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MENTAL MAPPING TO EXPLORE THE RISK LANDSCAPE OF WINE PRODUCERS IN THE FACE OF CLIMATE CHANGE

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Abstract: This study uses individual mental mapping to examine the risk environment of Hungarian vine growers. While the focus is on the challenges posed by climate change, it is important to note that grape growers do not respond only to climate change but also to the complex environment that surrounds them. This research focuses on the Mátra wine region and explores how climate change affects market, institutional, financial, and labour market risks. Through qualitative interviews and collaborative mental mapping exercises, this study reveals that producers are confronted with an intricate and interconnected web of risks. Although short-term adaptation practices to the negative effects of climate change are common, long-term strategic responses remain limited. Institutional inflexibility, particularly regarding regulations on grape varieties and support schemes, further restricts their capacity for adaptation.

Keywords: Climate Change, Mental Mapping, Risk Landscape, Vine Growers, Adaptation, Hungary

Highlights

- Hungarian vine growers face a multifaceted risk environment.
- This study uses an individual-based mental mapping approach.
- Long-term strategic responses of growers are limited by institutional and market factors.
- Labour shortages are considered a more pressing issue than climate risks.
- Holistic, cross-sectoral adaptation strategies and supports the integration of qualitative tools are needed.

1. Introduction

A frequently cited statement in studies on the agricultural aspects of climate change is that agriculture is a dynamic system that constantly responds to changing circumstances. These changing conditions are mostly related to climate, natural resources, and stimuli; however, there are other factors such as market fluctuations, agricultural policies, access to technology, and extension (Anwar et al., 2013). This wide range of changing *conditions* generates constant risks and pressures for farmers to manage and adapt, making it a routine activity for those living on their land (Arbuckle et al., 2015). Farmers are accustomed to dealing with climate variability and uncertainty; however, as the range of climate variability increases, farmers need to become more adaptive (Crane et al., 2011). However, farmers are also considered particularly resistant to change, restricted by tradition, support policies, and social and behavioural variables (Wreford et al., 2017). Consequently, a rapidly growing body of work aims to understand the impacts of climate change on agriculture, as well as farmers' perceptions of climate change and their likelihood of adopting adaptive and mitigating practices (Sietsma et al., 2021).

Within this research strand, the status of viticulture has always been an indicator of the changing climate in the past, as well as in the present (Chuine et al., 2004; Marx et al., 2017). This is explained by the sensitivity of grape plants to year-to-year variability and the limited regions where grapevine growth is suitable (Schultz and Jones, 2010). Studies suggest that the major challenges induced by climate change are likely to have significant social, economic, and ecological consequences for the wine sector (Mosedale et al., 2016). Ideal conditions for growing grapes are found in areas with no severe cold spells in winter or late frosts, a warm climate that allows the grapes to ripen, and a relatively dry climate that prevents disease. In the medium term, climate change can significantly alter the geography of the world's wine-producing regions. Traditional wine-producing regions, such as Spain, Italy, and Greece, as well as the coastal and lowland areas of southern California, account for the majority of global wine production. These regions are particularly vulnerable to the adverse effects of climate change, including extreme drought and increased frequency of heatwaves, with the potential for complete disappearance by the end of the century (van Leeuwen et al., 2024). This would have a considerable impact on the labour market and local economies (Bernetti et al., 2012; van Leeuwen et al., 2024). Conversely, moderate warming may improve grape ripening in many parts of Central and Eastern Europe. Regions such as Hungary, Slovakia, the Czech Republic, Romania, Bulgaria, Poland, and the Baltic States are expected to have new opportunities for grape cultivation owing to local climate warming (Droulia and Charalampopoulos, 2022). However, this is not an entirely positive change, as climate change also means more frequent extreme weather events, which will test the adaptability of these regions to climate change. Research that considers the results of climate modelling, as well as the characteristic grape varieties and adaptive capacities of a given wine region, paints a less optimistic picture. According to Tscholl et al. (2024), five percent of European wine-producing regions are considered extremely sensitive to climate change. These regions include the southern Black Sea coast in Bulgaria, Oltina in Romania, Mátra and Hajós-Baja in Hungary, Abruzzo in Italy and Sierra de Salamanca in Spain. This vulnerability assessment clearly shows that a better understanding of local adaptation options is essential for developing successful adaptation strategies. The Mátra wine region is therefore a promising but under-researched area for studying the adaptation behaviors and risk perceptions of local producers in relation to climate change. The findings could serve as a reference point not only for Hungarian wine regions but also for those in other European countries with similar issues and vulnerabilities, such as Romania, Bulgaria, and Slovakia. This study intends to contribute new observations to the rapidly growing discussion on risk perceptions and climate change adaptation by focusing on a wine area from the under-researched Central Europe. This study was guided by the following research questions:

- What is the nature of the perceived impact of climate change on viticulture in Hungary?
- How can mental mapping be used in risk-focused behaviour research?
- To what extent do adaptation strategies integrate institutional and market dimensions beyond production?

The risks induced by climate change and those from other sources were systematically assessed, elicited, and presented as a network of interrelated concepts to create a risk landscape using an individual-based mental-mapping technique. This study intends to combine three related research tracks. First, it contributes to the discussion on the effects of global and local climate change on viticulture in Hungary and worldwide. Second, it highlights the importance of incorporating qualitative analytical methodologies alongside traditional data-based approaches in risk-focused behavior research. Third, it shows that adaptation to climate change cannot be limited to the production sphere in the narrow sense but must necessarily include the institutional (regulatory) environment and consider changes in the market risk environment.

2. Risk assessment in agricultural economics

Hardaker et al. (2004) asserted that risk is an intrinsic characteristic of agricultural production. Consequently, risk management is essential for the sustainability of farms, their families and employees. Thus, farmers must proactively strategize and mitigate risks to guarantee the long-term viability of their operations and ensure their livelihoods. In agricultural economics, the conventional and dominant views on risk premise rational risk attitudes and behavior. This widely accepted theoretical perspective is based on the assumption that decision-makers, when considering all relevant factors, arrive at decisions that optimally serve their objectives, whether those objectives pertain to profit, long-term growth, or environmental sustainability (Green 2002). This assumption also describes risks as quantifiable concepts measured using quantitative techniques (Hardaker et al., 2004). These rational approaches often misrepresent farmers in risk assessment studies because they are assumed to act in accordance with rational decision theory. However, research on agricultural production choices has revealed that farmers' behavior differs from neoclassical assumptions. For example, they tend to use 'rules of thumb' when allocating inputs, making supply decisions, and adhering to safety rules (Wueper et al., 2023).

Accurate prediction of the decisions and responses of farmers to risks is seen as key knowledge in the agricultural policy arena. However, capturing and measuring the heterogeneity of risk references has been challenging for researchers willing to support the development of risk management instruments (Iyer et al., 2020). In relation to these challenges in risk description and analysis, we emphasize two factors that motivated this study. Agricultural economic literature is predominantly based on studies concerning production risks. According to Hardaker et al., (2004), there are five types of risk that farmers need to manage: production, market(-ing), institutional, financial, and personal risks. The unpredictability of the weather and the performance of crops and livestock constitute production risks. Market risk stems from changes in sales prices, input prices, or exchange rates. Institutional risks are generated by government-related decisions such as income tax provisions, regulations, trade agreements, and development programs. Personal risks are related to major life events that may influence the profitability and sustainability of a farm business. However, in a review of the international literature on agricultural risk published between 1974 and 2019, Komarek et al. (2020) found that the largest number and proportion of studies focused on production risk, and a much smaller number focused on market risk. Two-thirds of the 3,283 studies reviewed focused on production risk alone, and only one-sixth of the studies reviewed focused on more than one risk. As these studies often characterize climate change-related impacts solely as contributors to production risks, one might conclude that the relationship is linear and unidirectional. However, it has often been concluded that risks are not isolated concepts, as they interact in complex ways and often amplify each other. Risk management-focused studies should explore the interaction between risks and interpret them as a system of interconnected elements (OECD, 2009). Moreover, the IPCC 5th Assessment Report (Oppenheimer et al., 2014) has already concluded that many previously unassessed or unrecognized risks related to climate change can be identified, in particular, indirect effects and unintended negative impacts of adaptation and mitigation measures. It has also been stated many times that the interpretation of climate change-related risks accurately reflects vulnerability only when assessment efforts adopt a cross-sectoral, cross-regional, and cross-boundary perspective (IPCC 2022). This is also accurate when assessing risk perception at the individual or farm level (Winsen et al., 2013). Furthermore, these risk assessment studies often regard climate change-related impacts solely as contributors to production risks, and one might conclude that this relationship is linear and unidirectional. (Komarek et al., 2020).

This leads us to the second factor motivating this study. Climate-adaptive behavior research first attempted to link perceptions of change and risk behavior and then incorporated evidence on individuals' perceptions of self-efficacy and beliefs (Burch and Robinson, 2007; Clayton et al., 2015; Grothmann and Patt, 2005). Despite this, adaptation case studies still do not make full use of behavioral theories, probably due to the context-specific embeddedness of the studies and the mechanisms of the multivariable effects. Several individual-based approaches, including the theory of planned behavior (Ajzen, 1985), value-belief-norm theory (Stern, 2000), and Model of Private Proactive Adaptation to Climate Change (Grothmann and Patt, 2005), have been developed to capture and provide insights into farmers' risk perception and climate adaptive behavior with the same common ground: they all claim that risk perception plays a fundamental role in adaptation decision-making. This has led to further enquiries and methodological novelties focusing on how people understand, perceive, communicate, and respond to climate change risks (Granderson, 2014). This implies that elements such as potential climate change effects or disruptive changes in personal or professional life are crucially interconnected with climate-adaptive choices. (Stern, 2016; Brown et al., 2017). This study seeks to contribute to our growing understanding of this hard-to-capture interconnectedness between perceptions and adaptive behavior through individual mental mapping conducted with wine producers in a Hungarian wine region (Khatri et al., 2023).

2.1 Mental mapping in agri-food research

Mental mapping stems from systems thinking. Systems thinking aims to depict and understand reality as purposively and coherently interconnected elements to identify leverage points to change the way systems work (Meadows, 2008). In agricultural and food studies, systems thinking-oriented academic efforts are on the rise; however, it has yet to become a driving force in comprehensive cross-scale coordination among societal, political, and market actors to tackle socio-ecological problems in food systems (Dentoni *et al.,* 2023). Actor-oriented approaches that seek to comprehend individuals' perceptions and decisions frequently employ mental model-based methodologies to develop a systemic understanding of the subject of interest (Van Den Broek *et al.,* 2024).

Mental models are similar yet simplified representations of the external world. These cognitive constructs are developed to interact with complex systems and serve as a basis for reasoning and decision-making by filtering and retaining information about reality. Mental models are inherently dynamic, indicating that they continuously evolve in response to prevailing circumstances and individuals' knowledge and experience. Owing to their dynamic nature and the limitations of cognition, mental models can only be an incomplete representation of reality (Jones *et al.,* 2011). Since mental models are simplified representations of the external world, they are particularly useful in complex or uncertain decision-making contexts (Van Den Broek *et al.,* 2024).

Mental mapping and modelling present great potential for externalizing individuals or groups' causal understanding of complex systems, such as food systems, into analyzable and comparable visualizations. This potential is still under-utilized in the food system research context; however, these methods offer an innovative way of operationalizing how actors see complex system dynamics through nodes, relationships, and causal pathways while allowing diverse actor perspectives (Hoffman et al., 2014; Levy et al., 2018; Dentoni and Roglic, 2025).

Many techniques are available to capture, analyses, and visualize individuals' mental models. These techniques are called elicitation techniques. From a methodological perspective, the key distinction between these techniques is whether the engagement of subjects is direct or indirect. If the elicitation method is based on participants' direct involvement, such as individual or group interviews, it is called direct elicitation. In other cases, when the researcher is unable to interact with the participants, indirect elicitation techniques are used. (Harper and Dorton, 2019).

The utilization of this method is becoming increasingly common in agri-food research that concentrates on system dynamics, decision-making, or risk assessment (Winsen *et al.,* 2013; Sacchelli and Fabbrizzi, 2015; Akimowicz *et al.,* 2016; Findlater *et al.,* 2019; Hulst *et al.,* 2020; Tessier *et al.,* 2021). In the context of risk-focused investigations, the authors often emphasise the benefits of this technique, including bypassing the laborious processes of risk scoring and ranking. Instead, this approach offers participants easily understandable tasks, facilitating their participation in the co-creation of risk diagrams (Winsen *et al.,* 2013). Findlater and his colleagues reflected further on this when they argued that the assumption of an economically rational theory in decision-making may lead to analytical challenges in understanding farmers' climate adaptive behavior due to the complex, uncertain, and long-term risks posed by climate change (Findlater *et al.,* 2019). This is particularly true if we consider that climate change risks are not the only risks farmers face in their activities: farmers manage their activities within "landscapes of multicausal risks" (Findlater *et al.,* 2019).

Compared with conventional data collection techniques, mental mapping techniques offer a new means of enhancing the understanding of the complexity of participants' decision-making processes in various contexts. Moreover, it is flexible and easy to adopt in farmer interview situations; participants can easily understand and respond to the exercise because of its simple and intuitive nature (Winsen *et al.,* 2013). Mental mapping has a co-creating setting that allows participants to constantly reflect on and engage with their mental maps, ensuring that the final product reflects their views as much as possible (Hulst *et al.,* 2020).

2.2 Analytical approaches to study the links between climate change and viticulture

When certain physical and biological factors are altered by climate change, the local climatic and soil conditions that determine wine regions' terroirs are inevitably altered as well. This inevitably results in changes in viticultural practices that can be referred to as 'adaptation' (Naulleau et al., 2021). According to Holland and Smit, viticulture-oriented adaptation and vulnerability studies seek to explore and understand how vine farming and the wine industry adapt to climate change (Holland and Smit, 2010). This line of research is based on the widely accepted view that adaptation can alleviate the effects of climate change. Therefore, the capacity for adaptation must be explored, assessed, and understood to reduce the vulnerability of vine-growing systems to climate change. However, the authors also pointed out that these vulnerability studies frequently involve scenario-based impact analyses that do not place enough emphasis on the fact that these growing systems are operated by people living and working in various socioeconomic contexts. Taking this line of thought further, Mosedela and his colleagues reached a similar conclusion, pointing out that although there has been a growing interest in the inclusion of socioeconomic variables, they call for more primary research evidence on the wider risk context and factors that affect adaptive decision-making (Mosedale et al., 2016). This remark is supported by a review by Sacchelli et al., who indicated that although interest in studying adaptation methods has increased in recent years, this interest has primarily led to numerous research efforts concerned with the negative effects of climatic fluctuation and water scarcity, with limited attention given to risk perception and risk assessment of those working in the wine sector (Sacchelli et al., 2016). The vulnerability-centred adaptation theory (Dupuis and Biesbroek, 2013) emphasizes the need for further investigation into climate adaptive behavior, specifically gathering empirical data from practitioners not only about what climate change impacts they perceive and what adaptation practices they take, but also attempts to capture the multiple exposures and non-climatic risks that affect adaptation decisions. To explore, understand, and present these factors as interconnected elements that affect farmers' decision-making, adaptation studies are encouraged to take this holistic perspective (Eakin and Patt, 2011). The holistic approach has not only allowed researchers to encompass all elements that have a function in maintaining agricultural systems, but has also led to the realization of a complex landscape of risks that might fuel uncertainty in farmers' decision-making (Findlater et al., 2019; Winsen et al., 2013). This is especially important in viticultural and oenological research, as the concept of terroir implies an understanding of the complex interactions between physical, biological, and human factors that give a wine region its distinctive character (Leeuwen and Seguin, 2006).

3. Methodology

3.1 Study area and participants

The dominant climatic conditions in Central and Eastern Europe are defined by the fact that this is the meeting point of three distinct climatic zones: continental, Mediterranean, and oceanic (Matyasovszky et al., 1999). In addition, Hungary's wine regions, located at the northern limit of wine grape growing potential, have diverse grape and wine production due to the favorable climate of the Carpathian Basin. However, according to Mesterházy and Pongrácz, Hungary's climate will change significantly in the coming decades (Mesterházy et al., 2014, 2018). Based on climate projections, a wide spectrum of favorable conditions for late-and extremely late-ripening grape varieties can be expected by the middle of the 21st century. The extended growing season and stronger thermal effects may lead to an increase in the number of black grape varieties, including some Mediterranean varieties. However, the number of frosty days causing potential crop damage will decrease, with severe frost damage expected every 4–10 years by mid-century. Local vine growers may no longer face frost risk by the end of the century due to global warming. However, growers must be prepared for increasing drought and damage caused by significant heat, with the number of extremely hot days projected to increase to 27–40 days by the end of the century (Lennert et al., 2024; Mesterházy et al., 2014, 2018). The study area of this paper is the Mátra wine region, which is located on the southern slopes of the Mátra Mountains, where the Northern Great Plains and Northern Hungarian Highlands meet. The wine region has a temperate continental climate characterized by cooler temperatures. The unique aspect of its climate lies in the protection provided to its vineyards from the cold northerly winds by the Mátra Mountains. This creates a favorable microclimate for grapevine farming. However, the Mátra mountain range not only shields the area from low temperatures but also inhibits the occurrence of precipitation, leading to a more arid climate in the wine-growing region. Precipitation is most abundant during the early summer months, specifically from May to June, whereas the latter half of summer is generally characterized by dry conditions. The dominance of white grape varieties in the region is the outcome of a lengthy historical evolution; however, white grapes have never been the sole type cultivated because red grapes have consistently been present in different proportions. The extensive top-down replanting of vineyards under state socialism in the 1960s led to a significant increase in the proportion of white grapes, establishing the wine region as the primary source of white wine grapes in Hungary and other COMECON countries. Plantation of new vineyards was not followed by a corresponding growth in processing capacity, which led to a substantial amount of grapes being outflown unprocessed from the region.

According to the 2021 data from the National Council of Wine Communities, the area under vines in the Mátra wine region was 5,950 hectares after decades of significant decline. The land tenure structure of the region is extremely fragmented, with nearly 1,929 vineyard owners registered; however, the majority of them (1,016) cultivated less than one hectare of vineyard in 2021. In contrast, the number of vineyards with more than 10 hectares was barely over 100 (Figure 1). In the last three decades, the development of family-owned wineries has given a new face to the Mátra wine region, even though it is not one of Hungary's best-known wine regions (Király, 2018; Totth and Szolnoki, 2019). Currently, only one-tenth of registered vine growers process grapes, with only 213 producers in the region making wine. Wineries typically sell their wines as bulk wine or in cans, and only 83 wineries in the entire 6,000 hectare wine region bottle their products. Bottled wines are much more expensive than canned wines, and only the most prestigious wineries can sell them.

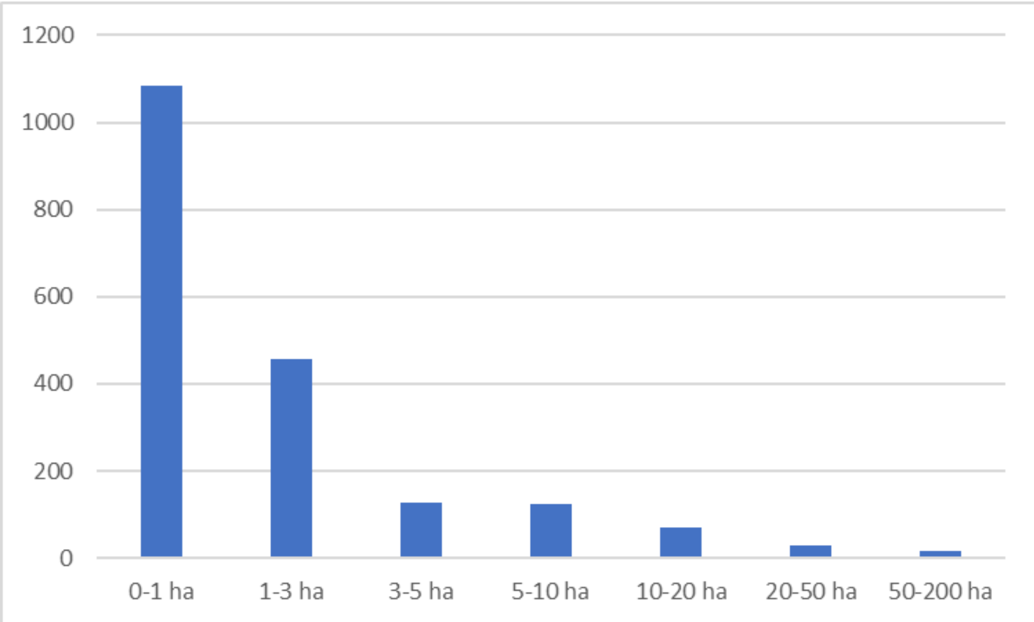

Fig 1. Size distribution of the vine growers in Mátra wine region (2021). Source: National Council of Wine Communities database, 2021, own calculation

The present study exclusively utilized qualitative data collected through interviews with vine growers and winemakers from the Mátra region (see Table 1). The interview process was divided into two stages. The initial stage focused on exploration. This entailed conducting exploratory interviews with local vine growers and winemakers. These exploratory interviews provided the authors with an opportunity to learn about the dominant perceptions of local climate change and gain insights into the most typical adaptation practices in the area. This initial stage lasted from August 2021 to April 2022 and resulted in nine interviews. The first group of interviews served exploratory functions, helping the authors in establishing a foundational comprehension of climate change related issues in the wine region. This allowed the authors to conduct more in-depth and comprehensive interviews with the research target audience in the second stage. The empirical data from the initial round of interviews was excluded from the study.

In the second phase, seven interviews were conducted with nine participants, none of whom had been interviewed in the first stage. The second stage was based on a purposive sampling strategy, aiming to recruit wineries with bottled wine production. Ultimately, seven out of the 83 bottling wineries in the Mátra wine region were included in the sample of the second phase, corresponding to a sampling rate of 8.4%. The seven bottling wineries surveyed are all vine growers, which, for vineyards over 5 hectares (236), indicates a sampling rate of 2.9%. The surveyed wineries are all family run and do not involve external capital. However, the number of non-family permanent employees increases with the size of holdings.

Tab 1. Descriptive characteristics of vineyards and position of the interview participants. Source: author's own compilations

Vineyard	No 1.	No 2.	No 3.	No 4.	No 5.	No 6.	No 7.
Position, responsibilities of the interview participants (P1…)	P1: owner, vine grower, winemaker	P2: owner, vine grower, winemaker	P3: owner, vine grower, winemaker	P4: owner, vine grower, winemaker	P5: owner (CEO, sales) P6: cellar master	P7: owner (administration and sales) P8: cellar master	P9: owner, vine grower, winemaker
Vineyard area (hectares)	7	16	5	22	108	10	15
Employment	Self-employment and seasonal workers if needed	Permanent employment of five workers	Self-employment and seasonal labour if needed	Permanent employment of five workers and seasonal workers	Permanent employment of 22 workers and seasonal workers (cca 10–15)	Permanent employment of five workers and seasonal workers (cc. 7– 8)	Self employment and seasonal workers if needed

After conducting all the interviews throughout the fieldwork, the authors concluded that they had reached code saturation. Code saturation refers to the stage in qualitative research at which no further themes or codes emerge during the data analysis (Hennink et al., 2017). The depth of individual insights regarding climate change perception and hazards, derived from the mental mapping exercises, was considered to have reached a point where no new observations were made by the authors of this paper. This emerged following the seventh interview in the second phase.

3.2 Mental model-based risk elicitation and analysis

The second phase included interviews with a mental model-based risk-elicitation exercise embedded in a qualitative interview protocol. Seven interviews were conducted between July 2022 and April 2023. All seven participants included in this stage had vineyards in the heart of the wine region in various settlements (Abasár, Gyöngyös, Gyöngyöstarján). These participants were also sampled by purposive sampling; however, being present in the domestic wine market with bottled wine products served as the primary criterion for choosing grape growers for participation. This decision is supported by two arguments. First, bottled wine is at the top of the grape and wine value chains. On the other hand, bottled wine is always a personalized product, which leads the authors of this study to assume that these producers follow careful farming practices with some level of anticipatory or adaptive mindset. Participants in the second phase are not only wineries that produce bottled wine, but they also farm a significant area of vine (minimum 5 hectares). This makes them major grape growers at the local level. Participants were identified through online sources, such as websites and social media channels. Each participant was instructed to share the most important information regarding their farms. This was followed by a discussion facilitated by the authors about the difficulties they faced on the farm and their concerns about the future. These facilitated discussions applied a co-creative card-sorting technique combined with a semi-structured interview protocol (Harper and Dorton, 2019) based on inspiration gained from recent research papers (Akimowicz et al., 2016; Findlater et al., 2019; Winsen et al., 2013). The protocol used in this study comprised three steps. First, the participants were asked to start talking about the risks, problems, or difficulties they faced in their day-to-day management. Each item was documented on a card (e.g., standard sticky notes) and placed on a large sheet of paper. In the second step, participants were asked to group all the "risk-cards" into two groups: manageable and unmanageable risks. This exercise not only formed the basis for creating the mental map but also allowed participants to elicit their own mental diagrams of risks, problems, or difficulties. As a final step, a talk-through session was held which participants could look through their own diagrams. This section was important because respondents typically explained why they considered risks manageable or unmanageable, that is, they identified the assumptions and constraints they faced.

A multi-component analytical procedure was developed to analyze the qualitative data obtained from the mental mapping interviews. The procedure was a combination of the Rich Elicitation Approach (LaMere et al., 2020) and a six-phase thematic analysis (Braun and Clarke, 2012). This multi-component analytical procedure included thematic analysis of the interview transcripts, creation of a thematic map based on thematic analysis, and a combination of the interviewees' mental maps. The final step of the procedure is when all these elements are taken together and synthesized in the form of a final mental diagram. This final joint map is considered the main end product of this study and is used to address its research questions, as it uniquely combines and presents the diversity and complexity that this research aimed to capture. This diversity and complexity is the result of the fact that risks are rarely caused by a single effect, but rather by a network or chain of effects (Winsen et al., 2013). In this sense, this multi-component analytical procedure allows us to look at this landscape as a whole and see the main underlying details that determine farmers' risk-related decision-making. This final map provides a comprehensive overview of how respondents perceive risks on their farms, how these risks are related, and what adaptation steps might be able to address these risks.

4. Results

This section aims to illustrate and present the risk environment faced by Mátra winemakers through their recognition of climate change-induced linkages between personal, institutional, financial, market, and production risks (Figure 2). The most important structural elements of this landscape are the casual linkages, as they provide insight into the mechanisms induced by climate change impacts and how particular risks start interacting with other risks as a result of these mechanisms. This visualization approach offers the possibility of following the evolution and culmination of different risk types, allowing us to present the ever-changing nature of the risk environment. The risks identified during the elicitation interviews and subsequent analysis of the interview transcripts are shown in Figure 2. Risks were categorized based on the five-element typology established by Hardaker et al. (2004). It is important to note that in all cases, the risks identified during the interviews were consistent with Hardaker's model and did not need to be modified.

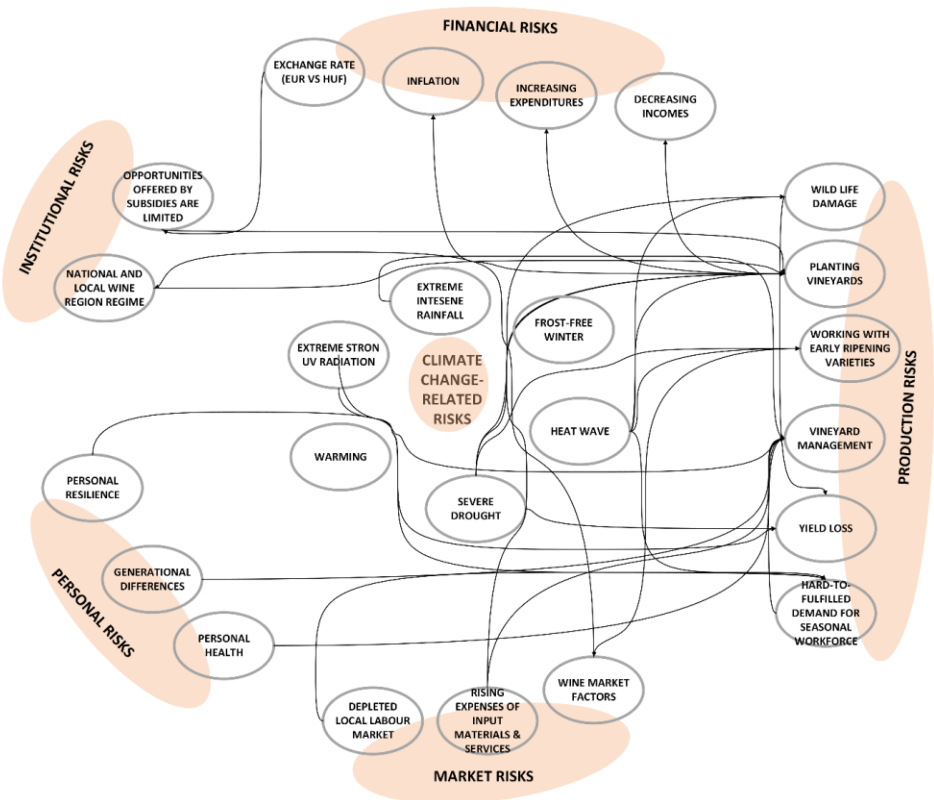

Fig 2. Risk landscape: direct and indirect linkages induced by local climate change between risk types. Source: author's own compilations

As the interviews progressed, the number of newly identified risks and relationships decreased, indicating saturation (Özesmi and Özesmi, 2004). Finally, after seven interviews, we stopped including the results of further interviews in the risk landscape, as this would have resulted in the confirmation of pre-existing relationships and risks. The complexity and dynamism of the resulting risk landscape are ensured through interconnected and interacting risks. Interactions are based on cause-and-effect relationships or indirect and direct influences. These interactions are connected to form a multi-element risk landscape that portrays the complex and multifaceted risk environment in which winemakers work.

Vine growers face a multifaceted risk environment comprising both climatic (e.g., heat stress, drought, UV radiation, and lack of winter frosts) and non-climatic risks (e.g., labour shortages, administrative burdens, and market volatility). Prolonged periods of extreme heat waves and droughts pose severe risks to vineyard operations and planting. The main problems with extreme heat and lack of precipitation stem from the phenological characteristics of the vine plants. Heat waves accelerate the ripening process, which may have a detrimental effect on the nutritional value of grapes and wine. As a result of extreme heat and dehydration, grape barriers shrivel and become too rich in sugar but are low in acidity. This results in unbalanced and flat wines, as the acidity that would later serve as the spine of the wine is weakened.

> *"So, the unpredictability of precipitation, the fact that in some cases the seasons disappear, the seasons become blurred, or there is no spring because summer comes right away. Temperature rise. So, let's say these are the three factors. And obviously, grapes can tolerate these changes a little more easily, but it definitely creates a stressful situation for them, primarily heat stress, which is now clearly observable. The lack of rainfall is perhaps less of a factor, but the fact that heat stress causes grapes to assimilate differently and absorb nutrients differently, and that this is already visible on the leaves, is, in my opinion, obvious, and I don't really see a solution." (Interviewee Nr. 5)*

Vineyard cultivation decisions tend to be short-term decisions characterised by reactive responses. Strategic and long-term responses rather feature in decisions upon vineyard planting, as they are decisions for the future (Neethling, Petitjean and Quénol, 2017). This study identified several short-term adaptation practices, such as leaf removal, water spraying before harvest, and an early start to harvest, similar to those described by Leeuwen et al. (2019). These practices do not require significant management amendments or substantial investments. Participants' long-term strategic decisions are not always based on climate change impacts. Such decisions usually include site selection, vineyard design, and plant material choice (Naulleau et al., 2021). In the Mátra wine region, site selection often aims to avoid wildlife damage, vineyard design ensures suitable training systems for mechanical harvest, and grape variety decisions are driven by market opportunities rather than long-term adaptation strategies.

Planting decisions driven by market opportunities demonstrate an interconnectedness between different risk domains when these decisions result in an unquestioned reliance on popular but climate-sensitive grape varieties such as Irsai Olivér (Vitis vinifera 'Irsai Olivér'). For over a decade, wine consumers have been seeking light, fruity, and aromatic wines, predominantly white and rosé varieties. Consumption data indicate strong and continual consumer demand for these wines in Hungary. Of these beloved varieties, Irsai Olivér (Vitis vinifera 'Irsai Olivér') stands out as the most popular among consumers and the earliest to ripen. Irsai Olivér is a Hungarian breeding white wine variety characterized by a strong Muscat profile. In the past 20 years, Irsai Olivér has risen from the 20th to the 7th most common variety, indicating its popularity in Hungary (KSH, 2020). Moreover, this variety has the second largest production area in the Mátra region, making it a key element in the local wine sector. Market risk arises from the potential for premature ripening and quality degradation, which can result in a decrease in the quantity and quality of the wine available for sale. Consequently, this leads to a loss of positions in the market that are already quite competitive.

> *"However, due to recent weather changes, we need to seriously consider that there are certain varieties that we may not be able to produce in 10 years' time. To produce wine of a quality that would be valued in the market. I am thinking here of Irsai Olivér. Ten to 15 years ago, Irsai Olivér was a very easy-to-grow variety, with a harvest period around 10 September. Today, it is certain*

to be ready between 1 August and 15 August. We have moved forward by a month." (Interview Nr. 2)

Continued growth and planting of this variety entails disregarding deteriorating climatic conditions in favour of market considerations. While the interviewees consistently expressed their frustration with farm gate prices, it was pertinent to note that Irsa Olivier had consistently been the top-selling grape variety for many years, making it a highly profitable and enticing variety to work with. This is for a local variety that is not regarded favorably in the global winemaking industry and is undervalued in the wine market.

This risk may spill over into another risk domain: institutional risk stemming from the characteristics of the national and local wine regime. In Hungary, the Wine Act is the central component of the national wine regime, governing grape cultivation, wine production, marketing, utilization of geographical indications, and administrative obligations in accordance with EU laws. The local wine regime (Ordinance) is the application of the national regime adjusted to consider the specific local circumstances of a particular region, allowing the local community to voice their opinions through the local wine administration body. The crucial factor in our case was the collection of grape varieties that the local wine regime permitted for cultivation and processing in the region. Currently, the local wine regime in the Mátra region authorises 38 wine grape varieties. These varieties are classified into different categories: four are considered prioritized, ten are recommended, fourteen are simply approved, and thirty are provisionally approved. Grouping is essential for planting and restructuring. The planting of the four priority and ten recommended varieties is financially supported by the EU's Common Agricultural Policy, whereas the planting of the 14 approved varieties can be done as self-financed investments. Producers face risks due to the inflexibility of the system, which prohibits the incorporation of alternative varieties. The wine regime's position is also understandable, as it seeks to strengthen the uniqueness of the wine-growing region's profile by clarifying the locally available varieties of wines. This is demonstrated by the new support programme, which gives producers bonus points for planting the four prioritized varieties when evaluating their applications for subsidies. Among the four prioritized varieties, Irsai Oliver is included, which contributes to the reinforcement of the variety's position within the local wine portfolio.

Considering all this leads us to link production and financial risks. Planting is the most expensive on-field investment in vineyard management. Growers observed that planting aid funds approximately 50% of the input material and labour costs associated with planting. This is a crucial component of producers' financial risk-taking strategies, as they must cover the remaining half of the budget through their own resources or loans. Weather also plays a crucial role in planting, as it can pose a significant threat to the survival of meticulously planned plantations. Furthermore, extreme heat and insufficient rainfall can jeopardise seedling germination by depriving the soil of water.

"And then there are other three hectares that I have planted twice, but both times they dried up. So now I've realized that I don't know what to do with them. Next year, well... it's already cost me the price of a family home, so I have to come up with something because this is not good. And I'm afraid that next year when I pass the five-year mark, they might come check it, and I'll have to pay back the planting subsidy." (Interviewee Nr 7)

There is also a strong connection between production and labour market-related risks. A persistent aspect of the interviews was the problematic availability of seasonal agricultural labourers in the wine region. Vine cultivation requires extensive manual labour. It is characterized by many work phases, such as harvesting, pruning, leaf removal, grapevine tying, and suckling, which traditionally require intensive manual work. Production is profoundly jeopardized by the major issue of meeting seasonal labour demand. The typical description of the situation tells us that only elderly residents aged fifty, sixty, and not infrequently seventy, and migrant workers, mostly from Romania, are available for seasonal vine work. However, their numbers are decreasing naturally, which is a concern for participants because it is difficult to find young vineyard workers with equivalent or comparable training as their older peers.

“This is a big question, because right now there are still people in their sixties and seventies who can come, but there are very few younger people we can hire”. (Interviewee Nr. 1)

Aside from natural demographic factors, another element contributes to the diminished pool of the economically active workforce in the region. Recently, there has been a notable increase in the number of legal jobs in areas that provide long-term employment opportunities. This can be attributed, in part, to the surge in industrialization and re-industrialization that has commenced in the area (Lengyel et al., 2017). This has led to a labour market characterized by a growing presence of labour shortages, while simultaneously improving the circumstances for job seekers due to increased competition among employers (Kovács et al., 2023).

However, winegrowers face competitive disadvantages in the labour market. Working in a vineyard is inherently challenging, as it involves physically demanding tasks performed outdoors, often subject to the influence of extreme weather conditions. The importance of the latter element is growing because summer heat waves not only make working in vineyards less appealing to job seekers but also present health hazards. While the summer heat in this area is nothing new, its duration is: during July and August, days and weeks of exceptionally high daily maximum temperatures can be anticipated. Climate change has resulted in a harvest season starting in early August, nearly a month earlier than the usual. Moreover, August is generally the warmest month of summer, making outdoor labour significantly more challenging. The conditions in the vineyards are worsened, lacking any form of shade, and are characterized by narrow rows and limited air circulation. The persistent challenges of seasonal labour shortages and adverse environmental conditions during the summer season pose risks that not only impact vineyard work management but also ultimately affect productivity performance.

In such instances, based on agro-economic theory, farmers are expected to respond by minimizing their reliance on human labour and implementing mechanization. The institutional risk environment for mechanization is analogous to that of planting subsidy. In this context, the usual financial arrangement for subsidies involves a fifty per cent reimbursable aid rate, meaning that the farmer is responsible for financing half of the investment. To make matters worse, the administration of applications is so slow that it can take years between tender submissions and payments. Such delays amplify the risk of inflation because the subsidized amount is exposed to the risk of depreciation if years pass.

Wildlife damage is another growing issue in the wine region. Two main reasons for wildlife damage are the population of animals, often due to mismanagement by hunting companies, and summer droughts, where animals seek alternative water sources in unprotected vineyards. Studies linking climate change to wildlife management and agricultural production are limited (König et al., 2020). As humans and animals adapt to new weather patterns, novel interactions are expected to occur, with the severity of these interactions increasing. The Mátra wine region may be a prime example of this, but the conflict is more human-human, as wildlife management in Hungary is both regulated and legally appointed. This issue requires further investigation and a transdisciplinary focus involving conservation biology, agriculture, and wildlife management.

“Our biggest problem right now is wildlife damage. It's been like this since 2019 (...) The thing is that we are particularly exposed to wildlife damage because of organic farming, because the animals are now selective.” (Interviewee Nr 7)

Overall, the participants showed confidence in their ability to continue their viticulture activities despite all the identified risks, such as labour shortages, variety selection, and various climate change-related impacts. Climate-related risks carry less weight in adaptation decisions than do labour-related risks, particularly labour shortages.

Labour-related adaptation measures tend to be long-term strategic decisions, while climate change-related adaptation measures aim to make tactical responses. Adaptation measures, such as mechanization and permanent employment, aim to tackle labour-related difficulties and are evidence of growers’ modernization and professionalization efforts. By contrast, vineyard cultivation and planting have mainly triggered only short-term adaptation measures. Although growers clearly perceive that warming and lack of rainfall will significantly impact the cultivation of some varieties, their mindset does not seem to be shifting towards potential long-term strategic adaptation measures.

5. Discussion

The findings of this study offer novel contributions to the discourse on agricultural climate change adaptation by examining Hungarian vine growers' risk perceptions using an individual-based mental mapping technique. Our findings have the following aspects that might be seen as relevant for consideration for future empirical research concerning agriculture and climate change.

First, the complex landscape of risks clearly indicates that risks in agriculture, regardless of their type, interact with each other. This study elicited farmers' mental maps to represent the risks, problems, and difficulties encountered in their farming operations. The aggregated map, developed based on farmers' individual maps, provides a comprehensive overview of how farmers perceive risks on their farms, how these risks are related, and what adaptation steps they can take to address these risks. The specifics of the risk landscape align with the current empirical understanding of risk (Belliveau et al., 2006; Hardaker et al., 2004; Komarek et al., 2020). Participants' interviews identified five common risk types: production, market, institutional, financial, and personal. Our results indicate that climate change not only impacts production risks but also leads to an increased perception of risk among farmers. Previous risk studies have primarily focused on production risks, which are crucial for identifying the limitations of sector adaptation. The findings of our research in the Mátra wine region demonstrate that treating different types of risks as discrete groups does not reflect the multifaceted, complex, and dynamic reality in which producers make their decisions (Findlater et al., 2019).

Our results clearly reflect production risks induced by climate change, but the study also shows that climate change (extreme heat waves, UV radiation, and droughts) not only affects production risk (making viticulture riskier) but also induces other risks that influence farmers' behaviour and planned adaptation. These observations are consistent with Europe wide assessments that mostly identify wine regions in Southern and Eastern Europe as being especially vulnerable to warming and water scarcity (Tscholl, et al. 2024). Climate change is also increasing the variability of the quantity and quality of grapes grown, but it is also increasing market and institutional risks for farmers. Moreover, accelerated ripening that tends to bring harvests into early August and yields higher sugars with lower acidity is also an observation that has been frequently reported in reviews documenting warming-driven changes in vine phenology and shifts in grape composition across Europe (Leeuwen et al., 2024). However, our findings on wildlife damage is a source of human–human conflicts caused by governance conflict in wildlife management. This observation points to risk that has not been yet explicitly treated in the literature, while pests-induced risks are more generally discussed.

For grape growers in the Mátra region, it is crucial to grow an early ripening local variety (Vitis vinifera 'Irsai Oliver) that can be sold well on the domestic market, but climate change is having a very negative impact on its production. Climate change does not make grape growing itself vulnerable, but it does make growing early ripening varieties riskier. In the longer term, this poses a market risk, as affected growers will be less able to supply the required quantity and quality of early grapes and may be priced out of their existing markets. The overreliance on Irsai Olivér due to the current strong market demand and its shift to a much earlier ripening variety together creates a cultivar-specific lock-in that has not been discussed in literature before. It seems that planting choices are still often driven by current market demands and not by future warming risks. However, adaptation may inevitably require shifting cultivars and wine styles even when these run against market preferences (Leeuwen et al., 2024).

In terms of adaptation, key practices identified by this paper -leaf removal adjustments, pre harvest water spraying or bringing harvest forward in time – match the literature's emphasis on tactical responses as so-called first line adaptations under heat and drought pressures (Leeuwen et al., 2024). Regarding strategic adaptation, shifting to late varieties that are more resilient to climate change could mitigate production risk, but entering new markets is resource-intensive and risky. There has been limited attention to the institutional risks associated with climate change, but this plays an important role in the producers' mental map, as the range of grape varieties that can be planted in the wine region is regulated, and unfortunately, the newer early ripening varieties that are more resistant to climate change are not included and therefore cannot be supported. The relevant part of the local wine-growing regulations could be amended, but this would require the joint support of all stakeholders, which is not the case currently. The inflexibility of the local wine regime can be viewed as an institutional risk. Institutional constrains – national and local wine regime – can often lead to reinforced reliance on climate-sensitive cultivars, such Irsai Olivér in our case. This is a finding that is often reflected in European analysis saying that legal rigidity of Geographical Indications can increase vulnerability by restricting varietal diversity and innovation, instead of increasing resilience. (Tscholl et al., 2024).

Findings show that persistent seasonal labor shortages, an aging local workforce, and increasing reliance on migrant labor are perceived as risks that outweigh climate risks. Circumstances related to the local labour market have implications for wine growers' risk landscape. Several factors (demographic trends, re-industrialization) have reduced the supply of reliable seasonal agricultural workers with a high level of experience in the region. However, new groups of seasonal workers represent a high degree of production uncertainty (the quality and quantity of work they can perform becomes unpredictable, etc.). In addition, climate change increases labour-related risks through two mechanisms. On the one hand, working conditions (heat stress, early start) in vineyards are significantly worsened by climate change, which in turn affects the supply of labour, further reducing the number of people able and willing to undertake seasonal agricultural work. Another effect of climate change is the deterioration of growing conditions, which may be compensated for by mitigation measures but ultimately raises the demand for labour. Overall, climate change is exacerbating labour shortages by reducing the number of people able to take up seasonal agricultural work and increasing the amount of seasonal work. Mechanization is seen as a potential solution, but the institutional risk environment poses challenges in terms of subsidies and the slow administration of applications. Late and ex-post payment of subsidies also poses serious financial risks in an inflationary environment, which works against the implementation of labour-saving measures.

Another aspect of this study that brings novelty to decision-oriented adaptation studies is the method applied to elicit and present farmers' risk perceptions as a network of interrelated concepts. Mental mapping has proven to be a useful tool for understanding and interpreting the external world. Although this individual-based mental mapping technique has not yet been firmly established in agricultural adaptation research, it has demonstrated positive outcomes in encapsulating the complexity and diversity of farmers' decision-making processes. Mental mapping has been proven a useful tool for understanding and interpreting the external world. Eliciting stakeholders' mental maps reveals their understanding of the connections within a system, and valuable knowledge can be gained about these actors' systems' thinking and their decisions about the topic under research (Van Den Broek et al., 2024). The visual representation of the results derived from mental mapping tools effectively illustrates the dynamic complexity of the human, social, and economic aspects of vine cultivation.

In the context of fieldwork, concerns were raised regarding the applicability of this experimental mental mapping method (the utilization of sticky notes as problem cards to visualize the interviewees' risk landscape). However, based on our experience, the method, its purpose, and operation were easy to understand for the interviewees, who had no difficulty visualizing the risk landscape using such co-creation methods. However, when summarizing the experience, it became clear that the process of co-creation itself, that is, commenting and rearranging the sticky notes, is at least as important as the risk landscape that emerges as a result of the co-creation process. One of the salient aspects of this sticky-notes method was that the interviewees were encouraged to emphasize the complex interrelationships of the problems or risks in the context of their decision-making processes. Based on this, we believe that this field-based mental mapping (eliciting) method can be applied to other agri-food investigations.

6. Limitations

The findings of this study are subject to limitations, primarily related to generalizability. The research focused on a specific viticultural region, the Mátra wine region in Hungary, which may limit the applicability of the results to other agricultural contexts or geographic areas with different climatic, institutional or socio-economic conditions. Additionally, the mental mapping technique, while effective in capturing individual perceptions and the complexity of risk interrelations, relies on subjective input from participants, which may introduce bias or variability into the data. Moreover, the co-creation process, including the use of sticky notes as visual aids, depends heavily on participants' willingness and capacity to articulate and externalize their risk perceptions. Variations in communication skills, cultural factors, or familiarity with such participatory methods could influence the quality and depth of data collected, limiting the method's transferability. Furthermore, the dynamic nature of climate change impacts and evolving institutional frameworks mean that risk perceptions and adaptation strategies could shift over time, requiring ongoing investigation to validate and update the findings. Finally, the study's focus on individual perceptions may not fully capture the broader systemic or structural factors influencing agricultural adaptation, suggesting that complementary approaches integrating multiple scales of analysis would enhance understanding.

7. Conclusion

This research investigates the risk perceptions of Hungarian vine growers through semi-structured interviews that incorporate an individual-based mental mapping exercise. Our findings underscore the intricate array of risks in agriculture, illustrating the interactions of risks originating from various sources. Conventional risk-oriented studies predominantly concentrate on production risks when evaluating the effects of climate change; however, the findings of this study illustrate that the risk environment in which farmers make decisions is more complicated and dynamic. Farmers' risk perceptions as a network of interconnected concepts formulated from individual mental maps of wine growers clearly illustrate that climate change exerts extensive adverse effects, contributing to a complex risk landscape in which wine growers operate. The application of an individual-based mental mapping technique provided valuable insights into farmers' perceptions and decision-making processes, revealing the complexity of adaptive responses. While the method proved effective and engaging in this viticultural context, limitations related to generalizability and participant subjectivity suggest the need for further research across diverse agricultural settings. Overall, this study contributes to a nuanced understanding of agricultural risk adaptation and offers a promising methodological approach for future investigations into climate-related challenges in agri-food systems.

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By signing a consent form, each interview participant acknowledged that the interview would be audio recorded and that the interview data would be handled confidentially. Later, the audio files were converted into verbatim transcripts. The respondents received no compensation for participating in the interviews.

Authors' contribution statement

G.K. developed and wrote the literature review with input from his Doctoral Thesis (Király, Gábor. Climate change adaptation research among vine growers: evidence from Mátra wine region. Diss. Budapesti Corvinus Egyetem, 2023). Data collection was performed by G.K. and B.K. Data analysis was performed by G.K. Both authors contributed to the description of the methods and interpretation of the results, including the discussions and conclusions.

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