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Sustainable Milk Production: Application of the Hierarchical Analytical Process Towards A Regional Strategic Planning

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Abstract

Milk corresponds to 20% of the Brazilian agribusiness GDP and its production is concentrated at Minas Gerais State. Different milk production systems co-exist in this region, which results in different sustainability performance and call for a multi-criteria analysis to subsidize decisions towards a regional milk production planning. This work uses the Analytical Hierarchical Process (AHP) to hierarchize milk production systems as for their sustainability. A cluster analysis considering 92 milk producers identified five distinct production systems: G1, G2, G3, G4, and G5. Social, economic, and environmental indices are calculated and used in the AHP to prioritize sustainability according to the decision-maker's egalitarian, or hierarchical, or individualist profiles. Results indicate that system G1 features higher priority degree (higher sustainability) for all three profiles compared to other systems assessed, reaching 27% for the egalitarian, 31% for the hierarchical, and 31% for the individualist profiles. The worst performances were fared by system G4 in the egalitarian (12%), and hierarchical (13%), and by system G3 in the individualist profile (10%). Numbers could be considered by decision makers in order to subsidize a strategic planning towards a sustainable regional milk production, whereby a given system could be politically, technologically, and economically prioritized in detriment of another. Notwithstanding, the objective approach discussed in defining criteria and their weights could be useful in future studies related to a hierarchization of sustainability of any production system in different regions.

1 Introduction

Among the greatest cow milk producers worldwide, Brazil ranks in the fourth position, reaching 5.3% from the total, behind the United States, India, and China. The importance of the dairy sector to Brazil is evidenced

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by the practically nationwide spread of producers, by the employment of more than 3 million workers throughout the production chain, and by the strong 20% influence in the national agribusiness gross domestic product (GDP). The recent 35 billion liters production allied to the goal of reaching 41 billion liters by 2023 renders milk a highly socially and economically important agricultural product for Brazil (CEPEA, 2014).

The state of Minas Gerais is the greatest milk producer state in Brazil, accounting for 27% of the total volume (IBGE, 2014). Eleven percent of that production comes from the south region of the state, where several production units exist, featuring variable levels of intensification, handling, productivity, and production. This variety results in different economic, social, and environmental performances, when individually assessed, but also regionally due to its spatial distribution in the milk-producing region. Under a regional perspective, those differences could be perceived as positive, assuming a higher diversity could result in a higher flexibility and resilience against external pressures, e.g. market price fluctuations. On the other hand, the large regional diversity of production systems may hinder decision-making on macro-scale strategic planning of the forwarding of governmental incentives aiming at improvements on the regional milk production sustainability. One question is, for instance, which milk production system should receive more incentive (economic or technical) through which regional production sustainability could be improved? Finding a simple and direct answer to this question is a tough task, due to the multi-criteria characteristic of the concept of sustainability. One rarely finds, for example, a production system - whatever type it may be – that has better economic, social, and environmental indices simultaneously compared to the alternatives. In this sense, the aid from decision-making tools is necessary.

Among the tools available in scientific literature that are designed to aid decision-makers' choices among alternatives considering multi-criteria, the Analytic Hierarchy Process (AHP; Saaty, 1991) is the one that has been used the most. Additionally, AHP deservedly stands out as it presents itself as a versatile tool that can aid with both simple and complex analyses based both on quantitative and qualitative elements. According to Saaty (1991), AHP is a decision-supporting methodology which, based upon establishing hierarchies aiming the establishment of priorities, and the use of a constant logic makes it an effective decision-making tool. AHP has been used in most varied study fields, such as the energetic (Tsoutsos et al., 2015; Abudeif et al., 2015), transportation sector (Macharis and Bernardini, 2015), management of supply chains (Boukherroub et al., 2015), agriculture (Veisi et al., 2016; Zhang et al., 2015; Karami, 2006; Chavez et al., 2012), health sector (Liberatore and Nydick, 2008), manufacturing processes (Bang and Chang, 2013), among others. Although recognizing the AHP as an important alternative tool to subsidize decisions, its results are strongly dependent on criteria definition and weights (*i.e.* importance) applied on them (Tsyganok et al., 2012), and this issue is rarely addressed by the majority of works that have used AHP (Russo and Camanho, 2015). Thus, besides applying AHP to support decisions on sustainable milk production, this work contributes towards a detailed and objective presentation of methodology applied in defining criteria and its weights.

The aim of this work is to use AHP to hierarchize the milk production systems in the south of Minas Gerais state as for their sustainability based on multi-criteria analysis. It is expected that this type of ranking can be used in subsidizing decision-makers in the strategic planning of regional scale milk production. Additionally, the methodology used in this work could be applied in other study-cases and regions.

2 Methodology

2.1 Cluster Analysis

The south region of the state of Minas Gerais studied herein (Figure 1) features varied milk production systems, with different productivity indexes, feed types, handling methods, level of technology applied, and management. The Brazilian Agricultural Research Corporation (EMBRAPA; Assis et al., 2005) classifies milk production systems in four main types: (i) extensive system, featuring under 1,200 L_{milk}/year per-animal productivity, and exclusively pasture-fed animals; (ii) semi-intensive system, featuring 1,200 to 2,000

L_{milk}/year per-animal productivity, pasture and forage based feed during drought seasons; (iii) intensive system, with 2,000 to 4,500 L_{milk}/year per-animal productivity, high nutritional quality pasture and forage based feed, with occasional ration feeding on certain periods of the year; (iv) intensive system with full confinement, per-animal productivity above 4,500 Lmilk/year, ration based feeding throughout the year. During *in loco* primary data collecting period, however, an operational difficulty was faced in classifying the production units under the four types defined by the Assis et al. (2005). The intensification of milk production systems is continuous, free from established limits, which results in difficulties classifying those systems as per by the EMBRAPA-established types. In other words, those units could fit two or more classification types, which generated the call for a cluster analysis, aimed at grouping the systems with similar features.

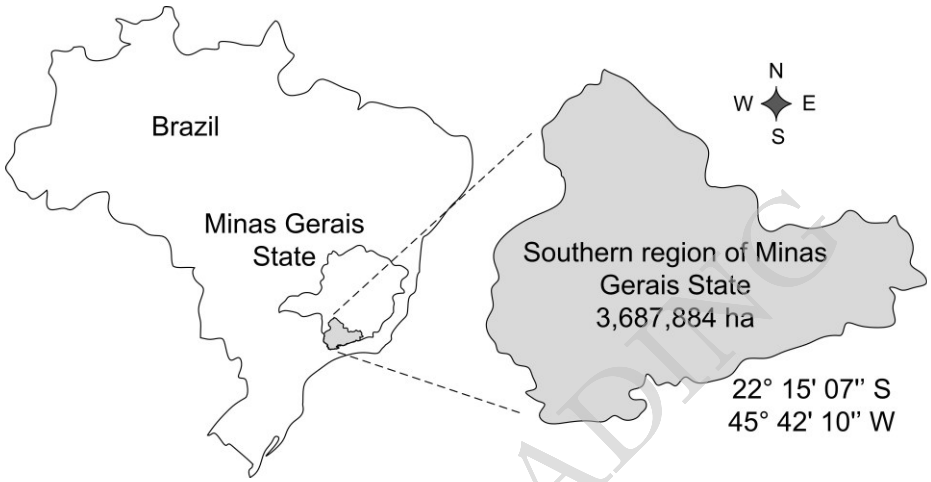

Fig.1. Geographical location of the Southern region of Minas Gerais State, Brazil.

For that purpose, the production systems were re-classified into three types: (i) extensive system, whereby animals are raised in pastures and fed supplementary forage during drought periods; (ii) semi-intensive system, with animals raised in pastures but are fed ration and supplementary forage throughout the year; (iii) intensive system, with animal total confinement, which are fed ration and forage. This new classification form was validated – through personal communication – jointly with the technical staff at State Institute of Agriculture (IMA), Technical Assistance and Rural Outreach Corporation (EMATER), and some regional dairy industry professionals. For the cluster-analysis, 92 milk production systems were considered as south-of Minas-Gerais regional production samples. Social, economic and environmental information were obtained *in loco* by means of questionnaires. Using Microsoft Excel® add-in software "Action 2.5" (www.portalaction.com.br), a cluster analysis on these systems was run considering the following criteria for grouping: (i) L_{milk}/cow day, (ii) L_{milk}/labor day, (iii) L_{milk}/ha yr, (iv) animals/$ha_{pasture}$; (v) kWh/L_{milk} yr, (vi) kg_{ration}/ L_{milk} yr, (vii) animals breed. A maximum of five similar milk production systems was established, based upon the authors' knowledge on the existing production systems in the region, the Assis et al. (2005) classification standard, which considers four different production system types, and a validation by local cattle breeders, via personal communication.

After identifying the five groups, only one property was selected as representative of the group, and considered for a case study. This selection results from using the productivity index (L_{milk} /cow day), considering the property with productivity closest to the its group average. Such approach was used in detriment of average values from each group, since it was desirable that the properties considered for case studies be real ones, not hypothetical.

2.2 Analytical Hierarchy Process (AHP)

Developed in the 1970's by Thomas Saaty, AHP aids decision-making in a wide range of human-relations areas. According to Saaty (1991), AHP collaborates to the study of systems by means of a sequence of comparisons of indicators in pairs, linking the results to the global aim. Saaty (1994) argues that being able to work quantitative and qualitative aspects simultaneously is one advantage offered by this method, by means of which a hierarchic sequence of priorities is put forward.

AHP basically consists of (Figure 2) (i) hierarchically structuring the process, starting out by setting the global objective, on to establishing the assessment criteria, calculating indicators, and, finalizing with the alternatives; (ii) establishing indicators for each criterion and comparing the alternatives, considering the indicators established under an importance rate between each pair. This importance rate is represented by a scale from 1 to 9, where 1 means "of equal importance", whereas 9 stands for "extreme importance"; (iii) as a result, an auto-vector with relative weights is obtained for each sequence of comparisons. Detailed information on AHP definitions and methodology are available on Saaty (1991; 2008); Appendix A presents the procedures in assigning importance to indicators on AHP as considered in this work.

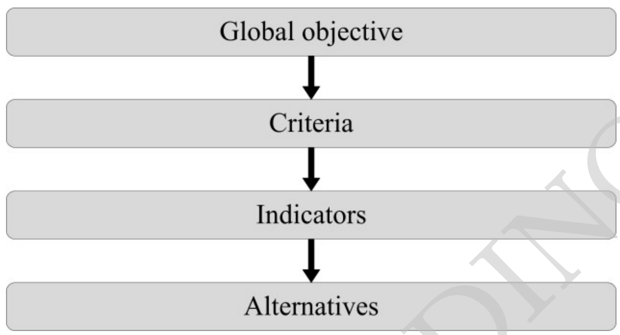

Fig.2. General application structure of analytical hierarchy process (AHP).

In this work, AHP is used with the aid of Expert Choice® software, to rank the milk production systems in the south of Minas Gerais state as for their sustainability, which is the global objective of the analysis. The following sections feature detailed criteria and indicators considered in the AHP analysis. Among several sustainability models and their interpretations (see for instance Paracchini et al. (2015) that have considered the Agronomic, Economic, and Ecological dimensions to express sustainability of farms), this present work considers as for criteria, social, environmental and economic perspectives, since they are the pillars of the sustainability conceptual model adopted herein. Three indicators were considered for each criterion: traditional economic and social indicators, and environmental indicators derived from Emergy Accounting (with an "m"; Odum, 1996). Alternatives were obtained from the previously presented cluster analysis.

2.2.1 Establishing criteria and weights

While an objective approach is used for comparisons among indicators – since indicators result from quantitative and objective data –, the intermediary scale that results from the AHP structure (Figure 2) is of subjective nature. In other words, assigning weights for the social, environmental and economic priority levels is a subjective task. According to ESI (2005), different methods for determining weights have been developed, including statistic tools, and the opinions of specialists based on personal judgment. Statistically determined weights have the advantage of being considered as neutral, *i.e.*, data-dependent. However, statistic weights do not always reflect decision-makers' priorities, or budget restrictions that limit the choices diversity.

Subjective pondering can usually be done in three distinct ways: (i) by the analyst's assuming values which he/she considers as satisfactorily representative of reality, according to their experience with the theme (see for instance Paracchini et al., 2015); (ii) by means of a community approach whereby methods of participative diagnosis are used in specialists meetings aiming to reach a consensus over adequate weights (see for instance Chavez et al., 2012; Karami, 2006; Shrestha et al., 2004; and Reed et al., 2014); (iii) by using quantitative data from related published works. The participative approach could be considered the best option, however, due to the time necessary for the application procedure, the specialists' willingness to participate, and the costs involved, it was decided to use approach "iii", using Ecoindicador 99 data (Goedkoop and Spriensma, 2000). Ecoindicador 99 is one of the existing methodological approaches inside the calculus structure of Life Cycle Assessment methodology. Table 1 shows the weights used in Ecoindicador 99, which were previously obtained by means of participative diagnosis methods. In a general sense, depending on the cultural perspective (or psychological profile) of an individual, the weight assigned for each category may differ. An individualist, for example, perceives human health as more important than capital reserves, whereas one with a hierarchical profile understands that there must be a balance between human health and eco-system quality, so reserves deserve less attention.

Table 1 Weights considered for the AHP criteria.

Individual's cultural perspective		Category		
		Human health	Eco-system quality	Reserves
Egalitarian	Reserves cannot be controlled, but wishes can (substituting reserves for alternatives).	30%	50%	20%
Hierarchical	Wishes or needs cannot be controlled, but reserves can.	40%	40%	20%
Individualist	The exhaustion of fossil fuels is not perceived as an actual problem, but the decrease in mineral resources is.	55%	25%	20%

Adapted from Goedkoop and Spriensma (2000). Human health: carcinogens, respiratory diseases, climatic changes, ozone layer depletion, ionizing radiation; Eco-system quality: acidification, eutrophication, eco-toxicity, territory use; Reserves: availability of minerals and fossil fuels.

An analogy is made in this work between Ecoindicador 99 (Table 1) categories with the economic, social, and environmental criteria featured in the sustainability conceptual model considered herein, where: human health category corresponds to social criteria, eco-system quality to environmental, and reserves to economic. As for the social scenario, the government favors social issues in its long-term politics; as for the environmental scenario, environmental questions have reached levels so alarming that they are favored in decisions; as for the economic scenario, there is *business as usual*, *i.e.*, the same development standard focused on economic growth is considered. In this way, the weights presented on Table 1 can now be considered in the general structure of Figure 2.

2.2.2 Sustainability indicators

Instead of using recognizably important local environmental impact indicators, such as gas emissions (CO_2, CH_4, etc), areas occupied by pastures, among others, the focus of this work is on the assessment of regional milk production, aiming to provide subsidies to decision-making in a regional scale. Thus, emergy accounting was selected as the methodology to represent the environmental indicators, since it considers the donor of goods and services' perspective, instead of the willingness to pay. Emergy considers all the work performed by man and nature to generate and make available the resources used by the systems, even those considered as unveiled (Odum, 1996; Agostinho and Siche, 2014).

Table 2 shows a summary of indicators used in this work. For the social criterion, indicators relating to labor applied in production were used. For the economic criterion, the indicators related to product cost, gross profits, and productivity per animal. These indicators were used herein, as they are the most commonly used ones in milk production systems assessments (Vinholis et al., 2006).

Emergy accounting, introduced by Odum (1996) is based upon energy analyses of biological systems, in the general theory of systems, and systems ecology. Emergy is defined as the available energy of one type, which was previously directly and indirectly used to make a product or service. All energy and materials inputs that cross the boundaries of the system under study, either from nature or economy, are converted into energy units of the same kind, the solar energy joules (seJ). The quality of the energy is quantitatively expressed, in this methodology, by the unit emergy values (UEV), which is the relation between all the emergy demanded by a system to produce the available service or good. Further details on this methodology can be found mainly on Odum (1996) and Brown and Ulgiati (2002, 2004). The environmental indicators used in this work were obtained from the work of Oliveira and Agostinho (2015) who applied emergy accounting to assess the milk production systems evaluated in this work.

Table 2 Indicators used in this work to express sustainability of milk production systems.

Criterion/Indicator	Description	Source
Social Criterion		
h_{labor}/L_{milk}	Total labor hours employed in producing one liter of milk. The lower this indicator value, the higher the efficiency.	This work
h_{labor}/yr	Total labor hours employed in one year's production. The higher this indicator value, the better the performance.	This work
BRZ/h_{labor}	Average worker's wages. The higher this indicator value, the better the performance.	This work
Economic Criterion		
BRZ/L_{milk}	Cost of producing one liter of milk. The lower this indicator value, the higher the efficiency.	This work
BRZ/yr	Gross yearly profit by the production system. The higher this indicator value, the better the performance.	This work
L_{milk}/cow yr	Liters of milk produced per animal in one year. The higher this indicator value, the better the performance.	This work
Environmental Criterion		
seJ/L_{milk}	Emergy demanded to produce one liter of milk. The lower this indicator value, the higher the efficiency.	Oliveira and Agostinho (2015)
ESI	Emergy sustainability index. Values from 0 to 1 indicate low sustainability; values from 1 to 5 indicate moderate sustainability, whereas values higher than 5 indicate high sustainability. Dimensionless indicator.	Oliveira and Agostinho (2015)
EIR	Emergy investment index. Relates economy inflows and renewable and non-renewable natural resources. The lower this indicator value, the better the performance, as it indicates the system's efficiency in using the emergy invested. Dimensionless indicator.	Oliveira and Agostinho (2015)

BRZ is the Brazilian currency "Reais"; exchange rate in March/2016 is about 4 BRZ/USD American dollars.

3 Results and Discussion

3.1 Cluster analysis: identifying representative milk production groups

Table 3 shows the results from the cluster analysis, considering the five groups that were previously defined as representative of the milk production systems from the south of Minas Gerais state. Group G1 represents a highly technified semi-intensive system; group G2 comprises most of the semi-intensive systems; group G3 comprises all the extensive systems; G4 includes three intensive systems; G5 has two highly technified intensive systems. With the groups defined, the L_{milk}/cow day indicator pointed out the representative systems for each group as being property 77 for G1, 60 for G2, 46 for G3, 88 for G4, and 91 for G5.

Table 3 Cluster analysis summary.

Group	Classification	Production System	Average L_{milk}/cow day	Representative system in the group
G1	Semi-intensive	77	21	77
G2	Semi-intensive	47, 48, 49, 52, 53, 54, 56, 57, 58, 59, 60, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 73, 74, 75, 76, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87	12	60
G3	Extensive	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40,	5,5	46

		41, 42, 43, 44, 45, 46, 50, 51, 55		
G4	Intensive	88, 89, 90	20	88
G5	Intensive	91, 92	32	91

G1 representative is a farm property with 4,400 L_{milk}/day production, 21 L_{milk}/cow day productivity, animal feed based on grazing in pickets, ration and forages throughout the year, Dutch cattle, hired labor with a total of 6 employees. G2 is a small farm with a 360 L_{milk}/day production, 12 L_{milk}/cow day productivity, adding pasture and forages to ration during the winter, half-breed animals and family labor. G3 is a typical family extensive milk production system at 33 L_{milk}/day, 5.5 L_{milk}/cow day productivity, pastures demanding better handling, and family-labor force. G4 is an intensive system with total cattle confinement (so-called free stall model), using ration and forages as feed, and producing 1,060 L_{milk}/day, 21 L_{milk}/cow day productivity, hired labor with 4 employees. G5 also uses the intensive system with total confinement (free stall model), but producing 3,600 L_{milk}/day, 31 L_{milk}/cow day, cattle feed based on ration and forages, hired labor performed by 6 employees.

After identifying the groups established by cluster analysis and defining the representative systems within each group, the hierarchical analysis (AHP) to establish the system sustainability ranking for the southern region of Minas Gerais state could be carried out.

3.2 Sustainability indicators for the assessed milk production groups

Table 4 shows all indicator values for every milk production system assessed in this work. The social and economic indicators were obtained directly from the information given by the production systems owners, by means of questionnaires, and later validated by experts in agricultural production field who work in the region, via personal communication.

Table 4 Social, economic and environmental indicators for the assessed milk production systems.

Indicators	G1	G2	G3	G4	G5
Social Criterion (source: this work)					
h_{labor}/L_{milk}	0.015	0.044	0.242	0.030	0.014
h_{labor}/yr	18,368	4,592	2,296	9,184	13,776
BRZ/h_{labor}	5.62	3.08	3.08	4.62	6.42
Economic Criterion (source: this work)					
BRZ/L_{milk}	0.56	0.57	2.00	1.05	1.00
BRZ/yr	953,427	57,116	-13,259	39,723	194,883
L_{milk}/cow yr	7,665	4,380	2,008	7,300	11,680
Environmental Criterion (source: Oliveira and Agostinho, 2015)					
seJ/L_{milk}	2.67 E12	2.58 E12	13.60 E12	5.60 E12	4.30 E12
ESI[a]	0.17	0.39	1.36	0.05	0.06
EIR[a]	6.11	3.02	0.79	19.90	14.91

[a] ESI and EIR emergy indicators are dimensionless.

As for the social criterion, it is noteworthy that high-producing systems, such as G1 (4,400 L_{milk}/day) and G5 (3,600 L_{milk}/day) yield the best indicator values, as they demand greater yearly amounts of labor (18,368 h and 13,776 h, respectively) while simultaneously paying their employees the highest wages (5.62 and 6.42 BRZ/h_{labor}, respectively). For a comparison, Nascif (2008) obtained 778 L_{milk}/day and 9,592 h_{labor}/yr as representative average values for milk production systems in Minas Gerais state as a whole. Efficiency in the use of labor for milk production is also higher in G1 and G5. The G3 system yields the worst performance as for all three social indicators.

In the economic criterion, again G1 and G5 yield good indexes, in comparison with the other systems. It is noteworthy that G2 holds the best performance as for cost per liter of milk produced indicator, in comparison with G5, even though featuring lower productivity, and higher annual gross profit than G5. Again, one observes that G3 fares the worst performance as for all three economic indicators. It is worth it pointing out that all construction infrastructure, machinery and equipment associated with production was considered (considering their lifespan), not only the annual inputs. Thus, besides yielding only 33 L_{milk}/day, the G3 extensive system yields 0.85 BRZ/L_{milk}, which results in a gross profit loss of 13,259 BRZ/yr, as shown on Table 4. This can be explained by the prices paid for a liter of milk in 2013 that ranged from 0.85 to 1.15 BRZ, depending on the quantity and quality of the milk, and on a 0.90 BRL/L average cost of milk production in Brazil (CEPEA, 2014). The economic survival of G3 can be explained by the co-production of other farm products (coffee, corn, sugarcane, etc.), by the human services performed outside the property, by adding value to the milk by producing cheese, and, occasionally, by informal milk commerce in the region (which is prohibited by regulatory instruction 51/2002; BRASIL, 2002).

Opposing social and economic criteria, G3 has the best ESI sustainability index performance (1.36), and emergy investment ratio (EIR) index at 0.79, as compared to the other systems. Jaclik et al. (2014), for a comparison, obtained ESI values ranging from 0.04 to 0.16 for milk production systems under varied handling methods in Slovenia. On the other hand, G3's low productivity results in lower efficiency in use of emergy for producing milk (13.60 E12 seJ/L_{milk}), value higher even than those found by Vigne et al. (2013) for milk production in Mali and France (from 1.52 to 4.06 E12 seJ/L_{milk}). Systems G4 and G5 hold the worst performances under the environmental criterion, since they are far from the emergy efficiency obtained by G1 and G2, have low sustainability, and high emergy investment, that is, they demand plenty of resources from the economy.

3.3 Hierarchical analysis process towards a sustainable milk production

Figure 3 presents the hierarchical structure tree used in this work. By following this structure, three approaches are considered in the hierarchical analyses evaluation, as previously described on Table 1, for each cultural perspective of the decision-maker. The three approaches are separately discussed in the following sections, for a clearer understanding.

3.3.1 Decision-maker's cultural perspective: egalitarian

In this perspective, the environmental criterion is more important than the social and the economic ones (50%, 30%, and 20% respectively; Table 1), which, used simultaneously with the quantitative indicators of Table 4 on the Expert Choice® software, resulted in the hierarchical structure of milk production systems of the south of Minas Gerais, shown on Figure 4.

Figure 4 indicates that system G1, with a 27% priority level, has the best final performance, followed by G3 (25%), G2 (21%), G5 (16%), and G4 (12%). G1's representative system has its grazing area divided into pickets for better efficiency in production, and biomass consumption as feed, using forages and ration as complementary feed for the milk-production specialized cattle, and hired labor. Figure 4 indicates that G1 has lower priority than G3 and G2, under the environmental criterion, however, its better performance in the social and economic criteria renders G3 the highest priority system, when focusing on sustainability under the decision-maker's egalitarian profile.

It is interesting to notice that the priority level of G3 is very close to that of G1. Despite yielding the worst performances under the social and economic criteria, G3 shows the best environmental performance, which, under an egalitarian perspective that puts great importance on the environmental aspect, its priority level becomes similar to that of G1.

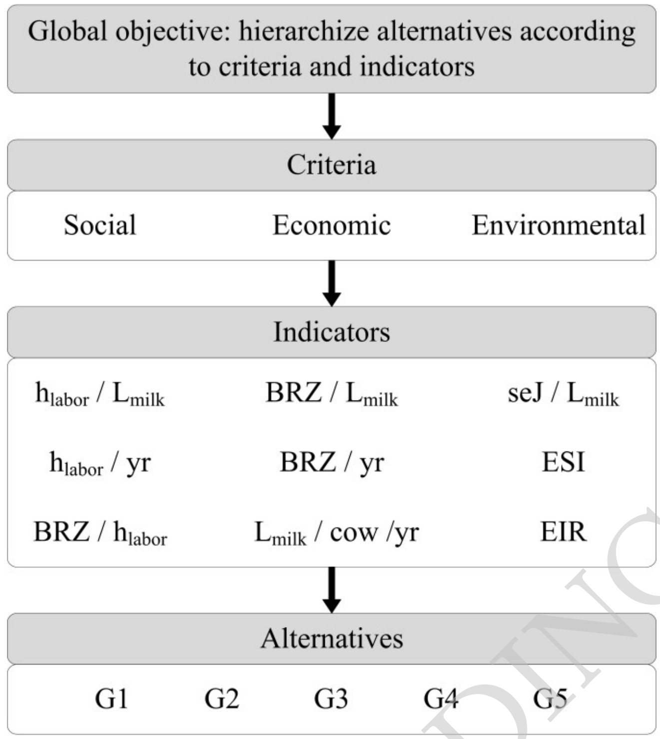

Fig.3. Hierarchical structuration tree of the evaluated milk production systems.

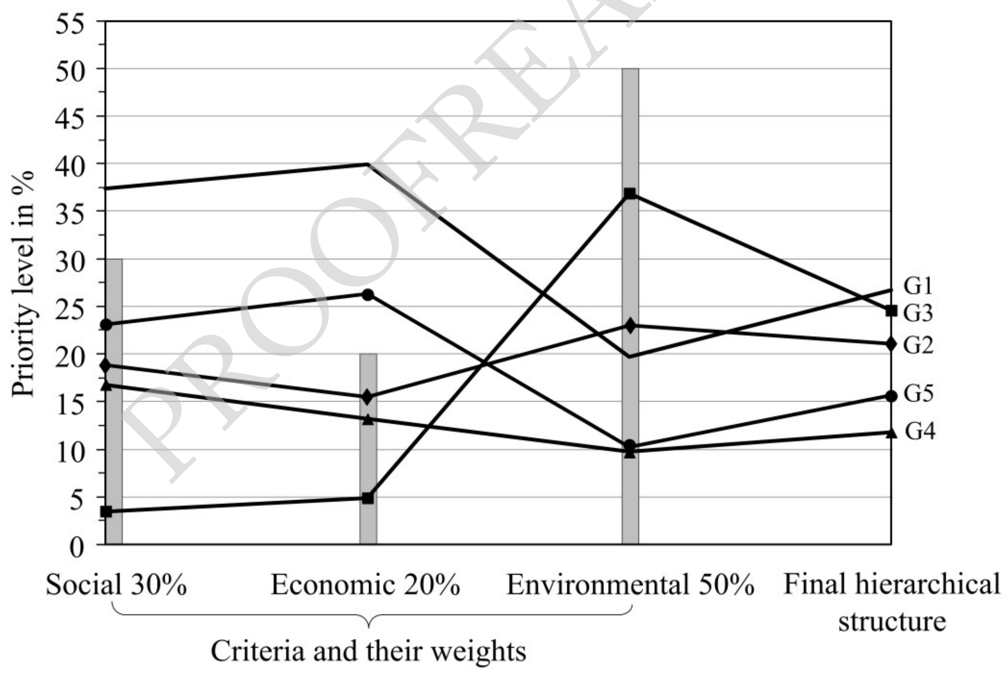

Fig.4. Hierarchical structure of the milk production systems of the south region of Minas Gerais state, according to decision maker's egalitarian cultural perspective. Weights for the different criteria from Table 1.

Still regarding Figure 4, system G4, which represents an intensive milk production system with total animal confinement, yields the worst performance under the environmental criterion, as compared to the other systems. It ranks in the fourth position under social and economic criteria, which results in a lower general priority level of 12%.

3.3.2 Decision-maker's cultural perspective: hierarchical

A manager with a hierarchical cultural perspective equally considers social and environmental criteria as for importance. Figure 5 shows the evolution of the pondering on production systems posterior to applying the hierarchical analysis. Under that perspective, hierarchy was so established: G1 (31%), G2 (20%), G5 (19%), G3 (17%), and G4 (13%).

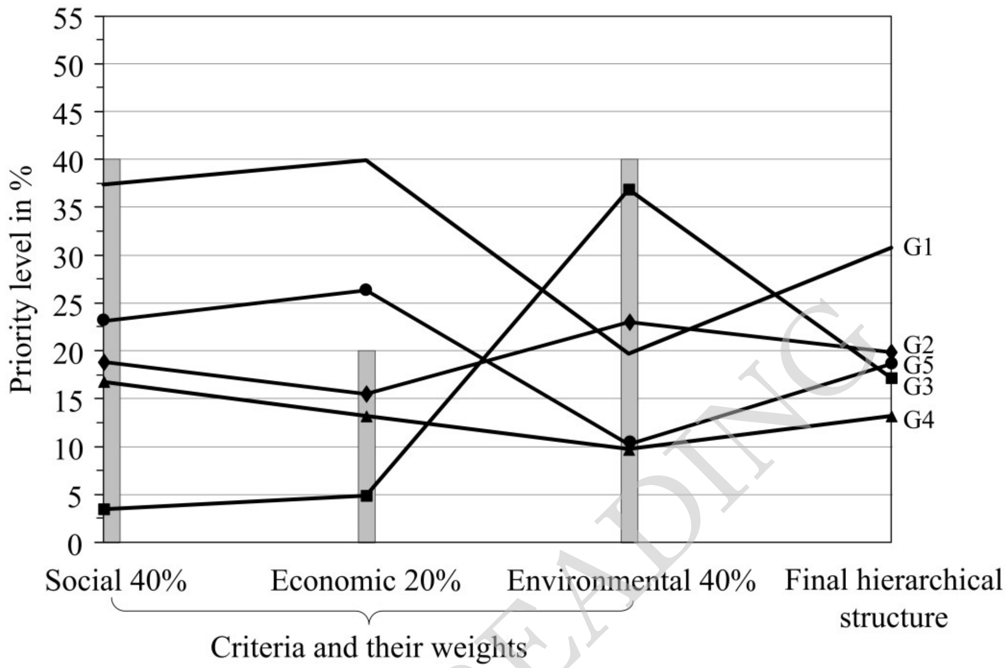

Fig.5. Hierarchical structure of the milk production systems of the south region of Minas Gerais state, according to decision maker's hierarchical cultural perspective. Weights for the different criteria from Table 1.

With social criterion's increase and the environmental criterion's decrease in importance in relation to the egalitarian profile, now the G1 yields an even better final performance, as compared to the other systems. Systems G2, G5 and G3 have similar priority levels, ranging from 20 to 17%. These systems were slightly differently characterized by the cluster analysis (semi-intensive, intensive, and extensive, respectively), nevertheless, the final AHP result shows that, for a decision-maker's hierarchical profile, all systems feature approximately the same priority level. G3 yields the best environmental performance; however, the performance of its social and economic indicators is worse than those of G2 and G5. System G4 ranks in the penultimate position as for social and economic performance, and in the last position in environmental performance, resulting in priority level of merely 13%, a performance inferior to those of all the other systems.

3.3.3 Decision-maker's cultural perspective: individualist

A manager with an individualist cultural perspective values the social criteria above the others. In this perspective, hierarchy was so defined (Figure 6): G1 (34%), G5 (21%), G2 (19%), G4 (15%), G3 (10%). One notices that under this cultural perspective, the more intensified and larger production systems yielded the best importance levels (G1, G5 and G2), except G4, which, albeit intensive and featuring moderate production, as compared with the other assessed systems (1,060 L_{milk}/day), ranks in the penultimate hierarchy position. G1 yields 34% priority level, and it is again considered the best system for the conceptual sustainability model adopted in this work. This is the reflex of the good performance of its social and economic indicators.

Worth noticing, as Figure 6 shows, is the fact that G3 yields the best performance under the environmental criterion, whereas under the social and economic criteria, it yields the worst performances. That, allied to an individualist perspective, which strongly prioritizes the social criterion, gives the G3 extensive system, represented by the small-family managed system, the last hierarchical position, with a 10% priority level.

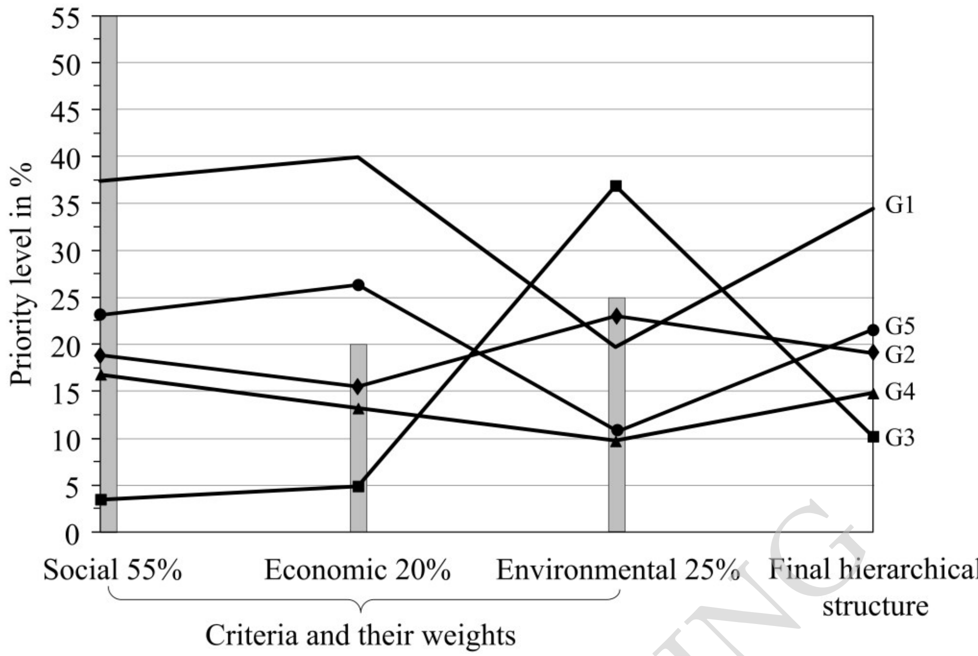

Fig.6. Hierarchical structure of the milk production systems of the south region of Minas Gerais state, according to decision maker's individualist cultural perspective. Weights for the different criteria from Table 1.

4 Conclusions

Numbers shown that System G1, classified as intensive with high productivity, highly technified, and yielding the best social-economic performance among all the assessed systems, is the milk production system that yielded the best overall results (highest priority levels) for sustainability under the egalitarian (27%), hierarchical (31%), and individualist (34%) decision-maker's cultural perspective. System G4, classified as semi-intensive with moderate productivity, yields the worst social-economic performances, as compared with systems G1, G2, and G5, and the worst environmental performance, as compared to all the other systems assessed herein. Thus, system G4 presented the lowest priority levels for sustainability under the decision-maker's egalitarian (12%), and hierarchical (13%) cultural perspectives. Finally, System G3, classified as extensive with low productivity, lowly technified, and exclusively family labor, yielded the best environmental indicators, as compared to all the other assessed systems – except for global efficiency index, expressed by the seJ/J ratio. On the other hand, its social-economic indicators yield the worst performance among all the systems assessed, which resulted in a low priority level as for sustainability under the individualist decision-maker's cultural perspectives (10%).

Priority levels obtained in this work can subsidize decision-makers' regional strategic planning for milk production in the south of Minas Gerais state, since those are quantitative approaches, rather than subjective, which is normally the type such decisions are based upon. At this point, an important variable to be considered when making decisions is "time", i.e., are the strategic planning desired goals aimed at short, medium, or long terms. In this sense, the interpretation of priority levels could be done in different manners, among which: (i) prioritizing political, technological (i.e. information), and economic aid to the systems with the lowest priority levels (G3 and G4), so that their sustainability-related performances can be improved at medium to long periods; (ii) incentives could be directed to the production systems with the highest priority levels (G1), since expanding those could improve at short time period the milk production sustainability in a regional scale.

The methodological approach exposed in this work could be useful for future studies with similar goals, i.e. prioritize production systems with different performances regarding their sustainability. The presented ideas could be useful towards a more objective rather than the usual subjective approaches in identifying criteria to be used during an analytical hierarchy process.

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Appendix A. Methodology considered for assigning importance to indicators on the AHP

The procedure adopted to quantify the importance of an indicator in relation to one other took the following steps:

(1) The highest value (generically denominated herein as "m") of each indicator is divided by 9. The division by 9 is justified by AHP using the Saaty fundamental scale, as presented on Table A1. From this division, 9 groups are obtained.

(2) The first group ranges from zero to m/9, whereas the other groups are formed by the higher limit of their previous group summed with m/9, as shown on Table A2.

(3) Next, all the indicators in every alternative are compared with all the similar indicators belonging to the other Alternatives, i.e. considering Alternative 1 has the value "w" for any indicator "i", whereas Alternatives 2, 3, 4 and umpteenth have values s, y, z, and r, respectively (see Table A3). Pair-comparison is carried through by relating Alternative 1 with all other alternatives considering the difference between the same indicator "i" evaluated in this round of comparisons.

(4) Results from the comparisons in the previous step can now be linked to Table A2 intervals. The importance value for that relation is found in the Table A2 interval containing the result from the difference obtained by Table A3. *e.g.*, if the result from the difference between Alternative 1 and Alternative 2 to indicate "i" is in the interval "4 (m/9) to 5 (m/9)", then the importance value will be 5. In this case, it is read as: indicator "i" of Alternative 1 has an importance 5 times higher than indicator "i" of Alternative 2.

(5) If the difference obtained by Table A3 is negative, the procedure remains the same, however, the signal is inverted.

Table A1. Saaty's Fundamental Scale.

1	Equal importance	Both activities contribute, equally, with the goal.
3	Low importance of one over the other	One of the activities contributes to the goal slightly more than the other one.
5	High or essential importance	One of the activities contributes strongly more to the goal than the other one.
7	Very high importance	One of the activities contributes very strongly to the goal than the other one.
9	Absolute Importance	Evidence favors an activity in relation the other one with the highest level of importance.
2, 4, 6, 8	Intermediate values	When a condition of commitment between the two definitions is sought.

Saaty (1991)

Table A2. Groups, intervals and indicators importance.

Groups/Importance	1	2	3	4	5	6	7	8	9
Interval	0 to m/9	m/9 to 2 (m/9)	2 (m/9) to 3 (m/9)	3 (m/9) to 4 (m/9)	4 (m/9) to 5 (m/9)	5 (m/9) to 6 (m/9)	6 (m/9) to 7 (m/9)	7 (m/9) to 8 (m/9)	8 (m/9) to 9 (m/9)

m = highest value for indicator "i"

Table A3. Relations among indicators.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative "n"
Alternative 1	= w – w	= w – s	= w – y	= w – z	= w – r
Alternative 2		= s – s	= s – y	= s – z	= s – r
Alternative 3			= y – y	= y – z	= y – r
Alternative 4				= z – z	= z – r
Alternative "n"					= r – r

w, s, y, z, and r represent the quantitative values of indicator "i" for Alternatives 1, 2, 3, 4, and umpteenth, respectively.