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Short communication

A library of climate adaptation measures in agriculture and their economic assessment

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Abstract. The objective of this study is to present the CAMBIA library, created by ARPAE, which collects more than 100 measures of adaptation of the agricultural sector to climate change, together with their evaluation, developed by CREA PB, in terms of costs and benefits to encourage their adoption by Italian farmers. The study was conducted as part of the LIFE ADA project, which aims to improve the resilience of the agricultural sector by providing farmers with knowledge and tools to adapt to climate change. Users' adaptive capacity will be enhanced by the ADA web tool, which will include the CAMBIA library and cost-benefit assessment of measures, and will be used to define adaptation plans at both farm and supply chain levels. This is an innovative tool that offers the possibility to consult and compare a set of climate change adaptation measures, together with the cost/benefit assessment related to their adoption so as to help farmers make an informed choice of the measures best suited to their farm reality. In addition, such a tool could encourage the engagement of policymakers and practitioners in their promotion, further fostering farmers' engagement in adopting climate change adaptation and resilience measures based on their possible cost-effectiveness.

Keywords: climate change, adaptation, climatic risk, costs/benefits, sustainability.
JEL codes: Q54.

HIGHLIGHTS:

- Concerns about the increase in adverse climate events prompted the European policies to suggest a critical recommendation for mitigation in agriculture.
- The climate adaptation measures contribute to increasing the resilience of the agricultural sector.
- Ability to consult and compare in a database a range of climate change adaptation measures, along with cost-benefit assessments related to their adoption, so as to help farmers choose the most appropriate measures.

1. INTRODUCTION

The impacts of climate change on economic sectors, as well as the sustainability of agri-food production as a whole, continue to be a heated issue of public debate (EEA Report No 04/2019) at global and local level. According to a Eurobarometer survey conducted in 2021, after health, economy and food security, climate is considered, in Italy, to be the fourth main emergency. The current challenge is to demonstrate that adaptation is a valuable strategy, consisting of taking appropriate measures to prevent or minimize impacts. The requirement for adaptation involves the agricultural sector in particular, which is one of the sectors most vulnerable to climate change (Reidsma *et al.*, 2010; Mushtaq *et al.*, 2013; Pontrandolfi *et al.*, 2016; Abbass *et al.*, 2022) because of its high dependence on meteo-climatic conditions. In the next decades, the expected modifications to the climate, in terms of average values, as well as the intensification of hard-to-predict extreme weather events will put pressure on the agricultural sector, impacting farmers' incomes and farms' survival (Schmitt *et al.*, 2022). The productivity of some crops is expected to increase, while yields of other crops will decrease.

Several studies have demonstrated that wheat output is negatively affected by the rising temperatures (Garcìa *et al.*, 2015; Ortiz *et al.*, 2021) and wheat productivity trends are negatively influenced by extreme temperatures (Lobell, Feld, 2007). Agriculture both contributes to and is affected by climate change (Parker *et al.*, 2019) and is affected both positively and negatively depending on geographical regions. As a result, climate change determines risks and opportunities to agricultural production in the European agroclimatic regions (Iglesias *et al.*, 2012) and site-specific (El Chami, Daccache, 2015); for this reason, adaptation measures can show heterogeneous results depending on regions and agro-ecosystems.

These considerations highlight the need for the agricultural sector to implement immediate adaptation actions. According to Matthews (2020), at institutional level, the fight against climate change will continue to be one of the strategic objectives of the CAP even in the post 2020 framework (reg. EU 2021/1119). Although climate adaptation measures are considered necessary to increase the resilience of the agricultural sector and to limit its vulnerability, the literature contains few studies evaluating the costs and benefits of their adoption. Iizumi *et al.* (2020) for example, estimate the adaptation cost and residual damage to climate change for global crops. Wreford and Renwick (2012) estimate global adaptation to climate change costs in the agricultural sector, while a few studies assess the cost of climate change adaptation options for the agricultural sector in the Near East and North Africa region (El Chami *et al.*, 2022). In addition, some authors analyse the factors that determine willingness to adopt adaptation measures, including socioeconomic conditions – such as age, education level, household size, household income, farm size, and farming experience (Bryan *et al.*, 2009; Masud *et al.*, 2017 [a], 2017 [b]; Frame *et al.*, 2018; Kabir *et al.*, 2020; Kabir, Alam (2021) and agronomic ones (Ulukan *et al.*, 2008; Dednath *et al.*, 2021) that influence their adoption.

Adaptation measures are therefore case-specific and cannot be generalized, as costs and benefits depend on the specific cropping systems. In this context, EU-funded projects that focus on adaptation in agriculture both with specific research activities on actions to be taken at farm and supply chain level and with cost and benefit assessment to reduce economic and environmental damages due to climate risk, can be strategic in providing valuable support to environmental economists and policies.

Under this perspective, we contribute to this topic by presenting part of the results of the Life ADA project (ADaptation in Agriculture). More in detail, the overall objective of this study is to present the CAMBIA library (Catalog of Actions and Measures collected in the Adaptation Library), which collects more than 100 measures of adaptation of the agricultural sector to climate change, together with their evaluation in terms of costs and benefits in order to encourage their adoption by Italian farmers. This is an innovative tool that offers the possibility to consult and compare a set of climate change adaptation measures, together with an evaluation of the costs/benefits related to their adoption so as to help farmers make an informed choice of the measures best suited to their farm reality. In addition, such a tool could encourage the engagement of policymakers and practitioners in their promotion, further fostering farmers' engagement in adopting climate change adaptation and resilience measures based on their possible cost-effectiveness.

This manuscript is organized in four sections: the first section discusses the relationship between adaptation and climate change, while the second one shows data and research methodology; the research results and discussions are presented in the third section and, finally, the main conclusions and future research design are reported in the last section.

1.1. The Life ADA project

The Life ADA project – Adaptation in Agriculture (https://www.lifeada.eu/it/), is co-financed by the European Commission through the Life Program and aims at fostering the capacity of the agricultural sector to define adaptation plans to climate change, in order to enhance the management of risks and prevention of damages.

The project is addressed to individual farmers and aggregated forms of producers (POs and cooperatives) for three food chains (wine, fruit & vegetables and dairy) with the following aims:

- to transfer knowledge about future climate change projections, risk management and adaptation measures to improve the ability of farmers to deal with current and future climate risks;
- to develop proper tools to support decision-making processes in defining efficient adaptation plans, including the CAMBIA library that allows the user to consult the main existing adaptation actions and choose the most effective ones for each specific context;
- to promote an innovative approach by insurance to strengthen the ability to reduce (current and future) climate risk in order to maintain farmers' long-term insurability.

One of the technical objectives of ADA is the development of a web tool aimed at supporting farmers and POs in the adoption of adaptation plans. One of the information sources that feeds the ADA tool is the CAMBIA library, focus of the present study.

2. METHOD AND MATERIALS

2.1. Description of the CAMBIA library

Knowledge of the state-of-the-art concerning the adaptation measures in agriculture is the baseline to accomplish "ad hoc" adaptation plans tailored to actual farm needs and, ultimately, to enhance the resilience of the agricultural sector; therefore, the development of the CAMBIA library has been foreseen in the Life ADA project.

The rationale behind the design of CAMBIA is the development of a tool addressed to farmers where the main existing adaptation measures are described. This specific task implies that a combination between a scientific approach and the practical needs of the users is needed, by means of the inclusion of decision filters useful in order to assess the degree of application, the benefits and limits of a specific adaptation measure for a specific farm.

The CAMBIA library is a database (in spreadsheet format) designed according to the entity-relationship scheme shown in Figure 1: the rectangles represent the entities shown in Table 1, defined by the attributes within the rectangles, whereas the ovals represent the relationships between the entities.

The core of the database is the Action entity, whose attributes, helpful to assess and evaluate the adaptation

Figure 1. Entity relationship scheme.

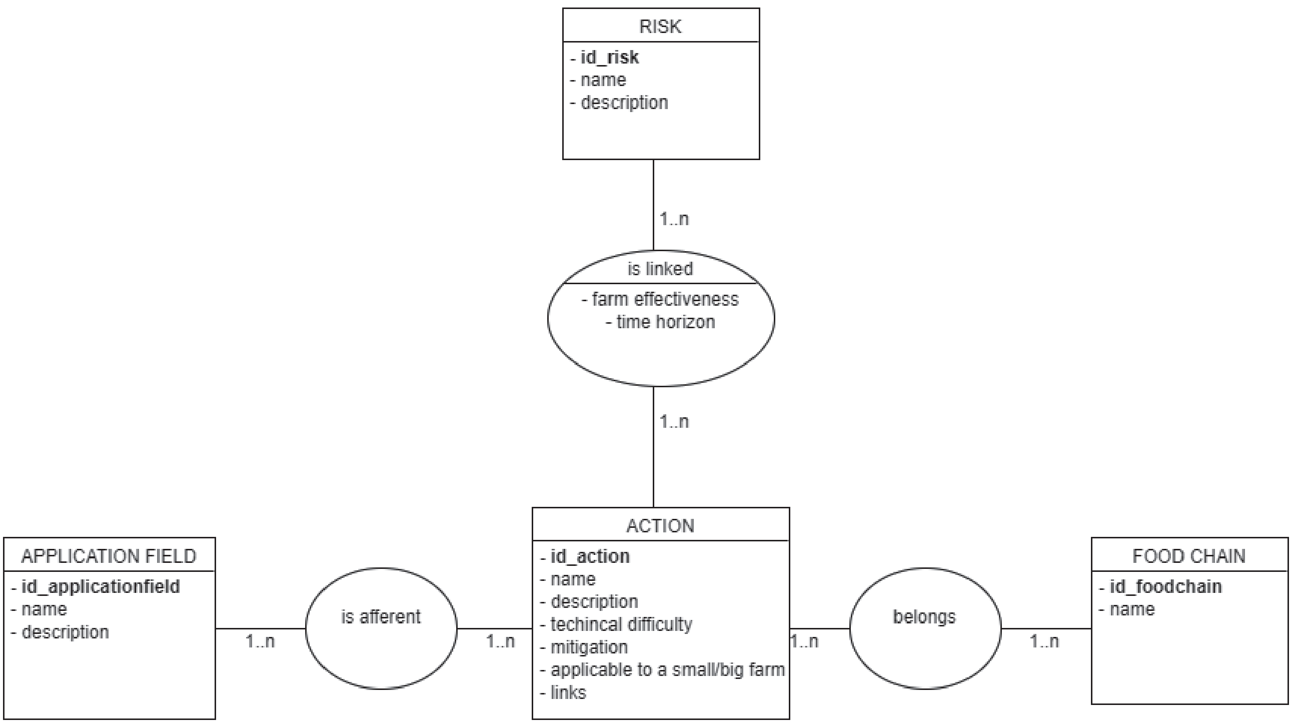

Table 1. Entities description.

Entity name	Description	Type | Possible values
Action	Name of the adaptation measure	-
Risk	The climate risk that the adaptation measure is tackling	Filter | drought, wind, hail, water surplus, floods, damages by extreme maximum temperatures, damages by extreme minimum temperatures, intense precipitation, loss of suitability of the territory, saltwater intrusion, erosion, phytosanitary damages
Food chain	The food chain to which the adaptation measure can be applied	Filter | Dairy (Parmigiano Reggiano), wine production, fruit and vegetables
Application field	The agronomic topic concerning the adaptation measure	Filter | soil, water, agronomic management, crop systems, animal welfare, oenology

Table 2. Attributes of the entity Action.

Attribute name	Description	Possible values
Description	Detailed information, explanation about the implementation, advantages and limits, suggestions, specific references to the food chains	-
Mitigation	Evaluation of the potential beneficial effects on climate change mitigation	Yes/No
Technical difficulty	Degree of technical difficulty in the implementation	1 (Low), 2 (Medium), 3 (High)
Effectiveness for the farm	Degree of effectiveness of the measure in relation to the risks	1 (Low), 2 (Medium), 3 (High)
Applicable to a small/big farm	Evaluation of the suitability of the measure in relation to the size of the farm	Yes/No
Time horizon	Time required for the measure to become effective from an economic, agronomic and environmental point of view in relation to the risks	1 (Short term: 1 year or crop cycle), 2 (Medium term: from 3 to 5 years), 3 (Long term: from 7-10 years or more than 10 years)
Links to further information	Link to in-depth researches, interviews and case studies about the empirical application of the measure	-

measures are listed and described in Table 2. Each action could be applied to one or more food chain, application field, farm effectiveness and time horizon: in other words, one action can tackle *n* climate risks, with *n* time horizon and *n* degree of effectiveness.

CAMBIA has been designed following two main steps: first, a review of similar tools in the literature or in outcomes from EU projects was carried out, then the library was defined and populated, according to the specific aims of the ADA project. The review of similar projects highlighted that two tools have been developed within two Life EU projects on adaptation to climate change in agriculture:

- AgriAdapt (AWA webtool: https://awa.agriadapt.eu/en/) and,
- Adapt2Clima (Adapt2Clima tool: https://tool.adapt2clima.eu/en/home/).

They both provided a relevant overview for the design of CAMBIA as they were aimed at facing the vulnerability to climate change of the agricultural sector through the implementation of adaptation measures and plans. For instance, the AWA tool, which is characterized by filters for the identification of the most suitable adaptation measures for farms, offered a meaningful starting point for the structure of the library: as described above, the use of filters is in fact a key element for CAMBIA as well, even if it is applied to different entities. On the other hand, the Adapt2clima tool was relevant for its contents and goals: it consists of a decision support tool based on extreme climate scenarios and indicators related to several dimensions, such as climate, hydrology, agriculture and socio-economic aspects in order to provide adaptation to climate change measures for the agricultural sector.

To be consistent with the final objective of ADA project, namely supporting farmers in the adoption of farm adaptation plans, a second step followed: the application of further attributes and evaluation methods for the description of each adaptation action. The selection of contents and design of the library (i.e., adaptation measures) were performed by referring to the main reports by the European Environment Agency and according to the support of experts within the Environmental Agency of Emilia-Romagna (ARPAE) and project partners.

As a final stage, the structure and contents of CAMBIA were validated by means of twenty interviews with experts in the three food chains involved in ADA and during a workshop of co-design. During this event, three focus groups were organized in order to provide an in-depth review of the tool focused on a selection of the most relevant climatic risks and best adaptation measures. This meeting was the occasion for a second evaluation, after the editing stage.

To conclude, CAMBIA is the result of a development process composed by different levels of review and it remains open to further implementation and enrichment. The on-going project activity on CAMBIA library is two-fold: the collection of adaptation actions and the release of a web tool based on the library. The first point will be carried out for the entire duration of the Life ADA project; so far, the number of collected measures is 78 actions for the fruit and vegetable sector, 61 for the wine production sector, 58 for the dairy (Parmigiano Reggiano) sector. The second activity is addressed to integration of the CAMBIA database into the ADA web app.

2.2. A methodological framework on cost and benefit assessment of the measures listed in the CAMBIA library.

Each adaptation measure collected in the library will also have information on the costs and benefits of its adoption. Based on this information, an assessment of its cost-effectiveness is provided.

To collect the information, a questionnaire was sent to various experts in the sector, surveyors of the Agricultural Accounting Information Network – RICA, using the CAWI methodology (Computer Assisted Web Interviewing (Giuca *et al.*, 2022).

A total of 82 questionnaires, divided by measure group, were compiled. Therefore, each surveyor completed several questionnaires. In order to obtain as much information as possible and to investigate the issues and specificities that emerged from the answers to the questionnaires, more than 30 operators in the sector were interviewed: thematic experts, agronomists, researchers, manufacturers of technical means – of crop protection – of irrigation systems. At the same time, a bibliographic research was conducted in order to survey existing studies on the impact of adaptation measures on specific production activities. The investigations performed by means of questionnaires, interviews and bibliographical research enabled us to provide the following information for each individual measure:

Information on costs to be incurred:

- investment cost (if any):
- average annual cost per hectare;
- cost compared with usual practice (if relevant).

Costs vary according to multiple variables: farm characteristics (physical and economic size of the farm, farm location), region, altitude, soil and climate characteristics of the farm territory. Consequently, we provide an average reference cost, varying in range, useful to guide the farmer's possible decisions in the choice of adopting the measure.

Information on benefits:

- degree of effectiveness of the measure with respect to climatic risk as already reported in the CAMBIA library: high, medium, low;
- influence on production quality and yield: i.e. positive effect of the measure on production quality and yield even in the absence of an adverse climatic event;
- environmental benefits;
- possibility of receiving public support.

Evaluation

On the basis of the above-mentioned information, a qualitative assessment of the costs/benefits of adopting the measure is provided. Furthermore, a graphical representation of the degree of convenience in adopting the measure is reported based on an exemplificatory estimation model.

The exemplary estimation model is based on entity of avoided damage by means of the adaptation measure. The damage could come from adverse climatic events.

Considering the average of the yield losses in agriculture in the last years with a strong effect on income (European Environmental Agency, 2021), our model assumes that adverse climatic events can with a high likelihood cause an average damage equal to or greater than 30% of the value of the farm's production. It has been taken into account that adverse climatic events are increasingly frequent and are causing always greater damage. Furthermore, they are more unpredictable, so they can strike anywhere. The economic damage is calculated using FADN data: the average farm value Gross Production is calculated on type of farming and its economic size (we considered three classes: small, medium, large). The benefit of each measure, deriving from damage avoided, is calculated on a qualitative degree of effectiveness of the measure in relation to the risks (high, medium, low), derived from CAMBIA library to prevent/reduce such damage.

The following assumptions were made regarding effectiveness of the measure:

- High = capable of reducing the damage from 70% to 100%.
- Medium = capable of reducing the damage from 30% to 70%.
- Low = capable of reducing the damage from 10% to 30%.

In our approach we considered the average damage reduction based on the previous assumptions. Furthermore, other economic benefits are identified and added to the description of the form: benefits related to the improvement of production quality, the possibility of benefiting from CAP payments, the environmental benefits that can have positive economic impact, as they are increasingly appreciated and requested by consumers. Finally, the overall benefit is compared to the annual average cost to be incurred for the adopted CAM. In order to test this methodological approach, the CAM *agro-meteorological software system for phenological forecast measure* has been analysed according to the costs and benefits assessment presented. In the next section a discussion about the results is provided.

3. RESULTS AND DISCUSSIONS

The methodological approach for cost-benefit assessment was applied to one of the measures of the CAMBIA library: the agro-meteorological software system for phenological forecasting. This adaptation action uses observed weather data as input, namely temperature and precipitation, in order to simulate crop development (phenological stages), soil water content and crop pests or pathogens. This measure counteracts damage from drought, extreme maximum and minimum temperatures, and crop diseases. The implementation of the measure could be achieved in two ways: the software service could be fed by data owned by the service provider or by data collected by weather stations installed by the farm owner. The collected data showed that if the measure is implemented as indicated in the second option the investment cost is between 1,000 and 3,000 euros per installation. The estimated weather stations network density is on average one station every 5 ha in hilly areas and one station every 10 ha in plain areas. The annual cost per hectare is estimated between 80 and 130 euros, considering the linear depreciation of the investment (duration 10 years) and maintenance, while it is estimated to be less than 20 euros, if the weather data are provided by the software service. The effectiveness of the measure is high in counteracting the associated climatic risks, therefore, according to our assumption, it can prevent/reduce damages from 70% to 100%. According to the methodological approach, the evaluation is optimal for its application by the farmer.

According to FADN data the economic benefit, deriving from avoided damage, is higher than the costs to be incurred for the adoption of the measure in the three ADA food chains and in the three economic size classes. Moreover, the measure offers additional economic and environmental benefits.

In detail, the benefit, deriving from avoided damage, results higher for both the options described above. In addition, the cost for its implementation has a marginal impact on farms total output. We found that in the fruit and vegetable chain and in the wine chain the benefits are higher than cost (>100%) and cost impact on total output is lower than 10%. In the SME of livestock chain the benefits with respect to costs are lower/equal to 50%. These considerations suggest that this measure is highly recommended.

4. CONCLUSIONS

Climate change directly affects productivity and profitability of farmers, especially small and medium-sized farmers, and their ability to survive, also negatively affecting the quality of production. Therefore, adaptation to climate change plays an important role in counteracting possible damage by adverse weather events. Our study contributes to this research topic, on the one hand by providing an innovative tool that collects a significant number of climate change adaptation measures, and on the other by providing an assessment of the degree to which it is cost-effective to implement the individual measure. Consultation of several adaptation measures at the same time, together with their possible costs and benefits, allows farmers to choose effective adaptation plans suited to their characteristics. To the best of the authors' knowledge, our research uses the FADN sample to explore the costs and benefits assessment of adaptation measures. With regard to the limits of the proposed methodology to assess the economic convenience in adopting a measure, it has to be mentioned that implementation of the measures involves a wide spectrum of costs depending on different factors, such as farm size, farm location, methods of implementation and others. Another limit concerns the investments to adopt the measures, as a large number of solutions with a wide range of prices is offered by the market. As the model consists of estimations derived from the use of average data it cannot represent the peculiarity of a specific context. However, the strength of this methodology is the lean approach of the cost and benefits assessment able at the same time to provide valuable information about adaptation measures. Thus, in future research our findings could be applied to a wide spectrum of climate risks and a large number of adaptation measures and have a more integrated view on the issue. According to the EU adaptation strategy (EU COM 2021/82), the present study contributes to the scientific literature that investigates farms' resilience and adaptation to climate change, central themes of scientific research, and on the combination of different approaches to assess the resilience of farming systems (Martino *et al.*, 2016; Meuwissen *et al.*, 2019; 2022). The effort of this study is to provide a contribute on methods to evaluate climate change impacts on the economic vulnerability of farms and their resilience in tackling climate change impacts in a continuous development context.

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