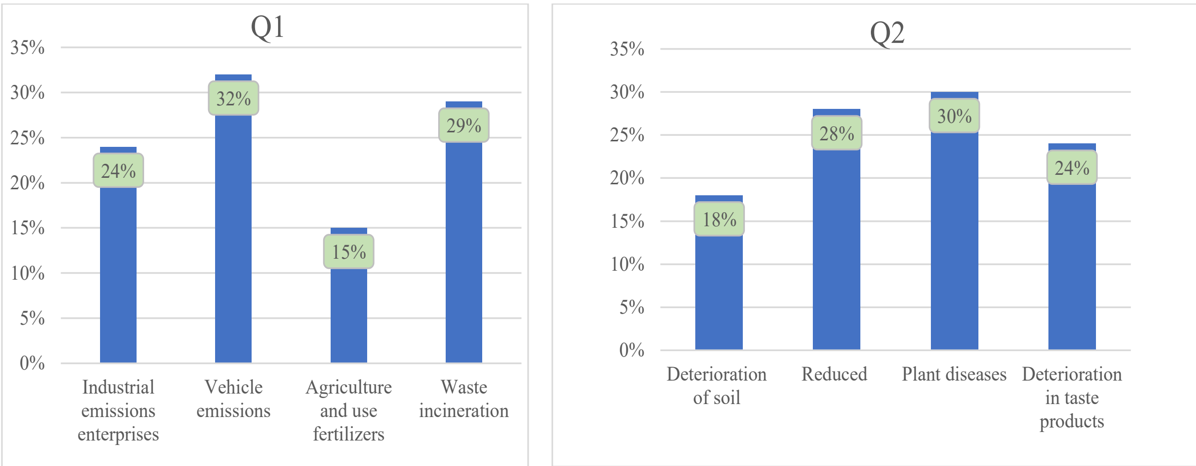


Figure 6 - Emissions issues affecting crops and types of air pollution

**Q1 – Emissions issues*
**Q2 – Types of air pollution*

Note: compiled by the authors

Most respondents, namely 32%, most often encounter problems associated with pollution caused by vehicle emissions. Also, 29% of respondents noted that they face problems associated with emissions from waste combustion. These data highlight that transport and waste emissions significantly influence respondents' perceptions of pollution. This is important to consider when developing strategies and measures to reduce air pollution, as they reflect the daily concerns and problems people face. The responses indicate the varied impacts of emissions on agricultural production. Problems include deteriorating soil quality, reduced yields, plant diseases, and deteriorating product flavor. This demonstrates the complex impact of pollution on various aspects of agriculture, which can potentially threaten the sustainability and quality of agricultural products. It is essential to consider the cumulative impact of these problems to develop effective strategies for their prevention and management.

Next, in Figure 7, results for methods of reducing air pollution emissions evaluation.

Analysis of the presented histogram reveals that most respondents, namely 33%, preferred tightening legislation and control as an effective method of reducing air pollution emissions. This indicates a high degree of support for regulation and strict control in the context of environmental issues. It is also worth noting that a significant proportion of respondents, 28%, are of the opinion that increasing public awareness and education is an effective means of solving the emissions problem. This points to the importance of educational and awareness-raising initiatives in reducing air pollution, emphasizing the role of an informed society in solving environmental problems.

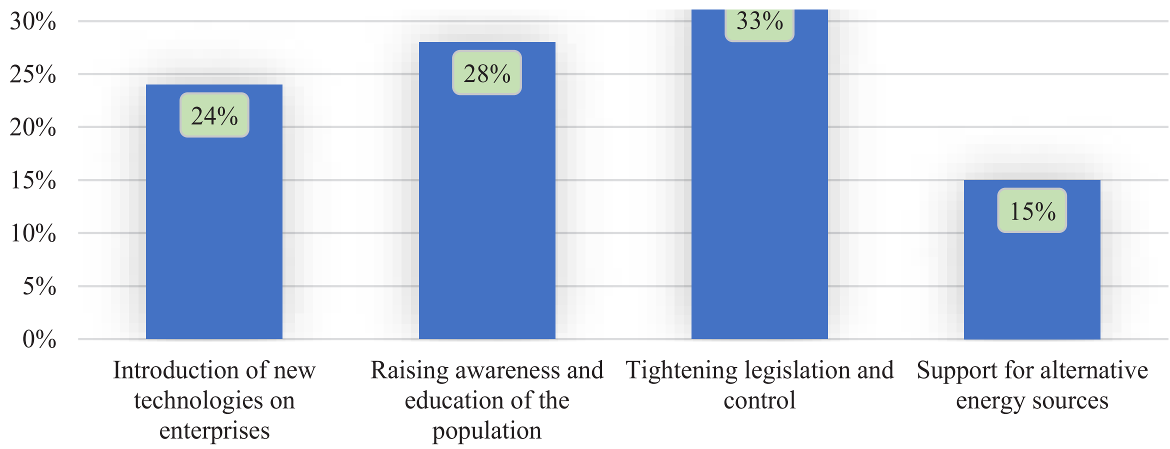


Figure 7 - Methods of reducing air pollution emissions

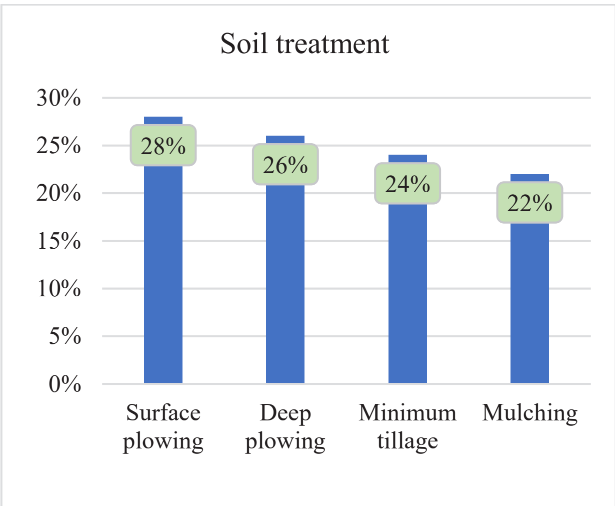
Note: compiled by the authors

Next, in Figure 8, methods and techniques to reduce air pollution are given.

Respondents prefer a variety of soil treatment methods to reduce air pollution. Shallow, deep tillage, minimum tillage, and mulching received significant support. This demonstrates a desire for versatile and efficient processing methods, possibly to reduce environmental impact and air pollution.

Farmers widely use a variety of water management techniques to reduce air pollution. Effectively using irrigation systems is the most common method and has received significant support. Drip irrigation systems, rainwater harvesting, and irrigation zoning are also widely used, indicating a desire for efficient and environmentally sustainable use of water resources for agriculture.

Next, Figure 9 shows data on respondents' preference for environmentally friendly plant protection methods.



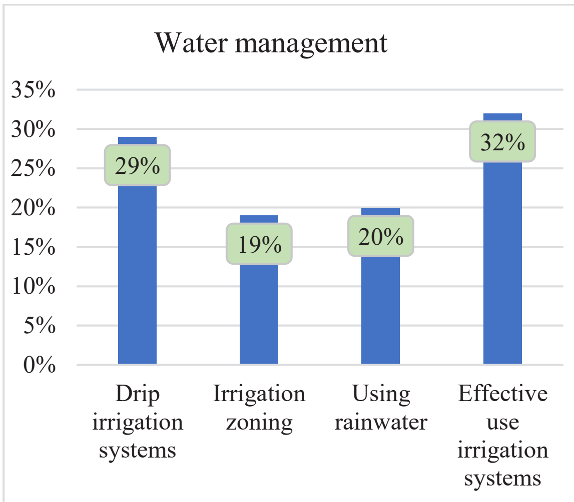


Figure 8 - Methods and techniques to reduce air pollution

**Q1 - Soil treatment*
**Q2 - Water management*

Note: compiled by the authors

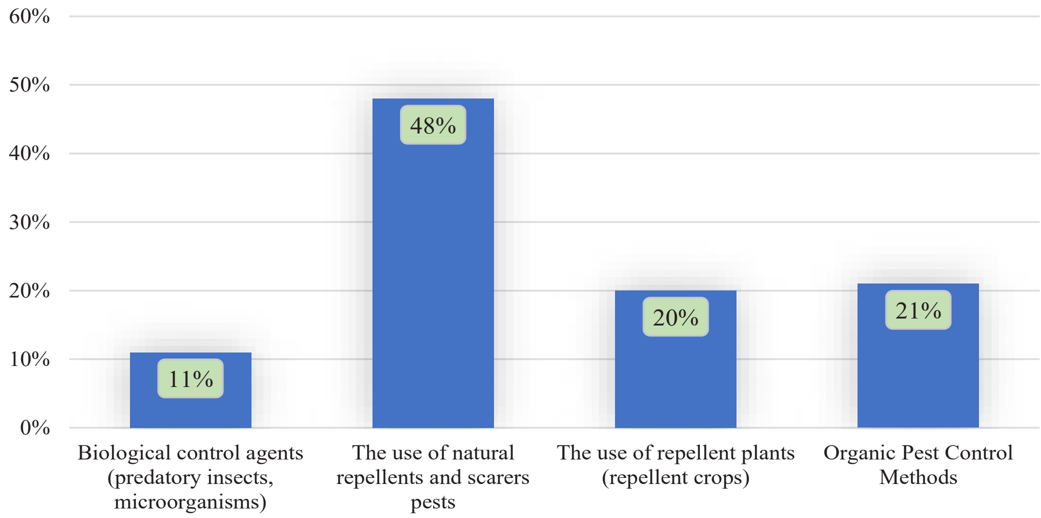


Figure 9 - Environmentally friendly plant protection methods do respondents prefer?

Note: compiled by the authors

Respondents mainly prefer to use environmentally friendly methods of plant protection. The use of natural pest repellents received the highest support, which may indicate a desire to minimize chemical exposure. Organic pest control methods also have a significant share, highlighting farmers' interest in sustainable and natural approaches to farming. Biological control agents and repellent plants are also present, although to a lesser extent. This indicates that agricultural practices are becoming more environmentally conscious and sustainability-oriented.

Most respondents (38%) preferred education programs to combat air pollution, emphasizing the importance of educational initiatives in solving environmental problems. An additional 31% of respondents preferred workshops and training events, emphasizing the importance of hands-on learning and community involvement in addressing air emissions issues.

Farmers are actively taking measures to improve energy efficiency on their plots/farms. More than half of them prefer to use energy-saving technologies in production processes, indicating a desire to optimize energy consumption in various aspects of agriculture. The introduction of energy-efficient irrigation and heating systems has also received significant support, indicating attention to the efficient use of energy in important aspects of agriculture. The use of solar panels is rated at a lower level, and minimizing the use of energy-consuming devices and equipment is also found to be a practice. These results indicate that farmers are seeking more efficient and sustainable energy use in various aspects of their operations.

Next, results for the transition to sustainable agriculture are provided (Figure 10).

Experts see significant social and economic benefits in transitioning to more environmentally sustainable agricultural practices. Increasing yields and product quality, leading to increased income, is a critical benefit that has received significant support. This indicates an awareness of the link between sustainable practices and economic success in agriculture. Reduced healthcare costs due to improved worker health are also noticeable, highlighting the social aspects of environmental sustainability. Attracting environmentally conscious consumers and reducing negative environmental impacts are important factors supporting environmentally sustainable agricultural practices.

The majority of respondents (37%) expressed a preference for financial support for training farmers in environmental practices. 23% suggested grants for the development and research of environmental methods, 22% - subsidies for the implementation of environmental technologies, and 18% were in favor of tax breaks. This demonstrates the demand for various financial measures to support the transition to organic agriculture.

Next, in Figure 11, information is given on the personal experiences of farmers.

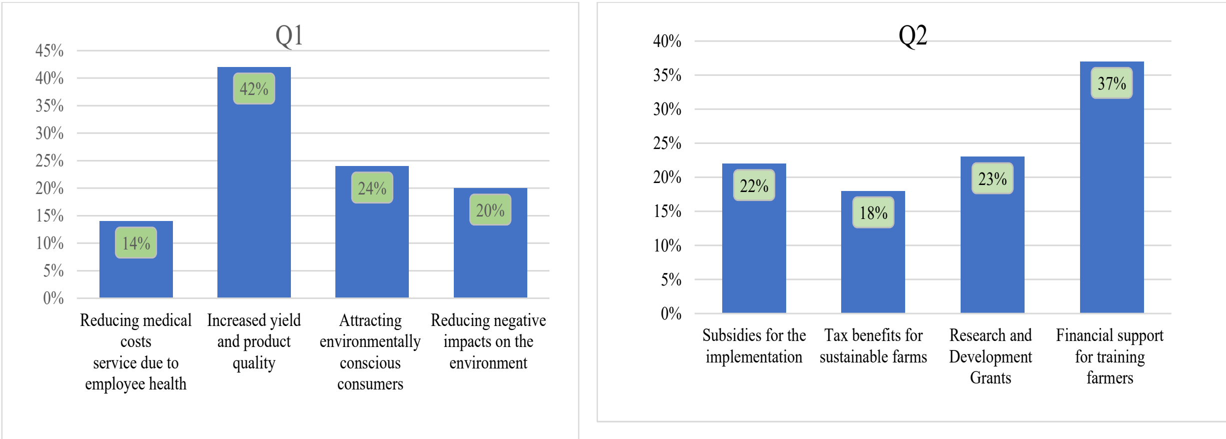


Figure 10 - Transition to sustainable agriculture

Note: compiled by the authors

**Q1 - Social and economic benefits of moving towards more sustainable agricultural practices*
**Q2 - Financial state initiatives to support the transition to organic agriculture*

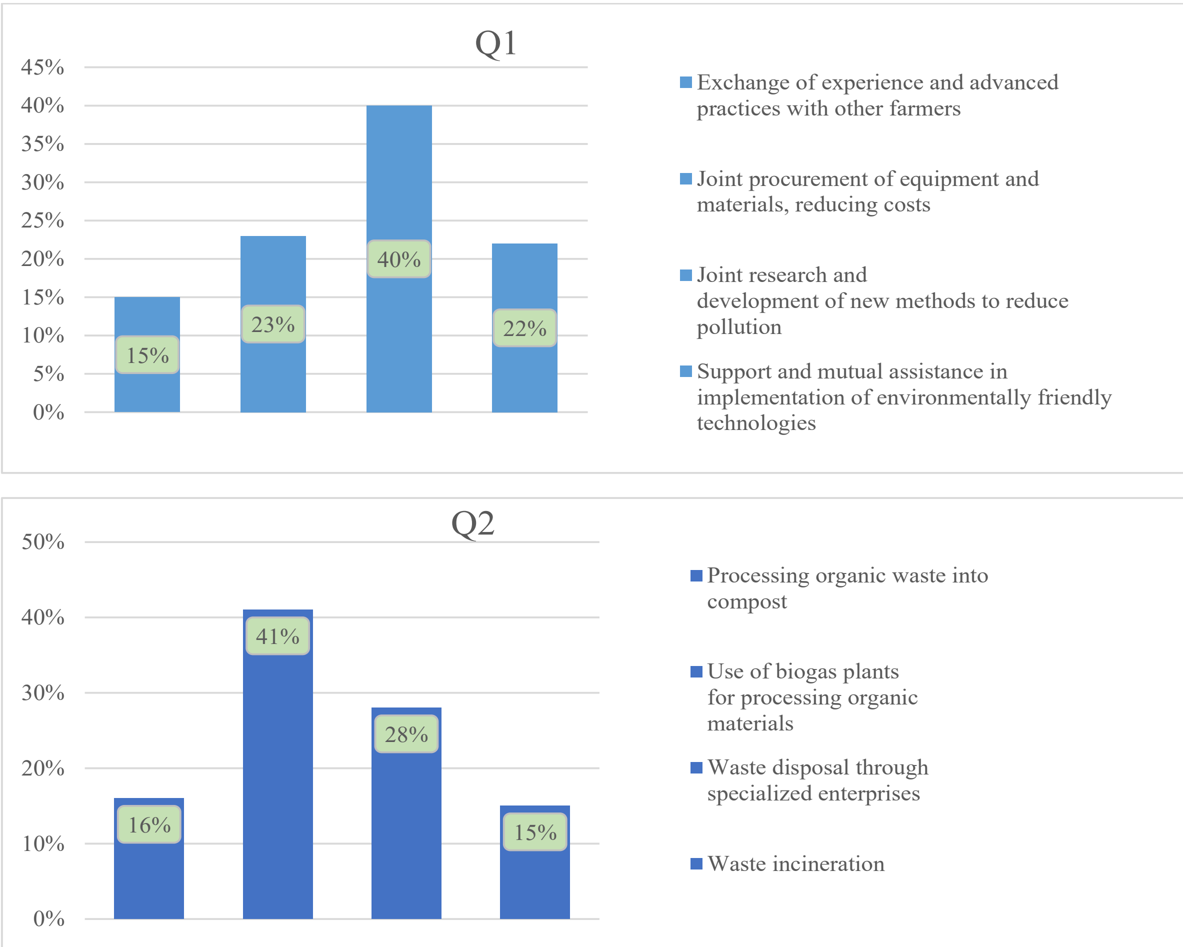


Figure 11 - Personal experience

Note: compiled by the authors

**Q1 – Benefits of collaborating with other farmers to reduce air pollution together*
**Q2 – Measures taken to manage waste on site/farm*

Farmers highlight several benefits to working with others to reduce air pollution together. The importance of collaborative research and development of new pollution reduction methods is particularly emphasized, demonstrating a commitment to innovation and the collective development of sustainable practices. Joint procurement of equipment and materials is also important for saving resources and reducing costs. Sharing experiences and best practices with other farmers highlights the importance of training and experience in organic farming. Support and mutual assistance in implementing environmentally friendly technologies are also important for successfully adapting new practices and technologies. These aspects support a collaborative approach to addressing air pollution problems in agriculture.

Specialists are actively taking measures to manage waste on their sites/farms. The use of biogas plants to process organic materials stands out as the most common method, possibly due to the desire for energy sustainability and reduced environmental impact. Waste management through dedicated facilities is also widely supported, emphasizing the importance of collaboration with external resources for effective waste management. Recycling organic waste into compost is also being assessed, although to a lesser extent, and may be related to the use of compost in one's agriculture. Incineration remains the least common method, possibly due to the process's negative environmental impact and energy inefficiency.

Farmers place significant emphasis on environmental education and training programs for their workers. Waste recycling and water management training programs take center stage, with high participation rates (45%). This demonstrates a focus on specific aspects of sustainability and responsible use of resources. Training on resource management and air pollution reduction is also significant (19%), highlighting the importance of training employees in agriculture with a sustainability focus. Seminars, lectures on organic agriculture, and participation in environmental conferences and exhibitions form a less significant but still noticeable part of educational programs. A small percentage of farmers admit that they do not have education and training programs, which may indicate a need for expanded training and education initiatives.

The results show that the main difficulty for respondents (38%) is the lack of qualified specialists to maintain new environmentally friendly systems. This highlights the need to ensure access to education and training to implement new technologies in agriculture successfully. Additionally, 25% identified difficulties in adapting to new production processes. This may reflect the challenges businesses face in changing current production methods to more environmentally sustainable ones.

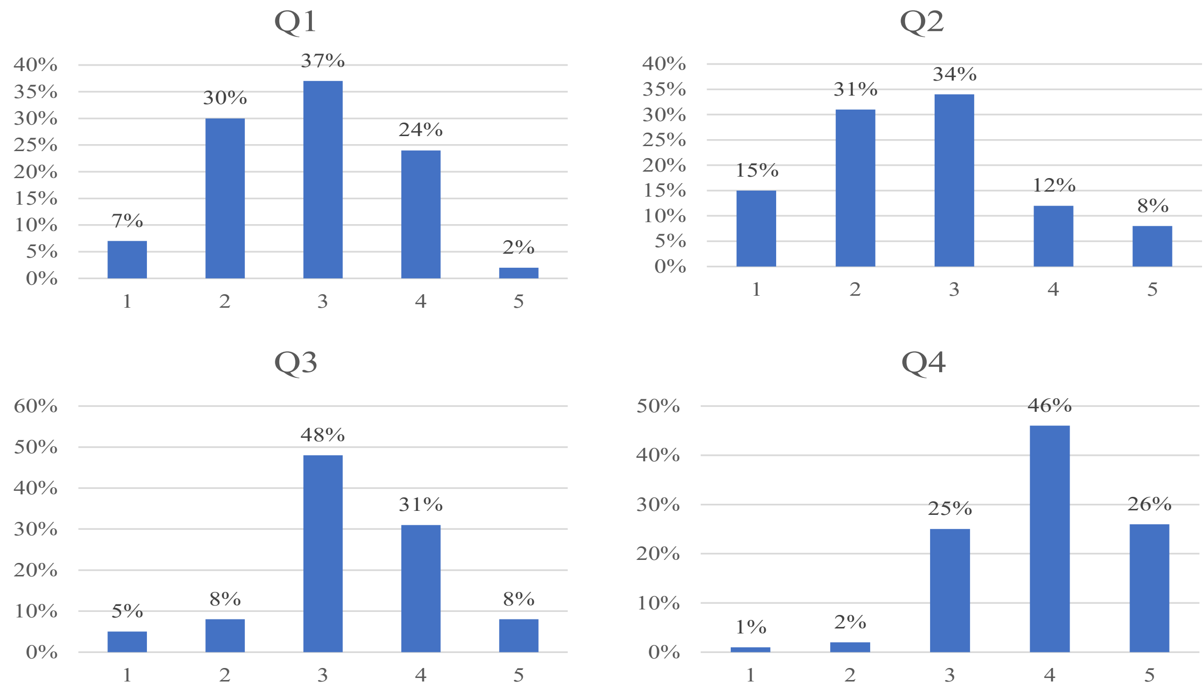


Figure 12.

Note: compiled by the authors

**Q1: How effectively does the enterprise/site cope with reducing air pollution emissions?*

**Q2: How satisfied are the respondents with the results of introducing environmentally friendly technologies on the plot/farm?*

**Q3: How would you rate cooperation with supervisory and control authorities in emission limitation?*

**Q4: Importance of using environmentally friendly agricultural practices to maintain soil quality and yields*

An assessment of the effectiveness of reducing air pollution emissions at an enterprise/site shows that most farmers rate their efforts as average (37%) or below average (30%). A significant proportion of respondents note that their enterprise/site copes with this task unsatisfactorily (7%). The presence of ratings "4" and "5" suggests that there are farmers who consider their methods to be quite effective, but their percentage is relatively small (26%). The overall trend points to the need for additional efforts and innovative approaches to improve farm air pollution abatement performance.

Responses to the question about satisfaction with the results of implementing environmentally friendly technologies on the farm show that most farmers assess the effectiveness of these technologies as average (34%) or below average (31%). A significant proportion of respondents express high satisfaction (ratings "4" and "5") at only 20%, which may indicate unsatisfactory results from the implementation of environmentally friendly technologies for the majority of farmers. On the one hand, the high percentage of "1" and "2" ratings indicates that some farmers are dissatisfied with current results, perhaps due to limited efficiency or poor integration of these technologies. The overall analysis highlights the need for more efforts to develop and implement more effective and satisfactory green technologies on farms.

The assessment of cooperation with control authorities in emission control is generally positive, mainly concentrated in high and medium ratings. Most respondents (48%) rated "3," which may indicate stable and satisfactory interaction. Additionally, 31% rated cooperation as a "4," emphasizing good relationships with regulatory authorities. Despite this, a small proportion of respondents expressed dissatisfaction, awarding marks of "1" and "2" (only 13%). This may indicate some difficulties or misunderstandings in the interaction between enterprises and regulatory authorities.

An assessment of the importance of environmentally friendly agricultural practices for maintaining soil quality and crop yields shows that most farmers consider these practices necessary (scores of 4 and 5 combined for 72%). However, a small proportion of respondents (3%) rate the importance of using environmentally friendly practices as minimal. Most farmers recognize the importance of such practices in maintaining soil quality and crop yields, which may indicate an increased awareness of the link between environmental sustainability and thriving agriculture.

Next, there was conducted data clustering (Figure 13).

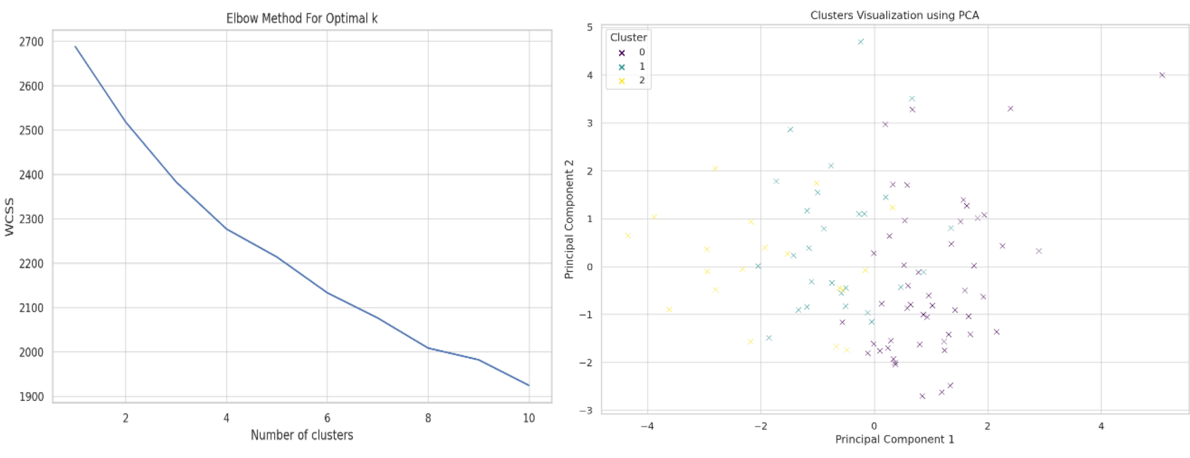


Figure 13 - Elbow Method

Note: compiled by the author

The Elbow Method graph above determines the optimal number of clusters for K-Means clustering. The "elbow" point in the graph is where the Within-Cluster Sum of Squares (WCSS) starts to decrease at a slower rate, indicating a good balance between the number of clusters and the variance explained. The graph shows that the elbow point is around 2 to 4 clusters. This range is a good starting point for our K-Means clustering. I will proceed with K-Means clustering and analyze the results using this range of cluster numbers.

The scatter plot above visualizes the results of the K-Means clustering. Each point represents a respondent, colored based on their cluster. The PCA has reduced the multidimensional survey data into two principal components, allowing us to visualize the clusters (Figure 14). These clusters represent groups of respondents with similar demographics, crop types grown, air pollution perceptions, and attitudes toward eco-friendly practices. The box plots provide a statistical summary of the responses within each cluster, focusing on two key aspects: the effectiveness of emission reduction and satisfaction with eco-friendly technologies.

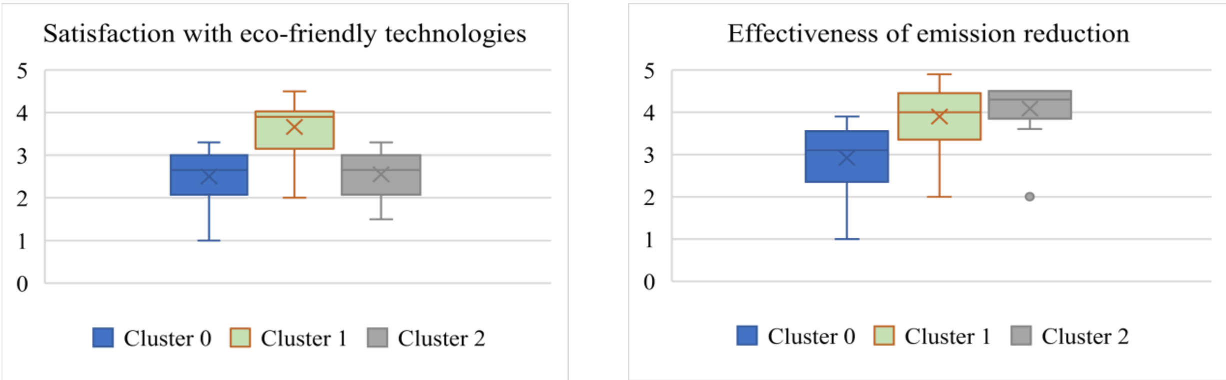


Figure 14 - Effectiveness of Emission Reduction by Cluster

Note compiled by the authors

Cluster 0. It shows a lower median effectiveness score, indicating that respondents in this group generally perceive their emission reduction efforts as less effective. The narrower interquartile range (IQR) suggests that opinions in this group are more consistent or less varied.

Cluster 1. It has a higher median effectiveness score, suggesting that respondents in this group generally find their emission reduction efforts to be more effective. The IQR is also relatively narrow, indicating consistency in positive perceptions.

Cluster 2. Exhibits a moderate median score with a wider IQR, indicating more varied experiences or perceptions regarding emission reduction effectiveness.

Satisfaction with Eco-friendly Technologies by Cluster:

Cluster 0. Indicates lower median satisfaction, with a compact IQR, suggesting that respondents are generally less satisfied with eco-friendly technologies, and their opinions are pretty consistent.

Cluster 1. Features a higher median satisfaction score, consistent with their higher ratings of emission reduction effectiveness. The narrower IQR implies a strong consensus on satisfaction with eco-friendly technologies.

Cluster 2. Shows moderate levels of satisfaction with a wider IQR, reflecting diverse experiences or views on the effectiveness of eco-friendly technologies.

Cluster 0 may represent a segment less engaged with or benefiting from eco-friendly practices, possibly due to financial constraints, lack of technological access, or insufficient knowledge about sustainable practices. Economically, this group might be operating in a context with lower investment in sustainable technologies or facing barriers to adopting such practices.

Cluster 1 likely includes respondents who have invested in eco-friendly technologies and are witnessing tangible benefits in crop yield and environmental impact. This group might represent a more economically advanced segment with better access to resources, knowledge, and support systems that facilitate adopting sustainable practices.

Cluster 2 could indicate a transitional group experimenting with eco-friendly technologies but has not fully realized or been able to measure their benefits. This group might be adapting to newer practices, facing mixed economic outcomes during this transition phase.

Cluster 0. Emission reduction efficiency is generally low. This cluster may include respondents who do not have access to advanced technologies or who face financial constraints. Satisfaction with environmental technologies is low, which may indicate insufficient implementation or unsatisfactory results. The main problems face difficulty adapting to new technologies, financial constraints, and lack of support or training.

Table 2 - Cluster Characteristics

Cluster	Emission Reduction Efficiency	Satisfaction with Environmental Technologies	Main Issues
0	Low	Low	Adaptation to new technologies, financial restrictions
1	High	High	High start-up costs, technology scaling
2	Average	Average	Lack of specialists, equipment upgrades

Note compiled by the authors

Cluster 1. Emission reduction efficiency is high. This cluster may represent more experienced or better-resourced respondents with access to advanced technologies. Satisfaction with environmental technologies is high, indicating positive perception and successful application of these technologies. Key challenges are high initial hardware and technology costs, which can be a barrier to scaling.

Cluster 2. Emission reduction efficiency: Average. Respondents in this cluster may have limited experience or mixed results in using technology. Satisfaction with environmental technologies: Moderate, reflecting various experiences and possible implementation challenges. The main problems are a lack of qualified specialists and difficulties updating equipment and training staff.

From an economic standpoint, these insights suggest varied levels of adoption and satisfaction with eco-friendly practices in agriculture, potentially influenced by economic factors such as resource availability, access to technology, and knowledge dissemination. Understanding these differences is crucial for policymakers and stakeholders in designing tailored interventions, financial incentives, and educational programs to promote sustainable agriculture practices across different economic contexts.

This analysis underscores the diverse perspectives and challenges regarding environmental sustainability within the agricultural sector. It highlights the potential for targeted, informed interventions to promote more widespread adoption of eco-friendly practices. By understanding the specific needs and constraints of different groups within this sector, stakeholders can develop more effective strategies to support the transition towards sustainable agriculture.

Conclusion

Overall, the study of air pollution has revealed the significant impact of transport and waste emissions on people's daily lives. These results acquire high social relevance, highlighting the causes and consequences of air pollution. The significance of the study is that it becomes a key component in developing pollution reduction strategies that consider society's real concerns and preferences.

The analysis reveals significant diversity in adopting and perceiving eco-friendly practices in agriculture. Clustering uncovers three distinct groups, each representing unique views and practices. The economic interpretation suggests that varying levels of resource availability, technological access, and knowledge dissemination influence differences in sustainable practice adoption. Regions like Karaganda and Pavlodar exhibit contrasting trends in emissions, indicating differing economic and environmental strategies.

The study underscores the diverse perspectives within the agricultural sector regarding environmental sustainability. It highlights the potential for targeted, informed interventions to promote eco-friendly practices more widely. The findings suggest that understanding the specific needs and constraints of different groups within the sector is crucial for developing effective strategies to support sustainable agriculture. The study concludes that a multifaceted approach, including regulation, education, and technical innovation, is essential for comprehensive environmental problem-solving that involves government, society, and the business sector.

This analysis provides a nuanced understanding of the agricultural sector's response to environmental challenges in Kazakhstan, offering valuable insights for policymakers, environmentalists, and economists in planning sustainable economic development.

The study demonstrates that effective measures to reduce air pollution include stricter legislation and active public awareness. Supporting agricultural education programs, seminars, and financial initiatives is critical to success in combating environmental problems. Based on the preferences of those surveyed, it can be concluded that successful strategies must be multifaceted and include both regulation and education. Also, it is essential to consider the technical aspects of introducing environmentally friendly technologies and ensure the training of qualified specialists. Despite the high willingness of society to implement new technologies, it is necessary to consider various challenges and difficulties, such as shortages of specialists and adaptation to new production processes. An assessment of cooperation with regulatory authorities shows generally positive results but highlights the need to improve communication and resolve possible difficulties in interaction. Thus, the study provides essential data on air pollution and points to ways for a comprehensive solution to environmental problems that require interaction between government, society, and the business sector.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: KA; research design: KA and NN; data collection: KA and MN; analysis and interpretation: KA, NN and MN; writing draft preparation: KA; supervision: NN; correction of article: KA and NN; proofread and final approval of article: KA and NN. All authors have read and agreed to the published version of the manuscript.

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