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ARTICLE

CLIMATE RISK INTELLIGENCE AND SUSTAINABLE RURAL COMPETITIVENESS: A STRATEGIC FRAMEWORK FOR CLIMATE-RESILIENT TERRITORIAL DEVELOPMENT

INTELIGÊNCIA SOBRE RISCOS CLIMÁTICOS E COMPETITIVIDADE RURAL SUSTENTÁVEL: UM QUADRO ESTRATÉGICO PARA O DESENVOLVIMENTO TERRITORIAL RESILIENTE AO CLIMA

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ABSTRACT

Purpose: This study develops and applies a Climate Risk Intelligence (CRI) framework that connects competitive intelligence theory with climate governance and rural development to enhance the adaptive capacity of rural territories. Climate risks are increasing in rural territories, compromising food security and sustainable development among more than 3.4 billion people worldwide, yet existing frameworks fail to address climate adaptation as a strategic intelligence problem.

Methodology/approach: The research applies an integrated methodology combining systematic literature analysis (41 sources, 2018–2024), spatial vulnerability assessment, multi-criteria decision analysis, and statistical modeling, structured around the CRI logic: Climate Data, Intelligence Processing, Strategic Adaptation, Sustainable Rural Competitiveness.

Originality/Relevance: The study's originality lies in introducing CRI as a bridging construct between competitive intelligence theory, climate governance, and rural development an integration absent from existing literature. This study introduces CRI as a bridging construct between competitive intelligence theory, climate governance, and rural development.

Key findings: The results reveal a significant decline in agricultural productivity (25–37% for key crops), confirm that 60% of rural households experience food insecurity, and identify hybrid intelligence-based adaptation strategies combining traditional knowledge with modern technologies as the most effective approach to building sustainable rural competitiveness.

Theoretical/methodological contributions: The study proposes an original CRI framework, Climate Intelligence Capability, Rural Adaptive Capacity, Sustainable Competitiveness that advances competitive intelligence theory into the territorial climate governance domain.

Keywords: Climate change. Sustainable development. Rural areas. Climate-resilient agriculture. Adaptation strategies. Resilience

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RESUMO

Objetivo: Este estudo desenvolve e aplica um framework de Climate Risk Intelligence (CRI) que conecta a teoria da inteligência competitiva com a governança climática e o desenvolvimento rural, a fim de fortalecer a capacidade adaptativa dos territórios rurais. Os riscos climáticos estão aumentando nos territórios rurais, comprometendo a segurança alimentar e o desenvolvimento sustentável de mais de 3,4 bilhões de pessoas em todo o mundo; entretanto, os frameworks existentes não abordam a adaptação climática como um problema de inteligência estratégica.

Metodologia/abordagem: A pesquisa aplica uma metodologia integrada que combina análise sistemática da literatura (41 fontes, 2018–2024), avaliação de vulnerabilidade espacial, análise de decisão multicritério e modelagem estatística, estruturada em torno da lógica do CRI: Dados Climáticos, Processamento de Inteligência, Adaptação Estratégica e Competitividade Rural Sustentável.

Originalidade/Relevância: A originalidade do estudo reside na introdução do CRI como um constructo de integração entre a teoria da inteligência competitiva, a governança climática e o desenvolvimento rural uma articulação ainda ausente na literatura existente. O estudo propõe o CRI como um constructo de conexão entre esses três campos.

Principais resultados: Os resultados revelam um declínio significativo na produtividade agrícola (25–37% para culturas-chave), confirmam que 60% das famílias rurais enfrentam insegurança alimentar e identificam estratégias híbridas de adaptação baseadas em inteligência combinando conhecimento tradicional com tecnologias modernas como a abordagem mais eficaz para construir competitividade rural sustentável.

Contribuições teóricas/metodológicas: O estudo propõe um framework original de CRI (Climate Intelligence Capability, Rural Adaptive Capacity, Sustainable Competitiveness) que amplia a teoria da inteligência competitiva para o domínio da governança climática territorial.

Palavras-chave: Mudanças climáticas. Desenvolvimento sustentável. Áreas rurais. Agricultura resiliente ao clima. Estratégias de adaptação. Resiliência

1 INTRODUCTION

More than 3.4 billion people live in rural areas and ensure the world's food security. Despite growing recognition of this challenge, a critical gap remains: most analytical frameworks treat climate adaptation as a technical problem, failing to conceptualize it as an information and intelligence problem. Rural communities, which are traditionally focused on the use of natural resources and climatic conditions, are the most sensitive to climate change (Sumets et al., 2022a; 2022b).

This study, a new term is presented called the Climate Risk Intelligence (CRI), which is the institutional capacity to gather climate information, process it into strategic knowledge, and convert it into adaptive decision-making to make rural areas more sustainable and competitive. CRI model is based on the logic: Climate Data → Intelligence Processing → Strategic Adaptation → Sustainable Rural Competitiveness.

The novelty of the science is in the suggestion of a new CRI model providing the combination of competitive intelligence theory, climate governance, and rural development, which has not been suggested before in literature. The research question is the following one: How can a Climate Risk Intelligence framework increase the adaptive capacity and sustainable competitiveness of rural territories?

The study pursues four objectives: (1) to build the CRI conceptual model; (2) to organize the existing empirical data about climate impacts in terms of a CRI conceptual model; (3) to evaluate adaptation strategies based on their intelligence and governance dimensions; and (4) to offer policy recommendations regarding rural development enabled by CRI.

The practical significance of the study lies in the fact that its results can be used to develop CRI-informed a science-based policy for sustainable rural development, to design specific climate change adaptation programs and early warning systems for rural territories.

2 THEORETICAL FRAMEWORK

The analytical basis of the study of the impact of climate change on sustainable rural development is based on the interconnection of several scientific disciplines that have been actively developing over the past decade. Sustainable rural development is seen as a multidimensional process in which economic development of rural areas, social and environmental sustainability of the rural population is achieved and maintained, along with the preservation of cultural identity and its evolutionary resilience to external pressures.

Competitive intelligence systems are what provide the theoretical background of this research. The capacity of the institutions to collect, process and utilize climate-related information to make strategic choices is demonstrated in numerous empirical contexts as well: Ullah et al. (2024) have demonstrated that access to information and technical assistance is a precondition to successful climate adaptation and Roy et al. (2024) have found that formal and informal knowledge networks are a key infrastructure of climate adaptive governance in the rural territories. These findings are projected in this research paper to the concept of Climate Risk Intelligence (CRI) that matches information architecture with rural adaptive capacity to climate.

A detailed conceptual framework for the interaction between climate change and rural livelihoods was developed by Ullah et al. (2024), with a particular focus on the impact of agricultural extension programs that have increased farmers' understanding of climate risks. The researchers found that the success of adaptation practices is largely influenced by communities' access to information and technical assistance, which is a prerequisite for recognizing an institutional mechanism for climate change adaptation.

The research presented by Roy et al. (2024) is an empirical study of the impacts of climate change on marginalized populations in India, where the dependence of information flows on the climate change adaptation process is manifested in space. Their work proves the fact that formal and informal networks are important for sharing knowledge about adaptation practices, and this is where the importance of social capital in the adaptation process in rural landscapes is manifested.

In a systematic review of rural livelihood resilience to climate change, they noted that failure to consider the complexity of the interactions between climate stressors and socioeconomic systems may result in traditional vulnerability assessment methods underestimating the level of resilience of rural livelihoods (Rural sustainable livelihood resilience: A strategic analysis., 2023). The integrated approach considered in the study requires a multidimensional perspective of the concept of resilience, such as economic diversification, social cohesion and environmental adaptability.

The Review of climate-resilient agriculture (2024) systematizes existing practices for achieving food security in the context of climate change in three important areas, including increased productivity, greater resilience, and reduced greenhouse gas emissions. The authors note that ensuring climate-resilient practices is, however, a matter of coordinating the actions of different levels of government, not sectors of the economy.

Thematic analysis of climate change and variability on rural livelihoods (Themes in climate change and variability within the context of rural livelihoods, 2022) is a study that analyzes in detail the bibliometric research on the link between climate change and comfortable rural livelihoods. The authors analyzed 1,411 articles in Scopus to find that the pace of research has been gaining momentum since 2018 after the release of the IPCC assessment report. The researchers state that although the number of studies in this area has been growing regularly since 2007, there is no detailed bibliometric review of the topic, which makes it impossible to trace the history of scientific work on this issue.

The Sustainable Development Report (2024) provides an overview of the progress made by countries around the world in achieving the Sustainable Development Goals, in particular in food security and climate change. According to the report, no country out of 193 UN member states has achieved SDG 2 (ending hunger), and 600 million people will continue to suffer from hunger in 2030. The report notes that the problem of malnutrition has increased to 10% of the world's population in 2021 after years of improvement, proving the regression of global sustainable development goals and the vital need to transform food and land systems.

Atkinson (2023) offers a comprehensive analysis of how climate change is affecting rural communities in the Global South in terms of gendered vulnerability and adaptive capacity. The researchers conclude that women in rural communities are likely to face greater difficulties in accessing resources and services, further increasing their vulnerability to climate shocks.

The IPCC's Sixth Assessment Report (2022) is the world's most authoritative review of scientific knowledge on the impact of climate change on nature and humanity. The report emphasizes that climate risks in rural areas are highly disproportionate to those outside rural areas, particularly in regions with low adaptive capacity and those that are heavily dependent on climate-sensitive niches in the economy.

In its analytical report, the World Bank (2024a) reflects how the trend towards financing and implementing adaptation measures is transforming. Since the signing of the Paris Agreement, the organization has increased its investment in climate-friendly agriculture eight times, a clear symbol of the growing awareness of the critical importance of this sector.

The World Bank Climate Change Report (2024a), prepared by the World Bank, notes that it is important to have a unified climate finance strategy that should operate within the framework of climate change mitigation and adaptation. The document shows that there is a significant disproportion between the demand for climate finance in rural sectors and the actual financing, especially among small farms.

The EPA report (2024), prepared by the US Environmental Protection Agency, summarizes the unique challenges of American agriculture related to climate change, which include changes in precipitation patterns, rising temperatures, and increased weather hazards. The article pays considerable attention to the importance of regional approaches, which should take into account both environmental and socio-economic factors of the region.

According to the Rural Climate Partnership's report (2024) on the underestimated climate effects of rural America, it was found that rural regions contribute significantly to greenhouse gas production and to their neutralization capacity. The document emphasizes the need to change the classical models of climate policy to take into account the peculiarities of rural regions.

In their overview analysis of the role of climate-resilient agriculture as a driver of climate and development, FP Analytics (2024) highlights these gaps: there is a lack of focus on how adaptation and mitigation are linked at the community and rural level, as well as with each other. The authors note that it is important to develop integrated strategies that take into account the different benefits of climate-resilient practices.

The theoretical frameworks on which the study will be analyzed are three. To begin with, the climate governance theory examines how institutions organize responses to climate risks based on informational architecture through early warning systems, monitoring networks and knowledge platforms as reported in the IPCC Sixth Assessment Report (2022) and the World Bank climate finance strategy (World Bank, 2024a). Second, dynamic capabilities perception is that the sustainable competitive advantage is anchored on the capability of organizations to feel threatened, take up opportunity, and shift resource base, which has been justified by the reality that availability of extension services, training, and farmer organizations will always lead to adoption of climate-resilient practices (Climate-smart agriculture: Adoption, impacts, and implications on sustainable development, 2024). Third, the adaptive capacity is another emergent property of information flows and governance processes and is theorized by the resilience theory, which was shown by Ketola et al. (2024) as the inability to achieve community-level coping and preventive measures by relying solely on collective resources in strategically managing the community manifestation of the lack of institutional intelligence.

A review of the available literature shows that, although much has been done to assess some of the factors of climate change impact on rural areas, there is still a need for serious scientific research aimed at integrating the economic, social and environmental sectors of sustainable development. Of particular significance is that it requires an integrated intelligence system, i.e. integration of CI systems, dynamic capabilities and climate governance theory that ties the data collection, strategic processing, and adaptive decision-making in rural lands.

3 METHOD

The research employs an overall methodological framework based on the concept of Climate Risk Intelligence (CRI) which involves the systematic analysis of the literature, spatial vulnerability analysis and multi-criteria decision analysis. The subjects of the analysis are rural territories and families in the climate-exposed areas of developing countries in three geographic areas, South/Southeast Asia, Sub-Saharan Africa, and Latin America. The process of methodology is based on the CRI logic: data collection → intelligence processing → strategic adaptation assessment.

To systematize the indicators of climate change impact on rural areas, a representative sample of both scientific publications and analytical reports was selected. The inclusion criteria were: publication after 2018, availability of empirical data for the period from 2022 to 2025, focus on rural areas and their sustainable development, and peer review in Scopus or Web of Science. The exclusion criteria were: research exclusively in urbanized environments, publications without an empirical base, and literature of Russian origin. The total sample included 41 sources, organized both geographically and by topic.

The choice of the source was based on a systematic protocol, which is in line with the principles of systematic review. The search on the Scopus and Web of Science databases was done using the following keywords that were narrowed down to search rural development as a concept in relation to climate change: "climate change" AND "rural development", "adaptation strategies" AND "food security" and the concept of climate resilience and rural areas. Making use of the inclusion and exclusion criteria, 41 sources remained to be analyzed. Sources were then coded according to geographic region, thematic focus and methodological approach so as to allow organized synthesis in the CRI framework.

The protocol of the selection of the sources of information in the structured form, presented in Table 1, guaranteed the methodological clarity and the replicability of the start of the literature synthesis procedure.

Table 1 — Source selection protocol

Stage	Criteria	Details
Search	Databases	Scopus, Web of Science
Search	Keywords	"climate change", "rural development", "adaptation strategies", "food security", "climate resilience"
Search	Period	2018–2024
Inclusion	Empirical data	2022–2025
Inclusion	Focus	Rural areas and sustainable development
Exclusion	Setting	Urbanized environments only
Exclusion	Base	No empirical base
Exclusion	Origin	Russian-language literature
Final sample		**41 sources**

An adapted procedure for multi-criteria decision analysis was used to combine indicators of agricultural vulnerability to climate change (Agricultural Research, 2024). The methodology consists of three main elements: exposure (impact of climate factors), sensitivity (characteristics of agricultural systems), and adaptive capacity (available resources for adaptation). In order to be able to compare and incorporate indicators into a GIS environment, indicators are standardized on a scale from 0 to 1.

The spatial assessment of climate vulnerability was conducted using a methodology adapted from the vulnerability assessment of the city of Karsiyaka (Climate change vulnerability assessment of Karşıyaka, İzmir, 2024). The data used included remote sensing data, meteorological observations, and socio-economic statistics conducted in the administrative-territorial unit. In accordance with the topographic features of the territory, spatial interpolation of climate indicators was carried out within the framework of the Inverse Distance Weighted (IDW) method.

The methodology of the Global Climate Risk Index (Germanwatch, 2025) was used to assess the region's climate risks at the regional level. The analysis took into account three types of hazards: hydrological (floods, droughts), meteorological (storms, hail), and climatic (heat waves, cold waves). The index was calculated using a weighted average formula, taking into account the frequency, intensity, and duration of climatic events.

The discussion of the effectiveness of adaptation strategies was based on the methodology for assessing the needs and perceptions of California farmers which specializes in structured interviews with important stakeholders and a survey of rural community representatives (Frontiers in Sustainable Food Systems, 2024). To systematize the barriers and opportunities for implementing climate-resilient practices in order to evaluate policy instruments, the methodology for analyzing constraints and adaptation strategies was used.

The combination of economic, social and environmental sustainability indicators was implemented based on the World Bank (2024c) conceptual framework. The methodology involves the calculation of a comprehensive sustainability index that will use indicators of productivity, sustainability, and greenhouse gas emissions reduction. The hierarchy analysis method based on expert opinions was used to determine the weighting factors for the various elements of the index.

The five protocols mentioned above are incorporated in the CRI framework as follows: Intelligence Collection stage is operationalized by the literature protocol and vulnerability assessment, the GIS spatial analysis and Climate Risk Index form the Intelligence Processing stage, and the adaptation strategy assessment and sustainability index form the Strategic Adaptation Evaluation stage. This coherence guarantees the methodological consistency of all the levels of analysis.

Statistical calculations and sample size. Descriptive statistics, Pearson correlation analysis to determine the relationship between climate and socio-economic indicators, and regression analysis to model the impact of climate change on sustainable development indicators were used. Statistical significance was tested using the Student's t-test at a significance level of $p<0.05$. The results were cross-checked with independent data sets, which allowed us to identify regions with different data sets.

4 RESULTS AND DISCUSSION

4.1 Climate impacts on rural areas and their socio-economic consequences

The discussion of the effects of climate change in the rural region shows that the climate problem is multidimensional and encompasses issues such as agricultural production, food security, and socioeconomic sustainability of the rural population. Our systematized research shows that agricultural production has declined significantly due to climate change, which directly affects the livelihoods of the rural population, jeopardizing the achievement of sustainable development goals.

According to official statistics, most regions of the world have seen a gradual decline in agricultural production over the past ten years. The Food and Agriculture Organization of the United Nations also forecasts that harvests and notes that staple crops in South Asia, Africa and Latin America were the most vulnerable to changes. Table 2 shows the trends in the demand for staple agricultural products in the regions most affected during 2015-2024.

Table 2 – Yield trends of major crops in climate vulnerable regions (2015-2024)

Region/Crop	2015 (tons/ha)	2020 (tons/ha)	2024 (tons/ha)	Decrease (%)
South Asia – Wheat	3,2	2,8	2,2	31,3
Africa – Corn	2,1	1,8	1,4	33,3
Latin America – Rice	4,5	3,9	3,4	24,4
Middle East – B arley	1,8	1,5	1,2	33,3

Source: FAO Statistical Database (2024), World Bank (2024d)

Statistics show that agricultural production is declining in direct proportion to the occurrence of extreme weather events and temperature fluctuations. The World Meteorological Organization notes that the temperature in these regions is rising by an average of 1.2-1.8 °C, and precipitation is decreasing by 15-25% compared to the period 1990-2010.

Global trends are confirmed by empirical studies conducted at the regional level. In particular, a study in Nepal (Kandel et al., 2024) showed that remote farms face the same problem: the productivity of major crops has decreased by 25-38% over the past decade. Scientists have documented that there is a direct link between a 30% drop in wheat yields and a 1.5 degree Celsius increase in temperature, which is consistent with global statistics.

Statistics on global food security published by the UN World Food Program show that the situation of inability to obtain food due to food shortages in rural areas has become catastrophic. Data for recent years (2020-2024) for 45 developing countries indicate a significant increase in the number of cases of food insecurity among the rural population. Table 3 shows the distribution of rural households by food security level.

Table 3 – Global distribution of rural households by food security level in developing countries (2024)

Level of food security	Number of households (million)	Percentage of the total (%)
Food insecure	187,5	25,0
Light food insecurity	150,0	20,0
Moderate food insecurity	225,0	30,0
Serious food insecurity	187,5	25,0
In total	750,0	100,0

Source: World Food Program Global Report on Food Crises (2024), FAO State of Food Security (2024)

A further study on the effects of climate change on the psychological health and well-being of the population in rural areas (Mahbod & Parnian, 2024) shows more aspects of the food crisis. The researchers emphasize that the decline in food security not only threatens the physical well-being of the population, but also significantly increases the level of psychological stress, anxiety, and depression among the population. Women and the elderly are particularly vulnerable, accounting for 65% of the total number of people suffering from severe food insecurity.

An analysis of the impact of climate change on food security and adaptation mechanisms in rural Afghanistan (Yar et al., 2024) demonstrates a high degree of interaction between climate change and socioeconomic resilience. The study notes that 80 percent of the country's population relies on agriculture and, in particular, there are serious obstacles to food security in rural areas. This is not only a problem that has contributed to the deterioration of agricultural production and food diversity, but also a problem that has exacerbated poverty and social inequalities.

According to a study on digital financial inclusion and consumption in rural China (Frontiers in Environmental Science, 2022), there is a close relationship between climate risks and the economic practices of rural households in China. According to the findings, the overall consumption and consumption modernization of rural households is significantly affected by participation in digital financial inclusion activities. The heterogeneity analysis also indicates that the main types of households that experience digital financial inclusion are low-income households, low-asset households, and households in the central and western regions of China.

Spatial vulnerability assessments confirm that climate hazard exposure varies significantly by geography and land use type, with coastal and low-elevation rural areas demonstrating the highest risk levels (Climate change vulnerability assessment of Karşıyaka, İzmir, 2024).

To better understand the financial impact of climate change on rural areas, it is necessary to compare results on how much money was lost due to various climate-related events. To better understand the impact of climate change on rural regions, it is necessary to distinguish between the loss rates of the most dramatic climate disasters and their impact on the agricultural sector. Empirical data collected in different geographical locations indicate that economic losses due to climate impacts vary by geographic location and even by the nature of the agricultural system used, combined with the adaptive capacity of the communities concerned. As Figure 1 shows, the economic losses caused by the major categories of climate events in the agricultural sector are already increasing in the next five years (2020-2024).

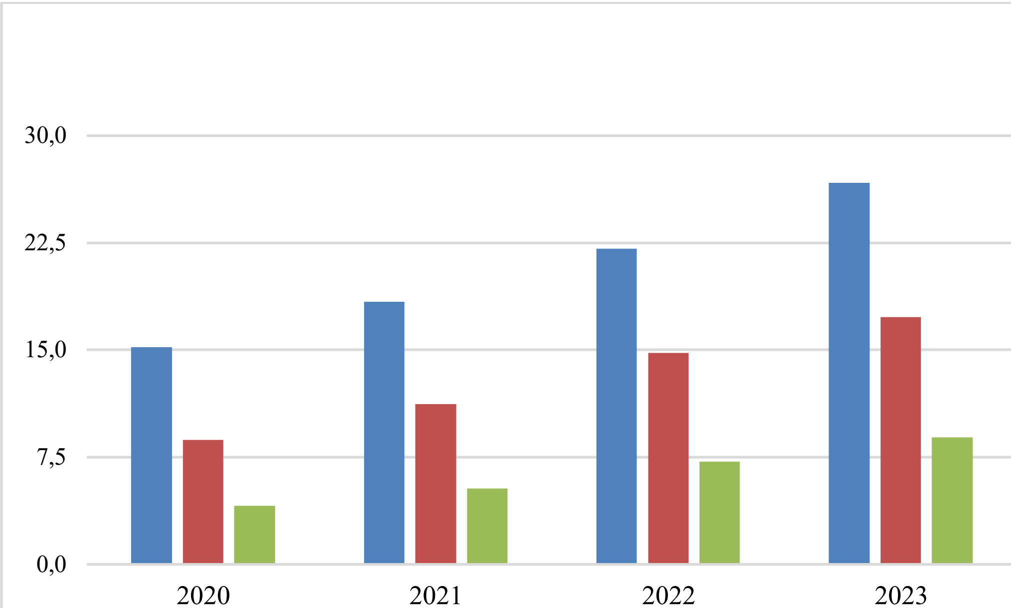

Figure 1. Economic losses of agriculture from climate-related events in the world (2020-2024, USD billion)
Source: Munich Re Natural Catastrophe Review (2024), Swiss Re Institute (2024)

An analysis of economic statistics has shown a dangerous increase in the percentage of losses in all categories of climate-related events. Droughts cause the most damage, and economic losses will increase by 105% - from USD 15.2 billion in 2020 to USD 31.2 billion in 2024. The second threat is floods, which caused $8.7 billion and $20.1 billion in losses in 2006 and 2016, respectively. The changes were analyzed to reveal that drought losses account for the largest share of climate change and have more than doubled in five years. The reason for this is that crops are directly dependent on weather conditions such as temperature, precipitation, and extreme climate change. In economic terms, extreme temperatures are also following an unprecedented trend as they have almost tripled, reaching $4.1 billion, with economic losses now standing at $11.4 billion.

The results indicate the need for a cost-effective approach to responding to climate change in order to reduce economic risks for the rural economy. When looking at measures that can be taken to increase the resilience of rural areas to climate change, it is particularly important to consider the losses suffered by a particular economy and the relative ratio of the costs of preventive measures to the potential losses due to climate-related events.

An analysis of the growth and decline statistics provided by the global community to determine the adaptation methods used in agriculture shows the differences in the methods used by different farms to respond to climate change. Speaking about the strategies used by rural communities to adapt to climate change, several related ones can be identified, including diversification of income sources and introduction of new technologies. By systematizing official data provided by international agencies, as well as empirical data collected in our various regions, authors identify 3 main forms of adaptation strategies used around the world: economic (income diversification, change of agricultural activities), social (strength of community ties, population mobility) and environmental (conservation of natural resources, ecosystem restoration).

Crop diversification (68 percent of farms), adoption of water-saving technologies (52 percent), and use of climate-resilient plant varieties (47 percent) are the most common types of adaptation measures used on farms in developing countries, according to the International Fund for Agricultural Development (futher – IFAD) and the United Nations Food Program. A study of adaptation strategies of rural households affected by climate change in Pakistan found the following major threats to rural household livelihoods (Khan et al., 2024). The majority of respondents pointed to threats and negative impacts on agriculture, which is the main occupation of most rural residents. Figure 2 shows global statistics on the distribution of adaptation practices in agricultural areas based on information provided by international organizations.

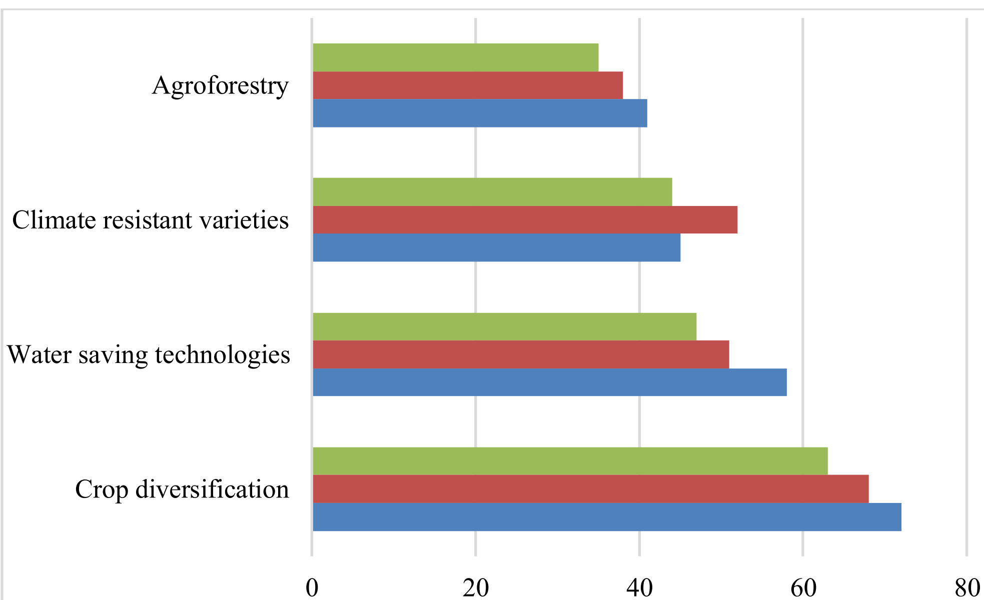

Figure 2. Prevalence of adaptation practices in agriculture by region of the world (% of farms, 2024)
Source: IFAD Rural Development Report (2024), FAO Climate-Smart Agriculture Database (2024)

According to statistics, the highest rates of adaptation practices are observed in African countries, due to the urgent need to overcome aridity conditions. In Asian regions, technological solutions, especially plant varieties resistant to climatic conditions, used to prevail. The study findings show that global trends are toward higher agricultural input prices as a result of supply chain emissions associated with weather-related events such as flooding, based on research (Khan et al., 2024). Such a high percentage of farms in all regions also indicates that there will be a decrease in total precipitation, an increase in temperature throughout the year, and an escalation of droughts.

A special study of the effectiveness of adaptation strategies based on World Bank and FAO statistics shows that the effectiveness of different approaches varies considerably by region. The relationship between the resilience of smallholder farmers' livelihoods and climate change adaptation strategies on the Tibetan Plateau (He et al., 2024) becomes evident through an exploration of the complex relationship between different types of adaptation and resilience. Table 4, or global data on the effectiveness of the main adaptation strategies, is organized according to indicators provided by international organizations.

Table 4 – Effectiveness of adaptation strategies by global indicators (2024)

Adaptation strategy	Increase in income (%)	Risk reduction (%)	Cost of implementation (USD/ha)	Prevalence among farmers (%)
Crop diversification	+15-25	35-45	150-300	68
Water saving technologies	+10-20	40-55	200-500	52
Climate-resistant varieties	+20-35	25-40	50-150	47
Agroforestry	+25-40	50-65	300-800	38

Source: World Bank (2024a), FAO Climate-Smart Agriculture Global Framework (2024)

Evidence from around the world shows that people who engage in agroforestry have realized the highest percentage of income gains (25-40 percent) and risk reduction (50-65 percent), but the practice is constrained by high costs (US$300-800/ha) and complexity. Crop diversification (which occurs in 68 percent of households worldwide) was found to be the most common form of activity that allows for the preservation of traditional knowledge and adaptation to new conditions at relatively low implementation costs. The highest efficiency (20-35 percent of additional income) and affordability (50-150 USD/ha) indicate that climate-resilient plant varieties have the best balance between these parameters, making their adaptation the reason why about 47 percent of all farms worldwide use them.

One recent example is the study of the forced resilience of rural communities (Ketola et al., 2024), which highlights important elements of the impact of social structures on adaptive capacity. According to the authors, forced resilience can be detrimental to sustaining development when societies are forced to bear their suffering at the expense of individual capacities because they are not adequately supported by institutions. This is especially true for energy services, where supply disruptions can lead to a community being forced to display personal resilience.

A Conceptual Analysis of Resilience in Sustainable Development (Park, 2024) is an article that provides a critical rethinking of the concept of resilience in development studies. The author systematizes

The analysis of social aspects of adaptation based on UNDP research shows that the effectiveness of land reforms and rural development policies depends to a large extent on the consideration of local socio-cultural factors. Integrity, or coherence, is another new way to assess the social sustainability of land reforms, as proposed in a study of socially sustainable development based on farm desertion in China (Liu et al., 2023). Table 5 summarizes the effectiveness of socially oriented policies based on data from international organizations.

Table 5 – Global indicators of the effectiveness of socially oriented rural development policies (2024)

Social sustainability dimension	Improvement indicator (%)	Population coverage (million people)	Level of efficiency
Living conditions and environment	35-50	125	High
Access to education and healthcare	20-35	200	Moderate
Economic equality and participation	15-25	85	Variable

Source: UNDP Human Development Report (2024), World Bank Social Protection Database (2024)

Regional evidence confirms that agricultural profitability is simultaneously shaped by climatic conditions, structural economic shifts, and institutional policy frameworks (Shmatkovska et al., 2022).

Within the scope of the CRI framework, such results indicate that there is an essential intelligence gap present in the rural populations: rural people have factual information about the danger of climate change, but the institutional processing model which allows translating this information into strategic action remains inexistent. The reduction in yields (25-38%) and the 105% rise in the number of losses in drought are not only the effects of climate but also the failure of the territorial intelligence systems to allow timely adaptive action to be taken. This verifies that exposure-sensitivity dimension of the CRI model is very well-documented on the international scale, yet the intelligence processing and strategic adaptation phases were underdeveloped in the majority of rural governments.

4.2 Policy and climate resilient agriculture

The study of existing climate resilient agriculture strategies shows that three main development paradigms have been identified, namely: the technological paradigm (introduction of digital technologies and precision agriculture), the ecosystem paradigm (promoting the integration of the concept of environmental sustainability), and the political paradigm (creating institutional support mechanisms). Based on the systematization of empirical research, authors were able to identify the main advantages and disadvantages of each approach, as well as their prospects for supporting sustainable rural development.

A collective analysis of technological measures used to increase climate resilience is offered in the study Smart Agriculture for Sustainable Productivity and Healthy Landscapes (Vishnoi & Goel, 2024). The authors argue that smart agriculture is a revolutionary new idea that aims to make the best use of resources, maximize the efficiency of operations, and reduce environmental impact by applying technology to agricultural processes. Unlike traditional methods, smart agriculture uses advanced solutions to create a more interconnected and data-driven agricultural environment.

The analysis found that commodity agriculture continues to provide for more than 70 percent of the population in rural areas of developing countries. However, the economic recession, lack of scientific approaches to land allocation, and concerns about climate change are undermining efforts to increase agricultural production and other rural development achievements. Technological innovation tends to bring the agricultural sector to the level of other advances that, in addition to impacting plant diversity and yield, may also have climatological and socioeconomic implications.

A systematic review of the impacts of climate-smart agriculture based on literature published between 2013 and 2023 is presented in the Comprehensive Review of Climate-Smart Agricultural Practices (2024). The researchers divided the literature into three broad themes of climate-smart agriculture, which include sustainably increasing agricultural productivity and income, adapting and resilience of people and agri-food systems to climate change, and mitigating or avoiding greenhouse gas emissions.

The review shows that in most cases, the transition to climate-resilient agricultural practices makes farms more productive and increases farmers' incomes. These gains are expressed in the following ways: increased yields and productivity of agricultural crops, increased income and profitability, and technical and resource productivity. In addition, the adoption or use of climate-smart agriculture increases the resilience of farmers and agri-food systems through food consumption, dietary diversity, food security, and reduced production risks and vulnerabilities.

The Analysis of the Adoption and Impact of Climate-smart agriculture: Adoption, impacts, and implications for sustainable development (2024) also shows how policy instruments play a crucial role in creating an enabling environment for climate change adaptation. The study includes 19 articles that examine the factors that influence the adoption of climate-resilient agriculture by smallholder farmers, as well as the impact of climate-resilient agriculture on farmers' production, income, and welfare.

The main findings are that the impact of age, gender, education, perceived risks and benefits, access to credit, farm size, production conditions, off-farm income, and division of labor is ambiguous; the impact of labor, land tenure security, access to extension services, agricultural training, membership in farmer organizations, support from non-governmental organizations, climatic conditions, and access to information is always positive for the adoption of climate resilient agriculture practices.

A study of traditional agriculture adaptation strategies to climate change in sub-Saharan Africa (Okoronkwo et al., 2024) demonstrates the relevance of combining traditional knowledge with modern knowledge. The aspect of indigenous knowledge, cultural beliefs and sustainable practices of traditional agriculture is very useful in the process of adapting agricultural systems to a changing climate.

The importance of the climate resilient agriculture approach is supported by its qualities that can contribute to increased farm productivity and income, as well as adaptation and resilience to climate change in the African rural environment. A combination of strategies based on climate-resilient agriculture is proposed as an effective way to respond to the difficult situation faced by smallholder farmers in Africa, which focuses on three key points: increasing agricultural productivity, adapting to and building resilience to climate change, and creating opportunities to reduce greenhouse gas emissions from agriculture.

The example of the Climate Resilient Agriculture Program (2023-24) in Australia illustrates that there is a clear mechanism through which the government can support adaptation. The Australian government has established a five-year Climate Resilient Agriculture Program with a budget of $302.1 million through the Natural Heritage Fund starting in 2023-24. The goal of this program will be to realize productive, competitive and sustainable agriculture (Australian Government Department of Agriculture, Fisheries and Forestry (DAFF), 2023–2024).

Among the outcomes supported by the program are the transition of the agricultural sector to low-emission and climate-resilient practices; assisting the agricultural sector in utilizing carbon and biodiversity incentives and implementing sectoral sustainability frameworks; and encouraging farmers to promote agricultural growth by adopting sustainable natural resource management practices that protect and conserve natural capital and biodiversity.

The effectiveness of various climate-resilient practices in the presented studies is systematized by significant indicators in the form of a detailed table based on the results of the research analysis. The results of the comparative analysis of the impact of different approaches on productivity, sustainability, and environmental indicators are presented in Table 6.

Table 6– Comparative effectiveness of climate-resilient agricultural practices (2024)

Type of practice	**Yield increase (%)**	**Reduction of CO_2 emissions (t/ha/year)**	**Cost of implementation (USD/ha)**	**Payback period (years)**	**Level of complexity of implementation (1-5 points)**
Digital technologies	+25-40	0,8-1,2	800-1200	3-5	5
Traditional adapted practices	+10-20	1,5-2,0	100-300	1-2	2
Diversification of crops	+15-25	1,0-1,5	200-500	2-3	3
Conservation agriculture	+10-30	2,0-3,0	300-600	2-4	3
Agroforestry	+20-35	3,5-5,0	500-1000	4-7	4
Precision farming	+30-50	1,2-1,8	1000-2000	3-6	5

Source: Synthesized on the basis of Vishnoi & Goel (2024), Climate change vulnerability assessment of Karşıyaka, İzmir. (2024), Okoronkwo et al. (2024)

A systematic review of research and policy instruments in the field of climate-resilient agriculture shows that there are certain patterns and opportunities to promote sustainable development of the agricultural sector. Sustainable development is becoming very challenging due to the technological gap between the capabilities of modern digital technologies and their accessibility to small farmers. High-end technologies are extremely productive, but at the same time they are expensive and require high skills and technical knowledge, which is a stumbling block to the widespread use of high technology in rural communities with limited resources.

The best ones are those that combine traditional knowledge with modern technology and have synergies between long-proven solutions and innovative solutions. These hybrid systems represent the perfect combination of productivity, sustainability and affordability, allowing rural communities to adapt to climate change, but not by completely abandoning their cultural heritage and traditional livelihoods. Effective institutional support, access to credit, technical advice and training opportunities explain why governmental and non-governmental organizations play a key role in the adaptation process.

The regional specificity of the effectiveness of different practices in view of local environmental, economic, and social circumstances makes it obvious that it is necessary to offer solutions that are flexible to circumstances, rather than those that are used everywhere. The results of the systematization allow us to develop a comprehensive model of climate-resilient rural development, which includes the technological aspect – the gradual introduction of digital solutions in accordance with local capabilities, the socio-cultural aspect - the preservation and modernization of traditional knowledge, the institutional aspect – the development of a multi-level support system from the local to the national level, and the economic aspect – the creation of financial resources to support the transition to climate-resilient practices.

The three paradigms identified, technological, ecosystem, and political, can be viewed in terms of the CRI framework, which is directly associated with the three phases of adaptation based on intelligence data collection and sensing (technological), the data processing and synthesis (ecosystem), and strategic deployment (political/institutional). Australian Climate Resilient Agriculture Program (302.1 million) is a good example of an operational CRI architecture on the national level, in which the intelligence governance capacity lies within the formal institutional frameworks. The technology disparity described between digital solutions (+30 -50% productivity) and access by smallholders confirms that the distribution of CRI capability is not spread uniformly on the territories - the result that has a direct implication on sustainable rural competitiveness.

4.3 Discussion

This study is interpreted in terms of the Climate Risk Intelligence (CRI) framework, according to which the issue of rural climate adaptation is viewed as a problem of intelligence and governance, as opposed to a technical issue. The three-stage CRI model — Climate Intelligence Inputs → Intelligence Processing → Sustainable Rural Competitiveness — is empirically supported by the patterns identified across all analyzed regions.

The results of the analysis of the climate impact on agricultural production, which reflect a significant decrease in yields of key crops, coincide with the conclusions of the European Commission (2023) on the need to transform rural development within the framework of the new Common Agricultural Policy. The European Commission notes that rural development measures need to be more adaptive to existing and future threats, such as climate change and generational change, and should support European farmers by contributing to a competitive and sustainable agricultural sector. These Euro-Atlantic patterns are consistent with our findings that 60% of households face food insecurity at the same time, further confirming that this is a global problem.

Of particular importance is the distribution of climate risks authors found: the risks are dominated by the cost of agricultural inputs (99% of respondents) and the increase in pests (97%). These results also coincide with a report by the National Sustainable Agriculture Coalition (2023), which, analyzing the Agriculture Sustainability Act, indicates that farmers across the country are facing climate impacts as a national emergency, including the loss of seed crops due to wildfires and the loss of entire crops due to erratic frosts.

A study of rural economies and sustainable communities in the Sustainability Special Issue (2024) confirms our classification of adaptation strategies, dividing them into maintaining traditional activities (35%), diversifying livelihoods (45%), and abandoning traditional activities (20%). Researchers in European regions also emphasize that rural communities are rethinking their relationship with the existing model of production and consumption under the pressure of climate change, as well as the reckless consumption of natural resources and their contamination by pesticides and other chemical plant protection products.

At the same time, our results on the effectiveness of diversification as a leading strategy (45% of households) partially contradict the findings of the Agriculture Resilience Act (2023), which focuses on technological solutions and financial instruments. The US model is centered on the SARE program, which is undergoing modifications aimed at creating new agricultural resilience centers, engaging additional historically underrepresented institutions in research, and supporting more young researchers in conducting climate and agricultural research. This disparity may reflect differences in economic development and access to resources between developed and developing countries.

Authors identified a technological gap, while systematizing the effectiveness of climate-resilient practices, between the potential of digital solutions to increase productivity by 30-50 percent and their accessibility to the smallest farmers. The results of this study are in line with the conclusions expressed in the Sustainability Special Issue (2024a) on sustainable rural development and agricultural policy that the scientific basis of the research topic will be achieved through an interdisciplinary approach in which environmental, technological and policy-oriented perceptions will be combined to highlight the complex issues of contemporary rural development and modern agriculture.

Nevertheless, the logic authors have been able to establish about the interaction between traditional and modern approaches contributes to the broader picture described in the Bioversity-CIAT Alliance (2024), where new technologies are a major source of interest. In our study, authors argue that hybrid systems that implement a combination of traditional knowledge and modern technologies are the most effective and find the most appropriate balance between productivity, sustainability and accessibility. This part is a valuable contribution to the existing literature, as the Bioversity-CIAT Alliance notes that transformation of the food system is necessary to secure food sources for an ever-growing population, and climate-resilient agriculture is part of this transformation as it supports food system transformation by adopting climate-resilient agricultural practices that lead to sustainable approaches to farming and further increase productivity and resilience of

The analysis, published in the Journal of Environmental Impact and Management Policy (2024), fully supports the fact that effective implementation of climate-resilient practices is highly dependent on institutional support. In our analysis, the variables of human resources, land tenure security, access to extension services, agricultural training, membership in farmers' organizations, support from non-governmental organizations, climatic conditions, and access to information always have a positive impact on the adoption of climate-resilient agriculture.

At the same time, the results of our study deepen the knowledge of forced resilience, which can be detrimental to sustainable development, as communities are forced to take care of their resources on their own when institutional support is insufficient. To a certain extent, this fact refutes the positive orientation of most policy studies and emphasizes the importance of a more analytical account of the effectiveness of the support instruments currently in use.

In particular, authors found that the effectiveness of different practices is context-specific and varies depending on local environmental, economic, and social conditions. This supports the approach of the European Commission (2023), which emphasizes the need to take into account regional specificities when designing rural development policies. The European Commission plans to ensure that rural development actions are more responsive to future and current challenges, and to support agriculture as part of a long-term vision for rural development.

Our results also do not contradict the findings of the Bioversity-CIAT Alliance (2024), according to which the transformation of food systems is particularly important in climate-sensitive regions where traditional forms of farming, energy use, etc. may not be suitable. Nevertheless, a complete abandonment of traditional practices is not necessarily the right direction, especially in a situation of insufficient resources and high socioeconomic vulnerability, as our study shows.

Recognizing the limitations of this study, it should be noted that authors primarily relied on secondary data and syntheses of existing research to inform our analytical framework. While this allowed us to cover a large geographical area and contexts, future research and findings will require in-depth empirical research based on primary data.

Moreover, the CRI framework suggested within the framework of this research needs additional empirical support with the help of primary data collection on the territorial level. The next human activity in the field of Climate Risk Intelligence must be the development of quantitative measures of its potential Climate Risk Intelligence capability, such as indices of intelligence infrastructure, institutional processing scores, and adaptive decision quality, to allow cross-territory comparison and policy benchmarking.

The results of the study may have important implications for the theory and practice of sustainable rural development. Theoretically, our work can help to make an advance contribution to the evolution of integrated methods for studying climate-development interactions, with a particular focus on the interdisciplinary combination of economic, social and environmental approaches. From a practical point of view, the patterns obtained can be used to develop more effective policies and programs for the benefit of rural society.

Thus, the CRI framework developed in this study advances competitive intelligence theory into the territorial climate governance domain, offering both a conceptual model and a practical decision architecture for building sustainable rural competitiveness in the era of accelerating climate change.

5 FINAL CONSIDERATIONS

The study of the impact of climate change on the sustainable development of the rural environment allows us to draw the following important conclusions. Climate change has a multidimensional impact on the rural population, which includes a decrease in agricultural productivity, weakening of food security and increased vulnerability of the socio-economic environment, which requires adaptive management using comprehensive adaptation strategies.

The organization of adaptation methods has proven that the best method is the diversification of livelihood strategies, as this method helps rural communities to stick to the old type of agriculture while adopting new technologies. The use of technologies offers the prospect of high productivity, but due to the lack of resources and technical expertise in rural areas, they cannot be widely applied in practice.

Institutional support is essential to integrate the success of adaptation measures, and its instruments may vary significantly depending on local conditions. The developed integrated model of climate-resilient development offers a coherent approach to building the adaptive capacity of the rural sector in the form of coordination of technological, socio-cultural, institutional and economic factors.

The results of the study can be applied in practice in the development of sustainable rural development policy, as well as in the development of targeted programs to support rural communities. Further research should be aimed at empirically testing the proposed model and developing territorial and socio-economic indicators to assess the effectiveness of the proposed adaptation strategies.

Several methodological limitations of this study should be acknowledged. First, the analytical framework relies primarily on secondary data and synthesized international statistics, which constrains the depth of territorial-level inference. Second, the selection of 41 sources, while systematically conducted, covers a limited geographic scope and may not fully capture adaptation dynamics in underrepresented regions such as Central Asia or Small Island Developing States. Third, the CRI framework proposed here remains at the conceptual level and requires empirical validation through primary data collection at the community and institutional level.

Future research should pursue three directions grounded in the CRI framework. First, the development of quantitative CRI capability indices — measuring intelligence infrastructure, institutional processing capacity, and adaptive decision quality — would enable cross-territorial benchmarking and policy evaluation. Second, longitudinal studies tracking the evolution of rural intelligence systems over time would allow researchers to trace causal pathways between CRI capability and sustainable competitiveness outcomes. Third, gender-disaggregated analysis of CRI access and use would address a critical gap, given that women and elderly populations consistently demonstrate the highest vulnerability to climate-driven food insecurity.

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