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A framework towards resilient Mediterranean eco-solutions for small-scale farming systems

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Abstract

Background: The impacts of climate change on crop and livestock sectors are well-documented. Climate change and its related events (e.g., high temperatures, extreme events, disease outbreaks) affect livestock production in various ways (e.g., nutrition, housing, health, welfare), and tend to compromise the physical productivity and the economic performances. Understanding animal responses to climate change may help planning strategies to cope with the adverse climatic conditions and also to reduce polluting emissions. Through an interdisciplinary approach, we develop a conceptual framework to assess and develop new organisational models for Mediterranean small-scale farming systems so as to mitigate the impacts of climate change, to improve farm management and farming technologies, and to achieve an effective adaptation to the climate changes. The conceptual framework consists of four phases: (i) community engagement, (ii) strategies development, (iii) data collection and analysis, (iv) business model generation and sustainability assessment. We assess strengths, weaknesses, opportunities, and threats of the eco-solutions by mean of a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis technique.

Results: The proposed eco-solutions are expected to increase the sustainability of agriculture and food production systems by introducing new and efficient uses of natural resources. The proposed models are expected to have an impact not only on the environment (in terms of mitigation), but also on the economic and social performances, as they are expected to foster the responses of small-scale farms to the increasingly frequent effects of climate change (adaptation solutions). Among the positive impacts, we emphasise the importance of more stable revenues, a tendency that would help farmers to raise their revenues. Last but not least, we found that the proposed models are likely to increase the social resilience of the farming systems to the challenges imposed by the climate change.

Conclusions: The eco-solutions can support stakeholders involved in Mediterranean small-scale farming systems by suggesting novel land, crop, and livestock management approaches to optimise revenue flows, business models and climate change mitigation strategies thanks to the adoption of a systemic approach, that is not only focused on specific components of the system but instead based on the linkages between environmental, social, and economic aspects.

Keywords: Ecosystem, Sustainability, Livestock, Heat stress, By-product, Feeding strategy

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Introduction

Farming systems are constantly exposed to and affected by climate change and related events. The direct and indirect exposures to the climate change-related conditions tend to provoke environmental concerns, social problems and economic disruptions: the need for adaptation and mitigation strategies is rather urgent (e.g., [11]).

Livestock farming systems are particularly vulnerable to the effects of climate change, partly because there is a natural high internal heat load and an evolved basal metabolism of animals. Along with the changes in climate, the small ruminants tend to be susceptible to heat-related disorders and their associated negative emotional states (e.g., thirst, frustration, discomfort). Despite the thermal comfort is normally guaranteed in the intensive production systems (e.g., in dairy farms), the management strategies are crucial to avoid that the animals suffer and possibly die. Differently, in semi-extensive and extensive farming systems (i.e. grazing) the animals tend to express their thermal stress-related behavioural modifications, resulting in natural coping strategies against the adverse climate conditions. Water and shade are very critical for livestock: an increased need for fresh water is also important, especially because it is becoming more and more scarce. In severe cases, hyperthermia may alter animal's mental state (i.e. behaviour) and compromise their ability to seek out some essential resources, even when they are available. In fact, climate change may induce several behavioural challenges to animals, by limiting environment-focused activity, disrupting group dynamics, imposing unavoidable sensory impositions, and limiting sleep or rest's duration and quality [36].

The effects we have described above are likely to alter animal welfare, which is strongly connected to animal health and to the efficiency of the productions; animal welfare is also important for the sustainability of farming systems (e.g., [43, 44]). Livestock welfare is an issue of global importance, as mentioned by the Global Bioethics, which sets important goals related to global public health (One Health) objective (ten [18]). A novel concept of "One Welfare" has highlighted the interconnections between animal welfare, human welfare, and the environment: in this framework, the reduction of veterinary costs, the improvement of animal performance, the increase in quality of the products are some of the benefits that the animal welfare may bring to the livestock farms [52].

The nutritional practices, a relevant component of sustainable management techniques in locally adapted livestock breeds, help developing more resilient farming systems. Studies have demonstrated that plants rich in secondary metabolites, such as tannins, have beneficial properties in ruminant physiological, nutritional and health traits (e.g., [8, 9]). Local alternative feed resources rich in bioactive compounds, such as agro-industrial by-products, could play a key role in small-scale livestock farming systems, allowing animals to cope with the adverse environmental conditions through their methanogenic mitigation, reproduction promoting, antimicrobial/antiparasitic, antioxidant and product quality enhancing properties [16, 21, 26, 27, 30, 37]. The nutritional intervention with these antioxidant bioactive compounds can reverse the negative effects of high ambient temperature on redox status by improving some physiological and immune responses of ruminants under heat stress [6]. Moreover, given the large availability of agro-industrial by-products at low prices, their use as ruminant feeding strategy provides a convenient and sustainable solution to the valorisation of agricultural residues, lowering feed costs for farmers, and also conferring added value to dairy and meat products at the local level.

Small ruminant farming systems are a major component of Mediterranean dairy and meat sectors. Their relevance increases in less favoured areas of Mediterranean countries, where they become the only viable production systems. Ensuring the sustainability of these farming systems is fundamental. Given the critical economic, environmental, and social roles of these farming systems, ensuring their sustainability is crucial and, at the same time, a challenge. Indeed, a number of factors threaten the livelihood of these farming systems at a progressive rate, preventing them from using resources efficiently, preserving natural ecosystems, enhancing rural livelihoods and social well-being of farmers, improving the resilience of communities and ecosystems under conditions of climate change.

The study proposes a framework to identify and develop organisational models, that operationalise novel strategies (both nutritional and management ones) and integrate them in the daily activities of Mediterranean small-scale farming systems. The study contributes to address the urgent need of new practices that are respectful for the environment and, at the same time, increase the benefits of the ecosystem services provided by sustainable agriculture. This would enable quick, precise, and effective responses to rising environmental threats.

Effects of climate change–livestock interactions on sustainability

Climate change and related phenomena affect all agro-ecological activities and are particularly challenging for the livestock sector [29, 50]. Over the last 30 years, global livestock production has declined by 1–5% per decade [3], partly due to the effects of climate change. Among several stressors, high temperatures and extreme heat events are the most detrimental phenomena for livestock

[48, 54]. The exposure to heat stress threatens animals' metabolic status and antioxidant defence systems, resulting in a reduced tolerance to stresses and, therefore, in productivity loss and quality decline [23, 25, 32]. Productivity loss tends to be associated with reduced feed intake, consumption of low nutrient feeds, loss of energy in thermoregulation activities, changes in the epidemiology of diseases [5, 14]. For instance, the heat stress exposure adversely affects milk yield and quality, especially in animals with high genetic value [4]. Milk production in dairy animals lowers because of a reduced feed intake due to heat stress exposition (50%) and of metabolic adaptations to heat stress (50%) [2]. Heat stress can affect milk composition through a reduction of fat and protein content [46]. In the Mediterranean basin, the increase in temperatures and the late stage of lactation of dairy ewes occur simultaneously with adverse effects on the mobilisation of body reserve for milk synthesis: this induces a decline in yield and quality of milk and, consequently, of derived cheese. The effects of climate change on livestock production, mediated by changes in feed resources, are indirectly observed in the productivity and quality of carcasses [51]. Even though sheep are low-demand animals, considerably resilient and well adapted to their environment [47], the effects of heat stress on their productivity can range from decreased body weight gain to altered carcass composition and meat quality [20]. The degradation of meat quality variables (e.g., pH, colour, texture, moisture) is referred to as dark cutting or dark-firm dry, high pH, low glycogen meat [45]. Heat stress causes adrenaline responses which stimulate peripheral vasodilatation and muscle glycogenolysis: if the heat stress exposure is protracted until slaughter, higher pH and darker meat are likely to occur. The heat stress exposition also leads to dehydration in water deprived animals with effects on the quality of meat which results darker, due to a shrinkage of the myofibrils, and losses less weight during cooking, due to its dryness [35].

Climate change affects also reproductive performances of animals. Heat stress may activate the hypothalamic–pituitary–adrenal (HPA) axis with consequent inhibitory effects on the hypothalamic–pituitary–gonadal (HPG) axis and on reproduction in both males and females [19]. The exposition to severe heat stress causes delayed puberty, defective gametes, aberrant expression of sexual behaviour, decreased oestrus duration and percentage, fertilisation failure, early embryonic mortality, retardation of foetal development and growth, decreased placental and birth weight, abortion and premature/still birth in females (e.g., [17, 33]), significant reduction in testicular volume, improper spermatogenesis and altered semen production in males [24]. The reproductive performances of small ruminants is particularly threatened when the heat stress exposition is coupled with an inadequate nutrition: amelioration strategies involving both heat stress management and nutritional supplementation need to be developed to optimise reproductive and, consequently, productive performance of small ruminants.

The biology of small ruminants is strongly affected by climate change, which in combination with host-specific and management-related factors might severely affect disease epidemiology [49]. Gastrointestinal parasites of small ruminants and other livestock have major economic impacts worldwide. At the global level, annual economic losses associated with coccidiosis amount to up to 3 billion dollars in the poultry industry and up to 140 million dollars in the small ruminant sector [12]. Major helminth infections in the European ruminant livestock sector (the reference is to 18 countries) result in a total annual cost of 1.8 billion euro [7]. Prophylactic or metaphylactic treatment of coccidiosis in ruminants requires the use of both synthetic drugs (e.g., sulphonamides, amprolium, decoquinate, triazines diclazuril and toltrazuril) and ionophores (monensin, lasalocid), due to the lack of vaccine-oriented approaches as compared to poultry. In Europe, however, only a few active pharmaceutical ingredients with anticoccidial action are registered and available in the market (i.e. decoquinate, diclazuril, lasalocid, monensin, toltrazuril): in fact, anticoccidials are groundwater and soil pollutants [31]. For instance, toltrazuril is of particular concern for the environment, due to its persistence and high phyto-toxicity, and not much effective for several ovine *Eimeria* species, due to their resistance [34]. Controlling parasites through synthetic drugs has proven to be unsustainable over the last decades. Resistance issues, emerged in the cases of gastrointestinal nematodes in small ruminants and of coccidiosis in the poultry industry, and concerns on the presence of drug residues in animal products (e.g., [40, 42]) have stimulated the search for alternative solutions. Plants rich in secondary metabolites, particularly tannins, have demonstrated anticoccidial contribution in small ruminants, albeit information on their action mechanism and required concentrations in their ratios are still lacking.

Livestock, especially cattle, are impacted by climate change and heat stress also indirectly through reductions in forage and feed grain yield [39]. Pastures composition is affected by both temperature and CO_2 increase. Changes in pastures composition reflect on feed imbalances and toxicity which, in turn, potentially increase negative consequences on animals' functions. Climate change affects the growth of herbaceous species, with greater impacts on C3 species (i.e. plants using a three-carbon compound in photosynthesis) because of an increase of carbon dioxide (CO_2) concentration, and on

C4 species (i.e. plants using a four-carbon compound in photosynthesis) because of temperature increase [38]. Similarly, higher temperatures and dryer conditions affect feed crops and forage quality, because they promote imbalanced concentrations of water-soluble carbohydrates and nitrogen. Plants affected by increased temperatures tend to increase lignin and cell wall components. Their presence reduces digestibility and degradation rates, leading to a decrease in nutrient availability for grazing animals [38]. More extreme consequences, such as intoxication and eventual death of animals, may occur after ingestion of *Pteridium aquilinum* L. during late summer when other feed is scarce and pasture richness is reduced.

A method to identify eco-solutions for small-scale farming systems

We develop a framework to adopt new organisational models for Mediterranean small-scale farming systems, based on eco-solutions (i.e. a bundle of nutritional and management strategies) implemented to adapt to climate-related challenges while mitigating climate change impacts. The framework consists of the following four steps: i.e. community engagement, strategies development, data collection and analysis, business model generation and sustainability assessment (Fig. 1).

As first step, a priority is to invest in trusted organisations and networks of different stakeholders (e.g., farmers, workers, suppliers of inputs) and interest groups (e.g., breeder organisations, professional organisations, cooperatives, policymakers), by establishing connections, assessing needs, strengthening community capacity, and building partnerships. The engagement of women and young stakeholders contributes to integrate the gender and age dimensions. Stakeholders and interested groups involved in a proactive participatory approach allow to better contextualise the proposed eco-solutions for Mediterranean small-scale farming systems.

The second step consists in the development of strategies based on the assessment of climate change impacts on agroecosystems and the identification of climate change adaptation solutions.

The third step consists in implementing the strategies identified in the second step at the farm level and in collecting and analysing farm-level data to test the internal validity of the proposed strategies. Using in vitro and in vivo approaches based on standard procedures (e.g., protocol for Thermal Heat Index measurement) are recommended to derive common indicators that allow comparison of strategies implemented in farms in different Mediterranean countries. The analysis of farm-level data allows to identify a list of adjustment to the strategies developed in the second step. These adjustments are preparatory to the implementation of strategies at a broad scale and in real market conditions to determine which ones work best in terms of environmental, economic, and social sustainability.

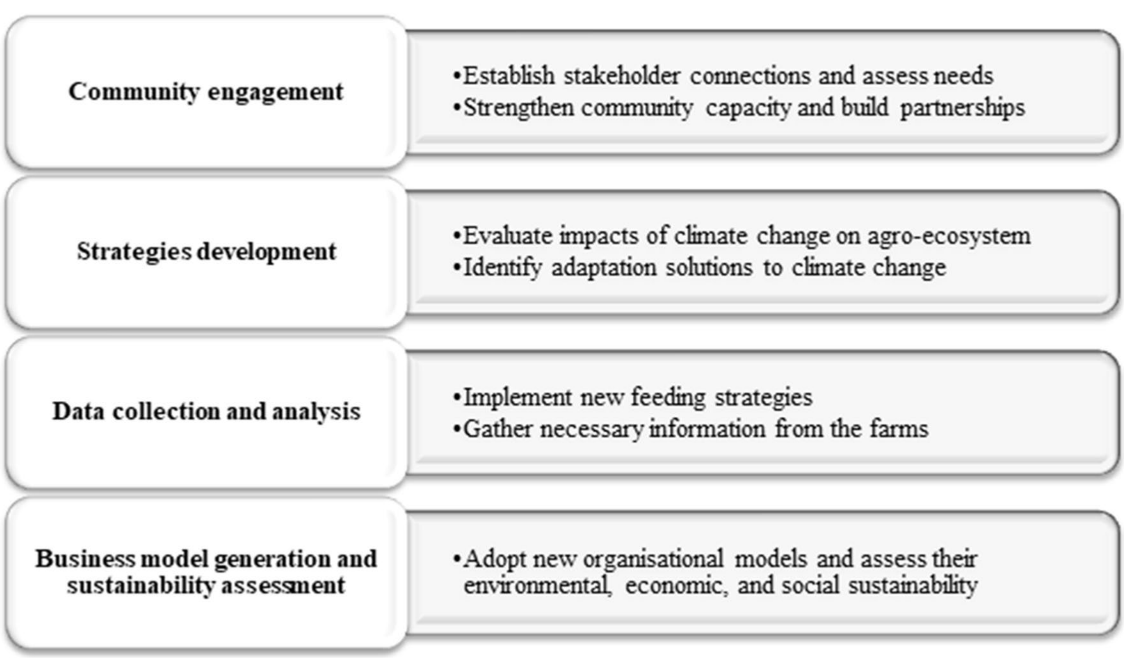

Fig. 1 Steps of the framework identifying eco-solutions for small-scale farming systems

The fourth step consists in developing a business model, coherent with the strategies selected in the third step, and in assessing its sustainability. This phase is the real operationalisation of the eco-solutions for Mediterranean small-scale farming systems and their effective integration in the stakeholders' daily activities. The assessment of environmental, economic, and social sustainability of these new organisational models has to be shared with stakeholders and interested groups.

The framework, positioned in the spectrum from 'idea to application', covers the whole process along the value chain. The assessment of strategies' potential in improving the resilience of Mediterranean small-scale farming systems to climate change starts from the conceptual development of strategies to improve the adaptation to climate change (second step) and ends to the validation of the developed strategies in laboratory through in vitro studies and on field through in vivo studies (third step). The assessment of micro-level impacts of adaptation solutions and the identification of organisational models that embed these solutions in a sustainable manner while taking economic, social, and environmental aspects into account, includes both the conceptual development of sustainable models and the quantification of model's benefits in terms of environmental, economic, and social sustainability (fourth step).

Discussion on eco-solutions for small-scale farming systems

Nutritional and management strategies, developed according to the described framework, once integrated in the daily activities of Mediterranean small-scale farming systems have the potential to increase the sustainability of production systems. The expected positive impacts are on the environment thanks to a novel and efficient use of natural resources (i.e. eco-solutions as mitigation options) and on economic and social levels due to an improved responsiveness of small-scale farms to the increasingly more frequent effects of climate change (i.e. eco-solutions as adaptation options). A SWOT (Strengths, Weaknesses, Opportunities, Threats) technique is used to assess the advantages and weak points, opportunities and threats of the eco-solutions developed using the proposed framework, considering as example a new feeding strategy based on agro-industrial by-products, both raw and processed animal feeds. The SWOT analysis matrix is in Table 1.

Strengths of eco-solutions

The introduction of eco-solutions in Mediterranean small-scale farming systems may contribute to improve the sustainability of production systems through a more efficient use of natural resources, and contribute to enhance climate change resilience/adaptation and mitigate climate change effects (Table 1, environmental strength). Implementing feeding strategies based on agro-industrial by-products, both raw and processed animal feeds (e.g., sainfoin, date and artichokes scraps, pomegranate pulp and grape pomace, olive cakes, tea waste) may upscale the efficient use of underutilised by-products, while drawing upon their antioxidant, anti-inflammatory, antimicrobial, and antiparasitic actions to enhance animals' resilience to heat stress exposition and to prevent production losses. The potential methanogenesis reduction should also contribute to mitigating climate change indices related to the livestock sector (e.g., [22, 28]).

The use of alternative feed sources as feeding strategies has the potential to increase the economic and social resilience of Mediterranean small-scale farming systems to climate change (Table 1, technological strength). This because of a lower dependence of alternative feed sources on climate change and water scarcity than fodder or cereals [20]. The use of alternative feed sources contributes

Table 1 Strengths, weaknesses, opportunities, threats of eco-solutions for small-scale farming systems

	Strengths	Weaknesses	Opportunities	Threats
Environmental	More sustainable agri-food production systems	Worse impacts than current management solutions	Adoption of a holistic approach	Idiosyncratic and systemic risks
Technological	Improved resilience of farming systems to climate change	Ensilaging of by-products	Value creation in daily routines	Extend the validity of best practices
Economic	Increased farmers' income	Low profitable ingredients	Improved business practices	Extend the validity of best practices
Social	Engagement of youth and empowerment of women	Social or consumer rejection	Close collaboration between research and industry stakeholders	Extend the validity of best practices
Legislative	Contribution to the zero-waste farming systems target	Contaminants above limit	Achievement of policy objectives	Lack of favourable regulatory conditions
Other	Decreased use of chemical inputs	Seasonality of production	Improved animal welfare	

to novel feeding frameworks that enable Mediterranean small-scale farming systems to better adapt to climate change and shrink their feeding expenses (e.g., [48]).

The implementation of strategies may also increase farmers' income thanks to the use of improved farming techniques and products certification (Table 1, economic strength). The introduction of the proposed local agro-industrial by-products in smallholder ruminant farms contributes, among others, to reduce land occupation for traditional feedstuffs (e.g., cereals) and allocate a proportion of agricultural area for other, more sustainable uses (e.g., [41]). These strategies should enhance cross-industry cooperation and decrease obstacles to market access for smallholders, while providing a context for high-valued production under climate-friendly schemes (e.g., [43, 44]).

Improved income and farming system resilience to the effects of climate change should be linked to the engagement of young farmers and women (Table 1, social strength). In Mediterranean countries, farming businesses are passed down through generations. Older farmers tend to rely on consolidated and traditional methods and be reluctant to integrate new practices and techniques.

In the context of the circular economy, eco-solutions may contribute to the goal of zero-waste farming systems (Table 1, legislative strength). The designed development of an agroecological industrial model based on short supply chains, valorisation of local by-products and promotion of fair trade between farmers should significantly reduce waste production from local agro-industries and regulate conventional farming practices for animal feed production (e.g., [20, 52]).

The strategies may reduce the use of chemical inputs and develop alternative solutions (e.g., new bio-based products, new techniques and policies) (Table 1, other strengths). The by-products utilised as feed additives should be rich in plant secondary metabolites (e.g., condensed tannins), to provide biological and physiological benefits, such as antioxidant, antiallergenic, anti-inflammatory, antithrombotic, and antimicrobial actions, on heat-stressed ruminants (e.g., [32]).

Weaknesses of eco-solutions and improvement proposals

The eco-solutions for small-scale farming systems developed according to the framework described above are not exempt from weaknesses (Table 1). First, the proposed solutions may have worse environmental impact than existing management solutions (Table 1, environmental weakness). An improvement could be the identification of main environmental challenges and the development of strategies achieving feasible eco-friendly approaches.

Unexpected obstacles may occur during the ensilaging of by-products when upscaling the processes at farm level. The variability of final products could not meet the standardisation requirement of end users (Table 1, technological weakness). To avoid such an issue, the scaling-up of food by-products valorisation processes should consider evidence from previous studies (e.g., [6, 22, 28]). Moreover, replicability and standardisation should be considered from the beginning of the implementation of each proposed eco-solution.

Another aspect is the value of the obtained ingredients, which may result in unprofitable solutions on large scale due to the production costs (Table 1, economic). The assessment of profitability of implemented eco-solutions for small-scale farming systems using a Life Cycle Assessment (LCA), both Environmental LCA and Social LCA (E-LCA and S-LCA), as well as a Life Cycle Costing (LCC) should be considered (e.g., [53]).

The use of agro-industrial by-products to produce alternative feeds may result in social or consumer rejection (Table 1, social weakness). The social acceptance of new feeds as well as the social implications of suggested solutions should be assessed and enhanced by incorporating new processes or skills. It is worth mentioning that the presence of pollutants above legal limits in agro-industrial by-products used as alternative feeds might prevent their use in some feeding strategies (Table 1, legislative weakness). To avoid such legal issues, contaminants should be monitored to ensure the fulfilling of legislation. Quality, safety, and legal aspects of the products should be reviewed and assured [41]. Other weaknesses are related to the seasonality of production that could hinder the availability of agro-industrial by-products to be used as alternative feeds in small-scale farming systems or to the availability of critical mass for animal feed (Table 1, other weaknesses). The seasonality and characteristics of the production of agri-food by-products should be carefully monitored. The availability of agri-food by-products should be studied to ensure sourcing of a sufficient raw material provision.

Opportunities of eco-solutions

Opportunities related to the eco-solutions include redesigning small-scale farming systems in a holistic way to harmonise productivity, sustainability, and climate issues. The sustainability of livestock production tends to be assessed through economic indicators. However, the need to examine climate change impacts on Mediterranean small-scale farming systems requires a multi-faceted, multi-actor approach (Table 1, environmental opportunity).

Covering the entire process from idea development to actual implementation, the eco-solutions for small-scale farming systems represent a definitive step beyond the current state-of-the-art. The declination of the strategies into organisational models, in particular, may allow for stakeholders to be provided with a list of practical activities to be integrated in their daily routines in order to extend the value created and increase the value captured for themselves (Table 1, technological opportunity).

The opportunity of the eco-solutions is not only related to the alternative feeding strategies themselves, but also to their usage for gathering information useful to decide, in the future, whether and how to modify existing organisational models in response to changes in external conditions (Table 1, economic opportunity).

The development of new strategies and guidelines for small-scale Mediterranean farming systems in close collaboration with industries and academia contributes to build a network of organisations that can foster innovative feeds and new products and processes into economic and social uses (Table 1, social opportunity).

The development of new organisational models for Mediterranean small farming systems, based on eco-solutions implemented to adapt to climate-related challenges while mitigating impacts of climate change may contribute to the achievement of many of the Sustainable Development Goals. The eco-solutions are also in line with the strategic goals of the EFSA focused on the risk assessment of animal welfare and production under climate change and the effects of welfare consequences on animal-based food safety, quality, and security [13] (Table 1, legislative opportunity).

Threats in eco-solutions

Production losses due to unexpected occurrence of pathogens or physio-pathologies (e.g., Xylella, oak processionary moth) and/or extreme weather (e.g., floods) and non-weather (e.g., fire) events that may reduce feed availability (i.e. olive trees' by-products) within experimental farms (e.g., [11, 15]) are potential risks related to the development of eco-solutions for small-scale farming systems (Table 1, environmental threat). Retrieving feeds from third local farms (e.g., located within a radius of 200 km) may contribute to manage these potential idiosyncratic and systemic risks. Further risks may be related to microbial and fungi contamination of raw materials (e.g., [1]). Feedstuff should be stored in an appropriate manner and farmers should deal with feedstuff by following good practices (Table 1, technological, economic, social threats).

A major impediment to the success of proposed eco-solutions is the lack of favourable regulatory conditions and an enabling framework that could increase investments and incentives (Table 1, legislative threat). Consequently, a critical aspect is engaging with policymakers to facilitate the discussion with them and their understanding of the practical aspect of eco-solutions for Mediterranean small-scale farming systems.

Conclusions

We proposed novel organisational models for Mediterranean small-scale farming systems, based on eco-solutions, to help farming systems becoming more resilient to climate-related challenges. These eco-solutions help transforming the systems into more productive and sustainable ones, by improving environmental, economic, and social performances of the small-scale farming systems.

The eco-solutions can support stakeholders involved in Mediterranean small-scale farming systems by suggesting novel land, crop, and livestock management approaches to optimise revenue flows, business models and climate change mitigation strategies thanks to the adoption of a systemic approach, that is not only focused on specific components of the system but instead based on the linkages between environmental, social, and economic aspects.

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Author contributions
F.G.S. contributed to the conception of the work; E.L. contributed to the design of the work and have drafted the work; A.B., M.C., M.G.C., C.C., M.A.K., M.K., M.L., C.L., U.P., A.S., M.T., I.V., S.O.Y. contributed to the analysis and interpretation. All authors read and approved the final manuscript.

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