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LETTER

Targeting farmers' heterogeneity to enrich climate change adaptation policy design: findings from northern Italy

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Abstract

With its scientifically proven effects and widespread acceptance, climate change stands as one of the most pressing and intricate challenges for society and economies. Farmers are on the frontline of managing climate change. Therefore, how they perceive and respond to climate change shapes their risk assessment and structures future resilience and adaptive capacity. Employing a bottom-up approach, we conducted 460 surveys randomly among farmers throughout the Lombardy region in northern Italy. A triple-loop approach considering climate change awareness, perceived impacts, and adaptation measures and barriers was implemented to characterize the potential heterogeneity of farmer behaviour and explore whether risk attitudes and adaptation actions differ between farmer profiles. We then profiled farmers through a clustering analysis. Four groups emerged, highlighting farmers' adaptation preferences and risk attitudes: (1) cropping-adapted and isolated farmers, (2) cooperation-adapted and insecure farmers, (3) risk insurance-adapted and confident farmers, and (4) climate services-adapted and aware farmers. Although the groups vary in terms of farmers' characterization and farming activities (e.g. young and highly educated vs. old and highly experienced farmers, rainfed vs. irrigated farms), similar patterns were observed regarding climate change awareness and perceived impacts—however, the contrast increased in terms of adaptation measures and barriers. Gaining a more comprehensive understanding of the diverse ways in which farmers assess risks and adapt can promote the transferability of bottom-up findings and inform the co-design of tailored and flexible adaptation instruments, minimizing the risk of maladaptation or ineffective transformation in the face of climate change.

1. Introduction

The evidence of climate change is both scientifically established and socially recognized: higher temperatures, irregular or unpredictable precipitation, and more frequent and intense extreme events have been reported in various places (Bednar-Friedl *et al* 2022) while stressing multiple economic sectors (Abbass *et al* 2022). Agriculture is one of the most sensitive and vulnerable activities to climate variations; climate change affects crop yield, soil processes, water availability, and pest dynamics (Barik *et al* 2023). Hence, farmers are at the forefront of coping with climate change-induced stressors, shifts, and shocks, tackling the challenges of being planners, performers, and innovators in an environment of high risk and uncertainty (Farhan *et al* 2022). The perception and response of farmers to climate change is ever-changing. Instead, the socioeconomic and environmental context plays a significant role in shaping attitudes, management practices, and co-shared strategies (Petersen-Rockney 2022), which means farmers may harbour differing beliefs regarding climate change and its underlying factors. Farmers' beliefs encompass comprehension, support, and trust in multiple hypothesis regarding the ongoing climate change (such as 'Is global warming occurring?' 'Who is accountable for it?' 'How does it align with meteorological data?') (Ricart *et al* 2022, Azeem and Alhafi-Alotaibi 2023). However, beliefs are not neutral; they involve different views on the effects of climate change that influence the strategic objectives of climate action (Luis *et al* 2018). For example, the level of exposure to climate risks can play a significant role in the awareness of climate change among individuals or communities (Ado *et al* 2020). Therefore, acknowledging risks prompts action and cooperation to face climate change, taking advantage of knowledge and past experiences regarding the causes, effects, and mitigation strategies at a local level (Karami 2023).

The success of adaptation strategies largely depends on a thorough understanding of farmers' awareness and perceived impacts, and how they may respond to both immediate and prolonged climate disturbances (Tiet *et al* 2022). The agricultural sector has had to adjust to climate change by effectively managing available resources (Liu *et al* 2022) and utilizing predictive data to prepare for extreme weather events (Brunner *et al* 2021). Various ways to adapt have been demonstrated through technological advancements and human ingenuity (Gardezi and Arbuckle 2020), government initiatives and programs, financial support, and extension services (Batung *et al* 2023), improvements in crop production techniques (Shah *et al* 2023), and gaining information, expertise, and abilities (Williams *et al* 2022). Strategies can differ based on intention (independent or self-directed), duration (short- or long-term), type and level of engagement (individual or community, local or global), and nature (technical, behavioural, financial, and institutional), whether they are applied before or after severe weather events (Hou *et al* 2023). The main aim of these options, whether used alone or in conjunction, is to enhance the cohesion between social, institutional, and structural changes to effectively achieve the triple goal of adaptation: improve adaptability, boost resilience, and reduce vulnerability. For instance, a farmer with enhanced adaptability is less likely to be harmed, therefore more resilient and better prepared to manage risks (Owen 2020).

As per the guidelines set forth by the theory of planned behaviour and the 'values-beliefs-norms' framework, farmers' attitudes and beliefs can be pivotal predictors of their intention to adapt, along with 'trust', which is also essential in promoting collaboration between individuals and decision-makers, particularly in situations of uncertainty or lack of information (Gholamrezai *et al* 2021, Moure *et al* 2023). The literature identified various factors as predictors linking farmer risk perception, preparation intention, and adaptive capacity. Some examples include exposure to risk factors (e.g. influenced by geography, economic status, and access to adaptation strategies) (Singh *et al* 2017, Cullen *et al* 2018), knowledge and understanding of risk sources (e.g. affected by experience, education, culture) (Ansari *et al* 2018, Han *et al* 2022), and individual or community attitudes toward risk (e.g. conditioned by the frequency and severity of extreme events) (Mitter *et al* 2019, Cisternas *et al* 2023). Intentions, as demonstrated in recent studies, directly reflect one's motivation and are strong indicators of future behaviour (Zhang *et al* 2020a, Savari and Khaleghi 2023). Furthermore, recent research has confirmed that factors influencing the acceptance and awareness of climate change can also forecast intentions and actions related to pro-environmental adaptation (Cao *et al* 2022, Hurst Loo and Walker 2022). Aligned with behavioural theories, risk predictors can also shape risk perception at the start of the reception stage, known as 'what comes in', while the eventual outcome is risk adaptation, also known as 'what occurs in', impacting decision-making processes (Schlüter *et al* 2017).

The effectiveness of a climate and agri-environmental policy in encouraging a shift towards sustainability and resilience depends on how well it considers the behavioural characteristics of its primary target group, the farmers. In the same way, understanding the reasons that drive farmers' motivations and actions can help in creating a forward-thinking adaptation policy agenda (Mahmood *et al* 2021, De Lauwere *et al* 2022). However, the timeliness of information translation from gathering to implementing can affect the willingness of farmers to act (García de Jalón *et al* 2018). Likewise, as stated by Chhetri *et al* (2019) or Wilson *et al* (2020), adaptation strategies, whether undertaken independently or collaboratively, can influence farmers' reactions, ranging from making gradual changes to transforming the entire system. This transformation is usually accomplished by using different adaptation strategies at the farm level, considering farmers' heterogeneity (Ricart *et al* 2023). That is, farmers are nothing but homogeneous (Bartkowski *et al* 2022); they are a complex and diverse community influenced by different socioeconomic factors and behavioural patterns (Barnes *et al* 2022). Different types of farmers need different adaptation paths to navigate, as their starting points and susceptibility to global trends may vary (Stringer *et al* 2020). Hence, it is imperative to conduct a conscientious assessment of the heterogeneity among farmers to gain a deeper understanding of their localized concerns and effectively aid them in adapting their tactical (short-term) and strategic (long-term) planning to the evolving climatic risks (Shukla *et al* 2019). In this regard, implementing group-based adaptation practices and categorizing farmers according to similar characteristics can lead to the development of efficient and locally embraced recommendations. This approach can also minimize the chances of intervention failures and the limited success of outreach adaptation programs (Eitzinger *et al* 2018, Jha and Gupta 2021, Singh *et al* 2022). Furthermore, a precise evaluation of risks and a plan for adaptive capacity should consider how individuals, groups, and communities are interconnected to tackle

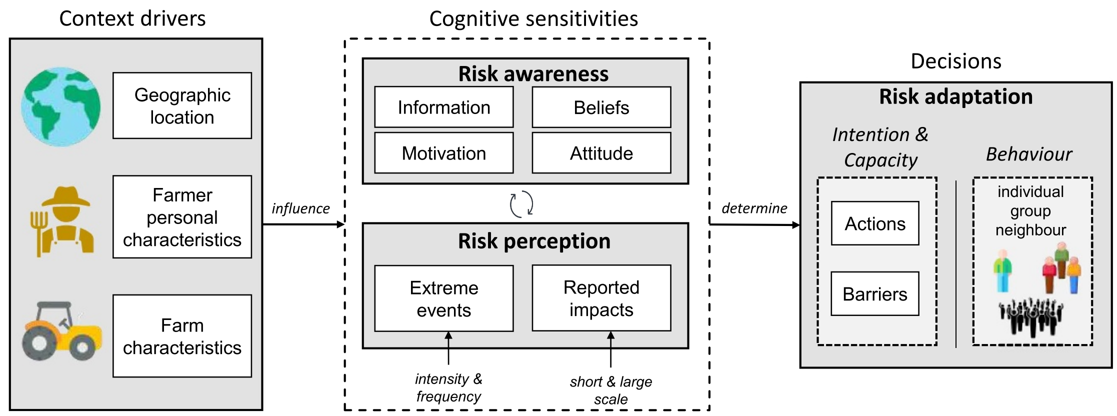

Figure 1. Theoretical model for analysing farmers' cognition and behaviour towards climate change. Source: own elaboration from icons content provided by Flaticon (www.flaticon.com) and Freepik (www.freepik.com) under free copyright permissions of the authors.

vulnerability to extreme events. This is because farmers' responses are influenced by not only formal but also informal interactions within the agricultural sector (Rodríguez-Cruz and Niles 2021).

The integrated concepts of risk awareness, risk perception, and risk adaptation are central to this paper (figure 1). The nexus between these risk dimensions enhances the understanding of farmers' attitudes and preferences when dealing with the impacts of climate change (Meuwissen *et al* 2019). As not all adaptation initiatives can be equally advantageous or suitable in a localized context (Bertana *et al* 2022), supporting farmers' resilience involves pointing out three main interconnected focal points. Firstly, farmers must possess the ability to grasp the dynamics of the climate system, accept the evidence of climate change, and be mindful of their vulnerability while considering their expected actions (Iturriza *et al* 2020). Secondly, it is paramount to recognize the farmers' ability to notice and handle changes brought about by extreme events, as well as their skill in recovering from these impacts and enduring external disruptions (Abid *et al* 2019, van Valkengoed and Steg 2019). Lastly, farmers tend to respond proactively, preventing negative effects and adjusting to both immediate and long-term scenarios (Peltonen-Sainio *et al* 2020).

This study focuses on the Lombardy region, renowned as one of the most productive agricultural areas in Europe. Historically farmers were primarily focused on managing water abundance and flood risk. However, they are progressively impacted by water stress and droughts. We aim to investigate if farmers' risk attitudes and actions differ based on their awareness, perception, and adaptive capacity towards climate change risks. Three primary objectives drove the study and response to the above question: (i) to examine the cognitive and experiential drivers influencing farmers' decisions in response to climate change; (ii) to assess the preference and relevance of each climate risk domain based on the prevailing farmer behaviour, and (iii) to characterize farmers' choices and attitudes and investigate how they differ (heterogeneity) in order to provide guidance and recommendations for policy makers. The research contributes to the literature (1) by categorizing farmers heterogeneity into different profiles using an innovative triple-loop risk approach (awareness, perception, and adaptation), (2) by encouraging a more solid foundation of community-based datasets on farmers' behaviour to enhance reliability in decision-making processes, and (3) by addressing the geographical dissonance with limited studies from European contexts even the increasing frequency and intensity of climate risks affecting farming activity. The paper is structured as follows. The case study is described in section 2, with section 3 covering the data collection and analysis methods. Subsequently, section 4 presents the results of grouping farmers based on their attitudes and behaviours, while section 5 discusses and summarizes their significance for reaching out to farmers, recognizing limitations and suggesting the need for additional research.

2. Study case

The Po river basin, in northern Italy, is the most productive agricultural area of Europe, where farmland covers 45% of the whole catchment area and accounts for roughly a third of the country's agricultural production (Zullo *et al* 2019), of which the Lombardy region contributes with more than 10% through nearly 47 000 farms distributed in less than one million hectares (ISTAT 2022). The plain covers 46 000 km^2, which is 71% of all the Italian plains, and it is crossed by the 652 km long Po River, the largest river in Italy. The main cultivated crops are maize, rice, wheat, meadows, and soybean, which are irrigated by a complex system of lakes, regulated reservoirs, rivers, and channels. The foothill (Prealpine) zone receives the highest amount of rainfall, with an annual precipitation of 1500–2000 mm. In contrast, the Po plain experiences annual precipitation ranging from 600 to 800 mm (Baronetti *et al* 2022).

The future effects of climate change are expected to intensify the pressure on the water cycle in the area, which is characterized by peaks of precipitation in late spring and autumn, and low rainfall during winter and summer. The melting of snow from May to July is important for gathering seasonal water reserves for agriculture (Giuliani *et al* 2020). The flow rate will likely be significantly impacted by the increase in average temperature, evapotranspiration, and decrease in rainfall in the upcoming decades. Based on a study by Spano *et al* (2020), it is estimated that under high emission future scenarios, there will be a 40% reduction in flow rate by 2080. Since 2001, droughts have been occurring more frequently and lasting longer, mainly due to changes in intra-annual precipitation distribution (Baronetti *et al* 2020). The International Disaster Database (EM-DAT 2022) has corroborated this statement: the past twenty years have been characterized by a series of hydrological (flash floods), climatological (convective storms, droughts), and meteorological (heatwaves) events, which have frequently disrupted snow accumulation and melting patterns and decreased water availability for farming (Casale *et al* 2021).

A case in point was the 2022 Europe's most extreme drought in half a millennium, wherein a combination of atypical low snowfall in winter, prolonged absence of rainfall for several months, and record-breaking temperatures during summer resulted in the direst circumstances in the Po River basin in 70 years, leading to the proclamation of a state of urgency in most of the surrounding areas in July 2022. Compared to 1991–2020, average temperatures in the region increased by 2.1 °C (Koehler *et al* 2022), while rainfall declined by 40% according to the Italian National Research Council. The agricultural sector was significantly affected by the episode, leading to a decrease in plant productivity and irrigation potential. The latest data from Coldiretti, Italy's main agricultural organization, shows that the extreme event resulted in $ 6 billion in damage to agricultural production (Coldiretti 2022). The 2022 event was not an anomaly, but rather a part of a larger pattern of increasingly frequent and intense droughts in the area (Montanari *et al* 2023). For the authors, this event could undergo a process of 'mediterranization' of the northern river patterns, where the rivers might become more intermittent, experiencing periods of dryness lasting several months (Levantesi 2022). This pattern could also help raise awareness about the risks of severe drought, supporting the ability to meet agricultural water requirements (Bonaldo *et al* 2023).

3. Material and methods

3.1. Data collection

The data was collected through a detailed online survey conducted from January to April 2022 using the Microsoft Forms platform. We gathered 511 samples, out of which 460 were deemed valid. The representative sample size, as per Cochran's formula for finite populations, was 382, with a 95% confidence level and a 5% margin of error. The survey, conducted in Italian, had an average completion time of 13 min. The questionnaire had 75 questions divided into six sections. The first two sections focused on exploring farmers and farming characteristics, with 10 and 12 categorical/dummy items each, respectively. These variables were selected based on previous studies like Azadi *et al* (2019), Zhang *et al* (2020b), Teshome *et al* (2021) and Ricart *et al* (2023) for quota sampling. Then, four 'behavioural' sections were defined to delve into independent variables regarding climate change awareness, perceived impacts, and adaptive capacity. First, a section of ten questions exploring climate change awareness (including occurrence, exposure, and responsibility), being items rated on a 5-point Likert scale (Alotaibi *et al* 2020). Subsequently, farmers were requested to answer 14 statements gauging their views on weather changes and disruptions impacting agricultural production and livestock. They could choose from *Yes, No,* or *I do not know/No answer* (Paudel *et al* 2020). The survey proceeded with a set of 20 questions to assess the use of strategies to address climate change risks. Respondents could answer with either *Yes* or *No* to the suggested actions (Orduño-Torres *et al* 2020). Finally, a section with nine items was used to identify the main internal and external challenges that farmers encounter when trying to enhance their resilience to climate change risks. Respondents were given the options of *Yes, No,* or *I do not know/No answer* (e.g. Singh 2020). The survey template is available in the supplementary material (table S1).

Cronbach's alpha, calculated using standardized items, was found to be 0.76, indicating the survey's reliability. The questionnaire was supported and piloted by 12 irrigation districts within the regional irrigation districts' union (ANBI Lombardy). It was pre-tested by managers from two irrigation districts to assess its suitability and the time required to complete it. The Ethics Committee and the Data Protection Office reviewed and approved the survey in line with the ethical principles of the Declaration of Helsinki and according to Regulation (EU) 2016/679 (General Data Protection Regulation). Likewise, each participant was informed of the focus of the survey and asked to sign a digital consent form.

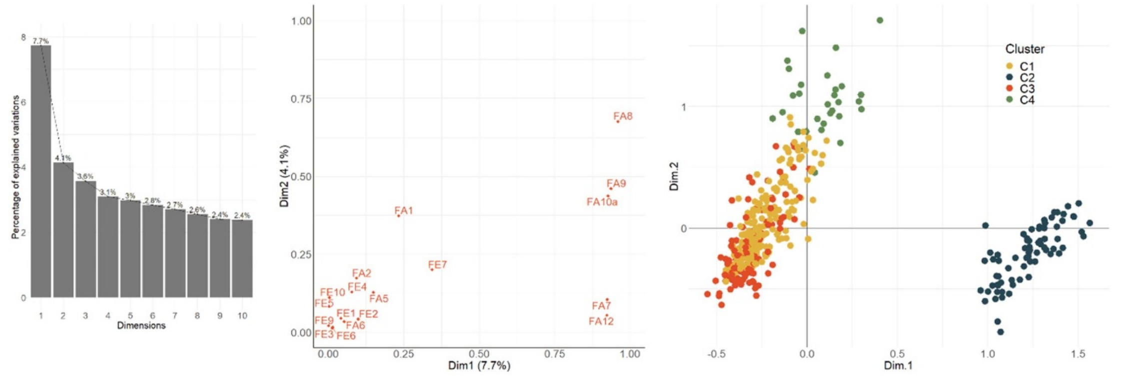

Figure 2. Dimensions (left) and components (centre) resulted from the factor analysis to identify the appropriate number of clusters (right).

3.2. Data analysis

Statistical analysis was conducted using IBM SPSS software version 27 and Origin Pro 2022. After obtaining the characteristics for the entire sample, such as the average, frequency, and standard deviation, and analysing how the variables interact, including outliers and distribution patterns, inferential statistics were used to assess the relationship and (in)dependence between trending traits and cognitive issues (Pickson and He 2021, Wheeler *et al* 2021). Bivariate analysis involved using parametric and nonparametric correlations, such as the chi-square test, along with logistic regression techniques. Distribution tools, one-way analysis of variance, and post hoc analysis were also used to examine variations between respondent groups and pinpoint internal influences (Abazinab *et al* 2022). A cluster analysis was conducted to explore farmers heterogeneity by comparing various factors related to climate change awareness, perception, and response. Multivariate analysis, including factor analysis, sequential agglomerative hierarchical and k-means clustering, was used to delineate different farmers' profiles (Alvarez *et al* 2018, Gebrekidan *et al* 2020, Sinha *et al* 2022).

Hierarchical clustering of principal components (HCPC) and multiple correspondence analysis (MCA) were performed using R software version 4.2.3 with the 'FactomineR' and 'Factoextra' packages for exploratory analysis. By using HCPC, we identified homogeneous farming patterns and highlighted the key exploratory variables that influence farmers' behaviour strategies. This method allows to summarise the variables into a few key elements (known as principal components) that are used to construct a factorial map and determine the similarity between farmers, resulting in a typology of them (Soltani and Mellah 2023). As most variables are categorical and the HCPC method requires continuous variables, an MCA method was conducted as a pre-processing step to convert categorical variables into continuous ones (Montcho *et al* 2022). Through MCA, contingency tables were simplified to display the associations between categorical variables and identify the key factors that define the farms in a dataset with multiple exploratory variables (Mărgărint *et al* 2021).

We used Ward's method to determine the sample's heterogeneity by grouping the farmers and farming characteristics that show the strongest correlation across dimensions (Amamou *et al* 2018). Due to the high-dimensional dataset, the ten most significant dimensions identified through factor analysis are statistically significant using the bootstrap eigenvalue method. However, they can only explain 34% of the variability in the data. The first two components are mainly linked to the farm's size (#FA1) and the agricultural practices (i.e., irrigated surface #FA8 and irrigation method #FA9). The combined agglomeration schedule was used to determine the optimal number of clusters for the dataset, indicating a four-cluster solution for categorizing the 460 farmers (figure 2). The cluster comparison included a bivariate analysis using the Cramer's V index (Datta and Behera 2022) to determine the strength and type of association between two categorical variables related behavioural aspects (awareness, perceived impacts, and adaptation measures and barriers). This analysis aimed to assess whether these variables could be seen as factors influencing farmers' adaptive capacity.

4. Results

4.1. Farmer's dominant profile

In the sample, the predominant farmer profile is a man aged 45–64, with higher education or vocational training (32%), and over 30 years of experience in farming (average details can be found in table 1). Family members primarily support the farmer as the main labour force, with help from a farmers' union and an

Table 1. Descriptive statistics of the independent variables for the whole sample.

Explanatory variables		Category	Mean ± SD	Mode (%)	Description and measurement
Farmer's characteristics	Age	Continuous (groups)	3.25 ± 1.19	4 (29.1)	If the age of the household head is: Less than 35 years (1), 35–44 years (2), 45–54 years (3), 55–64 years (4), and 65 years or more (5)
	Gender	Categorical	1.22 ± 0.45	1 (80.0)	1 if the household head is male, 2 if female, 3 if not specified (prefer not to say)
	Education	Categorical	2.97 ± 0.88	3 (38.3)	If the formal education level of the household head is: Illiterate (0), elementary (1), secondary (2), tertiary (3), or vocational training (4)
	Farming experience	Continuous (groups)	3.93 ± 1.26	5 (49.6)	Years of experience in crop and livestock farming: Less than 5 years (1), 5–10 years (2), 11–20 years (3), 21–30 years (4), or more than 30 years (5)
	Labour force	Categorical	1.91 ± 0.93	1 (48.7)	If the labour force is made up of: Family members (1), Non-family members (2), or both family and non-family members (3)
	Union farm membership	Categorical	1.57 ± 0.68	2 (58.7)	If the household head is a member of a farmers' union: Coldiretti (1), Confagricoltura (2), Confederazione Italiana Agricoltori (3), COPAGRI (4), or 0 otherwise
	Irrigation district membership*	Categorical		0 (26.1) Oglio Mella (20.7)	Takes values from 1 to 12 if the household head is associated with an irrigation district, 0 otherwise
	Off-farm activity	Dummy	0.31 ± 0.46	0 (69.3)	1 if the household head is involved in a non-farm job (external income), 0 otherwise
	Succession intention	Dummy	0.62 ± 0.64	0 (46.7)	1 if the household head identified a successor, 0 if do not, 2 if he/she does not know
Farming characteristics	Farm size	Continuous (groups)	4.27 ± 1.51	6 (29.1)	Total size of the household in hectares: Less than 1 ha (1), 1–5 ha (2), 6–10 ha (3), 11–20 ha (4), 21–50 ha (5), or more than 50 ha (6)
	Production system	Categorical	1.48 ± 0.96	1 (75.2)	If the agricultural production system is mainly: Conventional (1), organic or agroecological (2), transiting to organic (3), or mixed (4)
	Main crops**	Categorical		2 (70.2) Cereals–maize (66.3)	Takes values from 1 to 26 considering the preeminent irrigated or rainfed crop
	Livestock	Categorical	1.07 ± 1.53	0 (48.0) Cattle (34.6)	If the farmer combines cropping with: Cattle (1), Goats (2), Horses (3), Pigs (4), Poultry (5), Rabbits (6), Sheep (7), Buffaloes (8), 0 otherwise
	Fertilizers use	Categorical	1.04 ± 0.82	1 (77.8)	If the farmer uses some type of fertilizer such as mineral, compound or organic (1), natural (2), soil correctives (3), amendment (4), 0 otherwise
	Renewable energy use	Categorical	1.65 ± 2.27	0 (63.0)	If the farmer uses renewable energy such as biogas (1), biomass (2), hydroelectricity (3), methane (4), solar (5), other (specify) (6), 0 otherwise
	Farming practice	Categorical	0.95 ± 0.52	1 (72.2)	If the agricultural practice is rainfed (0), irrigated (1), or mixed (2)
	Irrigation surface	Continuous (groups)	3.57 ± 2.13	6 (24.8)	Total irrigated surface: Less than 1 ha (1), 1–5 ha (2), 6–10 ha (3), 11–20 ha (4), 21–50 ha (5), or more than 50 ha (6), and 0 for rainfed agriculture
	Irrigation method	Categorical	2.02 ± 2.10	1 (52.4)	If the farmer irrigates through surface (1), drip (2), drip by sub-irrigation (3), sprinkler by pivot or ranger (4), sprinkler by roll (5) or mixed (6), and 0 for rainfed agriculture
	Water source	Categorical	2.49 ± 1.55	2 (37.8)	If the water source used by the farmer is an aqueduct (1), canal (2), well (3), mixed canal and well (4), pipe (5), rainwater (6) or river (7), and 0 for rainfed agriculture
	Non-conventional water use	Dummy	1.66 ± 0.74	2 (82.8)	1 if the farmer uses alternative water resources, 2 if do not

Notes: *The irrigation district membership options are Est-Sesia, Est-Ticino Villoresi, Muzza Bassa Lodigiana, Media Pianura Bergamasca, Dugali Naviglio Adda Serio, Oglio Mella, Chiese, Garda Chiese, Territori del Mincio, Navarolo AgroCremonese Mantovano, Terre dei Gonzaga in Destra Po, and Burana. **The main crops include cereals (maize, wheat and spelt, barley), permanent grasslands (pastures and meadows), temporary forages, and vineyard.

irrigation district. Farm size is medium-high (>20 ha), mostly irrigated with surface water from canals to produce cereals (maize) and expand permanent grasslands, pastures and meadows for livestock (mainly cattle). There is less attention to introducing renewable energy sources (despite farmer's increasing interest in solar energy) or considering non-conventional water resources to address water scarcity periods. The main farmer sees climate change as the toughest challenge. Human ingenuity and innovation may not be enough to address the expected impacts. This highlights the crucial role of individuals and communities in minimizing crops, livestock, and multifunctionality exposure. The profiled farmer experienced extreme weather conditions (e.g. warmer temperatures and heatwaves, increased drought frequency or intensity, and more erratic rainfall patterns), which are faced by reducing the use of fertilizers or improving their efficiency while reinforcing crop diversification and rotation and promoting soil conservation techniques. The farmer often relies on weather forecasts and risks insurance to deal with severe weather conditions. However, farmer face limitations in their actions due to the lack of government support, poorly coordinated management, high investment costs at the farm level, and bureaucratic regulations and rules.

Logistic regression delves into the correlation between exploratory factors regarding the farmer's predominant profile and their climate change awareness, perceived impacts, and adaptive abilities (a detailed breakdown of the parameters can be found in table S2 of the supplementary material). Several outcomes support the expected significant interactions. For instance, age has a positive correlation with farming experience but a negative correlation with education level and succession intention. Similarly, there is a direct relationship between the education attainment of farm households and their involvement in non-farming pursuits, suggesting that educated farmers are more likely to diversify their income from non-farming activities. Similarly, larger farms tend to engage in traditional farming methods, focusing on cultivating cereals (maize) under irrigated land conditions. The results also revealed that novice farmers attribute climate change action to institutions and individuals, while those associated with union farms place the responsibility on economic sectors, such as agriculture.

Farmers' views on the primary effects of climate change are shaped by personal factors lick education level and labour force status. For example, less educated farmers and family-run farms notice changes in the timing of the rainy season and variations in the frequency and intensity of floods. Despite expectations, there is no significant association between age and farming experience with the parameters that define weather patterns. However, both factors are connected to the effects on crops. This means that younger and less experienced farmers tend to experience more significant effects on vegetation species and related biodiversity losses.

Farm characteristics significantly influence the actions taken in crops, such as introducing new varieties, crop rotation, or changes in the planting calendar. When dealing with larger and irrigated farms, the predominant farmer encourages crop diversification and planting crops earlier in the season. However, younger farmers and those who depend on support from union farms and irrigation districts often see livestock as a better way to adapt. Interestingly, experienced farmers overseeing larger irrigated farms prioritize implementing soil conservation techniques and using extra irrigation to combat soil erosion. In contrast, smaller irrigated farms with conventional practices tend to focus on tree planting. In water supply and management, there is a negative correlation between using non-conventional water sources and farming methods. This suggests that rainfed farms are increasingly relying on these sources to adapt to warmer temperatures and droughts. Finally, the extent to which fertilizers are used can be influenced by factors such as farm size, farming methods, irrigation area, and the utilization of alternative water sources. As a result, larger and irrigated farms may be inclined to reassess the advantages or enhance the effectiveness of fertilizer usage as a means of adapting to the impacts of climate change.

When it comes to using preventive adaptation strategies like getting risks insurance or using weather and climate services, the findings indicate a positive correlation between farm size and the use of forecasting tools to guide farmers' decisions. However, high investment costs at the farm level are negatively correlated with different exploratory factors. This is especially worrying for younger farmers with smaller farms, as they are the most impacted by the costs involved in growing more resilient crop varieties to adapt to increasing temperatures and droughts. In this context, the absence of government support and inadequate collaboration, along with overlay complex regulations and guidelines, is also inversely related to the majority of exploratory factors (such as workforce, primary crop, and water supply).

4.2. Farmers typology

Overall, groups exhibit similar farming traits such as their production system, water source, irrigation method, and common crop. However, each group also has notable differences and specific predictors, including factors like age, gender, education level, farming experience, and labour force. Furthermore, there are differences in the behavioural assumptions of the farmers, especially regarding the actions they have taken to adapt. A noteworthy aspect to consider when analysing the most used adaptation measures and their

Table 2. Descriptive of the groups according to adaptive and attitudinal appraisals.

Group	*N* (%)	Mainly adapted through	Related attitude	Variables considered for the description of attitude
1	210 (46)	Crop diversification and rotation	Isolated	Lowest % in 'Cooperation within the farming community (sharing local knowledge and best practices)' (AD18)
2	76 (16)	Cooperation and knowledge exchange	Insecure	Highest % of 'I do not know' responses in the impact (IM) block
3	142 (31)	Risk insurance	Confident	Highest % in 'Climate change is not a big issue because human ingenuity will enable us to adapt to changes' (AW2)
4	32 (7)	Climate services	Aware	Highest % in 'Climate change is the single most serious problem facing the world' (AW1)

distinctions among various groups is that two of the top three preferred strategies ('Access and use of weather services' and 'Reduce the use of fertilizers') were embraced by all groups (see supplementary material in tables S3–S6), while the third most prevalent measures was unique for each group. Within this framework, heterogeneity is seen as a key indicator of the distinct choices made by each group in terms of adaptation. This distinguishes farmers who choose to (1) introduce crop diversification and rotation, (2) enhance cooperation and knowledge exchange with peers, (3) being covered by risk insurance, and (4) use climate services (table 2). Furthermore, the way in which farmers reacted to various survey variables played a significant role in pinpointing their primary attitudes towards addressing climate change. This extra information can enhance the personalized adaptation narrative for each group. For instance, farmers in Group 1 address climate change by promoting crop diversification and rotation following an *isolated* attitude (i.e. lack of cooperation and poor knowledge exchange), while farmers in Group 2 exhibit cooperative behaviour but face challenges in identifying climate change impacts (*insecure* attitude). Similarly, farmers from groups 3 and 4 share a common viewpoint on the preventive nature of their preferred adaptation measures, which are risk insurance and climate services, respectively. However, there is a contrast in their attitudes: whereas those in Group 3 possess a resolute disposition towards opting for financial instruments that are congruent with their commitment to pioneering solutions to tackle climate change (*confident* attitude), those in Group 4 emphasize the use of forecasts due to their concern about climate change as a global phenomenon (*aware* attitude).

4.2.1. Group 1—adapting through crop diversification and rotation (isolated farmers)
As the largest group, half of the farmers are over 55 years old, and the group is male-dominated. One-third of farmers rely on vocational training (33%) while a similar proportion have completed the highest level of education (32%). Almost half of the farmers have been in the agricultural industry for more than 30 years. Two-thirds of the farms count on farming income without partaking in any off-farm activity and mainly operate on a family level. However, half of them (49%) believe that succession is not guaranteed. As for the characteristics of their agricultural practice, farmers mostly own medium to large farms, with half larger than 20 ha. The farming system mostly follows traditional methods (84%) and requires extensive irrigated areas (one-third larger than 20 ha) using surface irrigation (75%). Water is mainly sourced from canals supplied by river diversions (53%) and partially from wells (one-third using a mix of canals and wells). Renewable energy sources are scarcely implemented (31%), the most common being solar energy. Fertilizers are used by most farmers (90%), with a preference for mineral, compound, or organic (83%), while the remaining 10% tend to use liquid manure and digestate. The most commonly planted crops are maize (83%), temporary forages (35%), and wheat and spelt (32%). Additionally, half of the farmers (52%) also breeds animals, with a focus on cattle (36%).

4.2.2. Group 2—adapting through cooperation and knowledge exchange (insecure farmers)
Farmers in this group are generally younger than those in the previous group, with 68% being under 45 years old. The group is mostly male, but more than a third are women (36%). They have the second highest level of education (40% with tertiary education) but less farm experience (only one-third have more than 30 years of experience). They primarily depend on family labour, but to a lesser extent than the average, with 41% of farms employing a combination of family and non-family workers. Most of the farmers in this group (70%) rely solely on farming for income, and nearly half (46%) plan to pass down their farming activities in the future. Their farms vary widely in size, with the majority being medium to small. Although most farmers use conventional methods (59%), some use organic methods (21%) or are transitioning to them (5%).

Fertilizers are still commonly used, with mineral, compound, or organic types being the most popular (59%), but there is a group that uses fertilizers less frequently. Only 29% of farmers use renewable energy sources, with a preference for solar energy, making it the group with the lowest implementation rate. Farming activity predominantly relies on rainfed, with permanent grasslands accounting for 40% of the cultivated land, followed by maize at 34% (although rainfed maize is a choice limited to a minority of farms and is on the decline) and vineyards at 21%. Almost half of the farmers (49%) also raise livestock, especially cattle (22%) and poultry (17%).

4.2.3. Group 3—adapting through risk insurance (confident farmers)

This group consists mainly of older farmers (51% being above 55 years old), a varied educational background (38% vocational training, 44% tertiary education), and significant farming experience (63% with over 30 years old). Women account for 9%, while the majority of farms are composed of a mix of family and non-family workers (63%). Farming is the primary income source for 75% of the farmers, and 57% intend to pass down the farming activity to the next generation. The farms in this group are generally large, with 86% having an area larger than 50 ha, and predominantly engage in conventional agricultural practices (81%). Regarding irrigation methods, surface irrigation is the main favoured (59%), with a notable 27% employing both surface and sprinkler methods. The top water sources are canals (44%) and a combination of canals and wells (39%). A large majority of farmers use fertilizers (92%), with mineral, compound, or organic types being the most popular (87%). In addition, farmers have a high preference for renewable energy sources (48%), especially solar energy (36%). The preferred crops are maize (83%), temporary forages (52%), and wheat and spelt (29%), while nearly two-thirds of farms also raise animals (63%), predominantly cattle (46%) and pigs (19%).

4.2.4. Group 4—adapting through climate services (aware farmers)

Farmers in this group stand out for being the youngest (72% are under 55 years old), the most educated (half of them have attended tertiary education), and having the least farming experience (only 18% have over 30 years of experience). The female presence is at 38%, and farming mainly depends on family labour (53%). The majority of farmers do not have off-farm income (72%), making it difficult to ensure succession for three out of four. The majority of farms in this group are small-scale (69% cover less than 5 ha), and most of them either practice organic or agroecological farming or are in the process of transitioning to it (44%), while fewer than one-third (31%) use traditional practices. Drip irrigation is the preferred method among farmers (72%), while wells are the most common water source (44%). Renewable energy sources are used by 47% of farmers, most of them using solar energy (34%). Vegetables (38%), vineyards (28%), maize (22%), and wheat and spelt (22%) are the most common grown crops. Figure 3 synthetize farmers' groups characteristics attending to the triple loop approach (climate change awareness, perceived impacts, and adaptation measures and barriers). Further details are available in the supplementary material (tables S3–S6).

4.3. Comparison between groups

4.3.1. Awareness

No significant differences are observed between the groups in terms of the direction of the assessment of awareness statements, but in their intensity (figure 4). Farmers generally agree on their exposure to climate change concerning crops, livestock, and multifunctionality, as well as their responsibility to address the impacts, primarily from individuals and communities. Likewise, there is a consensus about the negative impact of climate change in the agricultural sector and the lack of trust in human ingenuity to confront its impacts. Interestingly, the first three groups show a strong similarity, but Group 4 (the youngest, most educated, and less experienced farmers) displays a unique pattern with significantly higher average scores across all issues. In the same vein, this group demonstrates the highest capacity for linking the different variables characterizing awareness of climate change, particularly those statements that draw connections between responsibility and exposure (e.g. farmers who acknowledge the responsibility of individuals and communities in addressing climate change are also aware of the vulnerabilities of irrigated crops and multifunctionality to climate change, Cramer's $V = 0.668$ and 0.696, respectively). Otherwise, rainfed farmers in Group 2 can correlate awareness statements with assumptions about perceived impacts and barriers to adaptation. For instance, farmers who notice warmer temperatures and heat waves are more conscious of their effects in multifunctionality, including landscape, biodiversity, and recreational activities (Cramer's $V = 0.802$), while farmers for whose economic sectors are the main responsible for tackling climate change are those who identify the business-as-usual (BAU) scenario as the main barrier to transformative adaptation (Cramer's $V = 0.723$). The complete list of associations can be found in supplementary material (table S7).

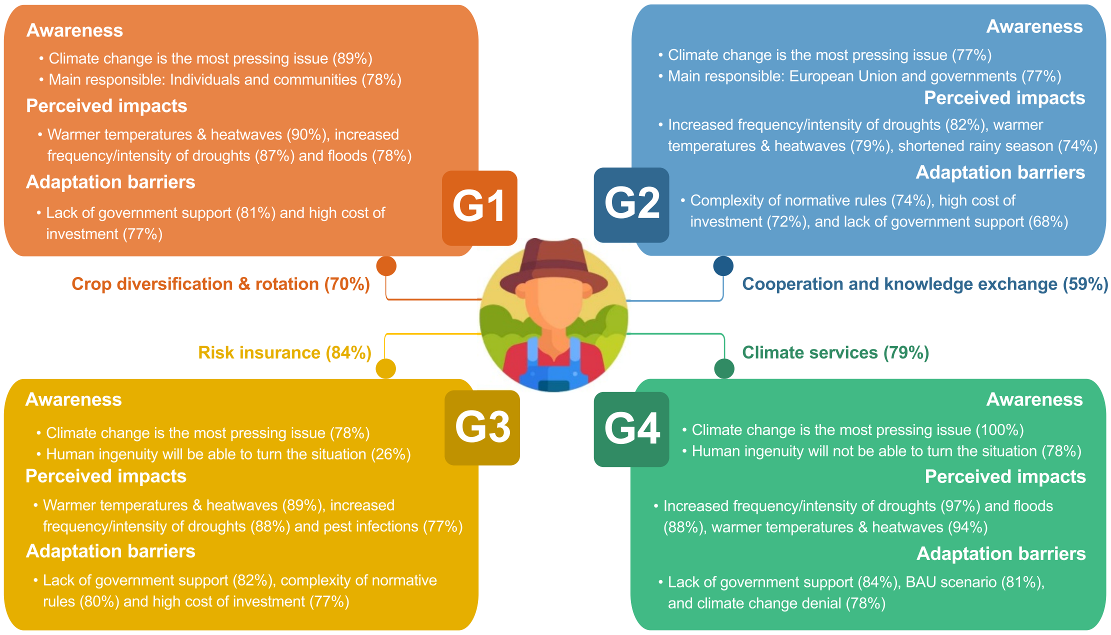

Figure 3. Farmers typology according to the triple-loop approach: climate change awareness, perceived impacts and adaptive capacity. Source: own elaboration from icons content provided by Flaticon (www.flaticon.com) and Freepik (www.freepik.com) under free copyright permissions of the authors.

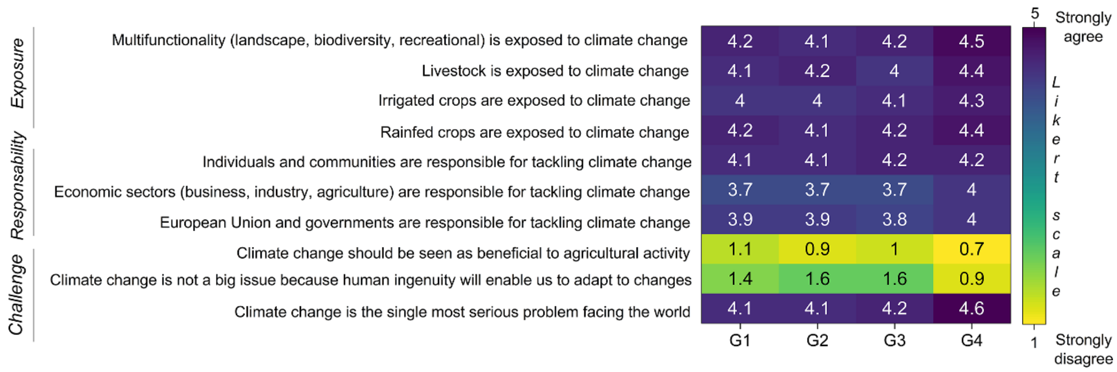

Figure 4. Average score obtained for each statement on climate change awareness according to groups.

4.3.2. Perceived impacts

A similar trend is observed among the groups when looking at the variety of assumptions about the effects of warmer temperatures and heat waves, and increased drought frequency or intensity. However, farmers practicing agroecology in Group 4 show the highest level of perception of these impacts (71% on average) (figure 5). The most significant variations between groups are seen in certain aspects: alterations in vegetation species and biodiversity (±32% between Group 3 and Group 4), changes in plant growth (±21% between Group 4 and Groups 2 and 3), and an increase in the frequency or intensity of floods (±20% between Group 4 and Group 2). Farmers in the four groups agree to associate two impacts: changes in plant growth and changes in vegetation species and biodiversity (Cramer's $V = 0.719$). Interestingly, rainfed farmers in Group 2 and older farmers in Group 3 are the only ones who mention changes in plant growth and increased weeds or new invasive species (Cramer's $V = 0.626$ and 0.607, respectively), while most experienced farmers in Group 1 associate changes in plant growth with less reliable water supply (Cramer's $V = 0.634$). Moreover, farmers from Group 4 identify a perfect association between warmer temperatures and heatwaves and an increased frequency or intensity of droughts (Cramer's $V = 1.000$).

4.3.3. Adaptation measures

In broad terms, all groups show a preference for measures that offer protection against impacts (e.g. risks insurance) and information to prevent their consequences (e.g. cooperation and knowledge exchange, weather and climate services) (62% on average) rather than proactive actions that strengthen water and soil

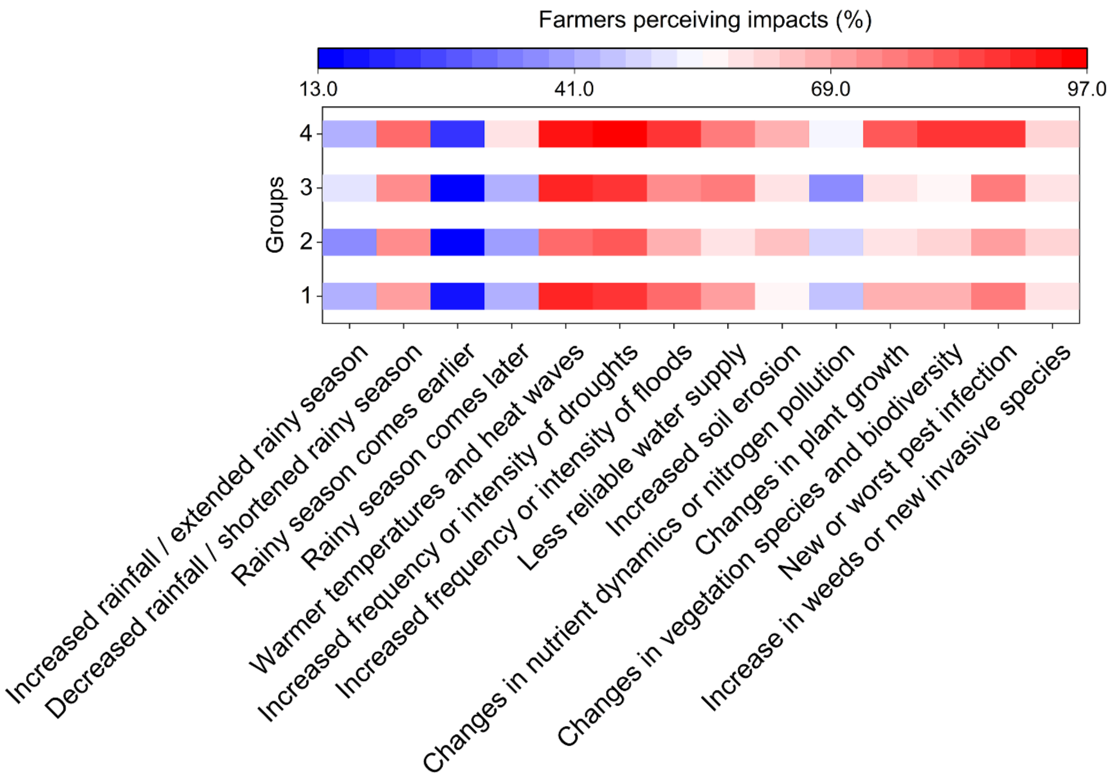

Figure 5. Perception of climate change impacts by groups of farmers.

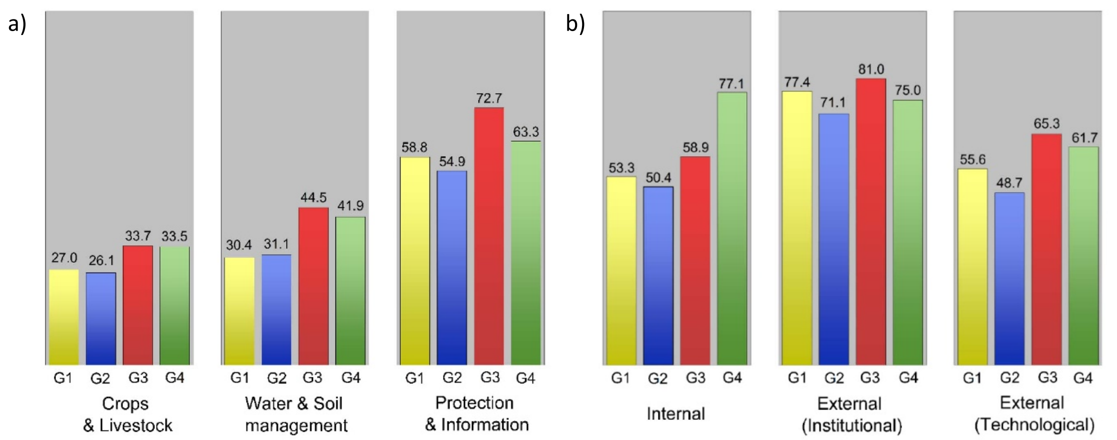

Figure 6. Type of adaptation measures (a) and barriers (b) according to group preferences (average scores in %).

management or advocate for changes in crops and livestock (37% and 30% on average, respectively) (figure 6(a)). Contrary to the common pattern observed in perceived impacts, it is possible to distinguish significant variations in adaptation preferences among groups. For example, older farmers in Group 3 and less experienced farmers in Group 4 exhibit the highest implementation rates (44% and 42% on average, respectively), with farmers in Group 3 being the most proactive in each type of measure (e.g. insurance and weather services are considered by more than 80% of the farmers) (table 3). No correlation exists between adaptation measures and the rest of the behavioural assumptions for farmers in Group 1 and Group 3. Nonetheless, there exist some correlations between rainfed farmers in Group 2 (e.g. access and use of weather and climate services in combination, Cramer's $V = 0.656$) and more educated and less experienced farmers in Group 4 (e.g. planting drought-tolerant or bio-energic varieties or crops combined with soil conservation techniques and crop diversification and rotation, Cramer's $V = 0.625$ and 0.615 respectively).

Table 3. List of adaptation strategies employed by farmers according to their cluster membership.

Issue	Measure	Group 1		Group 2		Group 3		Group 4	
		%	Rank	%	Rank	%	Rank	%	Rank
AD1	Planted different varieties or crops (drought-tolerant)	35.2	11	40.8	7	54.2	8	50.0	8
AD2	Planted different varieties or crops (bio-energic)	9.1	16	19.7	15	24.7	13	25.0	15
AD3	Crop diversification and rotation	**71.0**	**2**	55.3	4	72.5	5	46.9	10
AD4	Introduced inter-cropping	36.2	10	32.9	10	39.4	12	37.5	13
AD5	Different planting dates	42.4	8	36.8	8	54.2	8	53.1	6
AD6	Earlier planting	43.3	7	25.0	13	48.6	10	40.6	11
AD7	Later planting	10.0	15	21.1	14	21.8	14	31.3	14
AD8	Changing quantity of land under cultivation	15.2	14	15.8	17	18.3	16	25.0	15
AD9	Change from crops to livestock	8.6	17	1.3	20	9.9	18	3.1	18
AD10	Change from livestock to crops	3.3	19	6.6	19	5.6	19	3.1	18
AD11	Soil conservation techniques	45.7	6	44.7	6	73.2	4	50.0	8
AD12	Shading and sheltering/tree planting	22.4	13	31.6	11	21.8	14	53.1	6
AD13	Provided supplemental irrigation	32.4	12	29.0	12	48.6	10	59.4	4
AD14	Use of non-conventional water resources (e.g., reclaimed water)	0.5	20	7.9	18	5.6	19	9.4	17
AD15	Reduce the use of fertilizers/improve fertilizers use efficiency	**64.8**	**3**	**56.6**	**3**	**81.0**	**2**	**87.5**	**1**
AD16	Use biomass or biofuels for on-farm energy needs	8.6	17	17.1	16	14.1	17	3.1	18
AD17	Insurance for extreme weather conditions	57.6	5	36.8	8	**83.8**	**1**	40.6	11
AD18	Cooperation within the farming community (sharing local knowledge and best practices)	38.1	9	**59.2**	**2**	67.6	6	59.4	4
AD19	Access and use of weather services (short-term rain and temperature forecasts)	**80.0**	**1**	**69.7**	**1**	**81.0**	**2**	**84.4**	**2**
AD20	Access and use of climate services (seasonal rain and temperature forecasts)	59.5	4	54.0	5	58.5	7	**68.8**	**3**

Note: Highlighted in bold are the top 3 measures implemented by each group.

4.3.4. Adaptation barriers

Figure 6(b) shows the average relevance of each type of barrier based on whether it is internal or external (institutional or technological). When looking at internal barriers (BA1–BA3), a range of percentages shows that farmers in Group 4 are more aware of how denying climate change and sticking to BAU can weaken farmers' adaptive capacity. Similarly, farmers who see the BAU scenario as the main limitation also tend to have a low risk perception of being impacted by climate change (Cramer's $V = 0.671$–0.881) together with the lack of information about risks and vulnerability (Cramer's $V = 0.624$–0.761). There are no significant differences between groups when looking at the institutional external barriers (BA8 and BA9). These barriers have the highest average scores, with similar values ranging from 71% to 81% across groups (table 4). However, older farmers in Group 3 tend to focus on the of achieving regulation and rules, while all groups exhibit signs of inadequate government support and lack of coordinated management, albeit with less relevance for rainfed farmers in Group 2 (Cramer's $V = 0.712$ and 0.606, respectively). Differences among groups become apparent when looking at technological barriers (BA4–BA7), with older farmers in Group 3 and less experienced farmers in Group 4 showing more concern about the high cost of investments on the farm, the limited availability of drought-tolerant crop varieties, and the lack of access to innovation.

5. Discussion and conclusion

Farmers' awareness and perceptions, combined with judgements and attitudes towards climate change, are crucial for developing effective adaptation strategies that align with their diverse needs and concerns. This understanding helps anticipate and support farmers in making informed decisions (Ceci *et al* 2021, Farhan *et al* 2022, Mustafa *et al* 2023). Farm types are used in this context to capture, summarize, and gain insight into the heterogeneity of farms (Rodríguez-Bustos *et al* 2023). Nevertheless, in order to devise accurate policy measures that target specific groups, it is crucial to comprehensively understand the on-the-ground structure of farmers, rather than concentrating solely on individual aspects such as farm size, farmer age, or education level, which falls short of providing a holistic view of farmers' behaviour (Graskemper *et al* 2021, Cradock-Henry *et al* 2023). The literature provides several examples of farmer typologies, primarily centred on the agricultural production system (Productivist vs. Environmentalist, Innovator vs. Traditionalist, Innovator vs. Pragmatist (Hyland *et al* 2016, Daxini *et al* 2019, Braito *et al* 2020), while there are limited

Table 4. List of adaptation barriers according to their cluster membership.

Issue	Barrier	Group 1		Group 2		Group 3		Group 4	
		%	Rank	%	Rank	%	Rank	%	Rank
BA1	Climate change negationism or scepticism	57.1	4	56.6	4	60.6	5	**78.1**	**3**
BA2	Low-risk perception (I will not be directly affected)	55.2	5	43.4	7	56.3	5	71.9	4
BA3	Business-as-usual scenario: 'That is the way we have always done it, that is what we know, that is what we are familiar with'	47.6	8	51.3	5	59.9	6	**81.3**	**2**
BA4	Lack of information about risks and vulnerability	44.3	9	47.4	6	52.8	8	43.8	7
BA5	High cost of investment at farm level	**77.1**	**2**	**72.4**	**2**	**78.9**	**3**	**78.1**	**3**
BA6	Limited availability of drought-tolerant crop varieties	52.4	6	42.1	8	61.3	4	62.5	6
BA7	Unavailability of new technologies to increase resilience to climate change	48.6	7	32.9	9	61.3	4	62.5	6
BA8	Lack or poor government support and coordinated management	**80.5**	**1**	**68.4**	**3**	**82.4**	**1**	**84.4**	**1**
BA9	Regulations and rules are too complicated	**74.3**	**3**	**73.3**	**1**	**79.6**	**2**	65.6	5

Note: Highlighted in bold are the top 3 barriers identified by each group.

studies of using farming system typology to understand and target farmers' behaviour and actions in tackling climate change.

The goal of this research was to gain a deeper understanding of how farmers in the Lombardy region perceive and respond to climate change, considering their different risk assessments and proposed strategies for dealing with climate change. Four differentiated groups have emerged by pointing out farmers' adaptation preferences and risk attitudes among farmers: (1) cropping-adapted and isolated farmers, (2) cooperation-adapted and insecure farmers, (3) risk insurance-adapted and confident farmers, and (4) climate services-adapted and aware farmers. This farm typology provides additional value to existing classifications, which typically focus on socioeconomic factors, agroecological patterns, or pro-environmental attitudes (e.g. Teixeira *et al* 2018, Benitez-Altuna *et al* 2023), emphasizing the relevance of considering sociodemographic parameters, bio-physical scenarios, and risk management practices in a holistic approach (e.g. Maldonado-Méndez *et al* 2022, Sinha *et al* 2022). Our farm typology gathers farmers to discuss common interests or challenges, as suggested by Innazent *et al* (2022). This involved grouping farmers who manage their farms similarly and share common interests or constraints, focusing on behavioural aspects related to climate change awareness, perception, and adaptation.

Our findings align with existent research, showing different views on farmers and farming traits among various groups (e.g. younger and highly educated farmers vs. older and more experienced farmers, rainfed vs. irrigated farms, conventional vs. agroecological production system) (Irham *et al* 2022). Remarkably, a difference can be observed in the labour force, as all groups except Group 3 rely mainly on family members, potentially leading to increased decision-making agency (Petersen-Rockney 2022). Similarly, variations are observed in the production system: all groups mainly follow traditional farming methods except Group 4, which focuses significantly on organic farming or agroecology and has a larger number of female members (consisting with the results of Masi *et al* 2021 about the prevalence of agroecological principles among women farmers).

Similar patterns and priorities among groups are observed concerning climate change awareness and perceived impacts. Although farmers' groups are aligned on the necessity of confronting climate change impacts on crops, livestock, and multifunctionality, and the shared responsibility between individuals and communities to address these impacts), discrepancies appear about (1) the potential benefits of climate change (e.g. new species and potential yield increase) and (2) the conviction that human ingenuity will be able to face related impacts, contrasting the results obtained by Marescotti *et al* (2021) and Lahnamaki-Kivela and Kuhmonen (2022) when analysing smart farming technologies applied by Italian and Finnish dairy farmers. Interestingly, some authors associate human ingenuity with the 'risk perception paradox', for which farmers acknowledge the risk but still opt to take it because of potential benefits or the belief that the risk is beyond their control (Anderson *et al* 2023). In the same vein, Tiet *et al* (2022) report the detrimental effect of human ingenuity on farmers' ability to embrace adaptation efforts. Despite this, we observed that farmers in

Group 3, who have the highest rates of implementing adaptation measures, are also the most open to embracing human innovation.

Farmers perceived rising temperatures and heat waves, as well as an increase in drought severity or frequency. They can also associate changes in plant growth and impacts on vegetation species and biodiversity, exemplifying of how farmers can pinpoint interactions, trade-offs, and synergies among the environment, agriculture, and climate change, consistent with the systems thinking approach outlined by Ortiz *et al* (2021). The preferred strategies for addressing these impacts vary among farmers' groups, but they all recognize the significance of protective (e.g. insurance) and informative measures (e.g. weather and climate services), aligned with findings from Madaki *et al* (2023) and Yegbemey and Egah (2021). Farmers from all groups acknowledge the impact of external barriers from an institutional standpoint (such as regulation and rules, government support, and coordinated management. This constraint their ability to boost climate change resilience, similar to the outcomes obtained by Johnson *et al* (2022) in their research involving Californian farmers.

A major drawback of the stable farmer typology is its relatively inflexible and time-limited approach, which does not consider changing profiles or overlapping categories (Bartkowski *et al* 2022). Our findings revealed a partial similarity or 'fluid' profile between the farmers in groups 1 and 3. They were alike in terms of age, education level, and farming experience, but differed in terms of farm characteristics. In contrast, Group 2 (rainfed farmers) and Group 4 (the youngest, most educated, and least experienced farmers practicing organic agriculture or agroecology) were more distinctly defined. This limitation is mainly due to the reliance on cross-sectional data, whereas a longitudinal analysis would offer the opportunity of explore how adaptation might evolve within groups over time (Graskemper *et al* 2021). Validation through focus group discussions, as proposed by Sinha *et al* (2022), could be the starting point for policy co-design. Likewise, it would enable complete control for unchanging hidden differences, lack cultural factors or the neighbourhood effect that may influence adaptation behaviour (Skevas *et al* 2022).

In 2022, the European Union celebrated 60 years of the Common Agricultural Policy (CAP), a shared framework to support farmers, improve agricultural productivity, maintain rural areas and landscapes, and help tackle climate change. Transitioning from one reform to the next, the current framework was enforced in January 2023. It includes examples of green architecture by implementing mandatory environmental and climate conservation initiatives known as eco-schemes. These measures aim to promote climate mitigation and adaptation, while also protecting water, soil, and biodiversity (Barral and Detang-Dessendre 2023). Although dedicated adaptation measures have not been a major focus in past reforms, eco-schemes have included some adaptation measures that farmers in our research have viewed positively, such as crop diversification and rotation (CAP Pillar 1) or tree planting (CAP Pillar 2). As pointed out by Bartkowski *et al* (2022), there is no single 'European farmer', but rather a diverse range of behaviours, abilities, and priorities that can vary significantly, even within regions or local areas (Brown *et al* 2021). Our study provides a starting point for reimagining risk preferences by moving beyond applying a uniform decision-making heuristic to all farmers, and instead customizing measures based on the predispositions and motivations of different farmer groups. This tailored approach is seen as valuable in assisting the design of more effective interventions (Gebrekidan *et al* 2020, Meierova and Chvatalova 2022). Additionally, the triple-loop approach can serve as a methodological cornerstone in exploring the advantages of integrating behavioural inputs or creating local prototypes and patterns in decision-making processes to enhance regional and national policies (e.g. Italian National Plan for Adaptation to Climate Change approved by the Italian Environment Ministry in January 2023). This plan involves the parameterization of agent-based models through social learning (Malek and Verburg 2020), simulating how different agents (including farmers groups) proactively respond to and assess targeted adaptation measures.

Data availability statement

The data cannot be made publicly available upon publication because they are not available in a format that is sufficiently accessible or reusable by other researchers. The data that support the findings of this study are available upon reasonable request from the authors.

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Ethics statement

The Data Protection Officer of the Politecnico di Milano, Italy, through an ethical commission evaluation, confirmed that the study satisfied the requisites of the ethical guidelines for research regarding information and anonymity as set out in the European Code of Conduct for Research Integrity and in accordance with the principles embodied in the Declaration of Helsinki and related local statutory requirements. The survey platform does not collect identifying information of the respondents; they were duly informed of the objective of the research, the type of information collected, and data treatment process in the first page of the online survey. All participants gave written informed consent to participate in the survey, specifying that collected information and related results will be used for scientific purposes only.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author(s) contribution(s)

All authors contributed to the study's conception and design. Sandra Ricart performed material preparation, data collection, formal analysis and investigation. Claudio Gandolfi provided resources and supported data collection. Andrea Castelletti supported data analysis and funding. Original draft preparation was carried out by Sandra Ricart and reviewed and commented on by Claudio Gandolfi and Andrea Castelletti. All authors read and approved the final manuscript.

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