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Article

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Abstract: In this study, a farm-scale mathematical programming model for sheep and goat farms is proposed to simulate economic performance, including new resilience sheep traits that allow animals to counteract the presence of infectious and noninfectious diseases. The model was developed in the Small Ruminants Breeding for Efficiency and Resilience (SMARTER) Horizon 2020 project. The SMARTER model is a comprehensive and adaptable linear programming model that enables the assessment of hypothetical scenarios/challenges related to animal traits that prevent infectious and noninfectious diseases. The optimal performance and the structure of the farm are modeled under the presence of infectious and noninfectious diseases (disease plan) and under conditions where no diseases occur (future plan). A comparison of the model solutions, between presence and absence of diseases, provides suggested adjustments to the farming system and insights into the potential shape of new sustainable farm system profiles for the sheep and goat sector. Technical and economic data from five different sheep farms and one goat farm in Greece and France were used in this empirical application to assess different scenarios in the presence of mastitis, parasitism, and lameness in the flocks. The results showed that the profitability and sustainability of the farms are significantly improved when the resilience of animals reduces the impact of the diseases (the highest increase in gross margin was 23.5%). However, although there is substantial improvement in the economic performance of the farms that rear healthy animals, this does not affect the production and management plan of the farmer and does not alter the farm's structure.

Keywords: sheep and goat sector; farm modeling; linear programming; economic performance; infectious and noninfectious diseases

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1. Introduction

Small ruminant farms operate in a challenging and competitive environment, and efforts to intensify production threaten the multidimensional nature (economic, social, and environmental role) of these farms, which is a key characteristic of their resilience [1–4]. Resilience is a subject of debate when considering genetic trade-offs between traits, such as growth, milk production, prolificacy, or fertility, and resistance or tolerance to diseases [5–7]. Animal diseases reduce productivity, economic performance, and in some cases, the survival of livestock, constituting a significant constraint to the sustainability and profitability of small ruminant production [8,9]. The notion is that the development of new traits that increase resistance or tolerance to infectious and noninfectious diseases improves the sustainability of sheep and goat farms and allows for a more efficient management of such farming systems [8,10,11]. Such novel resilient traits are related to new immunological and phenotypic indicators of resilience/resistance to parasite infections, mastitis, and foot rot.

Previous research on the impact of new resilience traits that counteract the presence of diseases on the economic and environmental sustainability of small ruminant farms indicates that the potential benefits for the performance of the farms under these new traits are significant [12–17]. The findings of the studies show that resistance to diseases will reduce expenses on veterinary services and treatment costs, reduce labor use for checking and treating animals in the flock, and increase productivity and, hence, farm revenues. Resistance to diseases has also been shown to enhance animal welfare and reduce environmental impact through the reduced use of drugs and chemicals, improving in the long term the overall sustainability of the small ruminant sector. However, there is limited literature that explicitly models how the overall performance of a whole livestock farm is affected when animals are more resistant to diseases. An extensive review of studies that investigate the economic impact of diseases in sheep flocks can be found in Whatford et al. [18].

In this study, the objective is to propose a farm-scale mathematical programming model for sheep and goat farms to simulate economic performance by including new resilience sheep traits that allow animals to counteract the presence of infectious and noninfectious diseases. The model provides scenarios demonstrating how changes in a farm indicator (which are directly affected by genetics at the animal level) could affect other components of the farm or the overall system (e.g., gross margin, labor, land use, grazing, and profit) in terms of sustainability under optimal organization. The idea is to develop a comprehensive and flexible farm-scale model, applicable to various production systems, environments, and breeds, that can be used by policymakers to identify problems and propose innovative strategies to redesign small ruminant farming systems [19,20]. This adaptable linear programming (LP) model allows for the simulation of farm operations under different environmental, economic, and managerial challenges [21,22]. In this case study, the LP model is used to estimate the performance and resilience trajectories of farms under infectious and noninfectious diseases, and to describe the adjustments that will occur in the farm and the relative production system and, therefore, implicitly reveal the benefits of the new efficiency and resilience traits.

The model is applied using primary technical and economic data from typical sheep and goat farms in Greece and France that rear different breeds and operate under diverse production systems. In total, six different breeds, five sheep breeds (Chios, Assaf, Lacaune, Frizarta, Boutsiko) and one goat breed (Skopelos), were simulated using the LP model, and the impact of mastitis, gastrointestinal nematode (GIN) parasites, and lameness on farm structure (number of ewes reared, land used for the production of feed, grazing land, labor used, ratio composition, etc.) and profitability was assessed. Two alternative scenarios were examined; in the first scenario, the farm's performance is modeled under the presence of mastitis, GIN parasites, and lameness (disease plan), while in the second scenario, the model simulates the farm's performance under perfect conditions where no diseases occur (future plan). The solution indicates suggested adjustments to the farming system and provides insights into the potential shape of new sustainable farm system profiles for the sheep and goat sector.

2. Materials and Methods

2.1. Methodological Approach

Linear programming is a mathematical procedure for optimum resource allocation. Linear programming maximizes or minimizes a linear function of variables (objective function) that are subject to linear inequalities (constraints) and must assume non-negative levels [21–24]. The algebraic expression of an LP problem is

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

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

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

where

Z: the objective function, which is maximized in the optimization problem, denotes the gross margin (GM) (revenues less variable cost) achieved by a typical farm.

x_j: the M activities of the farm (milk production, lamb and ewe meat production, on-farm cheese production, crop cultivation for feedstuff, grazing, purchasing feed, etc.).

c_j: the contribution of each activity x_j to the objective function (GM).

a_{ij}: the requirements per unit of x_j, where its available resource is A_i.

The solution produces an optimum combination of activities for output maximization. It is worth noting that this model can also be converted to a parametric programming model, in which the available resources (A_i) of a certain input or the gross margin (c_j) vary within an acceptable price range, yielding a set of alternative optimal plans.

The method has been applied in the livestock sector for numerous research purposes. Sintori et al. [19] used a mathematical programming model to simultaneously assess the socioeconomic and environmental performance of sheep farms in Greece. In the dairy cow sector, Helmings [20] used a mathematical programming model to assess the impact of common agricultural policy, while Ragkos et al. [25] applied an LP model to assess the financial viability of operating an automated management system for mussel farms. Ragkos et al. [26] also applied a parametric mathematical model to assess different feeding strategies in the dairy cattle sector in Greece. In the sheep sector, recent applications of the method include the work of Almeida et al. [27], who studied the optimal structure of sheep production relative to the use of pastures, and of Wall et al. [28], who used a linear programming model to assess the effects of innovations in reproduction management in sheep flocks. Olaizola et al. [29] used a mixed programming approach to assess the adaptation strategies for sheep–crop mixed systems in Spain. In Greece, relevant examples include a study by Sintori et al. [30].

The model in this study was developed within the Small Ruminants Breeding for Efficiency and Resilience (SMARTER) Horizon 2020 project (https://www.smarterproject.eu/ accessed on 8 June 2023). This SMARTER LP model simulates the main interactions between the animal, management, prices, yields, and local conditions at the farm level and can assess the overall sustainability of farm types (production systems) under various scenarios. The basic idea behind the SMARTER LP model is to simulate the actual operation of a farm through the maximization of its economic performance. As the model integrates all aspects of the operation of a sheep and goat farm, it allows us to predict the impact of changes in one component on the others. With this design, the SMARTER LP model allows the examination of scenarios that accommodate the presence or absence of infectious and noninfectious diseases in a flock.

The generic LP model matrix is presented in Table 1, while the whole executable code (linear programming matrix in sparse "long" format) of the SMARTER model for the exemplary case of Chios sheep breed is presented in Spreadsheet S1. The optimization part of the model, which is explained below, involves the optimization of economic performance, which is defined as the gross margin achieved by the farm, subject to a set of economic and physical constraints. The solution includes the number of sheep carried under the maximum economic performance of the farm. The gross margin in the objective function is expressed analytically, and all its components are expressed separately. These are

Table 1. Linear programming matrix.

Objective Function (Max)		Production			Breeding	Purchased Feed			Home-Grown Feed			Labor
		MilkPrice	**MeatPrice**	**CheesePrice**	**VCsheep**	**VCpur1**	...	**VCpurN**	**VCcul1**	...	**VCculN**	**HLAB**
AL	Y≥								UL1	...	ULN	
AFL	Y≥			RFL1	RFL2				RFL3	...	RFLN	
	0≥			RHL1	RHL2				RHL3			−1
AHL	Y≥											1
AVC	Y≥				VCBreed	1	...	1	1	...	1	
	0≥				NutrReq	-NCpur1	...	-NCpurN	-NCcul1	...	-NCculN	
	0≥	Prod_Milk	Prod_Meat	Prod_Cheese								

Available land (AL) and used irrigated and nonirrigated land for the production of feed on farm (UL) and grazing. Available family labor (AFL) and required family labor (RFL) for animal breeding and production of milk and meat, cheese, on-farm production of feed, and animal grazing. Available hired labor (AHL) and required hired labor (RHL) for animal breeding and the production of milk and meat, cheese, on-farm production of feed, and animal grazing. Available variable capital to the farm for breeding animals, purchasing feed, and producing feed on farm. Nutritional requirements of the animals (NutrReq) and nutritional content of feed (NCpur and NCcul) and of grazing material.

- Revenues: Milk (yield × price), meat (yield × price); cheese (sales × price). Each type of product can include multiple sources, e.g., lamb meat and/or culled animal meat. All products do not apply to all breeds or production systems; e.g., in some systems, it is not typical for the farmers to produce cheese on farm, but to deliver their total production of milk to dairies. Prolificacy, weaning rate, mortality rate, and replacement rate are production traits that have been used in the calculation of the product yields per productive animal (ewe or goat). Yields of milk, meat, and cheese prices are expressed on an annual basis.
- Prices: For each product, prices are included separately in the model (in a separate column) and are linked to the constraint expressing product yields.
- Variable costs: The unit costs of all forms of variable capital are included (e.g., prices of purchased feedstuff, variable production costs of home-grown feed, which includes expenses for seeds, fertilizers, irrigation, pesticides, etc.). Veterinary expenses and drugs per productive animal are also included, as well as other variable expenses (water, electricity, detergents, additives, etc.).

Constraints are directly linked to the main factors of production and refer to

- Land

The model accommodates different types of land typically available to European sheep and goat farms. Therefore, the model accounts for the availability of cropland (crop production mainly for feed) and of grasslands. The average yields of each crop are included in the model. For grazing, the available land is linked to activities (objective function) by including the grazing capacities (annual production of grazing material) in the model.

The model design allows for flexibility when connecting land uses to the dietary needs of animals. In fact, farmers have three options: to let animals graze (natural or cultivated grazing land), to produce feedstuff on farm, or to buy feedstuff from markets. The importance of these three sources may vary, and this is reflected in the constraints of the model.

- Labor

Labor requirements are expressed in h/animal/year required to perform all tasks related to farm management (including grazing). In other words, the generic specification of the model requires only inputting the total labor requirements. The right-hand side (RHS) of the model, which expresses input availability, requires that the available labor is included. Here, the available family labor is included (hours/year) without additional costs (i.e., the implicit costs of family labor are not included). Farms have the option to resort to hired labor but, at a cost and in some specific systems, can hire up to three persons.

- Variable capital requirements

These include purchased feedstuff (forage silage, clover, straw) and concentrates (maize, barley, wheat, flakes, cotton cake, soya), veterinary expenses (services, drugs, and other treatments), crop production expenses for feedstuff (clover, maize, wheat, barley), etc. They are all included as separate constraints. An additional constraint sums up the individual elements of variable cost and expresses the overall capital requirements of the farm. The SMARTER model allows the RHS in this constraint to vary, corresponding to different levels of capital availability, examining scenarios of intensification of the production system.

- Animal and flock-related constraints

The model includes separate constraints for the energy and protein requirements of animals (metabolizable energy (ME, MJ/animal/year), effective rumen degradable protein (ERDP/animal/year), and digestive undegradable protein (DUP/animal/year)). In addition, separate constraints account for the nutritional content of feedstuff consumed in farms and for grazing material (ME, ERDP, DUP), based on the profile of a typical Mediterranean grassland of average quality. Additional constraints involve the minimum and maximum percentages of certain feeds.

The solution of the model indicates the appropriate structure of the farm and highlights the adjustments that are required at the farm and/or production system level to fully exploit its potential. However, to model performance under new traits that make animals more tolerant to infectious and noninfectious diseases, extra variables were added. Moreover, relative constraints were introduced to the model to account for (i) the prevalence of the disease in the flock for a typical farm, (ii) the impact of the disease on milk yield, (iii) the increase in veterinary expenses and drug cost for the treatment of the sick animals, (iv) the impact on labor requirements (extra labor time) for checking and treating the animals, and (v) the impact of the disease on lamb/kid and ewe/goat carcass weight. In the SMARTER model, the infected animals were modeled separately (variables "Sheep2", "Sheep3", and "Sheep4" in the LP code express the different diseases and are integrated in the model using separate columns).

Two scenarios are investigated with the SMARTER model. First, the model simulates farm performance under the presence of mastitis, GIN parasites, and lameness (Scenario 1: disease plan). In the second scenario (Scenario 2: future plan), the solution demonstrates the optimal organization of the farm under perfect conditions where no diseases occur. The results produced under these two scenarios are then compared, and the economic and structural adjustments are discussed, highlighting the impact of new traits that make animals tolerant to diseases on farm sustainability. LINDO 6.1 software provided by AUTH was used for optimization modeling.

2.2. Data

The technical and economic data for the empirical application model for 6 typical farms of different breeds (5 sheep breeds and 1 goat breed) were collected through a farm management survey during the 2018–2020 period. All farms were in Greece except for the Lacaune sheep farm that was located in France. The data for Frizarta sheep were provided by the FRIZARTA breeding organization, while the data for Lacaune sheep were provided by the Institute De L'elevage (IDELE) in cooperation with the French livestock farm network "INOSYS Réseaux d'élevage" in France. The selected breeds included in the analysis cover most of the prevailing production systems in Europe, ranging from extensive and semiextensive to intensive patterns.

Information for the prevalence of mastitis, GIN parasitism, and lameness and their impact on the farm indicators was based on relevant literature (Table 2). In cases where information was lacking, inputs were based on experts' judgement; animal husbandry experts and veterinarians who are familiar with the specific breeds and the systems in which these breeds are reared provided us with the required data. It must be mentioned that for the Lacaune sheep breed, IDELE experts did not provide us with data for lameness. Moreover, in cases where information was not available for a specific breed, data from another breed were used. It has to be mentioned that the use of different levels of prevalence and/or impact on farm indicators will produce different results.

Table 2. Impact of diseases on farm indicators.

Impact on Farm Indicators	Type of Disease	Chios Sheep	Assaf Sheep	Boutsiko Sheep	Frizarta Sheep	Lacaune Sheep	Skopelos Goats
Prevalence in flock (%)	Mastitis	15% [1]	10% [12]	27% [12]	20% [20]	22% [23]	24% [4]
	GIN	35% [4]	43% [14]	47% [17]	35% [5]	10% [23]	12% [26]
	Lameness	7% [8]	9% [7]	9% [10]	9% [22]	-	9% [7]
Reduction in milk yield (%)	Mastitis	38% [2]	37% [13]	43% [16]	21% [21]	10% [23]	15% [24]
	GIN	22% [5]	11% [15]	8.5% [18]	22% [4]	10% [23]	5% [27]
	Lameness	19.3% [9]	19.3% [9]	19.3% [9]	19.3% [9]	-	19% [28]
Increase in vet/drug cost for treatment (in EUR/ewe/goat)	Mastitis	EUR 4 [3]	EUR 4 [3]	EUR 4 [3]	4 [3]	EUR 3 [23]	EUR 1.6 [25]
	GIN	EUR 3 [6]	EUR 3 [6]	EUR 3 [6]	EUR 3 [6]	EUR 5 [23]	EUR 4.5 [29]
	Lameness	EUR 4.26 [10]	EUR 4.26 [10]	EUR 4.26 [10]	EUR 4.26 [10]	-	EUR 4.26 [10]
Extra time spent for treating disease (in h per ewe/goat)	Mastitis	1 h [3]	1 h [3]	1 h [3]	1 h [8]	0.25 h [23]	1 h [3]
	Lameness	1.8 h [11]	1.8 h [11]	1.8 h [11]	1.8 h [11]	-	1.8 h [11]
Reduction in ewe/goat carcass due to disease (%)	GIN	15% [7]	2% [5]	5% [19]	-	-	-
	Lameness	8% [11]	8% [11]	8% [11]	8% [11]	-	8% [11]

[1] Bramis [31]; [2] Saratsis et al. [32]; [3] Theodoridis et al. [10]; [4] expert judgement; [5] Mavrot et al. [7]; [6] Charlier et al. [33]; [7] Termatzidou et al. [34]; [8] Gelasakis [35]; [9] Gelasakis et al. [36]; [10] Winter and Green [37]; [11] Nieuwhof et al. [38]; [12] Vasileiou et al. [39]; [13] Leitner et al. [40]; [14] Martinez-Valladares et al. [41]; [15] Cruz-Rozo et al. [42]; [16] Martí-De Olives [43]; [17] Kouam et al. [44]; [18] Suarez et al. [45]; [19] Arsenos et al. [46]; [20] Skoufos et al. [47], [21] Albenzio et al. [48]; [22] Moschovas et al. [49]; [23] IDELE and INRAE expert judgement, [24] Gelasakis et al. [50], [25] Batzios [51], [26] Vouraki et al. [52]; [27] Papanikolopoulou et al. [53]; [28] Deeming et al. [54]; [29] SOLID project results (https://www.solidairy.eu/ accessed on 8 June 2023).

Data in Table 2 show that the prevalence of clinical and subclinical mastitis on these breed varies from 10% in Assaf sheep breed, which is reared intensively, and animals are fed exclusively on purchased concentrates and forage with very limited access to pasture, to 27% in Boutsiko sheep, which are reared under an extensive system, mostly grazing on natural grasslands. The prevalence of GIN parasites varies from 10% in Lacaune sheep in France to 47% in Boutsiko sheep, while the prevalence of lameness has been set to 7% for the Chios sheep and 9% for the rest of the breeds.

Milk yield reduction due to mastitis varied from 10% in Lacaune sheep to 43% in Boutsiko sheep. The impact of GIN parasites on milk yield is smaller; the reduction varies from 5% in Skopelos goats to 22% in Chios and Frizarta sheep. There is no information available regarding the impact of lameness on milk production, except from a study by Gelasakis et al. [36], who reported a reduction of 19.3% in sheep milk yield, and a study by Deeming et al. [54], who reported a reduction of 19% in goat milk yield. In the absence of data for specific breeds, the finding of Gelasakis et al. [36] was generalized for all sheep breeds under the present study.

The increase in veterinary services and drug cost for the treatment of mastitis is EUR 1.6 per goat annually [51] and EUR 3 to EUR 4 per ewe annually ([10], IDELE experts), while the cost for the treatment of parasites varies from EUR 3 to EUR 5 ([33], IDELE experts, SOLID project results). The increase in cost for treating animals with lameness is estimated to be EUR 4.26 per productive animal annually [37]. The extra time spent in checking and treating animals is estimated to be 1 h per animal annually for mastitis [10] (IDELE reported 0.25 h per Lacaune ewe) and 1.8 h per animal for lameness [38]. There was no information available for GIN parasites.

The reduction in the carcass weight of a ewe with GIN parasites compared with a healthy animal was 2% for Assaf sheep [42], 5% for Boutsiko sheep [46], and 15% for Chios sheep. There were no available data for the rest of the breeds. According to Nieuwhof et al. [38], the reduction in ewe meat production due to lameness was 8%, and this percentage was assumed for all breeds.

3. Results and Discussion

Tables 3 and 4 describe the current situation of studied farms and the results of the application of the LP SMARTER model under the two scenarios. The current situation describes the technical and economic characteristics of the farms under the existing organization of the farm. Table 3 presents the results of the semi-intensive and intensive farms (Chios, Assaf, and Frizarta farms), and Table 4 the results of the semiextensive and extensive farms (Boutsiko, Lacaune, and Skopelos farms). In Scenario 1, where all diseases are present in the Chios sheep flock (disease plan), the optimal structure of the farm rears 387 ewes and utilizes 1.3 ha of land to produce maize and for grazing. The optimal farm increases its flock size by 66% compared with the current situation to utilize economies of scale, since Chios sheep farms operate under semi-intensive systems with modern infrastructure and high investments on fixed capital. The results show that the available land for producing feed on farm is reduced substantially (from 17 to 1.3 ha) and relies mainly on purchased feed (the analytical results of the simulations are presented in Spreadsheet S2). The dependence on home-grown concentrates is reduced from 81.6% to 45%, while under the optimal structure, the farm only purchases forage, which includes silage and clover. The results also indicate that three workers are employed full-time to assist a family of two members fully committed to farmwork (the availability of human labor varies depending on the production system and the typical farm). The main product of the farm is milk; most of it is sold to the dairy industry, and the rest is used for cheese production on farm and is sold directly to consumers (analytical results in Spreadsheet S2). Moreover, in the optimal plan under Scenario 1, the gross revenues of the farm are EUR 358/ewe. Variable costs, such as expenses for purchased feeds, seeds and agrochemicals, veterinary expenses, and fuel, are EUR 75/ewe, while the gross margin is EUR 283/ewe. The future plan with no diseases showed remarkable similarity to the optimal plan of the current situation in terms of farm structure. However, the farm differs substantially in terms of financial output. More specifically, although the farm has the same number of animals and the same human labor with only marginal changes in ration formulations, the gross margin per ewe is increased by 15.9%, indicating a significant improvement in the economic performance of the farm.

Table 3. Results of the LP model under two different scenarios for semi-intensive and intensive farms.

Chios Sheep (GR)	**Current Situation**	**Optimal Situation**	
		Scenario 1 Diseases Present	**Scenario 2 No Diseases**
Ewes	233	387	387
Land [1] (ha)	17	1.3	1.3
Labor (h)	6425	6300	6300
Forage (tonnes) [2]	82 (36.6%)	123.7 (0.0%)	123.6 (0.0%)
Concentrates (tonnes) [2]	47.2 (81.6%)	30.9 (45.0%)	30.9 (45.0%)
Gross revenue (EUR) [3]	79,919 (343)	138,592 (358)	155,300 (401)
Variable cost (EUR) [3]	29,125 (125)	29,063 (75)	28,287 (73)
Gross margin (EUR) [3]	50,794 (218)	109,530 (283)	127,013 (328)
AssafE sheep (GR)	Current situation	Optimal situation	
		Diseases present	No diseases
Ewes	490	835	857
Land [1] (ha)	15	15	15
Labor (h)	4,820	8,400	8,400
Forage (tonnes) [2]	275.0 (0%)	652.9 (0%)	670.0 (0%)
Concentrates (tonnes) [2]	72.3 (37.4%)	163.2 (20.2%)	167.6 (19.7%)
Gross revenue (EUR) [3]	128,250 (262)	228,560 (274)	254,743 (297)
Variable cost (EUR) [3]	74,185 (151)	103,008 (123)	104,081 (121)
Gross margin (EUR) [3]	54,065 (111)	125,553 (151)	150,662 (176)
Frizarta sheep (GR)	Current situation	Optimal situation	
		Diseases present	No diseases
Ewes	240	263	270
Land [1] (ha)	35	26	26
Labor (h)	4200	4200	4200
Forage (tonnes) [2]	48.0 (100%)	36.0 (68.4%)	38.8 (62.8%)
Concentrates (tonnes) [2]	31.1 (3.5%)	28.4 (79.6%)	28.8 (79.6%)
Gross revenue (EUR) [3]	60,936 (254)	69,381 (264)	79,817 (296)
Variable cost (EUR) [3]	25,012 (104)	21,487 (82)	21,740 (81)
Gross margin (EUR) [3]	35,924 (150)	47,894 (182)	58,076 (215)

[1] includes irrigated and nonirrigated land for on-farm production of feed and grazing land; [2] the figure in parentheses indicates the percentage of home-grown feed in total feed; [3] the figure in parentheses refers to EUR/ewe.

Assaf sheep farms in Greece operate under intensive systems that depend mostly on concentrates and forage produced on farm, in which animals have very limited access to pasture. Farms usually cultivate relatively large areas and are large in flock size, with modern infrastructure and high levels of investment. They often use technologically advanced production practices. These farms are market oriented and pursue (and achieve) high yields and high productivity. They are less resilient to volatile international market conditions and abrupt or unforeseen changes in the market. The optimal structure under Scenario 1 indicates that a typical Assaf farm rears 835 ewes, showing a large increase compared with the current situation. This outcome can be attributed to the fact that access to more human labor is allowed in the model. The available nonirrigated land is used for producing concentrates (wheat) and does not present any differentiation compared with the current situation (analytical results in Spreadsheet S2). However, under Scenario 1, the dependence of the farm on home-grown concentrates is reduced from 37.4% to 20.2%, disconnecting sheep breeding from the use of land. The farm under Scenario 1 produces 33 tons of wheat and relies mainly on off-farm feed (cotton cake, silage, and barley). The whole of milk production is delivered to dairies, and meat production accounts for 25.2% of the revenues. The revenues per ewe under the optimal structure in Scenario 1 show a 4.58% increase compared with the current situation. Combined with the significant reduction in variable cost (18.5%), this results in a 35% increase in gross margin. The structure of the optimal farm and the management plan under Scenario 2 does not change compared with that in Scenario 1; however, the financial results are significantly improved. When diseases are not present in the flock, the revenues are increased by 8.4% (from EUR 274/ewe to EUR 297/ewe). Variable cost does not change markedly (EUR 123/ewe and EUR 121/ewe, in Scenarios 1 and 2, respectively), and gross margin is increased by 17.3% (from EUR 150/ewe to EUR 176/ewe).

Frizarta sheep farms in Greece are usually reared under semi-intensive, dual-purpose systems. Milk production constitutes the most economically important source of income; however, meat also contributes significantly. They use relatively new technology but with low levels of innovation. Grazing is common on these farms, covering a large part of animal nutritional needs. Meat production is mostly suckling lambs and on-farm production of forage, and some concentrates (mainly winter cereal) are not uncommon. Frizarta farms range from medium sized to very large. The results in Table 3 show that the optimal farm under Scenario 1 rears 263 ewes (23 ewes more than in the current situation) and uses 26 ha of land for grazing and the production of feed (9 ha less than in the current situation). The analytical results of the LP model (Spreadsheet S2) show that in the optimal plan, the land is used mainly for grazing (21 ha compared with 14 ha in the current situation). Moreover, the farm cultivates 1 ha for wheat and 4 ha for maize and clover. The dependence on home-grown forage decreased to 68.4% in Scenario 1, while the dependence on concentrates increased from 3.5% to 79.6%. The farm uses two people for breeding animals and cultivating crops for feed. The gross revenues increased by 4%, and the variable cost was decreased by 21.1%, leading to an increase in gross margin by 21.3% (from EUR 150/ewe to EUR 182/ewe). Under Scenario 2 (future plan with healthy flock), the farm rears 270 ewes, uses the same land as in Scenario 1, and accommodates the same labor. The ration formation does not change compared with Scenario 1, and this is reflected also in variable cost, which remains almost the same. Milk is delivered to dairies, and meat production (lamb and ewe meat) contributes 22% to gross revenues. Financial results improve when the animals in the flock are tolerant to diseases. Gross revenues and gross margin increase by 12.1% (from EUR 264/ewe to EUR 296/ewe) and 18.1% (from EUR 182/ewe to EUR 215/ewe), respectively.

Regarding the profile of new farms where animals are healthy, the optimal plan of the most intensive production systems, i.e., Chios, Assaf, and Frizarta, coincides with that described by Theodoridis et al. [55], Pulina et al. [1], Vouraki et al. [56], and Schuh et al. [57], who, based on the results of technical–economic analysis and efficiency analysis of farms, reported that farms that base their operation on fixed capital investments, highly productive animals, purchased feed, and hired skilled labor should utilize economies of scale by reducing the fixed cost per unit of product. These farms should be large, organize labor more rationally, implement labor-saving technologies, and reduce their dependency on home-gown feed, a strategy described by Ragkos et al. [26]. Moreover, these dairy farms should utilize meat production to increase their economic resilience and reduce their risk in a market where margins to lower production costs have been narrowed down [58]. In general, the shift of the sheep and goat sector towards intensification [4] indicates the need for optimal livestock management to ensure the survival and the resilience of the sector [2,59,60].

Table 4. Results of the LP model under two different scenarios for semiextensive and extensive farms.

Chios Sheep (GR)	**Current Situation**	**Optimal Situation**	
		Scenario 1 Diseases Present	**Scenario 2 No Diseases**
Ewes	108	86	87
Land [1] (ha)	16	48	48
Labor (h)	5250	3150	3150
Forage (tonnes) [2]	1.3 (0%)	-	-
Concentrates (tonnes) [2]	9.7 (0%)	7.6 (0%)	7.7 (0%)
Gross revenue (EUR) [3]	12,806 (118)	9077 (106)	10,320 (119)
Variable cost (EUR) [3]	9093 (84)	3238 (38)	3026 (35)
Gross margin (EUR) [3]	3713 (34)	5839 (68)	7239 (84)
AssafE sheep (GR)	Current situation	Optimal situation	
		Diseases present	No diseases
Ewes	400	468	468
Land [1] (ha)	70	46	46
Labor (h)	3500	3500	3500
Forage (tonnes) [2]	102.0 (100%)	101.0 (100%)	101.0 (100%)
Concentrates (tonnes) [2]	80.0 (100%)	73.0 (88%)	73.0 (88%)
Gross revenue (EUR) [3]	137,986 (345)	170,766 (365)	175,179 (374)
Variable cost (EUR) [3]	42,000 (105)	37,863 (81)	37,320 (80)
Gross margin (EUR) [3]	95,986 (240)	132,903 (284)	137,860 (295)
Frizarta sheep (GR)	Current situation	Optimal situation	
		Diseases present	No diseases
Ewes	300	399	399
Land [1] (ha)	15	28	28
Labor (h)	8825	8566	8429
Forage (tonnes) [2]	15 (0%)	-	-
Concentrates (tonnes) [2]	45 (0%)	47.1 (45%)	47.1 (45%)
Gross revenue (EUR) [3]	29,736 (99)	45,392 (114)	47,663 (119)
Variable cost (EUR) [3]	15,520 (52)	17,030 (43)	16,279 (41)
Gross margin (EUR) [3]	14,216 (47)	28,362 (71)	31,384 (79)

[1] includes irrigated and nonirrigated land for on-farm production of feed and grazing land; [2] the figure in parentheses indicates the percentage of home-grown feed in total feed; [3] the figure in parentheses refers to EUR/ewe or goat.

The results from the implementation of the LP model on the semiextensive and extensive farms (Boutsiko, Lacaune, and Skopelos farms) are presented in Table 4. Boutsiko sheep farms in Greece are, in most cases, relatively small, low-milk-yield dairy farms selling their milk to local cheesemakers. Boutsiko farms operate under extensive and/or semiextensive systems, and it is very common that these farms are transhumant, spending their summers in the highlands and winters in the lowlands, moving up to 300–400 km between the two, providing, therefore, ecosystem services in the uplands and the lowlands. These farms sometimes specialize in meat production of high quality, however, not under a formal certification scheme. These transhumant farms achieve acceptable incomes that ensure a fair standard of living and contribute to the viability and culture of their respective communities. The structure under Scenario 1 shows that, in the optimal plan, the farm rears 86 ewes, 22 ewes fewer than in the existing current situation. However, the optimal plan involves a substantial increase in the use of land for grazing (from 16 to 48 ha). Supplementary feeding is used mainly during the winter, and all concentrates are purchased off farm. The optimal plan also indicates a more rational utilization of human labor (from 48.6 h per ewe in the current situation to 36 h in Scenarios 1 and 2). The results show that under the appropriate structure in Scenario 1, revenues are decreased by 10.2% compared with the existing situation (from EUR 118/ewe to EUR 106/ewe); however, the decrease in variable cost, mainly due to the optimal feeding strategy, by 54.8% (from EUR 84/ewe to EUR 38/ewe) results in an improved gross margin (from EUR 34/ewe to EUR 86/ewe). Under Scenario 2, the structural characteristics of the optimal farm plan do not change; however, breeding animals resistant to diseases lead to improved financial results. Compared with the optimal plan in Scenario 1, revenues are increased by 12.3% (from EUR 106/ewe to EUR 119/ewe), and the gross margin is increased by 23.5% (from EUR 68/ewe to EUR 84/ewe), although the change in variable cost is trivial in Scenario 2.

The Lacaune sheep farm selected for the LP model simulation operates under the semiextensive farming system and is located in Roquefort areas in France. These farms meet the animals' nutritional needs mostly through grazing and supplementation with forage and concentrates produced on farm. Data were collected by IDELE in cooperation with the French livestock farm network "INOSYS Réseaux d'élevage". The results of the LP show that the optimal farm in Scenario 1 rears 468 ewes (68 more than in the existing current situation) and uses 46 ha (24 ha less than in the existing current situation). The land is used for grazing (26 ha) and the production of feed on farm (12 ha of nonirrigated land and 8 ha of irrigated land) (Supplementary Spreadsheet S2). The dependence on home-grown feed is very high in both production plans. The labor used does not change among the production plans (existing and optimal plan under Scenario 1); however, it is allocated more efficiently in the optimal plan. In the optimal production plan, revenues are increased by 5.8% (from EUR 345/ewe to EUR 365/ewe) compared with the current situation, variable cost is reduced by 22.8% (from EUR 105/ewe to EUR 81/ewe), and gross margin, which indicates the sustainability of the farm in the short run, is increased by 18.3% (from EUR 240/ewe to EUR 284/ewe). Under Scenario 2, the results show that the structural characteristics of the optimal farm are the same as those in Scenario 1. The financial results are also similar for the two optimal plans, since disease prevalence and its impact is relatively small. Moreover, the LP model implemented on Lacaune sheep did not simulate the impact of lameness due to lack of data. The farm that rears resilient animals achieves higher revenues by 2.5%, the variable cost is the same, and the gross margin is increased by 3.9%.

The Skopelos goat farms selected for simulation in this application are reared under extensive and semiextensive systems, situated predominantly in less favorable areas (LFAs). They typically achieve low milk yields and manufacture cheese on farm. Skopelos farms are characterized by low investment in facilities and machinery and the use of family labor. Animals mainly graze, but supplementary concentrates are also provided. In Scenario 1, where all diseases are present in the Skopelos flock, the optimal structure of the farm rears 399 goats (33% more than in the existing current situation) and utilizes 28 ha of land for grazing and for producing maize. In the existing current situation, the farm relies only on purchased concentrates, but the optimal plan under Scenario 1 recommends 45% dependence on home-grown feed. Meat production and on-farm cheese production account for 22% and 34% of the revenues in the optimal plan, respectively. Revenues in the optimal structure of the farm under Scenario 1 are increased by 15.2% (from EUR 9/goat to EUR 114/goat); variable cost is reduced by 17.3%, leading to a 51% increase in the gross margin (from EUR 47/goat to EUR 71/goat). In Scenario 2, where no diseases are present in the flock, the structure of the optimal farm does not change; however, the farm achieves higher economic results. Revenues are increased by 4.4% (from EUR 114/goat to EUR 119/goat), variable cost is reduced by 4.6% (from EUR 43/goat to EUR 41/goat), and the farm achieves a higher gross margin of 11.3% (from EUR 71/goat to EUR 79/goat).

The profile that is shaped under the optimal plans for the extensive and semiextensive systems of Boutsiko sheep and Skopelos goat farms is aligned with that described in Galanopoulos et al. [61], Atzori et al. [62]. Their findings confirm ours, which show that these labor-intensive farms should manage labor more wisely, reduce their feeding cost through proper use of rangelands, and increase their dependency on home-grown feed to mitigate mainly the risk that stems from the market for concentrates. In general, these low-input, grazing-based farms must utilize local breeds through the implementation of integrated breeding programs, develop transparent and sustainable value chains for the promotion of territorial and certified products, and adopt innovative solutions to modernize their operation. The evolution of Lacaune sheep and the production of Roquefort cheese in France constitute a successful example of how a semiextensive dairy sheep farming system should be designed. Lacaune sheep evolved through genetic improvement programs from a dual-purpose, low-yield to a high-performing breed that produces a popular, high-added-value PDO cheese [63,64]. The adjustments required by the Lacaune farm to fully utilize the existing technology and the available resources are smaller than in the rest of the breeds and conform with that of Theodoridis et al., who found that more efficient Lacaune farms have a lower dependency on pasture, rely more on purchased feed, and use less supplementary feeds.

The results of our study show that the development of resilient, disease-tolerant animals improves the economic performance and the economic sustainability of the farm. This finding is in line with those of Nieuwhof and Bishop [65], Knight-Jones and Rushton [66], Winter and Green [37], Nathues et al. [67], Limon et al. [68], and Tadesse et al. [69], who concluded that the reduction of incidences of infectious and noninfectious diseases has direct economic benefit for the farms and the industry. These studies follow a similar approach to ours, considering the associated costs of prevention and treatment but also the reduced animal performance and the corresponding production losses. Our study showed that the improvement in the profitability of the farms stems mainly from the increase in production and not from the reduction in health-care expenses and/or increased labor. This finding is in line with that of Nieuwhof and Bishop [65], who reported that the main cost source for animals infected with GIN parasites is production loss, but is not aligned with that of Winter and Green [37], who found that the main financial benefit from the prevention of lameness results from treatment cost reductions. In addition, the finding that extra time spent for the treatment of the animals constitutes a small proportion of the total treatment cost converges with that of Winter and Green [37].

4. Conclusions

A mathematical model accounting for parameters that could shape new farm profiles for different environmental, technical, and economic challenges was developed in this study. The model operates at the farm level and can be adapted to different breeds, farm types, and production systems. The model was applied using data from five different sheep farms and one goat farm in Greece and France to assess different scenarios in the presence of mastitis, parasitism, and lameness in the flocks. The results showed that the gross margin of the farms is significantly improved (from 3.9% in Lacaune sheep to 23.5% in Boutsiko sheep) when the resilience of the animals reduces the impact of the diseases. The results indicate that the structural characteristics of the farms do not change significantly if new resilience animal traits are developed to prevent diseases. This finding is interesting, because it shows that although the occurrence of diseases at a given prevalence changes economic performance, the impact is not considered important to impose on the farmer to change the management plan. Although the gross margin of the farm is increased in the disease-free scenario (future plan), the managerial decisions of the farmer do not change. Results also show that the improvement in the economic performance of the farm is the result of an increase in gross output, not the reduction in production cost.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su151511499/s1, Spreadsheet S1: LP code (Chios sheep); Spreadsheet S2: LP results (All breeds); Spreadsheet S3: LP data (All breeds).

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