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Assessing the vulnerability of agricultural sectors to climate change: a case study for Slovenia

Ocena podnebne ranljivosti za posamezne kmetijske sektorje: primer Slovenije

Tanja TRAVNIKAR (✉), Ajda BLEIWEIS, Maja KOŽAR

Agricultural Institute of Slovenia, Agricultural Economics Department, Ljubljana, Slovenia

✉ Corresponding author: tanja.travnikar@kis.si

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ABSTRACT

Food systems are becoming increasingly vulnerable due to changing weather conditions. The need to understand the impacts of climate change on food production is growing among researchers, policymakers, and agricultural producers. In Slovenia, an assessment of the climate vulnerability of individual agricultural sectors has not yet been conducted, which motivated this study aimed at developing a suitable methodology. This study introduces a methodology for assessing climate vulnerability, applied to 11 crop production sectors and 5 livestock sectors. The methodology is based on a structured questionnaire comprising three sections: exposure to climate impacts, adaptive capacity for each climate impact, and additional information related to the sector, data availability, and adaptation strategies. The vulnerability of individual agricultural sectors is assessed using a three-point scale that considers the combination of exposure and adaptive capacity for each identified climate impact. Based on the results, the sectors are ranked according to their climate vulnerability using a vulnerability matrix. The results indicate that the outdoor vegetable production has been identified as the most vulnerable agricultural sector. The proposed methodology provides a strong framework for advancing research in this area. However, future research efforts should emphasize the development of quantitative methodologies, which will require the systematic collection of specific data on the impacts and consequences of climate change in agriculture.

Keywords: climate change, climate vulnerability assessment method, vulnerability matrix

POVZETEK

Prehranski sistemi postajajo vse bolj ranljivi zaradi spremenjenih vremenskih razmer. Potrebe po razumevanju vplivov podnebnih sprememb na pridelavo hrane se povečujejo pri raziskovalcih kot tudi pri oblikovalcih politik in kmetijskih pridelovalcih. V Sloveniji še ni bila izvedena ocena podnebne ranljivosti posameznih kmetijskih sektorjev, kar je bil glavni povod za izvedbo te raziskave, katere cilj je bil razvoj ustrezne metodologije. V tej študiji je predstavljena metodologija za oceno podnebne ranljivosti, ki je bila uporabljena za 11 sektorjev rastlinske pridelave in 5 sektorjev živinoreje. Metodologija se začne s strukturiranim vprašalnikom, sestavljenim iz treh delov: izpostavljenost podnebnim vplivom, prilagoditvena zmogljivost za posamezne podnebne vplive in dodatne informacije, povezane s sektorjem, bazami podatkov in prilagoditvenimi strategijami. Vrednotenje ranljivosti posameznih kmetijskih sektorjev temelji na tritočkovni lestvici, ki upošteva kombinacijo izpostavljenosti in sposobnosti prilagajanja za vsak identificiran podnebni vpliv. Nato je uporabljena matrika ranljivosti, ki na podlagi dobljenih rezultatov razvrsti kmetijske sektorje glede na njihovo podnebno ranljivost. Rezultati kažejo, da je pridelava zelenjave na prostem najbolj ranljiv kmetijski sektor. Ugotavljamo, da je predstavljena metodologija zelo dobra osnova za nadaljnje raziskave. Vendar se mora prihodnje raziskovalno delo osredotočiti tudi na razvoj kvantitativnih pristopov, kar pa ni mogoče brez pričetka sistematičnega zbiranja specifičnih podatkov o vplivih in posledicah podnebnih sprememb v kmetijstvu.

Ključne besede: podnebne spremembe, metoda podnebne ranljivosti, matrika ranljivosti

INTRODUCTION

Climate change is already having a significant impact on a multitude of extreme weather and climate events across all regions of the world (IPCC, 2022). The continent of Europe is experiencing a greater rate of warming than the planet as a whole. Between 2018 and 2022, the global mean surface temperature was approximately 1.2 °C higher compared to the period 1850–1900, while in Europe, it was about 2.2 °C higher (EEA, 2024). Also, the climate projections for Slovenia indicate a high probability of continued temperature increases across all seasons and regions. By the end of the century, various scenarios indicate that temperatures in Slovenia will be between 1 °C and 6 °C above the 1981–2010 average (Bertalanič et al., 2018). In addition, broad climate projections indicate a significant increase in the number of days with elevated temperatures, a higher frequency of extreme weather events, and an increase in soil temperature, as well as the intensity and frequency of extreme precipitation.

As the atmosphere continues to warm, all systems will face increased exposure to climate hazards. However, food systems and agricultural production are particularly vulnerable due to their direct exposure and dependence on climate (IPCC, 2022). For this reason, understanding and assessing the vulnerability of agriculture is essential, as it helps us comprehend how climate changes impact agricultural systems and enables us to develop appropriate strategies for adaptation. This importance is highlighted by the growing number of vulnerability assessments published in scientific literature (Fellmann, 2012; GIZ, 2014; Jurgilevich et al., 2017).

The Intergovernmental Panel on Climate Change (IPCC), as the leading international scientific body for assessing climate change, has been addressing this topic for many years. In general, the concept of vulnerability is diverse (Birkmann et al., 2013; Dos Santos et al., 2023), including in IPCC reports (Das et al., 2020; Zebisch et al., 2021). Vulnerability in the IPCC Third and Fourth Assessment Reports AR3/AR4 (IPCC, 2001; IPCC, 2007) differs from the understanding presented in the IPCC Fifth Assessment Report AR5 (IPCC, 2014). The term vulnerability, as defined by AR3/AR4, refers to the degree to which a system is susceptible to and unable to cope with the adverse impacts of climate change, including climate variability and extremes. It is based on three key elements: exposure, sensitivity, and adaptive capacity (IPCC 2001; IPCC, 2007). In its AR5 report, the IPCC introduced the concept of risk for the first time, defined by three components: hazard, exposure, and vulnerability. The term vulnerability is defined as the propensity or predisposition to be negatively affected. Vulnerability comprises a variety of elements and concepts, including, but not limited to, sensitivity or susceptibility to harm, and the inability to cope and adapt (IPCC, 2014). For example, O'Brien et al. (2007), in the context of climate change, consider outcome and contextual vulnerability as the two key concepts of vulnerability. Outcome vulnerability, aligned with the AR3/AR4 report, conceptualises vulnerability as the net impact of climate change on a biophysical or social exposure unit, after accounting for feasible adaptations. In contrast, contextual vulnerability adopts a multidimensional, process-oriented perspective, considering climate variability and change within the broader framework of political, institutional, economic, and social dynamics that interact with specific exposure units, which aligns with AR5.

The multiplicity of interpretations and conceptualisations of vulnerability has led to the development of a diverse range of methodological approaches and tools for its assessment. The most recent report from the European Environment Agency (EEA, 2024) represents the latest assessment of climate change risks and vulnerabilities in Europe (EUCRA). However, it does not provide a detailed account of the methodological steps that led to this assessment. A similar conclusion can be drawn from the existing literature, which, despite the increasing importance of assessing agricultural vulnerability to climate change in recent years, a unified methodology cannot be found (Hinkel 2011; Kvalvik et al., 2011; Dong et al., 2015; Dos Santos et al., 2023). The vulnerability of agriculture is evaluated using various methods, including variable assessments, indicator-based approaches, and qualitative methods (Birkmann et al., 2013; Kociper et al., 2019; Neset et al., 2019; Mohapatra et al., 2022; Dos Santos et al., 2023). For example, Neset et al. (2019) explored the role of indicators in assessing Swedish agricultural vulnerability to climate change, combining quantitative and qualitative methodologies. Their findings enrich the literature by addressing the relevance, applicability, and limitations of commonly used agricultural vulnerability indicators. The study concludes that commonly used vulnerability indicators are often difficult to apply in practice, as their definitions and thresholds are highly dependent on geographical and temporal scales, as well as the regional context. Moreover, their study highlights the necessity of integrating quantitative and qualitative aspects. The literature indicates (Asare-Kyei et al. 2015; Parker et al., 2019) that some approaches have successfully merged these aspects by complementing complex quantitative methods with supplementary qualitative information, such as participatory workshops and stakeholder engagement.

The purpose of this paper is to present a potential approach for assessing agricultural vulnerability, which, due to data limitations in Slovenian agriculture, is built upon a qualitative strategy. This methodology aims to identify the negative impacts of climate change on various agricultural sectors and their adaptive capacities in Slovenia. The vulnerability assessment method introduced in the paper is supported by the AR3/AR4 framework, which defines climate vulnerability through three key components: exposure, sensitivity, and adaptive capacity. The developed methodology was applied to 11 crop production sectors (small grain cereals, maize, oilseeds, potatoes, vegetables, fruits, olives, grapes, hops, permanent grassland, and sown grassland) and 5 livestock sectors (cattle, pigs, poultry, small ruminants, and bees).

The methodology presented in this paper contributes to new approaches for assessing the vulnerability of agriculture to climate change and is particularly useful for comparing different agricultural sectors. Its main advantage lies in the fact that the theoretical framework builds on IPCC concepts, while its novelty is in enabling the ranking of agricultural sectors according to their vulnerability to climate change. The study also highlights the lack of widely accepted methodologies for assessing agricultural vulnerability, which further emphasizes the value of this approach.

MATERIALS AND METHODS

An analysis of various databases revealed a lack of quantitative data required to conduct a comprehensive assessment of the vulnerability of individual agricultural sectors. While numerous meteorological data sets are available, there is no systematic and detailed overview of agricultural parameters across different sectors and locations. Sector-specific data are available at the national level on an annual basis, but they are not monitored at regional or local scales or at different time scales, which is essential for linking with meteorological data. In light of the absence of quantitative information on exposure, sensitivity, and adaptive capacity of individual agricultural sectors, an adjusted vulnerability assessment was developed. This assessment relies primarily on qualitative evaluations, scientific literature, and field specialists' evaluations. The methodology is based on the IPCC AR3/AR4 framework (Figure 1) and incorporates current climate change impacts.

The methodology, used in this study, was implemented in 2023 and, encompassing eleven crop sectors (small grain cereals, maize, oilseeds, potatoes, vegetables, fruits, olives, grapes, hops, permanent grassland, and sown grassland) and five livestock sectors (cattle, pigs, poultry, small ruminants, and bees). The process was based on an interdisciplinary approach, involving approximately 30 experts from various specialized fields of agriculture, employed at leading research and professional institutions. These experts actively contributed to completing questionnaires and evaluating the results, thereby ensuring a high level of expertise and comprehensiveness in the analysis conducted.

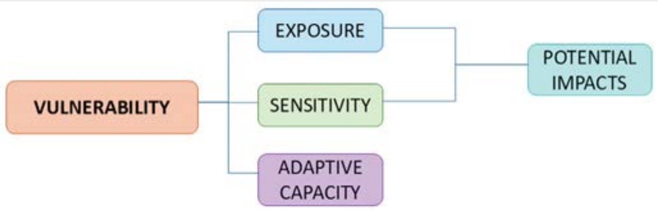
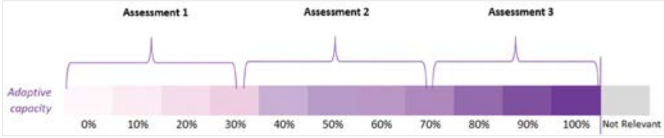


Figure 1. The concept of climate vulnerability (adapted from Fellmann, 2012)



Note: The sector is adapting slowly or there are no effective measures (score 1), the sector adapts moderately (score 2), or the sector is adapting effectively (score 3)

Figure 3. Three-point adaptive capacity rating scale

The initial step in conducting the qualitative methodology for the vulnerability assessment was the design of a questionnaire aimed at experts from various agricultural fields. The primary objective of the questionnaire was to identify and assess sector-specific negative climate impacts as well as corresponding adaptation measures. The first section of the questionnaire was designed to identify negative climate impacts and assess exposure. Experts carried out the exposure assessment using a three-level rating scale, ranging from 1 to 3 (Figure 2). Furthermore, additional information was gathered, including whether the impact is specific to a particular region or location in Slovenia, descriptions of the consequences of negative climate impacts on the sector, details on whether the climate impact and its consequences are quantified (and if so, where the data are collected), and the identification of data required for long-term monitoring of climate change impacts.

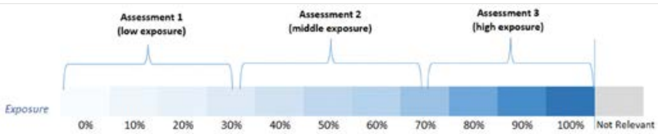


Figure 2. Three-point exposure rating scale

The second section of the questionnaire aimed to assess how each sector adapts to the adverse effects of climate change. To gather information on the adaptation measures implemented, a series of targeted questions was included. Experts assessed the adaptive capacity for each identified negative climate impact using a three-level rating scale, ranging from 1 to 3 (Figure 3). Furthermore, additional information was sought regarding adaptation, including data monitoring of the implementation measures and potential alternative approaches to adaptation.

Once all completed questionnaires were received, preliminary vulnerability assessments for each sector were prepared (the methodology is described below). Initial findings were then presented at a participatory workshop with a broader group of field experts. During the workshop, the full range of negative climate impacts affecting each sector was discussed, along with a detailed overview of existing and potential adaptation measures. This was followed by an in-depth analysis and discussion of the results, enabling a critical evaluation of the findings. Additionally, the results were individually assessed by experts specializing in the respective fields.

In the end, the results for each agricultural sector were categorized according to vulnerability levels using a vulnerability matrix (Figure 5). Ranging was based on a combination of exposure and adaptive capacity, considering nine possible combinations of vulnerability outcomes (Figure 4). The matrix illustrates the extent to which a sector is exposed to negative climate impacts and its capacity to adapt to those impacts. A rating of 1 signifies the lowest level of vulnerability, while a rating of 3 indicates the highest level. For example, as exposure to negative climate impacts increases and adaptive capacity is limited, vulnerability increases. Conversely, when exposure is low and adaptive capacity is high, vulnerability is reduced.

The vulnerability assessment for each sector was prepared for each specific climate impact using the Assessment template (Figure 6). This template in the first column provides a detailed list of sector-specific negative climate impacts, prioritized from most to least relevant. Each climate impact is then evaluated comprehensively in terms of exposure, adaptive capacity, and vulnerability.

Exposure	Adaptive capacity	Vulnerability
1	3	1
1	2	1-2
1	1	2
2	3	1-2
2	2	2
2	1	2-3
3	3	2
3	2	2-3
3	1	3

LEGEND	
Exposure	
High exposure	3
Medium exposure	2
Low exposure	1
Adaptive capacity	
The sector is adapting effectively	3
The sector adapts moderately well	2
The sector is adapting slowly or there are no effective measures	1
Vulnerability	
The sector is very vulnerable	3
The sector is medium to highly vulnerable	2-3
The sector is medium vulnerable	2
The sector is less to medium vulnerable	1-2
The sector is less vulnerable	1

Figure 4. Vulnerability as a combination of the outcomes of exposure and adaptive capacity assessments

Adaptive capacity \ Exposure to negative climate	10%	30%	40%	50%	60%	70%	80%	90%	100%
100%	1	1	1	1	1	1-2	1-2	2	2
90%	1	1	1	1	1-2	1-2	2	2	2
80%	1	1	1	1-2	1-2	2	2	2	2
70%	1	1	1-2	1-2	2	2	2	2	2-3
60%	1	1-2	1-2	2	2	2	2	2-3	2-3
50%	1-2	1-2	2	2	2	2	2-3	2-3	3
40%	1-2	2	2	2	2	2-3	2-3	3	3
30%	2	2	2	2	2-3	2-3	3	3	3
20%	2	2	2	2-3	2-3	3	3	3	3
10%	2	2	2-3	2-3	3	3	3	3	3

Figure 5. Vulnerability matrix

AGRICULTURAL SECTOR:	Sector name				
Identification of climate change impacts	Exposure	Adaptive capacity	Vulnerability assessment	Adaptation measures (for evaluating adaptation)	Regional differences - Impact specific to:
First negative climate change imapct	*Assessment (1-3)*	*Assessment (1-3)*	*Vulnerability Matrix*	*List of measures*	*Country / specific location*
Second negative climate change impact	*Assessment (1-3)*	*Assessment (1-3)*	*Vulnerability Matrix*	*List of measures*	*country / specific location*
Ect.	*Assessment (1-3)*	*Assessment (1-3)*	*Vulnerability Matrix*	*List of measures*	*country / specific location*
Overall assessment:	Weighted average	Weighted average	Vulnerability		

Figure 6. Assessment template

The template also contains a list of all adaptation measures implemented (both funded and unfunded) that are crucial for adaptive capacity evaluation, as well as information on regional-specific differences. The final vulnerability assessment for a sector is represented as a single value (the average of all assessments). It is important to note that this value is not a conventional arithmetic mean; instead, it is a weighted evaluation based on the importance of individual climate impacts and measures.

RESULTS AND DISCUSSION

The results illustrated in Figure 7 indicate that the majority of agricultural sectors, specifically seven, were categorized as medium to highly vulnerable (assessment level 2–3). These include maize, potatoes, intensive orchards, vineyards, permanent grassland, oilseeds and beekeeping. In contrast, six sectors were classified as medium vulnerability (assessment level 2), comprising hop growing, vegetables in protected areas, small grain cereals, sown grassland, olive growing and cattle farming. The remaining livestock sectors, including poultry, pig, and small ruminant farming, were rated as less to medium vulnerable (assessment level 1–2). Outdoor vegetable production has been identified as the sector most vulnerable to the effects of climate change (assessment level 3). No agricultural sector was assessed as level 1, representing the lowest degree of vulnerability.

In addition to vegetables grown in open fields, maize and potatoes are also highly exposed to negative climatic conditions. However, in contrast to vegetables grown in open fields, maize and potatoes have a higher capacity for adaptation, which is why they are classified as medium to highly vulnerable. Other crop productions are considered medium exposed to negative climate impacts, with varying degrees of adaptive capacity. For example, vegetables grown in protected areas, sown grassland, and hop growing demonstrate greater ability to adapt. Olives, on the other hand, stand out as an exception, exhibiting better adaptation to certain negative climate impacts.

These findings align with other studies, which have demonstrated an increasing frequency of climate-related hazards contributing to crop losses and a decline in food quality (Bisbis et al., 2018; Bras et al., 2021; IPCC, 2022). Climatological studies for Slovenia also indicate an increase in climate-related hazards. Climate projections

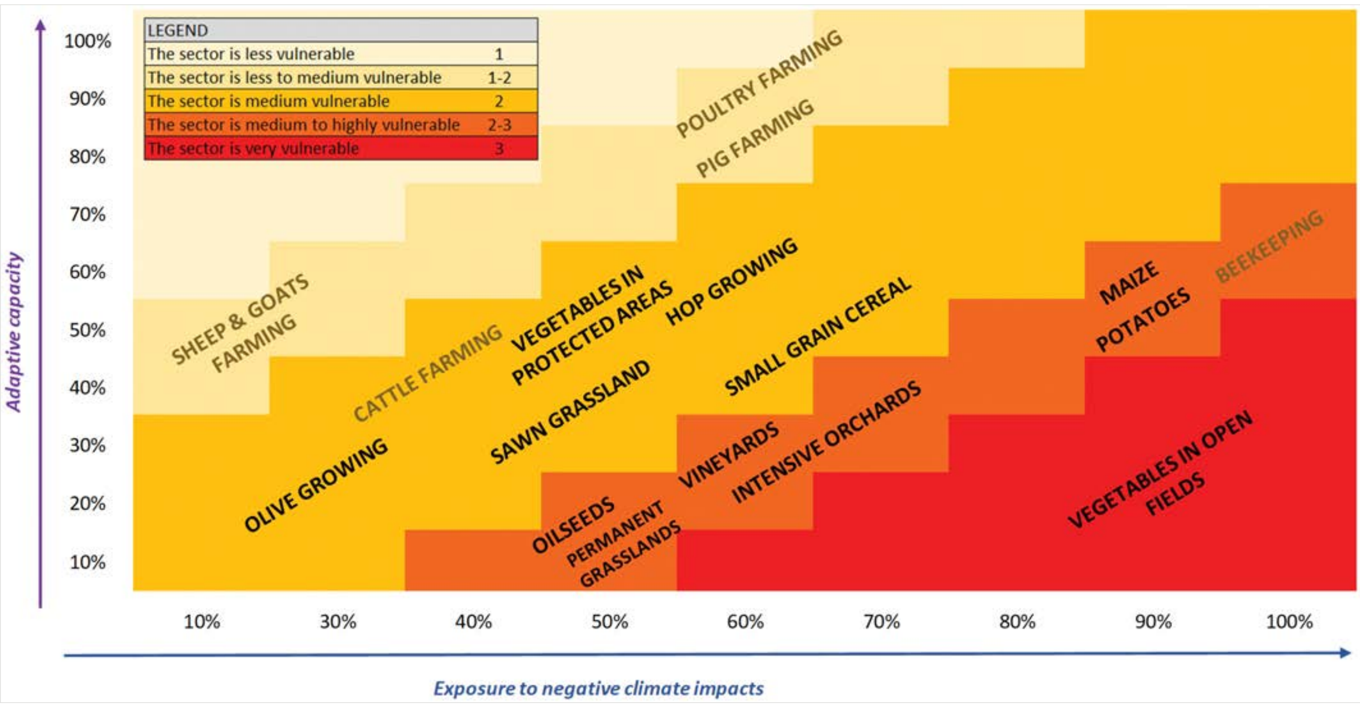


Figure 7. Ranking of agricultural sectors based on vulnerability levels

for Slovenia show that the increase in temperature will continue across all seasons and regions. By the end of the century, temperatures are expected to be between 1 °C and 6 °C higher than in the period 1981–2010, according to different scenarios. Projections indicate that the number of hot days will increase significantly, there will be more extreme weather events, and soil temperatures will also rise. Additionally, precipitation levels, intensity, and the frequency of extreme rainfall events are expected to increase (Bertalanič et al., 2018).

The combined impacts of heat and drought have reduced the global average yields of maize, soybeans and wheat by 11.6 %, 12.4% and 9.2%, respectively (Matiu et al., 2017). Moreover, drought and heat events have significantly affected below-ground vegetables, impacting tuber development rates, with yield losses varying by region (Ray et al., 2019; Bras et al., 2021). Although below-ground vegetables like potatoes are considered stress-tolerant, they are more sensitive to drought than cereals (Daryanto et al., 2017). In higher latitude regions, the primary concerns are temperature variability's impacts on harvest stability, as well as pest and disease pressures, and phenological shifts, such as meeting winter chilling requirements and the risks of early spring emergence (Santos et al., 2017; Gitea et al., 2019). In fruit growing, warming and climate variability lead to changes in fruit quality, such as alterations in acidity and texture in apples, or changes in skin color in grape berries (Sugiura et al., 2018). Still, the overall impact of climate change on various crop types remains under-researched and uncertain (Alae-Carew et al., 2020).

The greatest challenges in crop production are associated with rising air temperatures. The consequences of this include drought and heat stress in plants, leaf and fruit scorch, and increased evaporation. The most effective measure for adapting to drought is irrigation. In Slovenia, irrigation is practiced (excluding grasslands), but it is done on a relatively limited scale, which is insufficient for effective adaptation. Another negative climatic impact common to most crop sectors is the distribution and amount of precipitation, as well as the increasing frequency of extreme weather events. Several adaptation measures are available to mitigate this impact (e.g., hail nets, drainage systems); however, these measures are implemented to an insufficient extent. Intensive orchards, vineyards, olive growing, and outdoor vegetable production face a significant risk of frost damage. Various adaptation measures (e.g., sprinklers, heaters) are used, but frost damage remains a significant problem in Slovenia. The overall consequence of all these factors results in decreased crop yields and changes in product quality, which decrease the economic results of agriculture and reduce the availability of local food for consumers.

Livestock are often less vulnerable to negative climate impacts than crops. However, the results of this study show that reduced feed availability and changes in the nutritional profile of feed also have a significant impact on livestock farming (in line with other studies: Chapman et al., 2012; Godde et al., 2021). Additionally, the indirect effects of climate change are evident in the scarcity of water resources and the spread of infectious diseases and parasites. The most significant direct climate impacts on livestock are heat stress and an increased number of hot days, caused by rising atmospheric temperatures, particularly when coupled with high humidity. This leads to reduced animal production and declines in health and reproductive performance. Cattle and small ruminant farming are more vulnerable than pig and poultry farming, primarily due to their reliance on bulky fodder produced in Slovenia, which cannot be sourced on a large scale from global markets. In contrast, pig and poultry farming can compensate for domestic feed shortages by importing grains and oilseeds from foreign markets. All animals experience greater heat stress, but those kept in barns (especially true for pig and poultry farming) have relatively high adaptation potential due to the controlled conditions within the barns.

Furthermore, sheep and goats are better adapted to high temperatures compared to cattle. The findings of this study indicate that beekeeping is the most vulnerable sector within livestock farming, with the highest exposure to negative climate impacts, particularly more frequent extreme weather events and heatwaves. These climate changes affect bee pastures, increase disease and pest incidences, and slow colony development. These results are consistent with other literature studying the impacts of climate change on livestock (Chapman et al., 2012; Das et al., 2016; Rojas-Downing et al., 2017; Godde et al., 2021; IPCC, 2022).

The assessment approach follows the IPCC AR3/AR4 framework, focusing on exposure, sensitivity, and adaptive capacity. Similarly, Kociper et al. (2019) used the same IPCC approach to assess climate vulnerability in Slovenian agriculture across 12 statistical regions (NUTS3), however, at the aggregate level of the entire agricultural sector. A matrix-based assessment approach, similar to ours, is used in Smithers and Dworak (2023), who outlined a systematic sequence of steps for climate vulnerability and risk assessments and described the key elements of climate risk assessment based on the IPCC AR5 methodology. Due to the variety of approaches and concepts, direct connections and comparisons with other methods cannot be made. Nevertheless, the qualitative approach is commonly used in studies assessing agricultural vulnerability to climate change, such as those by IPCC (2007, 2014, 2022), Asare-Kyei et al. (2015), and EEA (2024).

One of the limitations of this qualitative approach is its potential subjectivity. While the framework used for the assessment is structured and systematic, the weighting of various factors (e.g., exposure, adaptation capacity) can be influenced by the researcher's perspective and judgment. Another limitation is the reliance on often incomplete or unmonitored data. The selection of variables for assessment depends on available data, which may be limited by factors such as geographic coverage and temporal scope. These constraints may prevent researchers from fully capturing the complexity of agricultural vulnerability. Ultimately, this dependence on data availability introduces uncertainty, emphasizing the need for improved data collection and standardization to enhance future assessments. For example, Slovenia monitors crop losses after weather events only if natural disasters occur and losses exceed 30%. There is no information available on crop losses below this threshold. Additionally, data on crop losses and related indicators is only available at the national level, not at the regional level. It is recommended to establish analytical databases for assessing agricultural vulnerability, tracking and publishing annual damage estimates for all crops and regions, rather than only during declared natural disasters.

Despite some limitations of the approach used, several advantages are recognized. One key advantage is its ability to assess vulnerability across different agricultural sectors and classify them based on vulnerability levels, which is crucial for prioritizing strategies. It is important to note that most vulnerability assessments rely on highly aggregated data, often at the global or continental level (IPCC, 2022). Furthermore, these assessments have typically focused on the most significant global crops, predominantly wheat and maize. Different agricultural sectors' vulnerability assessments allow policymakers and stakeholders to focus on the most vulnerable sectors and direct efforts toward developing adaptation measures tailored to the specific needs of each sector. If more detailed data on individual sectors becomes available in the future, the methodology is flexible enough to be expanded, providing a deeper understanding of the specific challenges each sector faces. Another significant advantage is its potential for applicability across different regions, countries, or sectors, beyond agriculture.

Location-specific climate impacts of individual sectors were considered in the evaluation templates (see Figure 6), where experts qualitatively addressed regionalization and factored it into the assessment of exposure and adaptive capacity. However, to achieve more accurate results, regionalization should be integrated more extensively. It is recommended to promote further research and analysis of agricultural climate vulnerability, including comprehensive monitoring of climate impacts specific to agriculture, with sufficient geographical coverage to enable regional analyses. A key advancement in this area is the development of a set of agroclimatic indicators. Only through adequate data monitoring, incorporating regional analyses, will it be possible to apply quantitative methods for vulnerability assessment, which could contribute to targeted agricultural policy measures and climate adaptation strategies. Currently, Slovenia implements measures at a horizontal level, without specific regional targeting, meaning that these measures are not designed for areas with higher vulnerability to climate impacts. Given the lack of detailed regional quantitative analyses, the findings of this study provide a robust scientific basis for designing strategies to enhance the adaptation of Slovenian agriculture to climate change.

The applicability and purpose of the research results provide a structured framework for further research and refinement within the scientific community, particularly for improving data quality and methodological robustness. In the broader professional and societal context, the results support the development of targeted adaptation strategies by identifying the most vulnerable agricultural sectors and providing insight into their specific risks. This enables agricultural advisors, planners, and professionals to make informed decisions tailored to sector-specific needs. At the level of national and regional decision-making bodies, the findings offer a practical tool for policy formulation, especially in light of the current lack of detailed regional data. The presented methodology fills a gap by providing a qualitative but systematic assessment framework that can inform policy priorities, guide the allocation of resources, and support the development of adaptation strategies. As such, the study serves as a bridge between scientific research, professional practice, and policymaking in the field of climate adaptation.

CONCLUSIONS

This paper presents a novel approach to the qualitative assessment and classification of individual crop and livestock productions based on their degree of vulnerability to the effects of climate change.

Due to the lack of a widely used and accepted methodology for assessing agricultural vulnerability (Hinkel 2011; Kvalvik et al., 2011; Dong et al. 2015; Dos Santos et al., 2023) and the numerous data limitations in Slovenia, the methodology presented in this paper primarily relies on qualitative analyses, expert judgment, and a review of relevant literature. This methodology was applied to eleven crop sectors and five livestock sectors. It provides a comprehensive vulnerability assessment, including detailed information on the identified negative climate impacts for each sector and their degree of exposure. Additionally, it includes information on adaptation measures for each sector and its adaptive capacity. By ranking the crop and livestock sectors according to their vulnerability, a deeper understanding of the specific risks faced by each sector has been identified.

The findings of this study indicate that vegetable production in open fields is the most vulnerable sector. The majority of agricultural sectors in Slovenia, including maize, potatoes, intensive orchards, vineyards, permanent grasslands, oilseeds, and beekeeping, are classified as medium to highly vulnerable to climate change. Other sectors, including hop growing, vegetables in protected areas, small grains, sown grassland, olive growing, and cattle farming, exhibit medium vulnerability. Livestock sectors, including poultry, pig farming, and small ruminants, demonstrate lower to medium vulnerability.

The methodology developed in this study offers significant advantages for the assessment of vulnerability to climate change in the crop and livestock sectors. One of its main strengths is its capacity for reproducibility across different sectors and/or countries. It serves as an initial step in identifying sectors by their degree of vulnerability, which is crucial for prioritizing adaptation strategies. If more detailed assessments of individual sectors become available in the future, the methodology is flexible enough to be adapted and expanded. By ranking sectors according to their vulnerability, policymakers and stakeholders can more effectively target interventions and develop tailored adaptation measures to address the specific needs of each sector.

The methodology employed for vulnerability assessment in this study mainly relied on qualitative analyses. While this approach has provided valuable insights, it is recommended that future research enhance the methodology by incorporating quantitative data. Establishing a comprehensive, ongoing data collection process across Slovenia, covering crop-specific data, soil conditions, and other relevant agricultural parameters, is essential. Agrometeorological parameters could then be combined with meteorological information for each specific region. Such an approach would allow for a more data-driven vulnerability assessment.

Current data availability in Slovenia is limited, with information on crop losses only accessible when natural disasters are officially declared and only at a national level. To address this gap, it is recommended that a more comprehensive analytical database be established to track and publish crop damage data on an annual basis, regardless of whether a natural disaster threshold is met.

In conclusion, this study provides a valuable framework for assessing agricultural vulnerability to climate change, offering insights into sector-specific vulnerability and adaptive capacities. By combining qualitative analysis with future quantitative data, this methodology can support shaping targeted adaptation strategies and improving the resilience of Slovenia's agricultural sector.

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