Greenhouse gas mitigation options in Greek dairy sheep farming: A multi-objective programming approach

Alexandra Sintori [1]
PhD Candidate, Agricultural University of Athens, tel: 0030-210-5294767, e-mail:
al_sintori@yahoo.gr

ABSTRACT

Dairy sheep farming is an important agricultural activity in the Mediterranean region. In Greece, sheep farming offers employment and income to thousands of families. On the other hand, ruminant livestock farming has been identified as a considerable source of Greenhouse Gases (GHGs). In this analysis, multiple objectives of policy makers are incorporated into a decision making model that yields a number of alternative mitigation strategies, for Greek dairy sheep farming. Each policy alternative achieves the environmental and socio-economic objectives at certain levels. The policy maker can then select the preferred alternative. The model utilizes detailed farm level data, which increases the accuracy of the results. The analysis is undertaken on two different farming systems identified in Continental Greece and indicates that there is a considerable degree of conflict among the GHGs minimization objective and the gross margin and labor maximization objectives. The results also indicate that the mitigation options for sheep farming involve the reduction or/and the intensification of the activity and also changes in the production orientation and feeding practices. The model, can, therefore, be a useful tool for policy makers, since it allows them to design appropriate measures, according to the mitigation option that best meets their preferences.

Keywords: sheep farming, multiple objectives, compromise programming, greenhouse gas emissions, mitigation

---

[1] Alexandra Sintori graduated from the Agricultural University of Athens (AUA), in 2004 and attended a M.Sc course in Integrated Rural Development in the same University. She has worked in the National Agricultural Research Foundation in Athens for over four years and she is currently a Ph.D student in the AUA. Her research focuses mainly in the management of livestock production systems.

1. INTRODUCTION.

Dairy sheep farming is an important agricultural activity in the Mediterranean region. In Greece, the activity is mainly located in less favored areas of the country and utilizes less fertile and abundant pastureland. The number of sheep bred in Greece is approximately 9,000,000, held in about 128,000 farms (N.S.S.G.[2], 2000). These farms are dairy farms, since they aim primarily at the production of sheep milk that is responsible for over 60% of their gross revenue and secondarily at the production of meat (Kitsopanides, 2006). It is estimated that almost 40% of the total milk produced in Greece is sheep milk (N.S.S.G., 2006). Furthermore, the activity contributes highly in regional development and helps maintain the population in the rather depressed areas, where it is located. It is apparent that the preservation of the dairy sheep farming activity is important not only for farmers but also for policy makers.

Most decision making models used in agricultural planning and policy reflect the basic socioeconomic criterion of gross margin maximization. But the rising public concern on the adverse effects of agriculture to the environment has encouraged the development of models that incorporate not only socioeconomic but also environmental criteria. A number of studies employ multi-objective programming techniques to address complex issues in environmental and agricultural economics. These studies mainly focus on irrigated agriculture and the optimal allocation of water and other resources (see for example: Zekri and Romero, 1993; Romero, 1996; Tiwari et al., 1999; Latinopoulos, 2007; Ragkos and Psychoudakis, 2009).

One major environmental concern associated with ruminant livestock farming is climate change and Greenhouse Gas (GHG) emissions. Livestock production and livestock systems undergo a number of changes as a result of climate change. The impact of climate change on livestock production involves quantity and quality of feeds, heat stress and production loss, water supply, animal health and reproduction, biodiversity, land use and livestock systems and other indirect impacts (Thornton et al., 2009 and Nardone at al., 2010). On the other hand agriculture has been identified as a significant source of GHGs, and therefore not only adaptation but also mitigation options have to be examined.

GHG emissions are particularly high in the case of ruminant livestock farming because of methane produced through enteric fermentation (Pitesky et al., 2009). Therefore, farmers are, nowadays, urged to adopt not only economically viable but also environmentally sound farming practices, while agricultural policy making should acknowledge the significance of this factor. The issue of GHGs abatement and the evaluation of alternative mitigation policy measures have been addressed in a number of studies that focus mainly in the estimation of GHGs in livestock farms and the impact of the abatement on the farm income. Furthermore, the majority of these studies refer to dairy cow and cattle farming (Olesen et al., 2006; Weiske et al., 2006; Briner et al., 2012) or to meat and wool sheep farming (Petersen et al., 2002; Benoit and Laignel, 2008).

It should be noted that though dairy sheep farming is an important and common activity in the Mediterranean region, there is little evidence on its contribution to GHGs and mitigation options have not yet been explored. As can be seen in Table 1, the 9,000,000 sheep that are bred in Greece are responsible for over 50% of the emitted methane from enteric fermentation, which is the main GHG associated with livestock production (M.E.E.C.C[3], 2012).

---

[2] National Statistical Service of Greece

[3] Ministry of Environment, Energy and Climate Change

Following the aforementioned studies that focus on the use of multi-objective techniques to address environmental issues, this study aims at the construction of a decision making model that is used to explore GHG mitigation options in Greek sheep farming. Moreover, the compromise programming technique is employed to derive a number of alternative options for policy makers, that each achieves the conflicting environmental (minimization of GHGs) and socio-economic (maximization of gross margin and employment) objectives at certain levels. The multi-objective model is based on a whole-farm, mixed-integer programming model that utilizes detailed farm level data and is build to reflect the complexity of the resource allocation problem in livestock farms.

	Population size (1000)	**CH_4 Production (%)**
Dairy Cattle	135.26	10.54
Non-dairy Cattle	514.66	18.65
Buffalo	1.91	0.07
Sheep	8,831.59	52.12
Goats	5,154.93	16.79
Swine	875.10	0.85
Poultry	29,079,22	0.36
Horses	27.39	0.30
Mules and Asses	45.65	0.32
Total		**100.00**

Source: M.E.E.C.C. (2012)

Table 1 – Population of livestock in Greece and their contribution to CH_4 production (%)

It should be noted, that Greek sheep farms are characterized by a high degree of diversification in terms of invested capital, production orientation, breeding system, herd size, milk yield and other technicoeconomic characteristics, indicating heterogeneity in economic performance and GHG emissions. In the extensive breeding system, feed requirements are met mainly through grazing, while supplementary feed is used only a few months of the year. These farms are characterized by low invested capital and low productivity (H.M.R.D.F.[4], 2007).

More modern and intensive farms are also present in lowland areas of the country. These farms have a higher invested capital and aim to increase their productivity through supplementary feeding, mainly from on-produced fodder. To take into account this high degree of diversification of the sheep farming activity in Greece, the alternative mitigation options are presented separately for the semi-intensive and the extensive sheep farming system, which are the prevailing farming systems in the country.

In the next section the multi-objective technique used in this analysis is presented. Next, the mathematical programming model and the data used are described in more detail. Section four contains the results of the analysis and the final section includes some concluding remarks.

2. METHODOLOGY

2.1. The compromise programming technique

As mentioned above, multi-objective programming (MOP) is commonly used to assist in the decision making process of policy makers, when the simultaneous optimization of multiple objectives is involved. MOP seeks to identify a set of efficient solutions (Pareto optimal solutions), among the feasible set, since optimal solutions cannot be defined in the case of several, conflicting objectives (Romero and Rehman, 2003). The most common techniques of MOP are the constraint

---

[4] Hellenic Ministry of Rural Development and Food

method and the weighted method. Both of the above methods are used to derive the efficient set, by transforming the multi-objective problem to a single objective one. The efficient set is then presented to the decision maker, who selects the optimal solution. The drawback of the above methodologies is the computational effort they require. Furthermore, they often yield a large number of alternatives and therefore other techniques are also implemented to reduce the number of alternatives presented to the decision maker.

A technique commonly used to accommodate these problems of MOP is Compromise Programming (CP) (Zekri and Romero, 1993). The main assumption of CP is that the decision maker seeks a solution as close as possible to the ideal point, since the ideal point cannot be reached (utopian point) (Romero and Rehman, 2003). In other words, the method aims to identify the best compromise solutions, through the use of distance functions.

To implement this method, all objectives are first express mathematically as a function of the decision variables. Thus,

$$\begin{aligned}
&\text{Max (or Min) } f_1 = a_{11}x_1 + a_{12}x_2 = + \ldots + a_{1n}x_n \\
&\text{Max (or Min) } f_2 = a_{21}x_1 + a_{22}x_2 = + \ldots + a_{2n}x_n \\
&\qquad \ldots . \\
&\text{Max (or Min) } f_q = a_{q1}x_1 + a_{q2}x_2 = + \ldots + a_{qn}x_n
\end{aligned} \tag{1}$$

where, q is the total number of criteria (objectives), n is the number of the decision variables x_j and α_{ij} the coefficients of the decision variables. Then, the pay-off matrix is estimated to obtain the ideal and anti-ideal values of the objectives and to observe the degree of conflict among them. To obtain the pay-off matrix, each objective is optimized separately over the feasible set and the values of the rest of the objectives are estimated at the optimal solution. The values of the diagonal of the pay-off matrix are the ideal values of the objectives.

To measure the distance from the ideal point, the family of L_p metrics can be used:

$$L_p(w) = (\sum_{i=1}^{q} w_i^p \left| \frac{f_i^* - f_i(x)}{f_i^* - f_{i*}} \right|^p)^{1/2} \tag{2}$$

where f_i^* and f_{*i} are the ideal and anti-ideal values of the i-th objective, identified by the pay-off matrix, w_i represents the weights attached to the deviations according to the relative importance of each objective and p is the parameter that acts as a weight of the magnitude of the deviations. For each set of p and w_i a best compromise solution is derived.

When the L_1 metric is used (p=1) the best compromise solution can be identified by solving the following linear programming model:

$$MinL_1(w) = \sum_{i=1}^{q} w_i \frac{f_i^* - f_i(x)}{f_i^* - f_{*i}} \tag{3}$$

subject to:

$$x \in F$$

where, F is determined by the constraints of the model. The objectives used in the above mathematical formation are normalized (they are divided by their range) (Zekri and Romero, 1993). When the L_∞ metric is used (p=∞) the maximum deviation (D) is minimized (when p=∞ is used emphasis is given on the largest deviation). The minimization of the largest deviation corresponds to the following linear programming model:

$$MinL_{\infty} = D$$

subject to:

$$w_1 \frac{f_1^* - f_1(x)}{f_1^* - f_{*1}} \leq D \qquad (4)$$

$$\vdots$$

$$w_q \frac{f_q^* - f_q(x)}{f_q^* - f_{*q}} \leq D$$

$$x \in F$$

Using other metrics to derive best compromise solutions, results in non linear algorithms (Romero and Rehman, 2003). But the two metrics presented above, define the compromise set, therefore all other best compromise solutions fall between the bounds provided by the L_1 and the L_{∞} metrics. Thus, to derive the compromise set, which is a subset of the efficient set, only the above two linear programming models for each set of weights need to be solved.

2.2. Modeling GHGs in Livestock farms

The multi-objective technique described above is based on a whole-farm, mixed-integer programming model. Whole-farm models are commonly used to represent farming systems because of their ability to capture the complexity of the farm operation and the interrelationships of the alternative activities, as well as the substitution possibilities between them. This is particularly important when issues of GHG emissions in livestock and crop-livestock systems are addressed, because of the diversity of the emission sources. Attempts to mitigate a particular greenhouse gas can cause the increase of gases from other sources and therefore, only when the whole-farm approach is adopted can these effects be predicted.

Most models used to estimate GHG emissions in livestock farms are either Life Cycle Assessment (LCA) models or Simulation models (see Table 2). Whole-farm optimization models are also commonly used for the estimation of GHG emissions in farming, because they can incorporate all possible sources of emissions and capture all trade-offs among them.

An extended review of whole-farm models used to estimate GHG emissions in beef and dairy cattle farms can be found in Crosson et al. (2011). Schils et al. (2006) also present four models used to predict mitigation options in ruminant livestock systems, namely DairySim, FarmGHG, $\text{SIMS}_{\text{DAITY}}$ and FarmSim. Table 2 includes a presentation of selected models used to estimate GHG emissions in livestock and crop-livestock systems and summarizes some of their basic characteristics. Specifically, the nature of each model and its methodological basis is presented. Furthermore, the table includes the main sources of emissions incorporated in each of the selected models.

	Method and objective	**Emission sources**
De Cara and Jayet (2000)	Farm level, linear programming models representing the French agricultural sector were used to estimate GHG emissions and abatement costs	Enteric fermentation and fertilizer use. Carbon sequestration was also taken into account
Petersen et al. (2002)	Emission sources are incorporated in the MIDAS linear programming model to assess the impact of GHG abatement policies on sheep farming systems in Australia	Enteric fermentation, manure management and application, fertilizer use, fuel use, stubble burning
Gibbons et al. (2003)	Farm-adapt a mixed-integer programming model was used to determine the most cost-effective adaptations at the farm-level for reducing GHG emissions in England & Wales	Enteric fermentation, manure management, N_2O from grasslands, pre-chain emissions from manufacture of fertilizers and pesticides
Olesen et al. (2004)	The FarmGHG, a C and N flow-based simulation model was developed to estimate emissions in livestock farms	Direct, indirect and leaching emissions: Enteric fermentation, manure management and application, fertilizer use,diesel and electricity. Pre-chain emissions are also included
Casey and Holden (2005; 2006)	The LCA method is used to asses emissions from the average Irish milk production system (2005) and from sucker-beef production in Ireland (2006)	Enteric fermentation, manure management and spreading, concentrate feed production transport and processing, N fertilizer production, transport and application, diesel and electricity
Smith and Upadhyay (2005)	A linear programming model is developed to explore mitigation options in representative crop-livestock farming in Canada	Enteric fermentation, manure management and application, fertilizer use, energy use, crop residues. Pre-chain emissions and carbon sequestration are also included in the analysis
Schils et al. (2007)	The DairyWise empirical model was developed and evaluated using data from 29 dairy farms in the Netherlands.	Enteric fermentation, manure management and application, grazing, fertilizer use, crop residues, mineralization from peat soils, grassland renewal, biological N fixation, diesel and electricity. Pre-chain emissions were also taken into account
Fiorelli et al. (2008)	The FarmSim simulation model was coupled with PASIM and CERES-EGC to predict greenhouse gas emissions in crop-ruminant farms	Enteric fermentation, respiration, manure management and use, fertilizer use, fuel and electricity. Pre-chain emissions were included in the analysis
Veysset et al. (2010)	Two models were coupled, Opt'INRA, a linear programming bio-economic model and PLANETE an environmental assessment model, to study the performance of French Charolais Suckler Farms	Enteric fermentation, manure management, N fertilization management, energy consumption, pre-chain emissions (including buildings and machinery). Indirect N_2O emissions were not taken into account
Foley et al. (2011)	The BEEFGEM simulation model was designed to quantify GHG emissions from pastoral suckler beef cow production systems	Enteric fermentation, slurry storage and spreading, deposition of excreta by grazing animals, fertilizer use, silage effluent, diesel use. Indirect N_2O emissions and other pre-chain emissions were included
Lesschen et al. (2011)	The MITERRA-Europe environmental assessment model was used to estimate emissions from livestock sectors of Europe. The model is based on the CAPRI and GAINS models and is supplemented with N, soil C and mitigation modules	Enteric fermentation, manure management and application, fertilizer use, crop residues, deposition of excreta by grazing animals, organic soils and liming, fossil fuel, electricity and fertilizer production emissions were included
Sise et al. (2011)	A software model was developed to estimate greenhouse gas emissions of sheep-beef farming systems	Enteric fermentation, urine and dung, fertilizer use, fuel and electricity. Carbon sequestration is also estimated
Briner et al. (2012)	The INTSCOPT linear programming model was designed to evaluate mitigation options in Swiss suckler cow farm	Enteric fermentation, manure management, fertilizer and manure use, diesel use and pre-chain emissions associated with production and transport of feedstuff and fertilizers. Emissions from electricity use were not included
Weiss and Leip (2012)	The LCA methodology is used, to assess greenhouse gas emissions of the EU livestock sector, with the help of the Capri simulation model	Enteric fermentation, manure management, and application,, excreta from grazing animals, fertilizer use, crop residues, on-farm energy use. Pre-chain emissions from production and transport of inputs and emissions (removals) of land use changes were also considered

Table 2 –Models used to predict GHG in livestock farms

3. CASE STUDY

3.1. Data

The decision making model used in the analysis utilizes detailed farm level data to capture the complexity of the livestock activity and GHG emissions. The farm level data was gathered from two sheep farms located in Continental Greece and refer to the agricultural year 2006-2007. The first farm represents the semi-intensive farming system, which is the prevailing farming system in lowland areas of the country and the second farm represents the extensive farming system, which is the prevailing farming system in mountainous and semi-mountainous areas. It is estimated that 33,452 and 24,445 sheep farms are represented by the semi-intensive and the extensive farm, respectively. The two farms are chosen to have a similar size, close to the average in Continental Greece. Semi-intensive farms are characterized by higher milk yield and gross margin per ewe. Also, the feeding of the livestock depends more on fodder, compared to the extensive system. The latter depends more on grazing and therefore, it is associated with higher GHG emissions. On the other hand, intensive farms are more efficient not only in economic but also in environmental terms since they yield low emissions per kilogram of milk. The results of the analysis are presented separately for the two farming systems so that the decision maker can select different optimal mitigation options for upland and lowland areas of Greece.

3.2. Model specifications

The decision variables of the model used in the analysis, the constraint matrix and the GHG emission sources that were taken into account are presented in this section.

Crop and livestock activities

Crop activities of the sheep farms involve, mainly, forage and grain production for livestock feeding. In the model, farmers can produce feed either for consumption in the farm or for sale. Livestock activities incorporated in the model refer to sheep milk and meat production per month and alternative lambing periods.

Feeding variables

The produced forage and grains are used for the feeding of the livestock. A set of variables is used to approximate monthly distribution of the produced feed. Additionally, monthly consumption of purchased feed corresponds to another set of model variables. Finally, the model includes decision variables that reflect the monthly use of pastureland and the consumption of grass.

Labor variables

The final set of variables incorporated in the model involves the monthly labor inputs. The model distinguishes between monthly family and hired labor used in crop and livestock activities.

Feed requirements

The main component of the model reflects the balance of the monthly feed requirements of the livestock. Minimum intake of dry matter, net energy of lactation, digestible nitrogen and fiber matter is ensured through monthly constraints. The feed requirements of the livestock are estimated according to Zervas et al. (2000). For the productive ewes these feed requirements include requirements for preservation, activity and pregnancy. Extra requirements for lactation are estimated per kilogram of produced milk. For the rams, the requirements refer to their preservation, activity and extra requirements during the reproduction period. For the replacement animals, the feed requirements are estimated every month taking into account the live-weight increase. The weight increase is also taken into account in the case of the lambs, for which feed requirements are estimated for the period that they remain in the farm. The lambs are allowed to consume hay after the first two weeks and grains after the first four weeks. It should be noted that lambing usually occurs in late autumn or early spring, or in both periods.

On-produced feed crops, external feed inputs and available pastureland are used for the balance of the feed requirements of the flock. The nutritional value per kilogram of feedstuff and grass are taken from Kalaisakis (1965), Jarrige (1980) and Zervas et al. (2000). Additional monthly constraints are incorporated in the model to ensure minimum and realistic intake of concentrate feed, according to the feeding practices of the farms.

Additional constraints

Another component of the model ensures that monthly labor requirements of all production activities are balanced, mainly with the family labor inputs. Additional hired labor can be used, if necessary, in both livestock and crop activities. Land constraints are also incorporated in the model to ensure that the total area utilized by the various crop activities and pastureland is smaller than the available land of the farm. Moreover, land constraints refer to the total irrigated land of the farms. A final set of constraints reflects the demography of the livestock and the maximum milk and meat production per ewe.

GHG emissions

In order to accurately derive mitigation options for the sheep farms, it is important to identify all potential sources of GHGs. Otherwise the model will substitute the activities with acknowledged sources of emissions with activities for which the emissions have not been included. The main GHGs, in livestock farms are methane (CH_4) from enteric fermentation and excreta and nitrous oxide (N_2O) from excreta. In addition, in a crop-livestock farm, nitrous oxide emissions (N_2O) from nitrogen fertilizers should also be accounted for (see for example Petersen et al., 2002; Schils et al., 2007a). Carbon dioxide emissions (CO_2) from the use of machinery are an additional source of GHGs. In our analysis, all the potential sources of GHGs have been taken into account. It should be noted that CH_4 and N_2O have been converted to CO_2-equivalents using the conversion factors proposed by the IPCC (2006). The method used to estimate emissions from various sources in the sheep farms is described in more detail in the following paragraphs. Emissions from all sources estimated as CO_2-equivalents are added together to estimate total GHG emissions of the sheep farms. Carbon sequestration has also been taken under consideration. Specifically, a carbon sequestration of 0.3 t C/ha for irrigated crops, 0.2 t C/ha for non irrigated crops and 0.1 t C/ha for pasture is assumed (see also Pretty and Ball, 2001). Net emissions are estimated after subtracting carbon sequestration from total emissions.

CH_4 from enteric fermentation

Methane production from enteric fermentation is the most important source of GHGs in livestock farms and it is associated with the feeding practices of each farm. Farmers choose to feed their livestock with on-produced feed and purchased feed taking into account their cost and their nutritional value. Mathematical programming models select the optimal combination of feedstuff and suggest the least cost ration. For this reason, the ration used in this analysis is not fixed and methane emissions are predicted from intake, taking into account the requirements of the livestock (see also Petersen et al., 2002). Following the work of De Cara and Jayet (2000), methane emissions from livestock are estimated according to the following equations, for simple and compound feedstuff respectively:

$$\text{E-CH}_4/\text{EB} = -1.73 + 13.91\ \text{dE} \tag{5}$$

$$\text{E-CH}_4/\text{EB} = 5.62 + 4.54\ \text{dE} \tag{6}$$

Where, E-CH_4/EB is the percentage share of gross energy of each feedstuff loss in methane and dE is a digestibility index. The digestibility index for each feedstuff is taken from Kalaisakis (1965).

N_2O from manure

Methane produced from livestock excreta is considered negligible, since the conditions that exist during the management of manure or grazing of livestock are mainly aerobic (Petersen et al., 2002; IPCC, 2006). On the other hand direct and indirect N_2O emissions from livestock excreta during manure management and grazing are included in the analysis. Direct and indirect N_2O emissions from manure management and pastureland are estimated according to the Tier 1 methodology proposed by the IPCC (2006). Emissions from leaching occurring in pastureland have also been taken into account but were considered negligible for manure management.

N_2O from fertilizer use

In our analysis, we have included direct and indirect N_2O emissions from the use of nitrogen fertilizers. First, the total amount of nitrogen applied in fields has been calculated using the amount and the type of fertilizer (De Cara and Jayet, 2000; Petersen et al., 2002). Then direct, indirect and leaching emissions from the applied N have been estimated according to the Tier 1 methodology and the emission factors proposed by the IPCC (2006).

CO_2 from energy use

CO_2 from energy use is another source of GHG emissions in crop-livestock farms. The main sources of energy in these farms are fuel (mainly diesel) and electricity (see also Olesen et al., 2006). To estimate the emissions from energy use, fuel or electricity, requirements for every operation and type of machinery is estimated and multiplied by emission factors (Petersen et al., 2002).

In our study, pre-chain emissions have also been estimated and included in the analysis, following the work of Olesen et al. (2006). As mentioned above, farmers choose whether to feed their flock with on-produced or purchased feed. Therefore, N_2O emissions from nitrogen fertilizers and CO_2 emissions from energy requirements have also been estimated per kilogram of purchased feed. Other inputs, like fertilizers and pesticides have also caused GHG emissions when they were manufactured. These emissions have been taken into account as well, using farm level data to estimate the amount of inputs used and related literature to estimate the emissions caused by the manufacture of these inputs. CO_2 emissions from the manufacture of fertilizers are assumed 1.2 kg of CO_2 eq/kg of fertilizer (see also Wood and Cowie, 2004). Energy requirements for the manufacture of herbicides are assumed 287MJ/kg, for insecticides 263MJ/kg and for fungicides 195MJ/kg (see also Helsel, 2006). Emissions are then calculated by multiplying the total energy requirements with 0.069 kg of CO_2.

3.3. Objectives of the policy maker

In our analysis, the main objectives concerning the sheep farming activity, from the perspective of the policy maker, are:

- *The maximization of gross margin.* In this analysis, the maximization of gross margin corresponds to the economic criteria of the decision maker.
- *The maximization of total labor.* Total labor is used in this analysis as a measure of the level of employment in sheep farms, which is considered an important social objective.
- *The minimization of GHG emissions.* This is considered as a major environmental objective in ruminant livestock farms.

4. **RESULTS**

First, the pay-off matrix of the objectives for the two farming systems is obtained (Tables 3 and 4). The first part of each table represents the solution for the representative farm and the second part contains the aggregate results, for the total number of farms that each farm represents. To obtain the pay-off matrix, each objective is optimized separately, over the feasible set. The first row of the pay-off matrix contains the results of the model when the gross margin objective is optimized. The second and third row, contain the results of the model, when labor is maximized and when GHGs are minimized, respectively. The values of the diagonal represent the optimal (ideal) values of the objectives, but because the objectives are conflicting, this optimal point is infeasible. This means that when all objectives are included in the decision making process, and there is some degree of conflict among them, then the objectives cannot be optimized simultaneously.

	Representative farm			**Total number of farms**		
	Gross margin (€)	**Labor (Hours)**	**GHGs (kg-CO_2 Eq)**	**Gross margin (1000 €)**	**Labor (Annual Work Units)**	**GHGs (1000 tonnes-CO_2 Eq)**
Max Gross margin	**14,543**	2,282	66,801	**486,477**	43,629	2,235
Max Labor	11,787	**2,487**	69,802	394,287	**47,540**	2,235
Min GHGs	10,180	1,172	**35,964**	340,534	22,407	**1,203**

Table 3 - Pay-off matrix for the semi-intensive farming system

The results of both farms indicate that there is some degree of complementarity among the gross margin maximization and the labor maximization objectives. This means that the optimum value of labor is very close to the value of labor when the gross margin objective is optimized. On the other hand, there is a high degree of conflict between the gross margin and labor maximization objectives and the GHGs minimization objective. In the case of the semi-intensive farming system the optimal value for the GHGs minimization objective leads to about 46% lower emissions compared to the gross margin maximization objective, but also to a 48% lower employment level and 30% lower gross margin.

	Representative farm			**Total number of farms**		
	Gross margin (€)	**Labor (Hours)**	**GHGs (kg-CO_2 Eq)**	**Gross margin (1000 €)**	**Labor (Annual Work Units)**	**GHGs (1000 tonnes-CO_2 Eq)**
Max Gross margin	**14,341**	1,720	54,671	**350,560**	24,026	1,336
Max Labor	11,681	**1,753**	56,469	285,539	**24,485**	1,380
Min GHGs	10,039	1,014	**29,872**	245,392	14,170	**730**

Table 4 - Pay-off matrix for the extensive farming system

In the case of the extensive farming system, similar results are obtained. GHGs are particularly high, when gross margin and labor are optimized. The optimal level of GHGs is over 45% lower compared to the value of GHGs when gross margin and labor are maximized. Reduced GHGs lead to a 30% reduction of gross margin and a to 41% reduction in total labor. This reveals the degree of conflict among the two objectives.

It should be noted that the solution the model yields, when gross margin is maximized, though utopian, is relatively closer to the existing situation in livestock farming, compared to the optimal solutions when the other two objectives are optimized. This is because, from the farmers' point of view, the maximization of gross margin is the main objective, and therefore, when gross margin is maximized the farm level model simulates the operation of the farms and represents their actual performance, more accurately than when the other objectives are optimized. From the policy maker's point of view, it is assumed that decision making is currently based mainly on the economic objective of gross margin maximization, since, so far, no GHGs mitigation measures have been introduced in Greece. This indicates that this environmental objective is not yet included in policy making.

After the pay-off matrix is obtained the compromise programming technique is used to derive the alternative best compromise solutions for the decision maker. The two linear programming models described in section 2, are solved for different sets of weights to reflect differences in the environment in which the decision making process takes place. First, equal weights are attached to the deviations of the objectives, assuming that the decision maker gives equal importance to all of them (Scenario 1). The second set of weights, reflects the decision making process for a policy maker that is mainly interested in the mitigation of GHGs. In this case, the weight attached next to the deviation of the environmental objective is two times the weight attached to the deviations of the socioeconomic objectives (Scenario 2).

The results for the L_1 and the L_∞ for each set of weights are presented in Tables 5 and 7 for the semi-intensive and the extensive farming system respectively. The tables also contain the results of the linear programming model when each objective is optimized. The values of some important variables, like the number of productive ewes and economic indicators, like the production value of milk, are also presented in the two tables. The model allows for the precise estimation of the changes the sheep farming activity undergoes under each scenario, which is important information for the selection of the optimal mitigation alternative, by the decision maker.

Finally, the aggregate results for the semi-intensive farming system and the extensive farming system are presented in Tables 6 and 8, respectively, so that the derived alternatives can be compared, according to their impact on the sheep farming sector. This way, the policy maker can conceptualize the impact various levels of mitigation may have on the sheep farming activity.

The analysis indicates that in both production systems, over 60% of the total emitted GHGs come from methane produced through enteric fermentation. The results also indicate that emissions (mainly methane) per kilogram of milk are higher in the extensive farming system. In general, the analysis indicates that the semi-intensive farming system is more efficient in socioeconomic and environmental terms. The following paragraphs contain a more detailed presentation of the results of the analysis, for each farming system.

4.1. Semi-intensive farming system

As far as the semi-intensive farming system is concerned, the results of the analysis indicate that the emissions per kilogram of produced milk are 2.4 Kg-CO_2 Eq. This is considered low since, all emission sources are taken into account. The main element of the emissions is methane (61%). Nitrous oxide emissions account for 19% of the total emissions and carbon dioxide emissions account for the remaining 20%. Methane emissions are lower in the semi-intensive system, mainly due to low grass consumption (0.6 tonnes/ewe/year). The proportion of carbon dioxide is significant because of the crop production in semi-intensive farms. This proportion may vary, according to the mitigation alternatives as indicated in Table 5. It is also different among the optimal solutions of the objectives. It should also be noted that the main production orientation of the semi-intensive farm is milk production, since in all alternatives milk accounts for over 59% of the total production value of the sheep farming activity.

When the optimal solutions for the three objectives are examined, it can be seen that in the labor maximization objective the optimal solution indicates a higher degree of specialization in sheep production. This is the result of the high labor requirements of the livestock activities compared to crop farming. Specifically, the number of ewes is increased and cash crop production is absent. Under the hypothesis of labor maximization, lambs are sold several months after lambing (up to six), compared to the case of gross margin maximization and GHGs minimization objectives. Also in this optimal solution, carbon sequestration is lower because of the small crop production. In the gross margin maximization solution homegrown feed is high, which indicates that the use of on-produced feed lowers cost and increases gross margin. Finally, it should be mentioned that there is a significant conflict among the environmental and labor objectives, since in the optimal solution of the environmental objective; the value of labor is 53% lower than its optimal value. Finally, in the GHGs minimization objective, the carbon dioxide emissions are higher, due to crop production.

Scenario 1: Objectives of equal importance
As indicated in Table 5, assigning equal weights to the deviations of the objectives results in a relatively small compromise set for the socioeconomic objectives but the set is larger for the environmental objective. In the L_1 solution, values are closer to the ideal, when the socio-economic objectives are examined, but the distance from the ideal value of the environmental objective is large. Livestock size is almost the same compared to the gross margin maximization objective, which results in only minor deviations in emissions compared to the gross margin solution (1% reduction). Mitigation is achieved in the L_1 bound through a small reduction of livestock size (less than 2%) and homegrown feed, which leads to a small reduction in carbon dioxide and nitrous oxide emissions (5% and 3%, respectively). But the reduction in homegrown feed leads to a higher grass consumption per ewe and a 2% increase in methane emissions. This solution can be considered as a low mitigation alternative for the semi-intensive farming system.

The mitigation level is higher in the case of the L_∞ solution (21% compared to the gross margin maximization solution) which corresponds to a 15% deviation from the optimal gross margin and a 26% deviation from the optimal labor. This solution resembles the optimal solution of gross margin maximization, in terms of farm structure. In specific, there is no change in production orientation, since milk and meat yields per ewe remain constant and there is also no significant change in livestock feeding, though the livestock size is 20% smaller. The reduction of the livestock size leads to a 20% reduction in methane emissions. In the L_∞ solution, cash crops are cultivated, and mitigation is achieved mainly by the restriction of livestock size.

Scenario 2: Emphasis on the environmental objective
In this scenario, and in both the L_1 and L_∞ bounds, mitigation is achieved with no adjustment on milk and meat yield per ewe. Like in the previous scenario, the milk and meat yield per ewe take their maximum values. But in this scenario there is a more evident change in the production orientation. Livestock size is reduced in both solutions, but this reduction is more significant in the L_1 bound.

In the L_1 compromise solution, mitigation is achieved by a significant shift towards crop production, which causes higher carbon dioxide emissions. Mitigation is also achieved by a significant reduction in livestock size (51%), which reduces nitrous oxide and methane emissions. The methane emissions are reduced by 53%, which indicates a modification of the feeding practices of the sheep farm. Indeed, a shift to more concentrate homegrown feed and particularly barley and wheat is also responsible for the total 45% reduction in net emissions.

				Scenario 1		**Scenario 2**	
	Max gross margin (f_1)	**Max labour (f_2)**	**Min GHGs (f_3)**	L_1	L_∞	L_1	L_∞
Objectives							
Gross Margin (€)	14,543	11,787	10,180	13,617	12,392	10,372	11,575
Total labour (hr)	2,282	2,487	1,172	2,228	1,839	1,173	1,593
Net emissions (Kg-CO_2 Eq)	66,801	69,802	35,964	66,387	52,645	36,652	47,473
Variables and economic indicators							
Number of ewes	102	115	50	100	82	50	70
Meat production value (€)	9,773	9,357	4,615	9,596	7,866	4,798	6,717
Milk production value (€)	13,770	14,563	6,750	13,500	11,070	6,750	9,450
Value of purchased feed (€)	3,447	5,684	8	3,903	2,226	90	1,538
Value of produced feed (€)	6,121	5,688	3,468	5,938	4,973	3501	4,461
Gross margin from cash crops (€)	989	0	2,840	838	1,137	2960	1,997
Greenhouse Gases							
CH_4 emissions (Kg-CO_2 Eq)	50,595	55,567	24,162	51,469	40,294	23,567	34,396
N_2O emissions (Kg-CO_2 Eq)	15,437	15,877	10,304	14,906	12,653	10,445	12,153
CO_2 Emissions (Kg CO_2)	17,293	13,871	17,814	16,364	14,973	18,279	17,062
Carbon sequestration (Kg CO_2)	16,524	15,512	16,317	16,351	15,274	15,639	16,138

Table 5- Results of the compromise programming method for the semi-intensive farm

	Scenario 1				**Scenario 2**			
	L_1		L_∞		L_1		L_∞	
	Absolute value	% Deviation from f_1	Absolute value	% Deviation from f_1	Absolute value	% Deviation from f_1	Absolute value	% Deviation from f_1
Socioeconomic indicators								
Gross Margin (1000 €)	455,520	-6,36	414,531	-14,79	346,967	-28,68	387,196	-20,41
Total labour (AWU)	42,593	-2,38	35,150	-19,43	22,376	-48,71	30,443	-30,22
Number of ewes (millions)	3,345	-1,96	2,743	-19,61	1,673	-50,98	2,342	-31,37
Milk production (tonnes)	501,780	-1,96	411,460	-19,61	250,890	-50,98	351,246	-31,37
Environmental indicators								
Net emissions (1000 tonnes-CO_2 Eq)	2,221	-0,62	1,761	-21,19	1,222	-45,13	1,588	-28,93
Methane emissions (1000 tonnes-CO_2 Eq)	1,722	1,73	1,348	-20,36	788	-53,42	1,151	-32,02
N_2O emissions (1000 tonnes-CO_2 Eq)	499	-3,44	423	-18,04	349	-32,34	407	-21,28
CO_2 emissions (1000 tonnes-CO_2 Eq)	547	-5,37	501	-13,42	611	5,70	571	-1,34

Table 6 - Aggregate results of mitigation alternatives for the semi-intensive farming system

Thus, the GHGs minimisation objective receives, under this solution, a value almost equal to the ideal value (less than 2% deviation), which is the lowest value of emissions, that can be achieved. On the other hand, the underachievement of the gross margin objective in this compromise solution reaches 29%, and the underachievement of the labour objective is 53%. Compared to the gross margin maximisation solution, labour is reduced by 49%, which corresponds to 21,253 AWU (see also Table 6). What should also be noted is that in this solution, the 51% decrease in livestock size causes analogous decrease in milk production which corresponds to over 260.000 tonnes.

In the case of the L_∞ bound, there is also a significant shift towards crop production and a reduction of livestock size, but to a smaller extent compared to the previous compromise solution. The GHGs minimization objective is underachieved by 32%, but the other two objectives are 20% and 36% smaller than their ideal value, for gross margin and labor, respectively. Compared to the gross margin maximization solution, the value of GHGs is 29% lower. This alternative, should also be chosen, when high levels of mitigation need to be achieved.

The alternative mitigation options of the semi-intensive farm are summarized in Figure 1. As can be seen, a switch to crop production is an alternative mitigation options for this farm type. However, in order to achieve the maximum mitigation level a combination of changes has to take place in the farm, namely livestock restriction, switch to cash crops and changes in feeding practices.

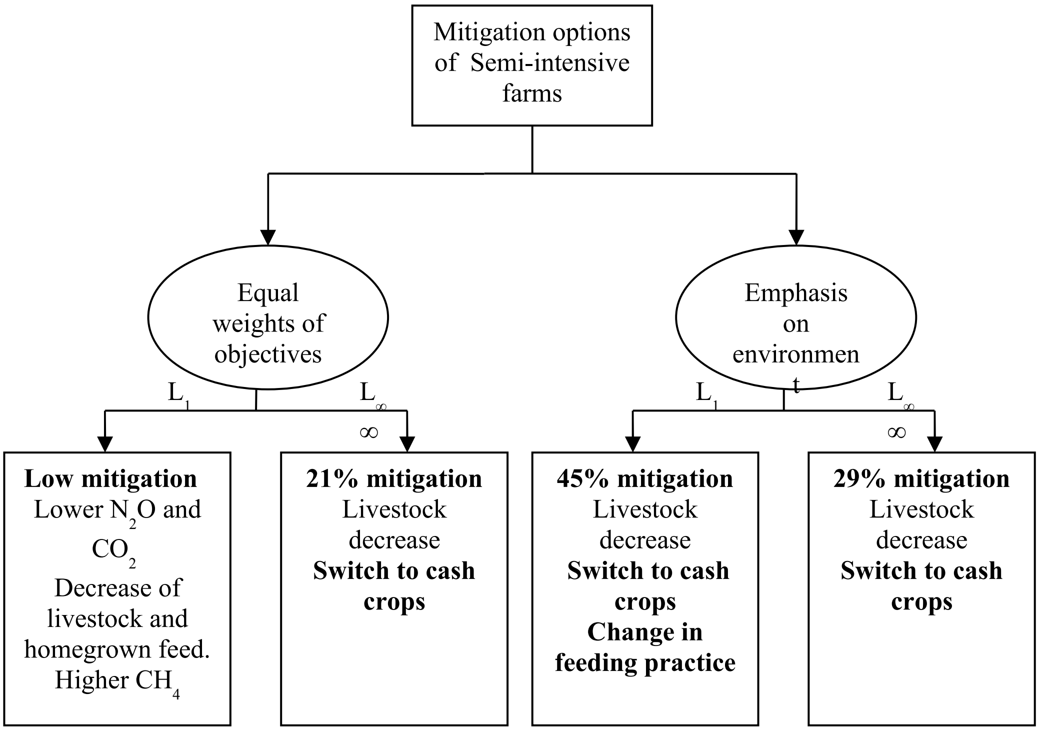

Figure 1 – GHG alternative mitigation options of the semi-intensive farm

4.2. Extensive farming system

In the case of the extensive farming system, methane represents 70% of the total GHGs (see Table 7). Another 21% refers to nitrous oxide emissions and only 9% of total emissions come from carbon dioxide. Carbon dioxide emissions are related mainly to crop production, which is less developed in extensive farms. On the other hand, in the extensive farming system, grazing livestock, consumes a lot of grass (1.6 tonnes/ewe/year), which is linked to higher methane and therefore net emissions compared to the semi-intensive system. Methane emissions are estimated at 2.3 Kg-CO_2 Eq/ kg of milk in the extensive system and are significantly higher than the methane emissions of the semi-intensive system (1.9 Kg-CO_2 Eq/ kg of milk). The analysis also indicates that meat production is very important in extensive breeding farms, since milk production accounts for only 52% of the total production value of sheep farming (Table 7). It should also be noted that the gross margin per ewe is smaller in extensive farms. As indicated in Table 7, the objectives of gross margin and labor maximization lead to similar farm structure. When GHGs are minimized, the livestock size decreases, milk yield per ewe increases and there is also a shift towards crop farming.

Scenario 1: Objectives of equal importance

The assumption of equal weights attached to the deviations of the objectives generates a relatively small compromise set in the case of the socioeconomic objectives. Mitigation is achieved differently in the L_1 and the L_∞ solutions. In the L_1 solution the value of GHGs is very distant from the ideal point, since less than 1% mitigation is achieved, compared to the gross margin maximization objective. This hardly affects gross margin and labor since there is a small increase in the cost of purchased feed but there is also a slight increase in milk yield. The feeding practices, and therefore methane emissions per ewe, remain almost constant. The L_1 solution corresponds to a *very low mitigation alternative* for the decision maker.

In the case of the L_∞ solution, the value of GHGs is underachieved since there is a 42% deviation from the optimal value. 23% mitigation is achieved by a significant reduction of the livestock activity, since the number of ewes is 23% smaller compared to the gross margin maximization objective. This leads to mitigation of both methane and nitrous oxide emissions. In the L_∞ solution labor and gross margin are closer to their ideal points, since they are 20% and 14% smaller than their ideal values, respectively. In this solution milk yield per ewe is significantly increased by 11%. Farms become more labor intensive, since labor per ewe increases by one hour compared to the gross margin maximization objective. Also, in this compromise solution, there is a shift towards crop production. This alternative is characterized *as a moderate mitigation alternative* for the extensive farming activity and is achieved mainly through reduction of the livestock size, significant increase of milk yield and a small shift towards crop production.

Scenario 2: Emphasis on the environmental objective

In the L_1 solution of the second scenario, the values of gross margin and labor are very close to the ideal (6% and 11% deviation, respectively) while the GHGs minimization objective is underachieved. In this solution, methane is decreased due to the reduction of the size of the livestock. Also, *changes in feeding practices* take place since homegrown feed per ewe is increased, and grass consumption and purchased feed decrease. Finally, milk yield also increases, which indicates that the farm tends to intensify. But in this scenario, intensification occurs not only in terms of milk yield but also in terms of feeding practices.

The L_∞ solution leads, as in the previous scenario, to a higher mitigation level, compared to the L_1 solution, since emissions are reduced by 30% compared to the gross margin maximization objective. This mitigation leads to a 19% deviation from the ideal point of the gross margin maximization objective and to a 26% deviation from the ideal point of the labor maximization objective. It is also significant to note that the number of ewes is decreased by 31%, compared to the gross margin maximization objective, which leads to a 24% reduction in milk production (Table 8). In the extensive farming system, the percent reduction of milk production is smaller than the percent reduction of the number of ewes, in all compromise solutions. This means that milk yield per ewe increases, compared to the gross margin maximization solution.

		Scenario 1	**Scenario 2**

	Max gross margin (f_1)	**Max labour (f_2)**	**Min GHGs (f_3)**	**L_1**	**L_∞**	**L_1**	**L_∞**
Objectives							
Gross Margin (€)	14,341	11,681	10,039	14,312	12,325	13,426	11,631
Total labour (hr)	1,720	1,753	1,014	1,734	1,407	1,567	1,290
Net emissions (Kg-CO_2 Eq)	54,671	56,469	29,872	54,419	42,365	47,875	38,249
Variables and economic indicators							
Number of ewes	116	117	62	116	89	100	80
Meat production value (€)	9,519	6,993	5,087	9,516	7,301	8,211	6,541
Milk production value (€)	10,288	10,429	5,797	10,500	8,731	9,810	7,831
Value of purchased feed (€)	188	458	0	392	290	0	207
Value of produced feed (€)	6,525	6,507	2,614	6,515	4,781	5,863	4,078
Gross margin from cash crops (€)	0	0	1447	0	524	233	851
Greenhouse Gases							
CH_4 emissions (Kg-CO_2 Eq)	49,914	51,946	27,970	49,506	38,690	43,285	35,256
N_2O emissions (Kg-CO_2 Eq)	15,315	15,789	9,079	15,353	12,215	13,412	11,207
CO_2 Emissions (Kg CO_2)	7,229	7,349	6,637	7,321	6,676	6,975	6,670
Carbon sequestration (Kg-CO_2 Eq)	17,787	18,613	13,814	17,761	15,215	15,797	14,885

Table 7 - Results of the compromise programming method for the extensive farm

	Scenario 1				**Scenario 2**			
	L_1		**L_∞**		**L_1**		**L_∞**	
	Absolute value	% Deviation from f_1	Absolute value	% Deviation from f_1	Absolute value	% Deviation from f_1	Absolute value	% Deviation from f_1
Socioeconomic indicators								
Gross Margin (1000 €)	350,560	-0,20	301,285	-14,06	328,190	-6,38	284,318	-18,90
Total labour (AWU)	24,026	-0,82	19,652	-18,21	21,886	-8,91	18,017	-25,01
Number of ewes (millions)	2.835	0,00	2.176	-23,28	2.445	-13,79	1,955	-31,03
Milk (tonnes)	279,446	2,06	237,141	-15,14	266,450	-4,65	212,706	-23,88
Environmental indicators								
Net emissions (1000 tonnes-CO_2 Eq)	1,336	-0,46	1,036	-22,51	1,170	-12,43	935	-30,04
Methane emissions (1000 tonnes-CO_2 Eq)	1,220	-0,82	946	-22,49	1,058	-13,28	862	-29,37
N_2O emissions (1000 tonnes-CO_2 Eq)	375	0,25	299	-20,24	328	-12,42	274	-26,82
CO_2 emissions (1000 tonnes-CO_2 Eq)	179	1,28	163	-7,65	170	-3,52	163	-7,73

Table 8 - Aggregate results of mitigation alternatives for the extensive farming system

The L_∞ solution of the second scenario corresponds to the intensification in terms of production alternative, since milk production and gross margin per ewe increase. But in terms of feeding practices, there is no shift towards supplementary feeding and concentrates, and therefore emissions per ewe remain high. Finally, the L_∞ solution indicates a shift towards crop production. This shift however is small, compared to the semi-intensive system. This solution achieves the highest mitigation level for the extensive farm as the result of a combination of mitigation options, namely livestock size decrease, intensive milk production, and shift towards crop production.

Table 8 summarizes the alternatives for the extensive farming system. It can be seen that in all alternatives, the percent reduction in GHGs is always higher than the percent reduction in gross margin and labor, which indicates that mitigation can be achieved at lower cost in extensive than in intensive systems (see also Table 6). In L_∞ solutions, though, the reduction in gross margin and labor can be significant and important for the mountainous and semi-mountainous areas, where this production system is commonly found.

Figure 2 presents the mitigation options of the extensive farm. Apart from livestock size restriction, increase in milk yield and intensification of the sheep farming activity are the main mitigation alternatives for this farm type, as opposed to the semi-intensive farms that can switch to cash crop production.

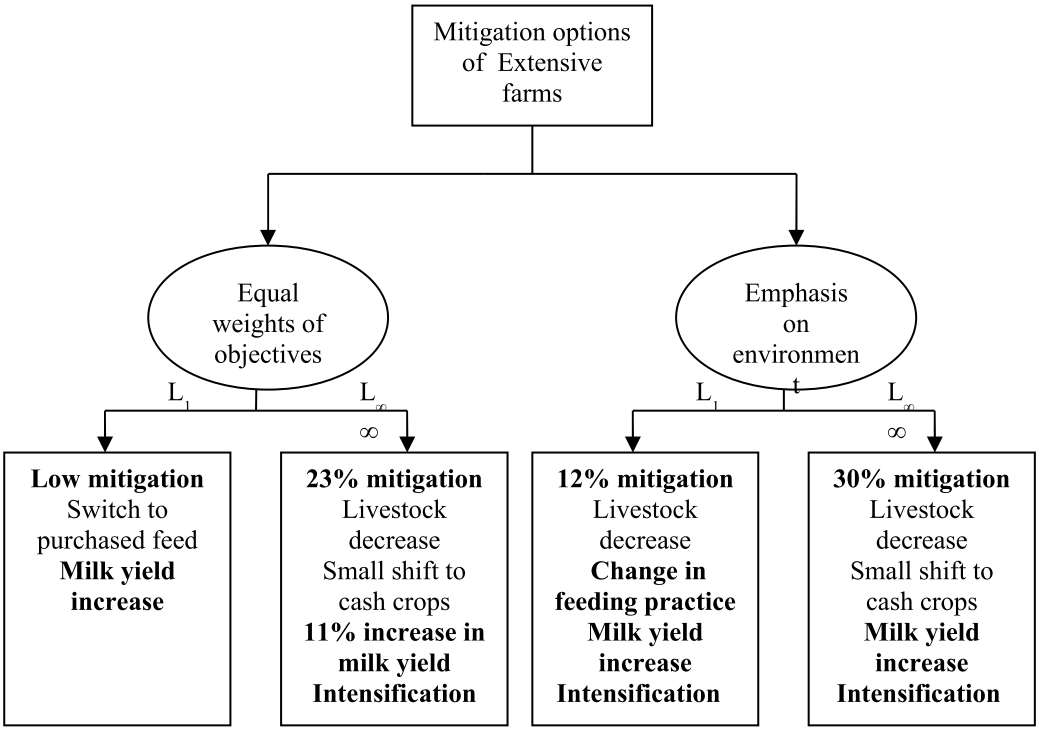

Figure 2 – GHG alternative mitigation options of the extensive farm

5. CONCLUSIONS

Sheep farming is an important agricultural activity in Greece, since it offers income and employment to a large number of families. On the other hand small ruminant livestock farming is responsible for a considerable amount of GHGs, mainly methane emissions. Although, most decision making models take into account the welfare of the farmers, in terms of income maximization, the adverse effects of the sheep farming activity, should also be considered in policy making. In this study, the environmental and socioeconomic objectives of the decision maker -in this case policy maker- are incorporated in a multi-objective model that yields a number of policy alternatives. Each of the alternatives achieves the conflicting objectives at certain levels, and the policy maker can then select the optimal one, according to specific preferences. Compromise programming is implemented, in order to identify the best compromise solutions.

The environmental objective in our analysis is the GHGs minimization, while the socio-economic objectives are the gross margin and the labor maximization. By giving alternative weights to the deviations of the values of the objectives from their ideal values, alternative mitigation strategies in the sheep farming activity can be explored. The model is built using farm level data, which allows for a precise estimation of the structural changes of the farms, associated with each best compromise solution. The data was collected from two sheep farms, selected to represent the extensive and the semi-intensive farming systems of Continental Greece. It should also be noted that the model used includes all main sources of GHG emissions associated with the sheep farming activity (CH_4, N_2O and CO_2).

The results of the analysis denote the high degree of conflict among the GHGs minimization objective and the maximization of gross margin and labor objectives. The results also indicate that the semi-intensive farming system is more efficient in economic and environmental terms. It can achieve mitigation mainly through shift towards crop production and livestock size decrease, but this mitigation has a significant impact on gross margin and especially labor and milk production. The extensive farming system, on the other hand, has smaller crop production abilities. In this case, mitigation is achieved by a decrease in the livestock size and intensification, mainly in terms of milk production, which leads to increase of the gross margin per ewe. In both cases the analysis indicates that mitigation is possible by a combination of actions that includes the reduction of livestock size, intensification and shift towards crop production.

Policy makers should consider the above findings when policy measures are designed. They should also acknowledge that the solution that best achieves the environmental objective, may have a significant impact not only on the income generated from the sheep farming activity and the amount of labour it utilizes, but also on the produced milk and meat. The high dependency of farms on the sheep farming activity should also be taken under consideration. The above findings emphasize the need for the incorporation of several socioeconomic and environmental criteria in the decision making models used in agricultural planning and policy.

Acknowledgments

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

6. REFERENCES

Benoit, M., and Laignel, G. (2008), Sheep for meat farming systems in French semi-upland area. Adapting to new context: increased concentrates and energy prices, and new agricultural policy, 8th Symposium of the International Farming Systems, Clermond-Ferrand, France 6-10 July. 2008.

Briner, S., Hartmann, M., Finger, R. and Lehmann, B. (2012), Greenhouse gas mitigation and offset options for suckler cow farms: an economic comparison for the Swiss case, *Mitigation and Adaptation Strategies for Glob Change*, Vol. 17, pp:337-355.

Casey, J.W. and Holden, N.M. (2005), Analysis of greenhouse gas emissions from the average Irish milk production system. *Agricultural Systems*, Vol. 86 (1), pp:97-114.

Casey, J.W. and Holden, N.M. (2006), Quantification of GHG emissions from sucker-beef production in Ireland. *Agricultural Systems*, Vol. 90, pp:79-98.

Crosson, P., Shalloo, L., O'Brien, D., Lanigan, G.J., Foley, P.A., Boland, T.M. and Kenny, D.A. (2011), A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems, *Animal Feed Science and Technology*, Vol. 166-167, pp: 29-45.

De Cara, S. and Jayet, P.A. (2000), Emissions of greenhouse gases from agriculture: the heterogeneity of abatement costs in France, *European Review of Agricultural Economics*, Vol. 27, Issue 3, pp: 281-303.

Fiorelli, J.L., Drouet, J.L., Duretz, S., Gabrielle, B., Graux, A. I., Blanfort, V., Capitaine, M., Cellier, P. and Soussana, J.F. (2008), Evaluation of greenhouse gas emissions and design of mitigation options: a whole farm approach based on farm management data and mechanistic models, 8th European IFSA Symposium, Clermont-Ferrand, France, 6-10 July. 2008.

Foley, P.A., Crosson, P., Lovett, D.K., Boland, T.M., O'Mara, F.P. and Kenny, D.A. (2011) Whole-farm systems modeling of greenhouse gas emissions from pastoral suckler beef cow production systems, *Agriculture, Ecosystems and Environment*, Vol. 142, pp:222-230.

Helsel Z.R. (2006), Energy in pesticide production and use. *Encyclopedia of Pest Management*, Vol. 1, Issue 1, pp:.1-4.

H.M.R.D.F. (2007), Sheep and Goat Sector Development. [Online]. Available at: http://www.minagric.gr/greek/ENHM_FYLADIA_ZWIKHS/ENHM_FYL_zoiki.htm. [accessed 2 February 2010] (in Greek).

Gibbons, J.M., Ramsden, S.J., Blake, A. (2003), Mitigation of greenhouse gas emissions from agriculture: socio-economic costs and impacts, DEFRA project CC0262, Final Report, 22 pp.

IPCC (2006), Guidelines for national greenhouse gas inventories.

Jarrige, R. (1980), Alimentation des Ruminants. 2e edition France, Paris: INRA[5].

Kalaisakis, P. (1965), Applied animal nutrition. Athens, Greece: Giourdas M. Publishing (in Greek)

Kitsopanides, G. (2006), Economics of animal production. Greece, Thessaloniki: ZITI Publishing (in Greek).

---

[5] Institut National De La Recherche Agronomique

Latinopoulos, D. (2007), Multicriteria decision making for efficient water and land resources allocation in irrigated agriculture, *Environmental Development and Sustainability,* Vol. 11, pp:329-343.

Lesschen J.P., van der Berg, M., Westhoek, H.J., Witzke, H.P. and Oenema, O. (2011), Greenhaouse gas emission profiles of European livestock sectors, *Animal Feed Science and Technology*, Vol. (166-167), pp:16-28.

M.E.E.C.C. (2012). Annual inventory submission under the convention and the Kyoto Protocol for greenhouse and other gases for the years 1990-2020. [Online]. Available at: http://www.ypeka.gr/Default.aspx?tabid=470&locale=el-GR&language=en-US, April 2012.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S. and Bernabucci, U. (2010), Effects of climate changes on animal production and sustainability of livestock systems*, Livestock Science*, Vol. 130, pp: 57-69.

N.S.S.G. (2000), Agriculture and livestock census. [Online]. Available at: http://www.statistics.gr/portal/page/portal/ESYE/PAGE-hemes?pparam=A1002&rparam=SPG11&yparam=200000&mytabs=0 (in Greek). [accessed 24 February 2010].

N.S.S.G. (2006), Annual agricultural survey. [Online]. Available at: http://www.statistics.gr/portal/page/portal/ESYE/BUCKET/A1008/Other/A1008_SPK63_TB_AN_00_2006_07_F_GR.pdf (in Greek). [accessed 24 February 2010].

Olesen, J.E., Weiske, A., Asman, W.A., Weisbjerg, M.R., Djurhuus, J. and Schelde, K. (2004), FarmGHG. A model for estimating greenhouse gas emissions from livestock farms. Documentation. DJF Internal report No. 202. Danish Institute of Agricultural Sciences, Tjele, Denmark, 54 pp

Olesen J.E., Schelde, K., Weiske, A., Weisbjerg, M.R., Asman, W.A.H. and Djurhuus, J. (2006), Modelling greenhouse gas emissions from European conventional and organic dairy farms, *Agriculture, Ecosystems and Environment*, Vol. 112, pp: 207-220.

Petersen, E.H., Schilizzi, S. and Bennet, D. (2002), The impacts of greenhouse gas abatement policies on the predominantly grazing systems of south-western Australia. International and development Economics, Working paper 02-9, Asia Pacific School of Economics and Government, Australian National University, Australia.

Pitesky, M., Stachhouse, K.R. and Mitloehner, F.M. (2009), Clearing the air: Livestock's contribution to climate change, *Advances in Agronomy*, Vol. 103, pp: 1-40.

Pretty, J. and Ball, A. (2001), Agricultural influences on carbon sequestration: a review of evidence and the emerging trading options, Center for Environment and Society Occasional Paper 2001-03, Center for Environment and Society and Department of Biological Studies, UK, University of Essex.

Ragkos, A. and Psychoudakis, A. (2009), Minimizing adverse effects of agriculture: a multi-objective programming approach, *Operational Research*, Vol. 9, pp: 267-280.

Romero, C., 1996. Multicriteria decision analysis and environmental economics: an approximation, *European Journal of Operational Research*, Vol. 96, pp: 81-89.

Romero, C and Rehman, T. (2003), Multiple criteria analysis for agricultural decision making. 2nd edition. Netherlands, Amsterdam: Elsevier.

Sise, J.A., Kerslake, J.I., Oliver, M.J., Glennie, S., Butler, D., Behrent, M., Fennessy, P.F. and Campbell, A.W. (2011), Development of a software model to estimate daily greenhouse gas emissions of pasture-fed ruminant farming systems, *Animal Production Science*, Vol. 51, pp:60-70.

Schils, R.L.M.,. de Haan, M.H.A., Hemmer, J.G.A., van den Pol-van Dasselaar, A., de Boer, J.A., Evers, A.G., Holshof, G., van Middelkoop, J.C. and Zom, R.L.G. (2007a), DairyWise, a whole-farm dairy model, *American Dairy Science Association,* Vol. 90, pp: 5334-5346.

Schils, R.L.M., Olesen, J.E., del Prado, A. and Soussana J.F. (2007b), A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems, *Livestock Science*, Vol. 112, pp: 240-251.

Smith, E.G. and Upadhyay, M. (2005), Greenhouse gas mitigation on diversified farms, *Western Agricultural economics Association-Western Economics Association International Joint Annual Meeting*, San Francisco, CA, USA 6-8 July. 2005.

Thornton, P.K., van de Steeg, J. Notenbaert, A. and Herrero, M. (2009), The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know, *Agricultural Systems*, Vol. 101, pp:113-127.

Tiwari, D.N., Loof, R. and Paudyal, G.N. (1999), Environmental-economic decision making in lowland irrigated agriculture using multi-criteria analysis techniques, *Agricultural Systems*, Vol. 60, pp: 99-112.

Veysset, P., Lherm, M. and Bédin, D. (2010). Energy consumption, greenhouse gas emissions and economic performance assessments in French Charolais suckler cattle farms: Model-based analysis and forecasts. *Agricultural Systems*, 103, 41-50.

Weiske, A., Vabitsch, A., Olesen, J.E., Schelde, K., Michel, J., Friedrich, R. and Kaltschmitt, M. (2006), Mitigation of greenhouse gas emissions in European conventional and organic dairy farming, *Agriculture, Ecosystems and Environment,* Vol. 112, pp: 221-232.

Weiss, F. and Leip, A. (2012), Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model, *Agriculture, Ecosystems and Environment,* Vol. 149, pp: 124-134.

Wood, S. and Cowie, A. (2004), A review of greenhouse gas emission factors for fertilizer production. IEA Bioenergy Task 38, Research and Development Division, State Forests of New South Wales, Cooperative Research Centre for Greenhouse Accounting, Uk, South Wales June 2004.

Zekri, S. and Romero, C. (1993), Public and private compromise in agricultural water management, *Journal of environmental management*, Vol. 37, pp: 281-290.

Zervas, G., Kalaisakis, P. and Feggeros, K. (2000), Farm animal nutrition, Greece, Athens: Stamoulis Publishing (in Greek).