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Optimal management plans and initiatives for the valorization and safeguarding of local breeds: a mathematical programming approach

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In this study, a parametric programming model was developed in order to deliver optimal management plans for various types of farms rearing endangered Greek sheep breeds under three distinct scenarios. The first scenario investigated the optimal internal organization of farms (i.e., management practices and resource allocation strategies that increase profitability of farms) under current market conditions (e.g., product prices) without, however, considering subsidies and compensations. The second assessed the impact of an agri-environmental support scheme on farm optimal structure and socioeconomic performance. The third investigated the effects of integrating farms into value chains and niche markets where premium prices prevail. For this purpose, a questionnaire survey was conducted in the wider region of Epirus and Thessaly, collecting management data from 16 farms rearing (i) Kalaritiko, (ii) Orino Epiru and (iii) Katsika rare sheep breeds. The main finding of this study was that the optimal internal organization of farms is essential for their self-reliance and viability. Therefore, it should be the basis in the designing of any initiative aimed at the preservation and valorization of local breeds. Furthermore, the analysis showed that a niche marketing strategy (i.e., a premium price strategy) can have a broader positive impact on farms structure and socioeconomic performance, particularly those engaged in cheese production, compared to an agri-environmental scheme. However, due to the fact that both initiatives possess limitations that may render them inefficient under specific external conditions, the development of an integrated incentive mechanism, which will combine both policy schemes and market-based initiatives, appeared to be a more effective strategy for the long-term viability of farms.

KEYWORDS

mathematical programming, local sheep breeds, agri-environmental scheme, niche marketing strategy, optimal management plans

Introduction

Local breeds (LB) (i.e., breeds found solely in one country (FAO, 2007a)) are a key component of traditional pasture-based production systems (PPs), which play multiple roles (including socioeconomic, environmental, and cultural) in many regions and settings around the globe (Teston et al., 2022; Ragkos et al., 2019a; Duclos and Hiemstra, 2010). Indeed, LB and PPs constitute the main economic activity in many marginal and remote areas, creating job opportunities and supporting livelihoods (FAO, 2007a). Due to their adaptability to local conditions (Legarra et al., 2007), LB can efficiently and sustainably use high-nature value rangelands, delivering a wide range of marketed products (milk, meat, wool, etc.) along with ecosystem services such as soil fertility, conservation of landscapes and biodiversity (Hoffmann et al., 2014; Rodríguez-Ortega et al., 2014; Leroy et al., 2018). LB and their PPs are also an integral and important part of the identity of local communities. The interaction of people (particularly farmers and their families) with LB and their agroecosystems led to the development of practices, knowledge and beliefs also known as Traditional Ecological Knowledge (TEK) (Colino-Rabanal et al., 2018).

In terms of production and markets, LB are endowed with several advantages that can lead to higher profitability. These include lower requirements for fixed and variable capital (Ragkos et al., 2019a), longevity (i.e., more lactation periods per ewe) (Papachristoforou et al., 2013), higher resistance to diseases (Piedrafita et al., 2010; Papachristoforou et al., 2013). And product quality (Teston et al., 2022). However, due to the widespread presence of highly productive breeds, all these benefits are often underestimated or even neglected (Ligda and Casabianca, 2013). This adverse situation is further burdened by the pricing policies of some dairy industries, which are primarily based on the quantity rather than the quality of milk (Ragkos et al., 2019a; Perucho et al., 2019). Because of these market forces, farmers focus on milk production, replacing or crossbreeding local breeds with highly productive exotic breeds (Juvančič et al., 2021; Perucho et al., 2021). As a consequence, sharp decline in their populations is being witnessed and, in some cases, even extinction (FAO, 2016).

In any case, the loss of domestic animal genetic diversity poses a threat to global food security and the livelihoods of rural areas (FAO, 2007b). Consequently, this issue has garnered significant attention in both scientific and policy making communities, which have proposed various initiatives and strategies for their preservation and sustainable management. According to Ragkos et al. (2019a), all these strategies fall into two equally important dimensions. The first dimension involves their short-term rescue and protection, which is primarily achieved through the provision of payments to farmers and their associations (e.g., a long standing, since 1995, agri-environmental scheme compensating farmers for income forgone caused by rearing LB). Nevertheless, there is a gap in the literature regarding the long-term effectiveness and impact of such strategies on conservation of LB (Gicquel et al., 2020).

The second dimension encompasses strategies aimed at the overall sustainability and self-reliance of farms, introducing an alternative pathway for the valorization of LB (Ragkos et al., 2019a). This approach refers to - but is not limited to - effective marketing strategies, which facilitate the integration of LB farms into value chains and niche markets, where premium prices prevail. A number of recent studies have suggested the design and development of niche marketing strategies as an integral part of a broader approach for preserving LB, particularly those that are in risk of extinction (Lambert-Derkimba et al., 2013; Zander et al., 2013; Martin-Collado et al., 2014; Juvančič et al., 2021; Varela and Kallas, 2022; Skordos et al., 2024), highlighting, at the same time, the key features that will render them effective (Di Trana et al., 2015). Apart from niche marketing strategies, optimal management plans for farms rearing LB may also be a strategy to enhance their overall sustainability and self-reliance.

The purpose of this study is to deliver optimal management plans for different farm types rearing three endangered local sheep breeds (LSB) in Greece, maximizing their economic performance and identifying potential organizational bottlenecks. In addition, the impact of two distinct incentives on farm optimal structure (particularly in their flock size) and internal organization is investigated. These incentives include the agri-environmental scheme for the preservation of endangered local breeds (particularly the sub-measure 10.1.9 of Rural Development Program [RDP] 2014–2020, which in the Greek Strategic Plan of the new Common Agricultural Policy [CAP 2023–2027] corresponds to the intervention I3-70-1.5) and a niche-premium pricing marketing strategy. For this purpose, a mathematical programming model is developed, using data from a farm management survey. Although mathematical programming models have been widely employed to derive optimal management plans for livestock farms (Sintori et al., 2013; Ragkos et al., 2020; Cecchini et al., 2022; Hlavatý et al., 2023; Theodoridis et al., 2023), it is the first time that this methodology is applied for farms rearing exclusively endangered LSB. To our knowledge, this is also the first attempt in Greece to investigate the impact of such strategies on the population of endangered breeds.

Materials and methods

Survey profile and data collection

This study uses data from a farm management survey of farms rearing (i) Kalaritiko, (ii) Orino Epiru and (iii) Katsika sheep breeds, which are mainly located in the wider region of Epirus and Thessaly (study area) in North-Western and Central Greece, respectively. The selection of these breeds was based on three main criteria. The first criterion is related to the fact that these LSB are a key element of PPs, which play a multifunctional role in many regions around the globe (Ragkos et al., 2020). Indeed, all these three breeds share important characteristics that render them ideal for transhumant and/or pastoral systems in harsh environments of Greece in general. In particular, they demonstrate high adaptability to local conditions (including grazing) and increased longevity. However, significant differences were observed in the implemented grazing practices among the surveyed farms. For instance, some of the farms graze their sheep throughout the year in natural rangelands near the facilities, while others are transhumant and move flocks from the lowlands to mountain pastures in the summer (mainly in Tzoumerka mountain range, from May to October) in order to take advantage spontaneous vegetation. However, for both systems, the provision of additional feedstuffs (forage and concentrates) is necessary during winter mainly due to the low availability and productivity of lowland rangelands and the high nutritional requirements linked with the lambing and milking periods. The second criterion is that all these breeds are endangered and therefore supported through the CAP (sub-measure 10.1.9 of the RDP). In 2021, according to FAO (2024), the combined population of these three LSB consisted of 701 males and 10,970 females. The third criterion refers to their similar production traits. Indeed, these breeds are of small sized animals (rams weigh approximately 64 kg and ewes 45 kg), with low milk yields (average 110 kg/ewe) and prolificacy indexes (1.15 lambs per ewe) (MINAGRIC: Hellenic Ministry of Rural Development and Food, 2015). Therefore, any differences in the economic performance of the surveyed farms cannot be attributed to the production traits of the breeds but rather to the management practices of the farmers.

In total, 16 farmers were interviewed, whose livestock represented 70% of the total population of the three breeds. Collected data involved description of the flocks (number of ewes, rams, replacement lambs, etc.); outputs (e.g., milk, meat and cheese yields and prices); subsidies - compensations (basic payment scheme, coupled payments, agri-environmental support, support for areas with natural constraints, etc.); annual labor requirements (e.g., hours of family and hired labor per task and wages paid to hired workers); rent and area (ha) of pastures and/or other irrigated and non-irrigated lands used for crop production (which in the case of transhumance farms were further distinguished to lowlands and highlands); description of grazing practices (period, hours of grazing per period, place etc.); variable capital (prices and quantity of feedstuff, veterinary costs, crop production costs, etc.) as well as fixed capital endowments (value of equipment, infrastructure, etc.).

Technical and economic analysis

After the collection of the data, basic technical and economic indicators along with the gross margin were calculated for the sampled farms. These indicators were not only essential for the implementation of the mathematical programming model (*Parametric programming model specifications*), but also depicted the overall performance of the farms in the existing situation.

Moreover, to highlight potential differences due to the farming system, farms were initially classified into two categories i) transhumant and ii) non-transhumant (sedentary) farms. However, the categorization based on transhumance did not reveal the heterogeneity of farms in terms of production orientation. Previous work with transhumance (Ragkos et al., 2019b) showed that the economic performance of farms producing cheese differs from dairy or dual-purpose farms. To accommodate this diversity, the typology of Theodoridis et al. (2017) was adapted to this study and five types of farms (ToF) were finally considered: i) dairy transhumant (DT) and ii) dairy non-transhumant farms (DNT); i.e., in these types of farms the income from milk exceeds 65% of total gross revenues and the only difference lies on the grazing practices [seasonal movement or not of the flocks]; iii) "dual purpose" farms (DU) (i.e., transhumant farms where the income from milk and meat are almost equal); iv) "meat" oriented (MO) farms (i.e., transhumant farms that produce only meat and the milk is used only for lamb rearing); and v) "cheese" oriented (CO) farms (i.e., non-transhumant farms that engage in cheese production for commercial purposes and where cheese sales represent more than 50% of their total gross revenues). Thus, the analysis indicated the potential of farms based on their farming system and production orientation.

Parametric programming model specifications

Parametric programming (PP) is an extension of Linear programming (LP), which is a non-parametric mathematical programming method (Rardin, 1998) that has been widely used in the field of agricultural economics (Alsheikh et al., 2011; Sintori et al., 2013; Baciu et al., 2023; Theodoridis et al., 2023). Both LP and PP models aim to deliver an optimal allocation of farm resources (i.e., to maximize or minimize (depending on the purposes of the research) an objective function (i.e., linear function of variables) that is subject to constraints (i.e., linear inequalities). Whether it is for cost minimization or output maximization, these models deliver an optimal combination of activities and therefore are considered an appropriate tool for policymakers and other stakeholders (Sintori et al., 2013).

The mathematical expression of a PP model is as follows (Eqs 1–3):

$$\max(\min)\sum_{J=1}^{M} c_j x_j = Z \tag{1}$$

$$\sum_{J=1}^{M} a_{ij} x_j \leq A_i \tag{2}$$

$$x_j \geq 0 \tag{3}$$

where:

Z = objective function (in this study, refers to the maximization of the gross margin (GM) of the ToF).

x_j = farm activities (in our case, corresponds to the number of ewes. Therefore, the model has the flexibility to maximize the GM as a function of the number of ewes reared).

c_j = the contribution of each activity to the objective function

a_{ij} = the requirements per unit of the activity x_j, where its available resource is A_j

Coefficients of some variables in the objective function (Price Parametric Programming) or the availability of a resource in constraints (Aij) (Right-hand Side Parametric Programming) are allowed to vary, fact that leads to a set of alternative optimal solutions for different parameter values. This capability of the model enables policymakers and other stakeholders to analyze the sensitivity and robustness of the optimal solution to changes in the external and/or internal environment.

In this study, a PP model was developed for each ToF, which simulates the optimal management plans (e.g., number of ewes reared, hours of hired labor required, quantity purchased feedstuff, etc.) that maximize their economic performance in the objective function (Eq. 4) under a set of physical and economic constraints. As it is depicted in Eq. 4, the economic performance of ToF was defined by their total GM (gross revenues minus variable expenses and the cost of hired labor). Due to its simplicity, GM has been extensively used in relevant optimization models (Alsheikh et al., 2011; Ragkos et al., 2020; Baciu et al., 2023; Theodoridis et al., 2023) to define the optimal economic performance of farms.

$$\begin{aligned}\text{Max GM} = & \left(\text{E x } q_1 \text{ x } P_1 + \text{E x } q_2 \text{ x } P_2 \ \ldots\ldots\ldots\ldots\ldots \ \text{E x } q_n \text{ x } P_n\right) \\ & - (\text{VE} + \text{HLAB}) - 0 \text{ x VC}\end{aligned} \tag{4}$$

Where E is the number of ewes, q_1, q_2, and q_x are the total quantity of the products per ewe, P_1, P_2, and P_x correspond to the product prices, VE account for variable expenses and HLAB stands for the cost of hired labor. In addition, in order to provide more flexibility to the models, variables with zero coefficients (transfer activities [VC]) were also included in the objective function.

Constraints in the models, which ensure that the results are realistic and feasible e.g., the workload of farms does not exceed the available hours of labor (both family and hired), were adjusted to the peculiarities of each ToF and referred to:

- *Land constraints,* which expressed the available area (ha) of arable land, non-irrigated (for wheat and barley) and irrigated (for alfalfa and maize), as well as pastures. In the case of transhumant farms, pastures were modeled separately between lowlands and highlands, as both their availability and productivity varied between regions and types of farms. Since there were no data available for pastures in the study area, such data on their average productivity and stocking rates were based on the specifications provided for the Rangeland Management Plans (Common Ministerial Decision, 2014).
- *Labor constraints,* which refer to actual and required family and hired labor. The actually employed family labor is determined by considering the hours that family members of each ToF currently dedicate to farm tasks. For the estimation of the average hired labor, an assumption was made that each ToF has the capability, if needed, to increase its current hired labor hours twofold. The actual family and hired labor are expressed in h/year. Moreover, labor requirements cover all farm activities, including those related to cheese and crop production, where applicable, and are expressed in h/ewe/year.
- *Variable capital constrains* include the cost of purchased feedstuff, the cost of crop production, veterinarian expenses, cheese production expenses (in the case of CO) and other variable expenses. All these expenses were introduced in the models as separate constraints.
- *Feeding requirements,* which ensure that all sheep (ewes, replacement lambs and rams) cover their dietary needs in dry matter, energy and protein throughout their production cycle (milking period, mating period, weaned lambs etc.) However, due to the fact that intakes from natural pastures are difficult to estimate, and based on the results of the study of Zervas et al. (1996) we assumed that sheep can cover at most 15% of their annual energy requirements from natural pasture. Although the LB examined in this study are well-adapted to local conditions and particularly grazing, we preferred to use this minimum constraint. The nutritional values of natural pastures as well as purchased and home-grown feedstuff (such as alfalfa, corn and barley) were also included in the model and were derived from Zervas et al. (2004).

In order to examine the economic performance of these diverse ToF, under different situations and challenges, three different scenarios were elaborated. The first Scenario (S1) investigated the optimal management of ToF under the current market conditions, without however taking into account CAP income support, highlighting the necessary adjustments (e.g., in the number of the reared ewes, hours of hired labor, the quantity of purchased feedstuff, etc.) for each ToF to maximize their GM. This way, an initial solution was yielded which "isolated" the effects of CAP income support and revealed the "true" potential of farms from the optimal use of resources and market sales. This solution provided a baseline to examine two additional Scenarios of future trajectories of LSB farms.

Scenario 2 (S2) examined the impact of the agri-environmental support scheme (sub-measure 10.1.9 of RDP 2014–2020) which compensates farmers for economic losses incurred from rearing endangered LSB. This payment was isolated from other CAP payments and was included in the objective function of the model (Eq. 4). This amount corresponded to €34.8 per ewe when the ratio of males to females is 1:15 or less, and €31.35 per ewe when the ratio exceeded 1:15 (MINAGRIC: Hellenic Ministry of Rural Development and Food, 2024). Scenario 3 (S3), on the other hand, investigated the effectiveness of a premium pricing strategy (i.e., a market-based strategy) towards the valorization of LB. In this scenario, although the objective functions and constraints were the same as those in the first scenario, the price of the primary product of each ToF (i.e., the product with the highest contribution to the gross revenues) was allowed to increase (Price Parametric Programming) investigating the effectiveness of a premium pricing strategy to the valorization of LB. In DT, DNT, and DU, the primary product was milk, in MO it was lamb meat and in CO it was cheese. However, in the case of CO, beyond the cheese price, the milk price was also allowed to increase, examining the consequences of this change on its production orientation and business model (Scenario 3b).

Results

Overview of the existing situation–results of the technical and economic analysis

Basic technical and economic indicators

Table 1 depicts the basic technical and economic indicators for each ToF. Milk price was approximately €0.96 per liter across all ToF. In contrast to milk prices, there were significant differences in the total quantity of milk (i.e., the total milk produced without considering the amount consumed by lambs). Dairy farms, both DT and DNT milked the highest quantity of milk (115.3 kg/ewe and 97.2 kg/ewe, respectively), while, leaving out the MO, where milk was solely used for lamb feeding, CO was the one that had the lowest one (49.5 kg/ewe). The total milked quantity in CO corresponded to 17666, 7lt per year, from which only 21.7% was sold to industries. When it comes to meat prices and yields, there was also a significant variation across all groups. MO achieved the highest meat prices for both lamb and ewe meat (€10.00 and 7.50 €/kg, respectively). As for lamb meat, DU was the one that achieved the highest yields per ewe (8.4 kg/ewe), followed by MO (8.0 kg/ewe).

Basic economic results

Indicators of economic performance for the various ToF were initially calculated without taking into consideration the various types of income support payments from CAP measures. In this case, revenues from markets and the value of self-consumption were considered, MO and DU had the lowest gross revenues (104.27 €/ewe and 123.53 €/ewe, respectively), nevertheless they were the only ToF with positive GM (42.01 €/ewe and 27.83 €/ewe) due to significant cost savings in purchased feedstuff and hired labor expenses. In contrast, CO operated with the highest losses (−45.93 €/ewe), followed by DT and DNT (−14.60 €/ewe and −2.21 €/ewe, respectively). These calculations of GM were used for the analysis of S1 with the mathematical programming model. However, the total sums of CAP income support - which stand for a very important part of the income of extensive pastoral farms in Greece (Ragkos et al., 2020) and also in various European regions (Arsenos et al., 2021) - are also reported in Table 1. When they were taken into consideration, GM was positive for all ToF which illustrates the vital importance of policy support for the viability of most LSB farms even in the short run.

Mathematical programming solutions

Table 2 presents the results of the S1. In this scenario there were small or no changes in flock sizes, in contrast with the GM/ewe which was increased in the majority of ToF, except for MO, mainly due to the reduced expenses for purchased feedstuff and the efficient use of available family labor. As regard MO, a small increase in purchased feedstuff resulted in slightly decrease in its GM/ewe. Nevertheless, this increase was minor and hence didn't have a critical economic impact. The highest GM per ewe was achieved by DT (50.75 €/ewe), demonstrating also the highest increase (a remarkable 320%), followed by DU (41.61 €/ewe). As in the existing situation (Table 1), CO was the ToF with lowest GM per ewe (15.67 €/ewe). However, in contrast with the existing situation, in S1 all the milk quantity was used for cheese production. In addition, across all ToF, the shadow price of labor [i.e., the additional gross margin that would result if one additional unit of labour (1 h) was used (Ragkos et al., 2020)] was lower than its cost (3.5 €/h), a fact that explains the non-use of hired workers.

When agri-environmental support was included in the model (S2) (Table 3), structural changes were observed primarily for DU and DT (the two largest ToF in the existing situation), through an increase in flock sizes by 39% and 9% respectively, which was accommodated by the use of additional hired labor. Hired labor was adequately valorized in the case of DU (2952 h),

TABLE 1 Basic techno-economic indicators and financial result that reflect the existing situation.

	Farm types				
	DT[a]	DNT[b]	DU[c]	MO[d]	CO[e]
Sample farms	**2**	**6**	**4**	**1**	**3**
Average flock size	**521**	**351**	**679**	**303**	**502**
Ewes	**408**	**259**	**508**	**235**	**357**
Replacement lambs/ewes	**92**	**72**	**140**	**47**	**114**
Rams	**21**	**20**	**31**	**21**	**31**
Total milked quantity (lt)	**47,040.0**	**25,171.7**	**34,250.0**	**0.0**	**17,666.7**
Total milked quantity per ewe (lt/ewe)	**115.3**	**97.2**	**67.4**	**-**	**49.5**
Total quantity of milk sold to industries (lt)	**46,000.0**	**24,916.7**	**33,000.0**	**-**	**3,833.3**
Milk sold to industries (lt/ewe)	**112.9**	**96.1**	**65.0**	**-**	**10.7**
Milk price (€/lt)	**0.96 €**	**0.96 €**	**0.97 €**	**0.00 €**	**0.95 €**
Lamb meat sold (kg/ewe)	**7.2**	**5.9**	**8.4**	**8.0**	**5.6**
Total quantity of lamb meat sold (kg)	**2,923.5**	**1,538.8**	**4,251.0**	**1,887.5**	**2,013.3**
Lamb meat price (€/kg)	**5.40 €**	**5.68 €**	**5.64 €**	**10.00 €**	**6.92 €**
Ewe-ram meat sold (kg/ewe)	**3.6**	**3.0**	**2.2**	**2.3**	**1.8**
Ewe-ram meat (€/kg)	**2.95 €**	**2.85 €**	**2.76 €**	**7.50 €**	**3.55 €**
Quantity of cheese sold (kg/year)	**0.0**	**0.0**	**0.0**	**0.0**	**2,894.7**
Cheese selling price (€/kg)	**0.00 €**	**0.00 €**	**0.00 €**	**0.00 €**	**7.90 €**
Labor (h/year)	**7,389**	**5,869**	**6,726**	**4,265**	**7,572**
Hired (h/ewe/year)	*2,636*	*2,351*	*1,295*	*0*	*5,052*
Family (h/ewe/year)	*4,753*	*3,519*	*5,431*	*4,265*	*2,520*
Cultivated land (ha)	**1.0**	**0.0**	**0.6**	**0.0**	**1.7**
Available pastures (ha)	**125.3**	**142.5**	**1,302.0**	**200.0**	**584.7**
Available Lowland pastures (ha)	*18.8*	*142.5*	*93.3*	*50.0*	*584.7*
Available Highland pastures (ha)	*106.5*		*1,208.8*	*150.0*	
Gross Revenue (€/ewe)	**165.63 €**	**140.40 €**	**123.53 €**	**104.27 €**	**125.78 €**
Milk (€/ewe)	*107.98 €*	*92.68 €*	*62.99 €*	*0.00 €*	*10.21 €*
Lamb (€/ewe)	*38.74 €*	*33.75 €*	*47.24 €*	*80.32 €*	*39.06 €*
Ewe-ram (€/ewe)	*10.49 €*	*8.44 €*	*5.95 €*	*17.23 €*	*6.45 €*
Cheese (€/ewe)	*0.00 €*	*0.00 €*	*0.00 €*	*0.00 €*	*64.12 €*
Self-consumption (€/ewe)	*8.42 €*	*5.53 €*	*7.35 €*	*6.72 €*	*5.94 €*
Expenses (€/ewe)	**180.23 €**	**142.61 €**	**95.70 €**	**62.26 €**	**171.71 €**
Total feeding cost (€/ewe)	*114.21 €*	*59.05 €*	*56. 98 €*	*33.87 €*	*60.60 €*
(of which) Purchased Feedstuff (€/ewe)	112.66 €	59.05 €	56.73 €	33.87 €	59.71 €
Hired labor cost (€/ewe)	*22.62 €*	*31.77 €*	*8.94 €*	*-*	*49.53 €*
Other (€/ewe)	*43.40 €*	*51.80 €*	*29.78 €*	*28.38 €*	*61.58 €*
Gross Margin (€/ewe)[f]	**−14.60 €**	**−2.21 €**	**27.83 €**	**42.01 €**	**−45.93 €**
CAP payments (€/ewe)	**79.78 €**	**80.37 €**	**62.26 €**	**56.70 €**	**91.05 €**

[a]Dairy Transhumant.
[b]Dairy Non- Transhumant.
[c]Dual Purpose.
[d]Meat Oriented.
[e]Cheese Oriented.
[f]Gross Margin (€/ewe) without CAP payments.

TABLE 2 Optimal management plans (Results of the Scenario 1).

	Farm types (average farm)				
	DT[a]	DNT[b]	DU[c]	MO[d]	CO[e]
Average size (number of ewes)	408	259	509	236	351
Total quantity of milk sold to industries (kg)	46,012.1	24,863.2	33,090.9	0.0	0.0
Milk price (€/lt)	0.96 €	0.96 €	0.97 €	0.00 €	0.95 €
Total sales of lamb meat (kg)	2,934.3	1,526.5	4,276.4	1885.1	1964.7
Lamb meat price (€/kg)	5.40 €	5.68 €	5.64 €	10.00 €	6.92 €
Cheese sales (kg/year)	0.0	0.0	0.0	0.0	17,296.7
Cheese price (€/kg)	0.00 €	0.00 €	0.00 €	0.00 €	7.90 €
Purchased Feedstuff (€/ewe)	62.28 €	53.21 €	45.10 €	36.17 €	48.31 €
Total feeding cost (€/ewe)	63.73 €	53.21 €	45.10 €	36.17 €	48.31 €
Hired (h/ewe/year)	0	0	0	0	0
Shadow price of labor (€/h)[f]	2.38	1.29	3.15	1.80	0.73
Gross Margin (€/ewe)[g]	50.75 €	29.31 €	41.61 €	32.70 €	15.67

[a]Dairy Transhumant.
[b]Dairy Non- Transhumant.
[c]Dual Purpose.
[d]Meat Oriented.
[e]Cheese Oriented.
[f]The shadow price of labor corresponds to the additional gross margin that would result from using one additional unit of labor (1 h).
[g]The Gross Margin in this scenario includes only the value of market sales. Thus, the value of self-consumption has not been included.

TABLE 3 The impact of agri-environmental support and premium pricing strategy (Scenario 2 and 3) on the optimal structure of farms (Scenario 1).

	DT[a]			DNT[b]			DU[c]			MO[d]			CO[e]			
	S1	*S2*	*S3*	*S1*	*S2*	*S3*	*S1*	*S2*	*S3*	*S1*	*S2*	*S3*	*S1*	*S2*	*S3a*	*S3b*
Number of ewes	408	446	446	259	259	466	509	705	705	236	236	332	351	351	800	396
Hired labor (hours)	0	697	697	0	0	4,704	0	2,592	2,592	0	0	1750	0	0	9,686	0
Gross Margin (€/ewe)	50.75 €	78.50 €	66.25 €	29.31 €	62.00 €	44.12 €	41.61 €	58.64 €	33.34 €	32.70 €	57.84 €	44.92 €	15.67 €	48.31 €	33.10 €	66.85 €
Primary product price	0.96 €	0.96 €	1.15 €	0.96 €	0.96 €	1.48 €	0.97 €	0.97 €	1.04 €	10.00 €	10.00 €	13.83 €	7.90 €	7.90 €	14.23 €	2.55 €
Agri-environmental support[f]	-	33.89 €	-	-	32.69 €	-	-	29.89 €	-	-	25.14 €	-	-	32.64 €	-	-

[a]Dairy Transhumant.
[b]Dairy Non- Transhumant.
[c]Dual Purpose.
[d]Meat Oriented.
[e]Cheese Oriented.
[f]Differences in the amount of agri-environmental support arise from variations in the ratio of males to females, as well as discrepancies between the number of ewes registered in herdbooks and the actual number of ewes on the day of the interview.

while in DT corresponded to 697 h (13% of the available hired labor). The remaining three types show only marginal or no changes in flock sizes, which can largely be attributed to the low productivity of labor. Indeed, even in this scenario, the shadow price of hired labor in these ToF was still much lower compared to its cost (3.5 €/h).

In contrast with S2, significant structural changes were observed in all ToF in S3 (premium pricing strategy). Particularly, due the increase in the price of the primary products (Table 3), all farms increased their flock size, valorizing hired labor. CO achieved the most substantial increase both in flock size (128%) and in hired labor (9,686 h), highlighting the benefits and prospects of a marketing strategy for high-added value products. As in S1, CO transformed the entire quantity of milk into cheese. Actually, the S3b indicates that only under "extreme" market conditions, where milk price increased by 168% (from 0.95 €/lt to 2.55 €/lt) compared to the existing situation, the sale of milk in dairy industries was the most viable option.

Discussion

The analysis revealed significant differences in the quantity of milk (i.e., milked quantity), fact that justifies the typology outlined in this study. As expected, the total milked quantity was higher in dairy farms (DT and DNT) and lower in CO. CO farmers' decisions to wean their lambs at an older age (73 days compared to the average weaning age of 57 days) constitute the main reason for the lower amount of milk. In contrast to total milked quantity, the analysis indicated that the extended weaning age positively influences lamb meat yields. Indeed, the increased lamb meat yields in MO (8.0 kg/ewe) can be largely attributed to the extended weaning period of lambs (90 days). Apart from product yields, a significant difference was also observed in the price of lamb meat. In particular, while lamb meat price, across all ToF, was around 6 €/kg, in MO it accounted for 10 €/kg. This variation can largely be attributed to the fact that MO was integrated into short supply chains, selling its products directly to consumers or high-end restaurants at a retail price, while the other ToF used to sell their meat to wholesalers (Skordos et al., 2024).

Among the key findings of this study is that the production orientation, along with implemented farming system (i.e., transhumance or non-transhumance), can significantly impact the potential of farms. For example, CO was the ToF with the lowest economic performance and potential in both S1 and S2. This suggests that the engagement of LSB farms in cheese production (i.e., forward vertical integration) is not an efficient strategy under current market conditions. This observation aligns with Ragkos et al. (2019b), who also noted that CO farms were less competitive and viable compared to farms with different production orientations and business models that examined in their study. In fact, in the Ragkos et al. (2019b) study this was due to the higher organizational levels required to undertake this activity, which could disrupt the operation of farms, and economic performance was largely due to the efficient use of inputs and labor. In this study, and particularly in S1, the results of the PP model led to a similar finding reflected in lower GM/ewe for CO farms compared to the rest ToF. In addition, S3a proved that the CO was under-valorized in S1, as premium pricing led to a notable increase in both the number of ewes and the GM/ewe (Table 3). However, ToF with higher potential do not always achieve better economic results. For example, although the S1 indicated that DT along with DU were the two ToF with the highest potential and those who achieved the highest improvement, the existing situation (Table 1) depicted a different picture for DT, as it witnessed significant economic losses.

Therefore, it can be argued that the optimal management of farms is a critical factor towards the fulfilment of their true potential and consequently the maintenance of LB. Indeed, in S1, all ToF achieved a positive GM, which indicates that they are viable and able to face their variable costs in the short run (Ragkos et al., 2015). However, even under optimal management, the shadow price of labor (Table 2) remained lower than the costs of hired labor (€3.50/h). This indicates the vital importance of EU income support for these farms, as not only does it stand for a significant part of their economic performance but rather guarantees their viability. In the other two Scenarios examined in this study, it seems that S3 provides a much more viable prospect for all ToF, as the use of hired labor indicates that the shadow price is higher than the 3,5 €/h threshold. The same is witnessed for only two ToF in S2. Therefore, in the long term, even a support-oriented strategy cannot guarantee the livelihoods of LSB farmers, especially for DNT, CO and MO.

In S1, apart from MO, all types of farms, and particularly DT and DU, enhanced their economic performance, through the implementation of rational feeding patterns (i.e., feeding patterns that cover the nutritional needs of animals at the lowest possible cost) and efficient use of labor. The inefficient use of those two equally important factors constitutes the main reason behind their reduced socioeconomic performance in the existing situation. However, the impact of these changes differs from type to type. Excessive feeding costs seem to occur in DT (accounting for 63% of the total expenses) while the inefficient use of labor seems to be aggravated in CO farms. The higher feeding cost of DT can be largely attributed to the fact that sheep graze fewer hours during winter compared to other ToF. As regards MO, it was the only ToF that, in the existing situation, was based solely on family members as well as the only one for which a small increase in purchased feedstuffs was necessary to cover the dietary needs of sheep, which led to a decrease in its GM. Recently, an eco-scheme was introduced remunerating farmers who develop balanced rations for their flocks also valorizing grazing, thus demonstrating that there is ample room for more efficient use of natural vegetation to increase economic performance.

The above highlight the need for advisory and technical support tailored for the specific characteristics of pastoral production in general but also for each type and system in particular. Within the Strategic Plan of CAP 2023–2027 (MINAGRIC: Hellenic Ministry of Rural Development and Food, 2023), the system for Agricultural Knowledge and Innovation (AKIS) is planned to be reconfigured in Greece, providing substantial roles to agricultural advisors towards the achievement of social, economic and environmental objectives of CAP. As CAP becomes more and more complex, farmers seem not to be able to take advantage of all the financial tools and support provided to them. Therefore, advisory service in the new period has an additional role—to help farmers access financial tools that can support their livelihoods in the short or mid-term. Apart from advisory, training initiatives (formal and informal such as seminars, workshops, etc.) should also be considered to ensure the optimal management of LB farms and the transition to more sustainable and resilient production systems. Today in Greece, there are no formal education curricula related to pastoralism. Hence the establishment and operation of pastoral schools, like the examples of other Mediterranean countries (e.g., the Catalan Shepherd School and the National School of Pastoralism in Italy), is also of high importance. Pastoral schools are expected not only to enhance the competitiveness of such farms, but also to secure the systematic transmission of TEK, which constitutes an integral part of the operation of systems based on LB and of their cultural heritage, to the young generation of farmers.

Another important finding of this study is that agri-environmental support schemes “artificially” led to an increase in farm size. This observation is consistent with previous studies (Gicquel et al., 2020), and with the experience of previous CAP periods. However, in contrast with Galanopoulos et al. (2011), who argued that subsidies primarily favor small, inefficient farms, this study indicates that support schemes related to the conservation of LB seem to favor the larger ones. Indeed, the two largest ToF in the sample, DT and DU, with flock sizes exceeding 400 ewes in the existing situation, were the only ToF that increased their flock size in S2. This structural change was accommodated by recruiting hired workers, underscoring the socioeconomic impact of such schemes. Despite the increase in hired labor, the fact that both ToF increased their gross margin per ewe indicates that both are currently underdeveloped and, so, have significant potential for improvement. Nevertheless, these agri-environmental schemes have faced considerable criticism (Martin-Collado et al., 2014; Varela and Kallas, 2022), as, in many cases they resulted in the isolation of LB farms from markets (Ragkos et al., 2019a), rendering them less resilient and more vulnerable to policy changes.

Furthermore, this study revealed that a strategy facilitating the integration of LB farms into niche markets (S3), where premium prices prevail, also fostered the valorization of LB. This Scenario had a broader impact in terms of structural changes and labor valorization, as all ToF, and not only the larger ones, increased their flock sizes and recruited hired workers. Hence, due to their higher socioeconomic impact, strategies oriented towards markets appear to be more relevant for rural development than income support payments. This finding aligns with Varela and Kallas (2022), who also emphasized that premium niche markets can positively impact the viability of farms and, consequently, the valorization of LB. Additionally, the fact that farms engaged in the production of high-value-added products (CO) benefited more from market-oriented strategies highlights the prospects of products under the approach “one place – one product – one breed.” Nevertheless, Narloch et al. (2011) have pointed out that these strategies may be fragile because they heavily depend on market conditions and forces and thus introduce pastoral systems in the conditions of national (or even globalized) markets and expose small farmers to a highly competitive environment. Particularly, volatile economic conditions and other external factors, such as cultural barriers (Verrier et al., 2005), can affect adversely the consumption of niche products and, consequently, their effectiveness (Narloch et al., 2011). Additionally, there may be cases where premium prices cannot fully offset the abolishment of agri-environmental support, potentially leading to a decrease in the LB population.

Given the above considerations, an important question arises regarding the choice of the best strategy (or mix of strategies) for the preservation and/or valorization of LB. The answer to this question is quite complex as both incentive payments and market-based strategies have their own advantages and disadvantages. Indeed, although support payments appear to be primarily associated with the conservation of the most vulnerable LB that are at high risk of extinction, ensuring a minimum population (Narloch et al., 2011), they seem to isolate farms from markets. On the other hand, premium pricing strategies, even though they proved to be more efficient, are highly vulnerable to volatile market conditions (Narloch et al., 2011). Hence, an increasing number of studies (Narloch et al., 2011; Hoffmann et al., 2014; Varela and Kallas, 2022; Skordos et al., 2024) have proposed the development of an incentive mechanism, where support schemes can be combined with niche premium pricing strategies. This incentive mechanism will remunerate farmers for maintaining LB, and so for the public goods they provide, as well as will enhance farm competitiveness through the integration into value chains and markets. Nevertheless, the results of this study indicate that to realize benefits from this incentive, the optimal management of farms should be ensured.

Another fundamental question is related to the expectations of society towards the role of LB farmers. In particular, If LB farmers are mostly viewed as the ones responsible for the conservation of these breeds (ERFP, 2021) and as long as society values this role, policy measures, which should reflect this societal recognition and appreciation, seem to be more tailored for them. On the other hand, market solutions could be proven more permanent from a valorization point of view assisting farmers to provide society with high quality products and also public goods as a result of their operation (Hoffmann et al., 2014). This option, however, could expose farmers to market competition and threaten their existence in volatile conditions.

Conclusion

The aim of this study was to develop optimal management plans for different types of farms rearing LSB, assessing their true potential and identifying challenges in the short and mid-term. Additionally, the effectiveness of strategies for the preservation and valorization of LB was examined through scenarios focusing on policy measures and market-based initiatives. The main finding of this study is that inefficient use of labor and excessive feeding costs are the two main bottlenecks that reduce the socioeconomic performance of the majority of ToF examined. The implementation of optimal management plans can address both issues, allowing ToF to reach their full potential and maintain local breeds. This finding highlights the lack of actually well-organized and defined advisory support for farmers rearing local breeds, which should meet each farm and system's specific needs and characteristics.

Moreover, while strategies and initiatives from both dimensions (agri-environmental support and a niche marketing strategy) positively impacted the population of LSB, each has some limitations that can render them inefficient under certain external conditions. Indeed, agri-environmental support schemes appears to isolate LB farms from markets (Ragkos et al., 2019a), while the effectiveness of a premium pricing strategy is highly depended on the prevailing market conditions (Narloch et al., 2011). Therefore, the development of an incentive mechanism, where conservation policies can work synergistically with market-based initiatives, appears to be more suitable for the safeguarding of LB in the long term. Nevertheless, the optimal management of farms should be a prerequisite for the design and implementation of any scheme and policy, including the valorization of TEK.

The mathematical programming model in this study could provide even more precise results regarding the optimal organization of the farms rearing LSB depending on the availability of data. Particularly, data on the quality and quantity of the natural vegetation of pastures in Greece are not available and estimates are used in this study based on existing legislation (Common Ministerial Decision, 2014). Integrated Rangeland Management Plans, which are expected to be delivered in Greece in the following period, could provide more accurate and site-specific data (Ragkos and Koutsou, 2021). Additionally, the assumption regarding the ability of farms to double the hours of hired labor in some cases and settings may be optimistic. According to Ragkos et al. (2019b) the livestock sector in Greece faces a shortage of trustworthy and skilled workers, posing significant obstacles to its structural development. This issue is further aggravated by the lack of farm succession (Nori, 2017). Due to a shortage of labor, farmers are compelled to adopt production practices that are less labor-intensive, which, however in many cases, may not be favorable from an agroecological point of view (Aubron et al., 2016).

Hence, future research on incentives and strategies that will contribute to attracting and retaining family and hired labor in the sector may be necessary. Apart from that, investigating the impact of farm size and/or other determinants (such as fixed capital), on the efficiency of farms - using for example, a Data Envelopment Analysis - is also an interesting topic to explore. It would be also useful to examine how various levels of pasture intake can impact the viability of farms, since LSB are well adapted to local conditions and could valorize even more natural vegetation. In future research, it would also be interesting to examine the effects of changes in total sums of CAP income support on LSB farms compared to the effects of the same changes on various other sheep farming systems in Greece. Indeed, given that CAP income payments are paid to all sheep farmers in the country, a change in them would not only affect LSB farms but the sheep sector in general.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors upon request and after the completion of an embargo period (two years from the publication date).

Author contributions

DS and AR contributed to the conception and design of the study. DS organized the database, collected and analyzed the data, as well as wrote the first draft of the manuscript. AR, PK, and GV revised and edited the manuscript. All authors reviewed the results and approved the final version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Alsheikh, S. M., Elnahas, A., Gala, S., Mousa, E., and Elshennawy, M. (2011). Strategy options to improve gross margin in mixed crop-livestock farming system in Sohag governorate, Egypt. *Egypt. J. Animal Prod.* 48 (2), 147–156. doi:10.21608/EJAP.2011.94067

Arsenos, G., Vouraki, S., Ragkos, A., and Theodoridis, A. (2021). Trends and challenges for sustainable development of sheep and goat systems. *Pastor. Sustain. Dev.* 13.

Aubron, C., Noël, L., and Lasseur, J. (2016). Labor as a driver of changes in herd feeding patterns: Evidence from a diachronic approach in mediterranean France and lessons for agroecology. *Ecol. Econ.* 127, 68–79. doi:10.1016/j.ecolecon.2016.02.013

Baciu, L. E., Vereş, V., Mortan, M., and Micu, A. E. (2023). An Empirical Approach for Optimizing the Production Structure of a Farm Using the Linear Programming Model. Annals of the University Dunarea de Jos of Galati: Fascicle: I. *Econ. Appl. Inf.* 29 (3). doi:10.35219/eai15840409366

Cecchini, L., Pezzolla, D., Chiorri, M., Gigliotti, G., and Torquati, B. (2022). Feeding management optimization in livestock farms with anaerobic digestion plant: A discrete stochastic programming (DSP) model. *Environ. Clim. Technol.* 26 (1), 587–605. doi:10.2478/rtuect-2022-0045

Colino-Rabanal, V. J., Rodríguez-Díaz, R., Blanco-Villegas, M. J., Peris, S. J., and Lizana, M. (2018). Human and ecological determinants of the spatial structure of local breed diversity. *Sci. Rep.* 8 (1), 6452. doi:10.1038/s41598-018-24641-3

Common Ministerial Decision (CMD), 2014. *Defining the specifications and content of temporary rangeland management plans*. Athens, Greece: Hellenic Ministry of Rural Development and Food. Available at: https://dasarxeio.com/wp-content/uploads/2015/01/117394_2932.pdf (Accessed July 6, 2023).

Di Trana, A., Sepe, L., Di Gregorio, P., Di Napoli, M. A., Giorgio, D., Caputo, A. R., et al. (2015). "The role of local sheep and goat breeds and their products as a tool for sustainability and safeguard of the Mediterranean environment," in *The sustainability of agro-food and natural resource systems in the Mediterranean basin* (Springer), 77–112.

Duclos, D., and Hiemstra, S. J. (2010). "State of local cattle breeds in Europe," in *Local cattle breeds in Europe*, 40–57.

ERFP (2021). *The animal genetic resources strategy for europe*.

FAO (2007a). in *The state of the world's animal genetic resources for food and agriculture – in brief*. Editors D. Pilling and B. Rischkowsky (Rome: FAO). Available at: https://openknowledge.fao.org/server/api/core/bitstreams/9a48dc48-f572-4c32-866b-810884c40f35/content (Accessed July 10, 2023).

FAO (2007b). *Global plan of action for animal genetic resources and the interlaken declaration. FAO commission on genetic resources for food and agriculture*. Rome, Italy: FAO. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/88062e21-b652-4c9d-bfdd-9090148430e8/content (Accessed July 10, 2023).

FAO (2016). *Status of animal genetic resources. Intergovernmental technical working group on animal genetic resources for food and agriculture. Ninth Session*. Rome: FAO.

FAO (2024). Domestic animal diversity information system (DAD-IS). Available at: https://www.fao.org/dad-is/en/ (Accessed September 19, 2023).

Galanopoulos, K., Abas, Z., Laga, V., Hatziminaoglou, I., and Boyazoglu, J. (2011). The technical efficiency of transhumance sheep and goat farms and the effect of EU subsidies: Do small farms benefit more than large farms? *Small Ruminant Res.* 100 (1), 1–7. doi:10.1016/j.smallrumres.2011.05.008

Gicquel, E., Boettcher, P., Besbes, B., Furre, S., Fernández, J., Danchin-Burge, C., et al. (2020). Impact of conservation measures on demography and genetic variability of livestock breeds. *Animal* 14 (4), 670–680. doi:10.1017/s1751731119002672

Hlavatý, R., Krejčí, I., Houška, M., Moulis, P., Rydval, J., Pitrová, J., et al. (2023). Understanding the decision-making in small-scale beef cattle herd management through a mathematical programming model. *Int. Trans. Operational Res.* 30 (4), 1955–1985. doi:10.1111/itor.13014

Hoffmann, I., From, T., and Boerma, D. (2014). *Ecosystem services provided by livestock species and breeds, with special consideration to the small-scale livestock keepers and pastoralists. Background Study Paper No. 66 Rev. 1. Commission on Genetic Resources for Food and Agriculture*. Rome: Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/3/a-at598e.pdf.

Juvančič, L., Slabe-Erker, R., Ogorevc, M., Drucker, A. G., Erjavec, E., and Bojkovski, D. (2021). Payments for conservation of animal genetic resources in agriculture: one size fits all? *Animals* 11 (3), 846. doi:10.3390/ani11030846

Lambert-Derkimba, A., Lauvie, A., and Verrier, É. (2013). How the development of products valorizing local breeds changes breeding goals: Examples from French cattle breeds. *Anim. Genet. Resources* 53, 135–140. doi:10.1017/s2078633612000768

Legarra, A., Ramon, M., Ugarte, E., and Perez-Guzman, M. D. (2007). Economic weights of fertility, prolificacy, milk yield and longevity in dairy sheep. *Animal* 1, 193–203. doi:10.1017/S1751731107657814

Leroy, G., Baumung, R., Boettcher, P., Besbes, B., From, T., and Hoffmann, I. (2018). Animal genetic resources diversity and ecosystem services. *Glob. Food Secur.* 17, 84–91. doi:10.1016/j.gfs.2018.04.003

Ligda, C., and Casabianca, F. (2013). Adding value to local breeds: Challenges, strategies and key factors. *Anim. Genet. Resources* 53, 107–116. doi:10.1017/s207863361300026x

Martin-Collado, D., Diaz, C., Drucker, A. G., Carabaño, M. J., and Zander, K. K. (2014). Determination of non-market values to inform conservation strategies for the threatened Alistana–Sanabresa cattle breed. *Animal* 8 (8), 1373–1381. doi:10.1017/s1751731114000676

MINAGRIC: Hellenic Ministry of Rural Development and Food (2015). Local sheep breeds. Available at: https://www.minagric.gr/ktinotrofia-examplepg/genetikibeltiosizoon/727-aftoxthones-fyles-agrotikon-zoon (Accessed June 6, 2023).

MINAGRIC: Hellenic Ministry of Rural Development and Food (2023). Strategic plan of Greece 2023-2027. Available at: https://www.minagric.gr/images/stories/docs/agrotis/KAP2023_2027/egkekrimeno_ss_kap_2023_2027.pdf (Accessed September 12, 2023).

MINAGRIC: Hellenic Ministry of Rural Development and Food (2024). Institutional framework of the sub measure 10.1.9. Available at: https://www.minagric.gr/programma-agrotikis-anaptyksis-2014-2020-proskliseis-metron/7157-plaisio-drash10-1-05 (Accessed April 4, 2024).

Narloch, U., Drucker, A. G., and Pascual, U. (2011). Payments for agrobiodiversity conservation services for sustained on-farm utilization of plant and animal genetic resources. *Ecol. Econ.* 70 (11), 1837–1845. doi:10.1016/j.ecolecon.2011.05.018

Nori, M. (2017). Migrant shepherds: Opportunities and challenges for mediterranean pastoralism. *J. Alpine Res.*, 105–114. doi:10.4000/rga.3554

Papachristoforou, C., Koumas, A., and Hadjipavlou, G. (2013). Adding value to local breeds with particular reference to sheep and goats. *Anim. Genet. Resources* 53, 157–162. doi:10.1017/s2078633612000495

Perucho, L., Hadjigeorgiou, I., Lauvie, A., Moulin, C. H., Paoli, J. C., and Ligda, C. (2019). Challenges for local breed management in mediterranean dairy sheep farming: Insights from Central Greece. *Trop. animal health Prod.* 51, 329–338. doi:10.1007/s11250-018-1688-2

Perucho, L., Hadjigeorgiou, I., Lauvie, A., Moulin, C. H., Paoli, J. C., and Ligda, C. (2021). Local breeds and pastoral farming on the North mediterranean shore: A univocal coevolution? An example of dairy sheep farming systems in corsica (France) and thessaly (Greece). *Genet. Resour.* 2 (4), 7–20. doi:10.46265/genresj.wuda2135

Piedrafita, D., Raadsma, H. W., Gonzalez, J., and Meeusen, E. (2010). Increased production through parasite control: Can ancient breeds of sheep teach us new lessons? *Trends Parasitol.* 26, 568–573. doi:10.1016/j.pt.2010.08.002

Ragkos, A., Koutouzidou, G., Koutsou, S., and Roustemis, D. (2019a). "A new development paradigm for local animal breeds and the role of information and communication technologies," in *Innovative approaches and applications for sustainable rural development. HAICTA 2017. Springer earth system sciences*. Editors A. Theodoridis, A. Ragkos, and M. Salampasis (Cham: Springer). doi:10.1007/978-3-030-02312-6_1

Ragkos, A., and Koutsou, S. (2021). "Collective and individual approaches to pastoral land governance in Greek silvopastoral systems: the case of sheep and goat transhumance," in *Governance for mediterranean silvopastoral systems* (London and New York: Routledge), 260–278.

Ragkos, A., Koutsou, S., Karatassiou, M., and Parissi, Z. M. (2020). Scenarios of optimal organization of sheep and goat transhumance. *Reg. Environ. Change* 20, 13–10. doi:10.1007/s10113-020-01598-6

Ragkos, A., Theodoridis, A., and Arsenos, G. (2019b). Alternative approaches of summer milk sales from transhumant sheep and goat farms: a case study from northern Greece. *Sustainability* 11 (20), 5642. doi:10.3390/su11205642

Ragkos, A., Theodoridis, A., Fachouridis, A., and Batzios, C. (2015). Dairy farmers' strategies against the crisis and the economic performance of farms. *Procedia Econ. Finance* 33, 518–527. doi:10.1016/s2212-5671(15)01734-7

Rardin, R. L. (1998). *Optimization in operations research*, 166. Upper Saddle River, NJ: Prentice Hall.

Rodríguez-Ortega, T., Oteros-Rozas, E., Ripoll-Bosch, R., Tichit, M., Martín-López, B., and Bernuès, A. (2014). Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. *Animal* 8 (8), 1361–1372. doi:10.1017/s1751731114000421

Sintori, A., Tsiboukas, K., and Zervas, G. (2013). "Evaluating socio-economic and environmental sustainability of the sheep farming activity in Greece: A whole-farm mathematical programming approach," in *Methods and procedures for building sustainable farming systems: application in the European context* (Springer), 219–235.

Skordos, D., Ragkos, A., Karanikolas, P., and Vlahos, G. (2024). How valuable are the ecosystem services of local animal breeds? The case of Kalaritiko sheep in Greece. *Livest. Sci.* 279, 105391. doi:10.1016/j.livsci.2023.105391

Teston, M., Orsi, M., Bittante, G., Cecchinato, A., Gallo, L., Gatto, P., et al. (2022). Added value of local sheep breeds in alpine *agroecosystems*. *Sustainability* 14 (8), 4698. doi:10.3390/su14084698

Theodoridis, A., Ragkos, A., Vouraki, S., Arsenos, G., Kominakis, A., Coppin, S., et al. (2023). Novel resilient and sustainable farm profiles in small ruminant production systems using mathematical programming model. *Sustainability* 15 (15), 11499. doi:10.3390/su151511499

Theodoridis, A., Ragkos, A., Zaralis, K., Smith, L., and Arsenos, G. (2017). "Towards a pan-european typology of sheep and goat farms: a meta-analysis," in *Innovation for sustainability in sheep and goats, proceedings of the 2nd joint seminar of the subnetworks on nutrition and on production systems of the FAO-CIHEAM network for research and development in sheep and goats* (Spain: Vitoria-Gasteiz), 3–5.

Varela, E., and Kallas, Z. (2022). Extensive Mediterranean agroecosystems and their linked traditional breeds: societal demand for the conservation of the Majorcan black pig. *Land use policy* 112, 105848. doi:10.1016/j.landusepol.2021.105848

Verrier, É., Tixier-Boichard, M., Bernigaud, R., and Naves, M. (2005). Conservation and value of local livestock breeds: Usefulness of niche products and/or adaptation to specific environments. *Anim. Genet. Resour. Inf.* 36, 21–31. doi:10.1017/s1014233900005538

Zander, K. K., Signorello, G., De Salvo, M., Gandini, G., and Drucker, A. G. (2013). Assessing the total economic value of threatened livestock breeds in Italy: implications for conservation policy. *Ecol. Econ.* 93, 219–229. doi:10.1016/j.ecolecon.2013.06.002

Zervas, G., Fegeros, K., and Papadopoulos, G. (1996). Feeding system of sheep in a mountainous area of Greece. *Small Ruminant Res.* 21 (1), 11–17. doi:10.1016/0921-4488(95)00820-9

Zervas, G., Kalaisakis, P., and Feggeros, K. (2004). *Farm animal nutrition*. 2nd ed. Athens: Stamoulis. Published in Greek.