Assay of a sustainable farming model for the Montemuro mountain (Portugal)

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Abstract: *This study constitutes an assay of a sustainable farming model for the Montemuro mountain (Portugal), integrated in project assigned "Integrated Management Plan of PTCON0025 Montemuro Site". This was developed by the University of Trás-os-Montes and Alto Douro (UTAD), which includes an action plan in the thematic areas of rural development, nature conservation and economic competitiveness, in disadvantaged areas of the mountain. The developed study aims to identify a number of proposals, given different scenarios, to implement a pilot-project of management model of a Natura/Mountain system type. This model must integrates a strategy to reverse the trend of abandonment of such spaces, promote the conservation of natural values through active management of traditional systems, be economically viable, socially attractive and conducive to more environmental gains. Given the multi-dimensional nature of sustainability as a result of interaction and complementarity between the economic, social and environmental dimensions, the planning of a farming system was carried through having for base the Multiobjective Programming (NonInferior Set Estimation Method complemented with Compromise Programming). Two objectives were considered to the mathematical formulation of the model. An economic objective - maximizing the gross value added - and the second target was the environmental scope - minimizing energy costs. Although the open nature of the obtained solutions to the developed models, it was evidenced that the balance between the considered objectives is established with the selection of the following activities: potato; temporary grassland, hay prairie, pasture, and use of community pasture. As livestock activities are always selected bovine of trunk Frisian breed and sheep. Bovines of local breed (Arouquesa) are also an option to consider in most of the situations, but in smaller numbers.*

Keywords: Agro-ecosystem management; ecological-economic modelling; farming systems; Sustainability.

Introduction

The Montemuro mountain site (PT CON0025) is one of 60 sites in the National List of Sites of Natura 2000 Network adopted by the Council of Ministers resolution nº 142/97. This site extends over an approximate area of 39 hectares, including part of the portuguese municipalities of Arouca, Castro Daire, Cinfães, Lamego and Resende. This is a typical mountain territory, with irregular declivity and steep slopes, cut by several lines of water, where the highest point reaches 1300 meters and most urban areas are situated at altitudes above 800 meters.

The Montemuro mountain region is one of the areas classified as more expression in the North of Portugal, not only for its dimension, but especially for its importance to the preservation of the natural, environmental and landscape inheritance of the region. However, this is an unpopulated and aged area, as the generality of the inner regions of the country. At agrarian level is detached as the most outstanding features the following (Azevedo *et al.*, 2009):

- Agriculture is an activity in decay in all of the parishes that comprise the region, showing a negative evolution in the number of farms with usable agricultural area (UAA) and in the UAA also;
- The agrarian structure is dominated by small farms, with a high degree of fragmentation;
- The woods and heath-land occupied most of its 38.762 hectares, being the area devoted to agricultural crops about 10% of the total surface;

- Given the soil and climate conditions specific of this area, permanent pasture occupy most of the UAA, providing supply for livestock of local farmers and those from regions further south, to the Estrela mountain;

- Cereals for grain, especially corn and rye, and, to a lesser degree, grass crops and forage, dried leguminous vegetables and potatoes are the most important annual crops, but they have been also to decline sharply;

- The vineyards and fresh fruits are the permanent crops with higher expression and the apple orchards and cherry trees have a very significant weight, nearly 600 hectares of orchards;

- The chestnut is one of the few cultures that have been developed positively. However, the local dimension of this activity is still very low;

- The livestock activity, the main source of income of the residents in the Montemuro mountain, is also rapidly decreasing. The cattle and small ruminants are the predominant livestock species in the study area, being the meat of the local cattle breed Arouquesa and of kid goat qualified with Protected Designation of Origin (PDO) and Protected Geographical Identification (PGI).

This study constitutes an assay of a sustainable farming model for the Montemuro mountain (Portugal), integrated in project assigned "Integrated Management Plan of PTCON0025 Montemuro Site". This was developed by the UTAD, which includes an action plan in the thematic areas of rural development, nature conservation and economic competitiveness, in disadvantaged areas of the mountain.

The developed study aims to identify a number of proposals, given different scenarios, to implement a pilot-project of management model of a Natura/Mountain system type. This model must integrates a strategy to reverse the trend of abandonment of such spaces, promote the conservation of natural values through active management of traditional systems, be economically viable, socially attractive and conducive to more environmental gains.

Methodology

The preparation of a farm plan, following the multi-dimensions of sustainability, was carried out using the Multicriteria Decision Theory paradigm, indicated by Marta-Costa (2008).

The combined use of different operative techniques of multicriteria decision with the development of mathematical programming models, including technical and economic data characteristics of regional activities, reveal to be "tools" of great significance for the development of systems to support decision making of managers and farmers (Carvalho, 2007). This is because the process of decision making in agriculture is a complex procedure that must take into account the different objectives, often in conflict, from the various actors involved (farmers, planners, politicians, consumers).

The concept of agricultural sustainability, integrating environmental, economic and social dimensions, has significantly increased the complexity of decision-making process, given the large number of targets involved and the conflict often generated in its optimization (Carvalho, 2006). This is because an increase in the level of performance of one of them may be accompanied by a decrease of others.

The economic competitiveness and environmental sustainability were the main objectives of the delineated model. These dimensions, as referred by Müller (1996), may be considered, in the short term, in conflict, recognizing in the long term, the interdependence more or less complementary between them. However, it isn't possible to attain sustainability through maximizing their targets simultaneously. It is necessary to find a balance to achieve it.

In order to arrive at the final farm plan Multiobjective Programming, in particular NonInferior Set Estimation Method (NISE) complemented with Compromise Programming, was used as methodology.

Mathematical model

The model constituted by 135 variables and 103 constraints (annex 1) was resolved with LINDO - Linear Interactive aNd Discrete Optimizer (LINGO 10 software), based on the operational aspects of the NISE method and of Compromise Programming, indicated in Cohon (1978); Zeleny (1982); Romero and Rehman (1989); Romero (1993); Poeta (1994); and Marta-Costa (2008).

The mathematical formulation of a model of an agro-sustainable farm was performed for two different scenarios: with (actual scenario) and without financial support (potential scenario) to the current activities integrated on the Common Agricultural Policy. In the real socio-economic context the subsidies exists and, for that, is interesting its integration into the model (scenario with financial support). Moreover, it is assumed that the subsidies may be a situation not sustainable in the long term. Because of that it is also necessary provide information about the situation in which financial support is nonexistent (scenario without financial support).

Two objectives are considered. The first objective, an economic objective - the maximisation of Gross Value Added (GVA), that is, the difference between selling products and buying goods and services, expressed in euros. For the situation where is considered the financial support to current activities in the form of subsidies, it was included its value in this objective, associated with its specific activity supported.

The second objective reflects environmental considerations - the minimisation of energy costs, expressed in megajoules (MJ), corresponding to the purchase of goods and services to the productive activity. The used energy coefficients were obtained from the reference for energy analysis adopted in the context of the "PLANETE" methodology - Méthode Pour L'ANalyse EnergéTique de l'Exploita-tion" (ENESAD and ADEME, 2002).

This first objective was selected since a farm's survival requires greater monetary incomes obtained via active participation in the market, i.e. the sale of products. The farm profitability is an essential condition for its sustainability and, consequently, for the economic development of the region and also a strong contribution for the human fixation in the territory. This objective was translated into the maximisation of the GVA, as this result can easily be processed in the form of a linear equation or inequation.

With regard to the second objective, it was intention that it would reflect the environmental considerations. Thus, among other possible objectives (for example, minimised water consumption, minimised consumption of pollutant factors of production - fertilizers and crop protection products, minimised use of machines and equipment in the ground, among others) the minimum of energy costs seemed the most suitable given the possibility of quantification of the energy cost in terms of each factor of production used. Even the consumption of water is implicit in this objective through the energy associated with the fuel needed for irrigation (for pump or sprinkler) (GPPAA, 2001).

This objective is framed in light of the fact that energy efficiency is an important factor to optimise, in the global economy, being a direct indicator of sustainability. Investigations into aspects of energy illustrate that its use is generally related to greenhouse gas emissions and to the depletion of natural resources. In order to reduce both effects, potential ways to save energy in farming must be identified (Moerschner and Lücke 2002), this being the main factor that induced the identification of energy saving as the second goal of farm planning.

Using this approach, it is proposed to improve the economic-environmental conditions of observed farms in the Montemuro mountain, through two deliberately chosen areas: (1) competitiveness in the market with products that present greater GVA and (2) minimal energy costs.

Other goals directly linked to this theme are found in the model, not directly as in the two previous ones, but imposed under the form of restrictions.

The mathematical formulation of the agro-sustainable farm model obeyed, still, a few assumptions which are exposed below.

- The model was constructed based on the information of the geographical area under study;

- The various parameters and technical coefficients were defined according to average characteristics of the farms. Others were based on data published in the literature (INRA, 1988; GPPAA, 2001; Moreira *et al.,* 2001). The price level of inputs and products in producers were obtained some of them by direct inquiry and the others by consultation of prices available on the website of the Information System of Agricultural Markets (http://www.gppaa.min-agricultura. pt/sima.html) and on the available statistics (INE, 2005);

- The availability of inputs was defined according to the average characteristics of the farms. For example, the self-owned area of the planned farm was coincident with the average size observed in the universe of farms in the Montemuro area, indicated in official statistics (3.6 hectares, INE, 2001). It was also considered as a familiar labour force available the deriving from the elements of the parental household (2 units);

- It was considered two different situations for the use / cleaning of the uncultivated commons land. First it was taken into account the practice of local grazing by farm animals. So, in this case, the pastures of the uncultivated commons land are just used / cleaned by the local breed of cattle Arouquesa and small ruminants and only during the summer, as indicated by Moreira *et al.* (2001). In the second situation it was considered that the uncultivated commons land is cleaned using mechanization. The fodder is cut and given green to the animals of any species present in farm and during all year;

- It were identified as main vegetable activities those observed in the Montemuro farms, namely potatoes, corn grain, corn fodder, rye, temporary grassland, permanent pastures for hay and for forage morass;

- The considered livestock activity is related to the raise of cattle, sheep and goat for meat and / or milk from different breeds. For the first it was considered adult cows of local breed Arouquesa and Frisian trunk, but with situations of descent (F1) of pure animals or resulting from crosses with beef breeds (not pure). For animals from trunk Frisian breeds it were also identified situations in which the calves are sold for slaughter to an average age of nine months, as found for the young descent of Arouquesa cows, and situations in which the cattle are sold on the birth. The sheep and goats raising has as objective the meat, milk and / or cheese production;

- The sale of products activities included the principal products derived from the established vegetables (potatoes, corn grain, rye and hay) and livestock activities (meat, milk and cheese) and also the sale of secondary goods (manure). The first ones constitute the main source of revenue. To develop this model, it was considered that all these crops are sold, including those intended for consumption by the family and the re-employment as a seed or used for animal feed (this is included as a variable charge in the calculation of coefficients of the objective function). The hay is traded only in cases where its production exceeds the needs of the animals. The rye straw is fully used in "beds" of the animals;

- It was considered the existence of provided flow in the market of the main products produced on the farm. The only exception was for the sale of manure because, although the existence of market for this product, its transaction occurs in limited levels;

- It was also taken into account the possibility of renting of land (limited to 25% of self-owner area), hand labour and mechanical traction, the purchase of fertilizers and food for cattle, with the objective that these factors were not restrictive to the expansion of the production process;

- According with practices often developed in the study area and taking into account the environmental conditions, there were established restrictions on the succession of crops and crop rotation. In the first was that the intercalary crops (green fodder) succeed or antecede, in the same year, the cultivation of potatoes and / or corn. For the latter it was taken the rotations of rye with potatoes and temporary pasture and also corn in rotation with temporary pasture. It should be noticed that this type of cultural practices have not only a great environmental but also an economic importance, mainly for reasons of fertility and health of crops. In crops, mainly cereals, as indicated by Ferreira *et al.* (2002), the rotation is

especially important to increase the biological fixation of nitrogen and soil organic matter, given the difficulty in obtaining and applying organic fertilizers over large areas;

- In the context of rational fertilization, that is, fertilization by measure, indispensable to obtain the best economic returns from agricultural production and to the preservation of the environment quality, namely the protection of surface and groundwater pollution (eutrophication) (MADRP, 1997), it were elaborated a number of constraints related to the use of fertilizers. These restrictions ensure that the consumption of principals nutrients necessary to vegetable activities are equal or less than the quantity conveyed by manure incorporated into the soil and by synthetic chemical fertilizers bought to the exterior. It was considered the nitrolusal 20.5%; the foskamónio 7-14-14 and the superphosphate of calcium 18% as the most widely used fertilizer, decompose into its elements (nitrogen, phosphorus and potassium);

- It was yet imposed to the model a reasonable use of nitrogen that does not exceed the amount per hectare specified in the EC's Nitrate Directive (EC, 1991). The objective is to protect the underground water from extreme contamination by agricultural nitrates and, in particular, from manure. The amount specified per hectare is the amount of manure that will hold 170 kg of nitrogen (Pau Vall and Vidal, 1999). The nutrient content and coefficient of utilization by crops of nitrogen from manure of livestock units was obtained from the "Código de Boas Práticas Agrícolas para a Protecção da Água contra a Poluição com Nitratos de Origem Agrícola" (Code of Good Agricultural Practice for the Protection of Water against pollution with nitrates from agricultural sources), published by MADRP (1997);

- To ensure the handle cattle compatible with the capacity of the natural environment, it was considered that the animal stocking density of farms must be less than or equal to three livestock units per hectare of Agriculturally-Used Area (AUA), in mountain areas, according to the "Good Agricultural Practices" (MADRP, 2003);

- The pasture production was estimated according to the values given in the document of Moreira *et al.* (2001): 12 and 5 tons of dry matter, per hectare, per year, for pastures more and less productive, respectively;

- The relationship between the production of grain and rye straw and the forecast production for uncultivated commons land were obtained from Santos (1991). Although this document refers itself to an area outside from the study area (rearing area of Barrosão cattle), it was considered as the approximated values for the Montemuro area, because both of them are situated in mountainous areas, with similar soil, climatic and floristic conditions.

Results

In this point there are presented the results of the two models outlined for Montemuro mountain, given the assumptions identified before. The used techniques allowed finding several solutions for each identified scenarios, being exposed in this work only compromise solutions. These solutions belong to the set of efficient solutions that are closer to the ideal solution (distance between L_1 e L_∞[1]). However, it is accentuated that belongs to the decision-maker to choose the options within the set of efficient solutions, dependent on preferences attributed to each goal and, consequently, the considered weights in the formulation of the problem. In the present situation were considered identical weights for each of the objectives.

It should be noted, nevertheless, that given the impossibility of the existence of a non-integer number of animals on farms, provided by the solutions of the initial model, it was searched new compromise solutions (changed compromise solutions). To do so, it was imposed to the initial models the condition that each livestock activity should be equal to the nearest whole number to that obtained with the first compromise solutions.

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[1] Points L_1 and L_∞ define the compromise set. They correspond to the efficient points closer to the ideal point.

The changed compromise solutions obtained in the model, in with and without financial support to current activities scenarios, are in Table 1.

Table 1. Obtained compromise solutions to the developed models, in with and without financial support to current activities scenarios

Extreme points	Without financial support		With financial support	
	L_1	L_∞	L_1	L_∞
Objectives				
GVA (€)	16.288,871	9.587,9554	18.747,7181	13.222,154
Energy costs (MJ)	246.827,465	146.435,1072	243.666,2572	159.572,1016
Principal decision variables				
Irrigated land (Ha)				
Potato	0,2040	-	-	0,3075
Rye	0,2040	-	-	-
Temporary pasture	0,2040	0,612	0,612	0,3045
Intercalary crops	-	-	-	0,1754
Dry land (Ha)				
Potato	0,6178	0,7379	0,8128	1,2644
Permanent and community pasture (Ha)				
Hay	0,7841	0,7841	1,4832	1,0317
Pasture	1,5919	1,5919	1,5919	1,5919
Community land with grazing by farm animals	5,1492	0,9092	2,9613	1,4012
Cattle (LU)				
Arouquesa (pure F1)	1	-	1	2
Frísia (pure F1 – sale 0 months)	1	-	1	-
Frísian Trunk (not pure F1 – sale 0	6	4	6	5
Sheep and goats (LU)				
Sheep (meat and cheese)	30	17	28	9
Crops and animal products sale (kg)				
Potato	9.703,739	8.515,302	9.380,255	18.472,68
Hay	5.513,064	7.240,944	11.386,5	7.406,462
Cow milk	44.550,80	25.457,6	44.550,8	31.822
Sheep cheese	1.080	612	1.008	324
Bovine manure	70.000	39.545,47	70.000	48.131,12

Table 1. Obtained compromise solutions to the developed models, in with and without financial support to current activities scenarios (cont.)

Extreme points	Without financial support		With financial support	
	L_1	L_∞	L_1	L_∞
Inputs purchase (kg)				
Dry arable land	0,0058	0,1259	0,2008	0,6524
Irrigated pastures			0,6992	0,2476
Man power (hours)	47,8777		58,2390	
N	31,3911	56,6191	57,1562	86,6085
P_2O_5	35,4034	81,6171	42,0593	101,0783
Corn grain	473,9619			1,4457
Comercial concentrate	37.145,447	20.148,123	35.740,12	20.411,242
Corn silage	33.176,872	27.280,914	35.658,743	18.519,747

Source: The authors' findings.

Observations: (1) For products of activities with different ends, only the portion sold is presented, with the rest reused on the farm (cases of manure and plant products).

(2) With the exception of animals for replacement, the remaining born is for sale, as well as refuse animals.

The analysis of the solutions obtained allows the following observations:

- The relationship of conflict between the considered objectives is confirmed, since the rise of GVA indicate an increase in its energy costs;
- The selected models activities reflect an accentuated use of the areas by crops connected to the cattle activity. For example, irrigated temporary grassland is an activity always present. The dry arable land is, in general, occupied with potatoes;
- The areas of permanent pastures for hay and for pasture are fully used, as imposed to the models. When the financial supports to current activities are considered it is necessary to rent irrigated pastures. The pastures from the common lands are used/cleaned directly by the animal grazing, rather than mechanical cleaning. They are generally consumed in a proportional relationship to the cattle identified in the solutions;
- Among the various hypotheses provided to the model for the cattle activities, it occurs, in all the solutions obtained, the selection of Frisian trunk animals with sales to the birth of their not pure young, in numbers ranging from 4 to 5 animals. Arouquesa cattle should also be present on farms, in number between 1 and 2 livestock units, with the exception of one solution. Pure cattle of Frísia are only considered in two solutions, which coincide with those where the economic objective assumes greater values (points L_1). In such solutions it is also denoted, in general, a higher number of Frisian trunk than the others solutions;
- In the context of small ruminants, the model considers, in all compromise solutions, the existence of sheep for meat and milk, being this entirety processed in cheese;
- It is observed the sale of vegetable products of the farm, including hay, when the availability exceeds the needs of the animals. This situation occurs mainly by the replacement of those foods for others with high content in protein and with lower volumes of dry matter (commercial concentrate and corn silage);
- Also manure is sold to the imposed limit, except in solutions whose environmental objective is improved;
- The hiring of temporary labour was relatively low, being only required in two situations that coincide with the highest animal density. It should be noted that while minimizing temporary labour is not a clearly objective defined in formal model, but identified indirectly on the objective of maximizing GVA through its economic cost, it was important its reduction due to scarcity of available temporary labour in the region. In fact, it is also observed the surplus of labour in all obtained solutions, but with non-uniform distribution for the periods in question;
- Also with the traction it is verified that the existing availability is more than sufficient for the needs and is not necessary to hire it;
- The quantities of fertilizers to be acquired to the exterior vary inversely with the amount of manure applied to land;
- The commercial concentrates and corn silage are identified in a proportional relationship with the cattle of Frisian trunk breeds. This should be distributed on a regular basis throughout the year.

Final considerations

Two models of agro-livestock farming for two distinct scenarios (with and without subsidies at current activity), in the context of sustainability, are presented in this work. The used techniques allowed the finding of various solutions and, to this extent, the system can be considered open. This means that all of the solutions present advantages and inconveniences, when the results are analysed within possible alternative scenarios with diverse socio-economic circumstances and where goals can have more or less importance.

Based on the obtained extreme compromise solutions, considering equal importance for considered goals, it appears that the balance between them is given to the selection of potato activities (irrigated and dry), temporary grassland (irrigated), marshes and hay grazing, and the use of

uncultivated common land. As livestock activities are always selected animals of Frisian trunk (between 4 to 6 animals with not pure descendants and 1 animal with pure progeny), for production of meat and milk; and sheep for meat and milk (between 9 to 30 adult animals), the latter being all transformed, in cheese, in order to ensure the economic performance of the farm. The animals of Arouquesa breed (the local breed) are also an option in almost all situations, ranging from 1 to 2 adult cows.

The development of defined models and its solutions have raised a few points, bearing in mind the framework of the objectives that pretends to be achieved. There are:

- The area of farms is one of the main limitations of results. Increasing the limit of the leased area, for example, the solutions differ from those achieved initially by improving economic performance. Moreover, on the hypothesis of food requirements relating to livestock activities were mainly fulfil by at least 50%[2] of food produced on farms this results in a absence of any livestock activity, with a penalty in its economic performance;
- There is a large surplus on labour force (in same periods) and in traction. In this sense, for labour force that is not used it is necessary to find alternative ways for its employment. Likewise, it must be considered the sale or use of machinery and equipment with very high hourly costs in exteriors works, to turn it profitable;
- The level of subsidies for animals of local breeds does not appear sufficient to encourage their raise, nor for overcome the profits from the animals of exotic breeds.

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[2] Condition defined in "Standard for Beef Cattle" in the Extensity Project - Environmental Management Systems and Sustainability in Agriculture Extensive. Its objective is get the forage-livestock balance obtained on the farm, but also to assure the autonomy of the production unit, fundamental condition to its sustainability (Domingos *et al.*, 2005).

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Annex - Mathematical model

1. Objective functions

The objective function Z_1 represents the economical objective, in this case the maximisation of the GVA, in Euro. This economical result is calculated by the difference between the value of the sold productions and the consumption of the variable production factors acquired to the exterior. For the situation that subsidies are considered, its value was included on the objective function (Z_1').

The objective function Z_2 represents the environmental objective, the energetic costs minimisation, express in Megajoules, that correspond to the goods and services purchased on the Z_1 function.

2. Constraints

The constraints system of the identified model was grouped into sixteen main categories, which are enumerated next. Its conception is based on the expression of the farm unit can do, that is, its field of choice and how it relates to the technological characteristics, the available resources, the satisfaction of demand and the limits of the market, having as base environmental conditions and the farm autonomy.

– Restrictions on use of land (Ha);
– Restrictions on use of manual labour (H);
– Restrictions on use of traction (H);
– Restrictions on use of fertilizers (Kg);
– Restrictions on nutritional balance of livestock with food from different situations for the use / cleaning of the uncultivated commons land (Kg of dry matter - DM);
– Restrictions on nutritional balance of livestock and on the sale of products supplied by agriculture (Kg);
– Restrictions on nutrition of livestock (Fodder unit - UF);
– Restrictions on nutrition of livestock (Kg of digestible protein in the intestine - PDI);
– Restriction on the maximum food ingestion capacity of livestock (Kg DM);
– Restriction on the minimum ingestion of food produced on farm (Kg DM);
– Restriction on the sale of products supplied by vegetable activities (Kg);
– Restriction on the sale of meat (Kg);
– Restriction on the sale of milk (Kg);
– Restriction on the sale of cheese (Kg);
– Restriction on the sale of manure (Kg);
– Restriction on animal stocking density (LU).