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Emergy evaluation for decision-making in complex multifunctional farming systems

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Abstract

In a *montado* farm, commonly found in the South Portugal, human activities benefit from important fluxes of renewable resources. In this study, traditional economic and emergy evaluations are compared to determine their potential contributions to understanding this complex system and applied to a case study of a farm. This allows us to determine how each method values local natural resources and purchased factors of production and services in an empirical context. Results show that the *montado* farm has a renewable component evaluated at 27% of the total social costs of the system and that the work of natural resources is undervalued in economic budget accounting. Economic evaluation's relative value of purchased factors and services is three and half times higher than their emergy share. We propose that complementing economic budget accounting with emergy accounting provides a benchmark to evaluate the environmental contribution to agricultural and farming systems. In this way, factors external to markets can be evaluated for farming systems, bringing to economic analysis a full evaluation of resources, including the bio-geophysical system's contributions to wealth, enlarging total economic value of resources with a donor perspective enabling a better informed and comprehensive accounting to attain sustainable economic decisions and public policies.

Keywords

emergy; nature's work; *montado* silvo-pastoral system; donor-based value

1. Introduction

In the regions most vulnerable to climate change such as the Mediterranean (Giorgi & Lionello, 2008; Schröter et al., 2005), the sustainable use of limited soil and water resources

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must be enhanced and optimised, avoiding carrying capacity overload and maintaining ecosystem functioning. In Europe, market-oriented policies encourage agricultural intensification, even in such regions, and create conflicts between management models (Pinto-Correia & Azeda, 2017), amplifying the vulnerability to local changes with effects at a regional level, as was suggested by Godinho et al. (2016b), who found that decreased tree canopy cover in Mediterranean silvo-pastoral systems may induce significant changes in landscape surface temperature and albedo. The conservation of these complex land use systems clearly depends on understanding the multiple mechanisms and interactions involved in their balance at farm level (Fonseca et al., 2016), with new approaches required to address such complexity (e.g. Guimarães et al., 2018).

Farm accounting and budgeting remain the main tools used by agricultural economists to assess agricultural systems and businesses and their returns. They do this by valuing, at market prices, the benefits of products sold and the costs of purchased factors and services. Owned factors such as land, capital and labour can also be assessed at their opportunity costs, namely based on the estimated market value of their alternative allocation (Kramer et al., 2013; Marques, 2012; Putz, 2000). However, these are often non-tradable goods and services and therefore should not be considered more than a residual return in this context (Fisher & Kinnard, 2003).

Nature's contribution to economic activities is also not captured by economic markets and not accounted for by farm managers, though it is relevant in the provision of limiting factors affecting agricultural productivity. These resources are appropriated through land property rights and represent *externalities* of economic activity (Pillet et al., 2001). The global value of resources must go beyond use-values, including non-use values and, therefore, resource availability and conservation (Dewsbury et al., 2016; Turner et al., 2003).

Throughout economic history, several attempts to value bio-geophysical resources have been made (e.g. Ghosh & Mondal, 2013; Kallis et al., 2013; Masiero et al., 2016; Nijkamp et al., 2008; Randall, 2007) with an attempt to value these resources on equal terms with the resources already valued by man. From these attempts, several biophysical theories of value based on thermodynamic and ecological principles have emerged (Cleveland & Ruth, 1997; Farber et al., 2002; Gowdy & Mesner, 1998; Hall & Klitgaard, 2006; Patterson, 1998). Odum (1996) proposed that the measure of the value of a commodity is the amount of energy required to produce it, that is, its *emergy*. Emergy was defined as the available energy of one kind previously used, directly or indirectly, to produce a service or product (Campbell, 2016; Odum, 1996). Instead of money, emergy analysis uses solar energy as an alternative common denominator (Odum, 1996). In this context, natural resources are assessed within the framework of the bio-geophysical system's donor-based value, whereas market evaluation is based on the consumer's utility preferences (Campbell & Tilley, 2014b).

Emergy evaluation has been proposed as a useful tool for assessing the contribution of the bio-geophysical system to market-valued products (e.g. Chen et al., 2011) and, therefore, for environmental accounting and system assessment (e.g. Fonseca et al., 2016; Ghisellini et al., 2014; Saladini et al., 2016). In emergy analysis, the market-based components required for

production (e.g. fuels, labour, purchased inputs) are evaluated on the same basis as the components which normally are not accounted for in economic evaluation, that is, the free flows of the bio-geophysical system or *emternalities* in the sense of Pillet et al. (2001).

When focussed on agricultural systems, emergy enables the assessment of energy flows through the different components of the system, quantifying not only the energy inputs and outputs, but also the several transformations of energy within the system in performing environmental work (Odum, 1996).

Emergy analysis has been applied to evaluate processes and systems in different fields (Campbell et al., 2014; Campbell & Lu, 2014; Chen et al., 2011; Morandi et al., 2015; Watanabe & Ortega, 2014; Zarbá & Brown, 2015). Emergy evaluation of agricultural systems was performed by almost all the agricultural systems of the world, from China (Chen et al. 2006) to Mexico (Diemont et al., 2006), Portugal (Fonseca et al. 2016), Italy (Ghisellini et al. 2014), Australia (Lefroy & Rydberg 2003), Argentina (Rótolo 2007) or Denmark (Wright & Østergård 2015). Agostinho et al. (2004) focuses on the importance and contribution of small-scale agriculture for food production in Brazil. Bastianoni et al. (2001) assesses a farm in Italy, in the Chianti area. Brandt-Williams (2001), Ghisellini et al. (2013) and Rydberg & Handen (2006) focus on broader evaluations of the agricultural systems of Florida, Italy and Denmark respectively. Several studies focus on more specific products as Cavalett & Ortega (2009) that focus on soybean production in Brasil, or Cuadra & Rydberg (2006) that studied the coffee production in Nicaragua. Other studies focus on livestock systems as Jakli et al. (2014) that studied the dairy sector in Slovenia, Rótolo et al. (2007) that focus on grazing cattle in Argentina's Pampas, Wright & Østergård (2015) that studied three Danish pig production systems and Fonseca et al. (2016) that focus on cattle production in a farm in the Portuguese Montado silvo-pastoral system. Diemont et al. (2006) studied an indigenous swidden agroforestry system in Mexico comparing six farms. Finally, Lefroy & Rydberg (2003) studied three cropping systems in southwest of Australia while Liu et al. (2004) focus on grain production systems in two different provinces of China.

In this paper we used economic and emergy approaches to assess a multifunctional land use system in the western Mediterranean context. These silvo-pastoral systems (*montados* in Portugal and *dehesas* in Spain) are an outstanding example of sustainable land use adapted to the natural constraints of Mediterranean Europe (Pinto-Correia et al., 2011b; Sá-Sousa, 2014) and are also recognised as high natural value farmland at an European level (Almeida et al., 2013; Godinho et al., 2016b; Pinto-Correia et al., 2018). *Montados* also provide a wide range of ecosystem services and public goods (Bugalho et al., 2009), which are of critical importance to well-being (Surová et al., 2018). These *montado*-related values are closely related to the high structural heterogeneity resulting from the use of both tree and understory layers in complementary activities, such as livestock grazing, cork and wood harvesting and hunting (Pinto-Correia et al., 2011b; Sá Sousa, 2014). Moreover, land use intensity and management models drive the structural diversity of *montado* (at stand level) and its spatial fuzziness (at landscape level) (Almeida et al., 2016; Godinho et al., 2016b; Pinto-Correia et al., 2011a).

Scattered trees, dominated by cork and holm oaks (*Quercus suber* and *Q. rotundifolia* respectively), are considered keystone structures in these wood pastures.

Despite their recognised value, *montados* are currently in decline (e.g. Godinho et al., 2016c) as are other agroforestry and silvo-pastoral systems across Europe (Bergmeier et al., 2010), and this trend will continue if tree aging and lack of natural regeneration are not reversed. Limitations in tree regeneration can result from high livestock density and the use of heavy machinery (Arosa et al., 2017; Dinis et al., 2015; Pinto-Correia et al., 2018). Under current biophysical conditions, grazing pressures have also emerged as a determinant factor in recent studies to explain increasing *montado* fragmentation at farm level (Almeida et al., 2016) and *montado* loss at landscape level (Godinho et al., 2016c). There is also evidence of decreasing resilience in *montados* to disturbance factors such as drought, but different physiological mechanisms seem to be driving chronic decline and sudden death (Camilo-Alves et al., 2017). Changes in disturbance regimes or the cumulative effect of different disturbances may also induce abrupt changes from oak-dominated systems to persistent shrublands (Guiomar et al., 2015; Acácio et al., 2017). These factors can also increase tree vulnerability to pests and pathogens, although doubts remain about the primary cause of mortality in some cases (Camilo-Alves et al., 2013). Finally, all these changes affect the overall balance of the system.

Given the above-mentioned complexity of the *montado*, the accelerated decline of tree density, and the fact that ecosystem equilibrium is strongly dependent on the interaction between multiple factors, it is critical to apply methodologies at farm level that enable the overall assessment of the system, as well as of the relative contribution of each one of its components, thereby enabling the development of place-based strategies for sustainable management.

As a system with a strong human component, the whole economy at farm level has a strong influence on the choices and management practices.

In this context, we aim to evaluate and compare the relative contributions of the different factors of production, as well as the renewable and non-renewable resource components, with a focus on the contribution of the bio-geophysical system's work to the agricultural production in this specific context. The theoretical background, methodologies and results from both evaluations of the case-study farm are presented and discussed in the following sections. The paper ends with major conclusions that can be derived from the comparative analysis of the two alternative evaluations.

2. Materials and methods

2.1. Study area

The study was conducted in 2012, in a *montado* farm located in Montemor-o-Novo municipality (Central Alentejo region, Portugal (Figure 1)). The farm has an area of 168ha, of which 59ha are covered by holm oaks (*Quercus rotundifolia*) and 2ha by cork oaks (*Q. suber*). Two open areas, comprising 43ha, are fertilised annually with 150kg/ha of superphosphate (18%), without tilling the soil, to produce hay to supplement cattle diet. The

remaining open areas are covered mainly by natural pastures occupying 64ha. In a 24ha area previously cleared by the former manager, natural regeneration of holm oaks can be observed.

The dominant soils are orthic luvisols with moderate to low water permeability. The farm is located on a steep slope area (slope angle up to 48%), with an elevation range from 250 to 345m. Soil organic matter is higher in one plot with cork oaks (~5%), a plot where cattle tend to stay for longer periods. However, the average soil organic matter for the whole farm is ~4%, which is high for this region, where average levels range from 0.5 to 2% (Teixeira et al., 2008).

The manager is a cattle producer who owns 2 bulls and 80 cows. Calves are crossbreeds from Saler and Limousin. These small animals are highly valued on the market and are sold in cattle auctions at 200Kg live weight with a mean age of 7 months. The cattle's diet is based on natural pastures, acorns from the holm oaks, hay, shrubs and tree leaves. Calves are exclusively nursed until the 4th month, when they start a transition to an adult diet. In 2012 the manager sold 20400Kg of calves at the average price of 2.56\$/Kg. The farm is divided into 8 paddocks separated by pole and wire fences.

The landowner receives rent and hunting rights each year and, every 9 years, money from the sale of ~105 ton of low quality cork. Firewood is not sold but exchanged for tree pruning.

2.2 Emergy evaluation

The emergy evaluation of the farming system has been described in detail in a previous paper (Fonseca et al., 2016). Emergy analysis enables systems' evaluation by converting all the inputs, outputs, flows through the system and storages of energy, materials, money, labour or information on a common basis expressed in *emjoules* of solar energy or solar emergy (Odum, 1996). The term means "energy memory", that is, the energy of one type required to produce energy of another type with higher work capacity.

Emergy is estimated by multiplying energy (or exergy), material or currency by a conversion factor - the Unit Emergy Value (UEV) - to obtain the *transformity* (sej/J), the *specific emergy* (sej/g) or the *emergy to money ratio* (sej/\$), respectively. This conversion factor represents the solar emergy required to make one joule, gram or dollar of a specific product or service. A product's solar transformity is its solar emergy divided by its available energy (Odum, 1996). According to the same author, in a chain of transformations within a system, much of the available energy dissipates in the form of heat with no ability to do extra work (entropy), but the emergy is transmitted while the transformity increases. This generates a universal hierarchy of the ability to perform work which can be seen, for example, through the chain of changes between solar energy, charcoal, coal, petroleum and electricity.

For a detailed description of emergy accounting see Odum (1996) and Campbell & Ohrt (2009). The first step involves the design of a diagram representing all linkages between all features of the system, thus defining the boundaries as the inputs and outputs to the system. The inputs that enter the systems are divided into renewable and non-renewable fractions

using their respective renewability factors (RNF) (Wang et al. 2017). Emergy evaluation of farms, depending on the most critical production factors, focuses, for example, on the following renewable natural flows: solar radiation, kinetic energy of the wind, geothermal energy, geopotential energy of the rain, evapotranspiration, net primary production and topsoil erosion. Regarding human flows, we can highlight the use of fertilisers, machinery, fuels, seeds, fences, medication, and services that may include contracted or owner labour, subsidies, taxes and a land-use permit if the land is leased. The outputs of the farm or the process under analysis are usually also evaluated and can include animals, straw, contaminated water, soil, biodiversity, game and biomass.

The diagram enables the identification of which flows are and are not accounted for in economic evaluation and the differences from ecological (emergy) evaluation.

Emergy evaluation is done in an emergy table format. Rows are organised according to broad categories of local and purchased goods and services. The raw units of each item and its unit emergy value and emergy are shown in the columns.

An important concept that allows the comparison between economic and emergy evaluations is the Emergy to Money Ratio (EMR) (Campbell et al., 2005). It represents the total available emergy that supports the Gross Domestic Product for one year and country. This is, the existing resources in the country, produced there or the balance between imported and exported resources that are at the base of the economy of that year. This indicator enables us to know the emergy embodied in the currency for one year allowing the allocation of an emergy value to the money that pays for a product. In Portugal and for the year 2012 the EMR or the emergy value for each \$ was $3.22\text{E}+12$ sej (adapted by Oliveira from Oliveira et al., 2012). If the value of 13335.00 \$ was paid for the cork in the year of 2012, it will correspond to a value of $4.29\text{E}+16$ sej of emergy received by the owner when she sells the cork. By dividing the emergy that is possible to buy with the money paid for a product, by the emergy that the system invested in the creation of this product the Emergy Exchange Ratio (EER) (Odum, 1996) is obtained, indicating if the system is gaining or losing emergy when the outputs are sold.

The prices of the items in the market and the corresponding emergy determined using the EMR, can also be presented in the emergy table.

2.3 Economic evaluation

Agricultural farming systems and related activities are assessed through budgeting or accounting techniques depending on whether the goal is planning or controlling the stages of decision-making, respectively. These farm budgets or accounts are organised lists of quantities used, unit prices and total values of all tradable outputs and inputs of agricultural systems or activities.

According to the type of analysis that is of interest, different formats to organise groups of outputs and inputs allow us to calculate selected results from different perspectives (Marques, 2012). However, all these perspectives include benefits and costs to the systems that are under evaluation (Fisher & Kinnard, 2003). While the benefits are the value of

outputs produced, the costs are the value of purchased and owned inputs to the systems or activities. Income transfers received and paid, namely through subsidies and taxes, are also accounted for.

Outputs or products sold are valued at their sales prices or through the monetary value received by the farmer after selling at the market place. Purchased inputs or resources used in agricultural systems are valued at market prices because they represent the value that the farmer has to pay to use those resources (Baumol, 1977). These might be goods, such as fertiliser, or services, such as the technical operation of a machine, including machine time and operator labour costs.

Production that is not sold and owned resources such as the stocks used in production (e.g., land, labour and capital of the farmer) are valued at allocated benefits and costs (Tietenberg & Lewis, 2012). Their value can be estimated in different ways, namely through the rates of substitution or opportunity cost (Tietenberg & Lewis, 2012). The opportunity cost refers to the return from production or a resource in an alternative allocation scenario, i.e., the return from an alternative economic use. Hence it is also valued at the market prices of those products and resources. Therefore, underlying the concept of opportunity cost is the possibility of trade that allows for valuation of the product in alternative ways.

Alternatively, the residual method has been used to calculate returns on those ownership resources which may not be considered in farm budgets and records and to evaluate their global return. Entrepreneurial net income is obtained by deducting all tradable factors from total income costs and constitutes the return on these resources.

To enable a comparison between the economic and emergy assessment of the farm, some adjustments had to be made to the initial evaluation (Fonseca et al., 2016). A key difference lies in the depreciation rates attributed to equipment, which differed significantly from the first evaluation. The lifetime periods attributed to the equipment in the first and second evaluations are presented in Table 1.

In the first evaluation, the useful life of equipment indicated in the manuals of agricultural machinery (Santos, 1996) was considered. In the second evaluation, the useful life of equipment from the point of view of the farm's financial accounting in accordance with tax rules was assumed. The lifetime periods attributed to the equipment in the first evaluation are, in general, longer and more realistic than in the second, whose objective is comparatively rapid amortisation of expenses in accounting terms. In this paper, faster depreciation rates were used in order to make a comparison with the economic evaluation, but this will lead to an increase in the weight of machinery, purchased and non-renewable inputs on the farm as well as less favourable values for the emergy indices.

All monetary values were collected in euros (€) and converted to United States dollars (\$) relative to the year 2005, applying a conversion rate of 1.143 (<http://www.x-rates.com/calculator/>, <http://www.usinflationcalculator.com/>).

3. Results

3.1 Emergy assessment of the *montado* farm

The emergy diagram for the *montado* farm is shown in Figure 2. Inside the box, which represents the system boundaries, there are a number of flows that describe the interactions among all the vegetation layers, soil organic matter, mycorrhizae, superficial water flows, groundwater and ponds, cattle and money.

Figure 2 also represents several types of outside resources used in the farm (also see Table 3 for a legend). Thus, in the above-mentioned figure we can identify the solar radiation that goes into different ecosystems (k1), wind (k2), the chemical potential of groundwater (k4), the rain geo-potential energy absorbed (k3) and the rain chemical potential (k5), and evapotranspiration (k6). These are considered local renewable resources. Another renewable sub-component considered within the system is the total nutrients mobilised by plants. This includes tree biomass (k7), acorns (k8), natural pasture (k9), hay for bales (k10) and the seeds (k11) used to improve natural pasture. Topsoil erosion (k12) is also included but as a local non-renewable resource.

Purchased inputs are arranged by product destination (e.g. hay bales, cattle). Other inputs also come from outside the system and include fuels (k13), fertiliser (k14) and mechanical equipment (k15), plastic (k16), feeding trough (k17), materials for fences (k18), and veterinary medication (k19). Finally, services include labour for different activities (k20). In addition, the government, market, manager and owner also give rise to transfers, which include subsidies (k21) and taxes (k22) and land-use permits (k23). Output flows are also represented, including hunting (k24), firewood (k25), cork (k26) and calves (k27), indicating the distribution between manager and owner. The values for these inputs in energy or weight and the corresponding emergy values and Unit Emergy Values, with services, were determined.

Table 2 presents the emergy accounting table for the *montado* farm used to carry out the comparison with the economic evaluation.

In the first two columns these flows are identified and related to Figure 2 through similar numbering. The emergy of resources is grouped into local renewable resources (R) non-renewable resources (N) and purchased resources (F), including goods (M) and services (S).

The prices of the items in the market for to 2012 and the corresponding emergy determined using the EMR, is also presented in Table 2.

The emergy evaluation results indicate that the farming system is very dependent on subsidies that represent 19.11% of the total emergy. Local natural resources reach 23.67% of the total emergy of the system. Services, that only include labour, are more important than the local natural resources in terms of their emergy contribution, representing 44.88%. Purchased materials make up only 18.74 % of the share of total emergy.

To have a better understanding about the system we calculated the renewable fractions of the purchased items. After finding values for the renewability factors of the items (RNF), whose

emergy was estimated in Fonseca et al. (2016) and using other renewability factors already estimated in the past by Panzieri et al. (2002) and Sharlynn at the National Environmental Accounting Database (<https://cep.ees.ufl.edu/nead/>), Table 3 was filled giving a first idea about the renewability of the farm.

Table 3 presents an estimate of the renewability for the inputs to the system of about 31%, while calves has an estimated renewability of 18%.

Table 4 presents the emergy in the outputs, the prices at which they are sold, the corresponding emergy in the money received by the manager or the landowner by selling their products and the determinations of the Emergy Exchange Ratio (EER) for the different outputs of the farm.

If the EER is higher than 1, the seller is gaining emergy, but if the EER is lower than 1, the seller or the system is losing emergy.

Data in Table 4 reveals that the owner is gaining emergy with the hunting activity and the cork harvesting but losing emergy with the firewood harvesting.

The manager is losing emergy when he sells the animals in the market. In 2012 he sold 20,400Kg of calves, at the auction, at the average price of 2.56\$/Kg in a total of 52209.92\$, losing 2.17×10^{17} sej of emergy.

Recalculating the Emergy Exchange Ratio for farm outputs by dividing the emergy that is possible to buy with the money paid for a product, by the non-renewable emergy that the system invested in the creation of this product (Table 5) it is possible to get a new ratio that was called Non-renewable Emergy Exchange Ratio (EERN) (Equation 1).

$$EERN = Y_M / Y_N \quad \text{Eq. 1}$$

After new determination of this ratio to farm outputs (cork and calves), values for EERN of 1.48 for cork and 0.53 for calves were obtained against the values obtained previously (Table 4) (1.25 and 0.44 respectively). These values are not very different and do not change the situation of the manager and the landowner when they sell the corresponding outputs. The landowner continues gaining in emergy terms when she sells the cork and the manager continues losing in emergy terms when he sells the calves. This means that the money received when the manager sells the calves in the market is not enough to pay even the non-renewable emergy invested in it. This means that the production is being done at the expense of the farm's natural capital, in this case of the farm erosion, as well as the natural capital outside the farm (by burning fossil fuels, land degradation, among others).

The way to offset the non-renewable emergy investment in the production of calves, would be to sell the calves at the auction at least at 4.78 \$/Kg instead the 2.56 \$/Kg actually charged. And this money could be used to compensate the non-renewable emergy spent in calves' production, in order to avoid farm degradation and the degradation of the system from which the other non-renewable inputs came. This money could thus be used in soil

conservation practices, in the adoption of renewable energy sources for agricultural machinery and for the manager's journeys. A more precise allocation, based on the non-renewable energy invested in calves' production (Table 6), can serve as a guide to areas of investment that can be made in the system in order to avoid its deterioration.

The manager could invest in reforestation and forests inside and outside the farm in order to compensate the forest degradation resulting from the eucalyptus plantations from where fences posts are sourced. Soil restoration can be done to compensate for the extraction of ores used in the manufacture of machines and equipment. The investment in a more sustainable lifestyle can include the use of renewable energy sources, the replacement of practices that include heavy machinery by other practices that do not require these machines or fuels. The pasture for hay can be fertilized using organic fertilizer made, for instance, from the waste from the neighbouring dairy farm, whose waste is currently a problem for the Holm Oaks Farm.

According to the same reasoning, the farmer's income should correspond to the renewable energy invested in calves' production, which is 21,118\$. As the non-renewable sources of energy were replaced by renewable sources, and the system fertility was restored, the manager investment in offsetting the negative impacts of production would be reduced. On the other hand, due to the managers' investment in the farm, the renewable energy available to obtain resources would increase, thus increasing the managers' income.

3.2. Comparing economic and energy evaluations

The farm balance sheet for the year 2012 was used to compare the energy and the traditional economic evaluation of this farm. One of the issues to be solved was that the monetary values specified in the farm balance sheet do not always correspond to the activities developed on this farm. As the manager owns another farm where he develops the same kind of activity, values expressed in accounts and corresponding invoices are often related to goods or services acquired for both farms. The only exception refers to the manager's remuneration, which is accurately represented by the value in the balance sheet. The rent paid by the manager to the farm owner is also clearly indicated, but corresponds to the sum of two different accounts. It was thus necessary, with the manager and the accountant, to isolate the amounts related to the *montado* farm.

A comparison table similar to Table 2 was built (Table 7), but with only the energy values corresponding to each item (column 3) and the corresponding percentage in relation to total inputs (column 4). When available, money values are presented (column 5), the corresponding energy after applying the EMR (6) and their percentage in relation to total inputs (column 7).

Basically these estimates provide an income statement or real budget accounting organised in an energy format table. Energy and economic evaluations can be easily compared using the relative values allocated to each individual and group of factors indicated above.

Social and private costs and returns are also calculated and included in Table 7. Total factors were considered first without government transfers, subsidies and taxes, which produced, in

economic terminology, social results. Transfers are wealth or work that do not constitute an input or output of the system. Hence, they affect the private results of the farmer but do not represent work or value to the system, i.e., social costs or benefits. These transfers are only considered in the private results.

3.2.1 Property rights and bio-geophysical system's work—A specific procedure was adopted to enable rigorous evaluation of emergy, as previously outlined. The property rights of landlords allow them to appropriate the bio-geophysical system's work on their farms. They benefit, for example, from rainwater used to produce plants that need water to grow. In the case of a rented farm, such as this one, land rent is the contractual payment that gives the tenant farmer access to the natural resources of the farm. Hence, land rent was considered to be a payment by the tenant for the availability of a set of local natural renewable and non-renewable resources, including sun, rain and top soil use, although the owner and not the bio-geophysical system receives the payment for that work. Since rent is a monetary payment for the local resources, it was included in this section and this monetary value was included in the budget accounting for the farm.

Total social costs for the *montado* farm are estimated to be 65.4 thousand dollars (\$65,364), while production benefits are estimated to be 68.6 thousand dollars (\$68,600). The net social return of the farm is thus estimated to be 3.2 thousand dollars (\$3,241), which represents 4.9% of total costs. Labour costs represent 29.08% of the total costs, followed by renewable and non-renewable local resources at 11.57%. Purchased resources make up most of the remaining 62.7% of total costs. Sales of calves represent 76.1% of the total benefits of the system, followed by cork, a benefit received by the landlord, which makes up 19.4% of the value of the total benefits. Hunting and firewood represent residual benefits of 2.4% and 2.0% respectively.

3.2.2 Subsidies and transfer payments—Agricultural policies of subsidies and transfer payments are very important to economic results. The *montado* farm receives 44.3 thousand dollars (\$44,300) per year. This government transfer (after taxes) is estimated to be 35.2 thousand dollars (\$35,200) per year, which represents 60.9% of total costs and results in a net private income return from the farm of 98.7 thousand dollars (\$98,762), or 151.1% of total costs.

3.2.3 Different inputs valuation by each method—Comparing emergy and economic evaluations in Table 7, it is possible to visualise what resources are not accounted for by farm accounting. Empty items in the economic evaluation that have a value in the emergy evaluation correspond to the bio-geophysical system's renewable and non-renewable resources that are not accounted for in monetary terms. Rent that globally relates to the cost paid for these resources represents 11.6% of total costs of the system in economic terms. It should be noted that in the case of an owner-managed farm, this monetary value would be zero. However, these resources represent 27.1% of total value in emergy terms. Local natural resources of the system are thus undervalued in economic terms relative to emergy. Markets do not describe social value in monetary terms to the bio-geophysical's contribution to the *montado* silvo-pastoral system, which should be done in order to ensure the long-term sustainability of the economic activity.

The services required by the system only include labour and the relative values allocated to it diverge widely in the two evaluations. Labour costs represent 29.1% percent of the total monetary costs, while the estimated contribution of labour in the emergy evaluation is considerably higher at 51.4%. In monetary terms, therefore, markets seem to socially value human labour at a value that is less than its real work contribution to the agricultural system.

Inputs purchased for the agricultural system represent by far the largest component of costs in economic terms. Annual costs of goods purchased to implement the agricultural system represent 62.7% of total costs, while the emergy of purchased factors relative to the total emergy of the system is only 21.5%. In terms of different purchased factors, mechanical equipment, the feeding trough and fuels are the main components of economic costs, with shares of 20.2%, 19.0% and 14.6% respectively. However, the emergy evaluation values their work contribution for the system at only 2.5%, 0.4% and 5.5% respectively. Thus, in the case of purchased factors, economic evaluation through markets socially overvalues their contribution to the system relative to emergy.

The comparison of economic and emergy evaluation methods indicates a large discrepancy in the standards of the two scales of value for the different factors that contribute to the *montado* silvo-pastoral system. In economic versus emergy terms, purchased factors of production for the system are overvalued relative to other factors, namely local natural renewable and non-renewable resources as well as labour services. In emergy versus economic evaluation, on the other hand, local natural renewable and non-renewable resources are overvalued relative to purchased factors.

Comparing the importance of agricultural policy in monetary and emergy terms is also possible. As referred to earlier, government net transfers have an effect equivalent to decreasing private costs by 60.9%, i.e., making private costs worth 39.1% of total costs. In emergy terms, transfers have a lower impact, representing a net decrease of 14.6% and resulting in private costs that represent 85.4% of total costs. In economic terms, net transfers derived from agricultural policy increase the social net return of the system from 4.9% of total costs to a private net return of 151.1% of total costs. In emergy terms, the effect of net transfers is to increase the social net return from 20.7% of total costs to a private net income of 35.3% of total costs. Estimating the impact of agricultural policy thus varies depending on whether an economic or emergy evaluation method is used.

4. Discussion

4.1 Addressing *montado* complexity through emergy assessment

The *montados* in Portugal and the *dehesas* in Spain are outstanding examples of land use systems well adapted to the scarcity of resources existing in the extreme southwest of Europe (Pinto-Correia et al., 2011b). Resulting from human intervention on Mediterranean oak woodlands, *montado* maintains a set of natural mechanisms or emergy fluxes which farmers take advantage of, such as cork and acorn production, natural pastures and hunting. This means that the manager of a farm in *montado* can take advantage of a larger set of free natural energies than in other more industrialised agricultural systems. In this evaluation, it

was estimated that 31% of the inputs to production come from renewable resources if subsidies, rent and taxes are not taken into account.

The common economic evaluation of the *montado* system neglects this natural component and, although some managers and government regulations aim to maintain the balance of these resources, if management strategies do not consciously take in account the role of natural resources, management oriented to short-term profit ends generally comes at the expenses of long-term continuity (Godinho et al., 2016c). Moreover, *montado* biodiversity is more than an existence value, being critical to maintain the functional balance between all the components of the system, particularly those related with soil. For example, ectomycorrhizal fungi are key components for the functioning and long-term persistence of *montados* (Reis et al., 2018), through establishing symbiotic relationships with tree roots that allows increasing tree survival and growth rate (Dinis et al., 2016), protecting plant from soil pathogens (Corcobado et al., 2014), improving drought resistance (Sebastiana et al., 2018), and providing nutrients (Sebastiana et al., 2017).

However, the overall balance can be compromised by management options. While soil tillage and shrubland management might affect the distribution of ectomycorrhizal fungi (Azul et al., 2009; Santos-Silva & Louro, 2016), grazing intensity and heavy machinery limits natural regeneration (Dinis et al., 2015; Arosa et al., 2017; Pinto-Correia et al., 2018). *Montado* loss and fragmentation due to unsuitable grazing intensity is also an evidence (Almeida et al., 2016; Godinho et al., 2016c). Tree loss, in turn, also influence mycorrhizal presence and abundance, changing plant-soil biota feedbacks (Corcobado et al., 2014; Ibáñez et al., 2015). High reductions of tree cover increases soil temperature (Godinho et al., 2016a) and reduces soil moisture, soil organic matter, microbiological activity and seedling survival (Caldeira et al., 2014; Shvaleva et al., 2014). Emergy framework allows to assess such complex network of dependencies between the different dimensions in *montado*.

Long-term persistence of *montados* depends on reversing recruitment failure and tree ageing (Pulido et al., 2001; Plieninger et al., 2010), and on balancing the relationship between the carrying capacity of the system and the land use intensity (Bugalho et al., 2011; García de Jalón et al., 2018). Nevertheless, management factors can mediate the effect of biotic and abiotic disturbances on *montado* (Acácio et al., 2017), such as drought (Camilo-Alves et al., 2017), fires (Guiomar et al., 2015), plant pathogens (Camilo-Alves et al., 2013) or insect pests (Tiberi et al., 2016).

This mismatch is the result of misaligned policies that induce conflicts between attitudes and behaviours of the *montado* managers (Pinto-Correia & Azeda, 2017). Emergy evaluation makes all the free inputs to the system visible, thus facilitating their full weighting not only to support management decisions but also to frame sustainable policy measures. The possibility of determining the non-renewable component of the different inputs of the system offers clues for actions that minimize its use or that compensate it, indicating areas of action at farm and policy levels and giving the value of the impact that is being exerted on them. It is thus possible to estimate the degree of investment that should be retro-invested in each area in order to maintain the productive system in the long term.

4.2 Economy versus Energy

One of the central concepts of economic evaluation is that money acts as a common denominator in establishing an absolute and a relative scale for the evaluation and exchange of goods and services (Hicks, 1989; Napoleoni, 1977). Prices establish values of contracts agreed upon between buyers and sellers, and goods and services must be tradable or exchangeable in a market. These prices result from the interplay of market supply and demand, or from the costs to producers of providing goods and services compared with the willingness of consumers to pay for them and from the respective differences in market power of these economic players (Baumol, 1977).

Many classical economists, biologists and physicists have considered biophysics as source of wealth (Christensen, 1989; Cleveland & Ruth, 1997; Hall et al., 2001; Smith, 1776). Georgescu (in Daly, 1995) noted that nature is also a source of low entropy value added, while the emergy evaluation method does not distinguish between “natural” or “human” value added. In this way, emergy accounting can be understood as viewing the equivalent added solar energy value in the same way economic accounting views added monetary value (Bowman & Ambrosini, 2000). Indeed, just like monetary value incorporated in a product, emergy accumulates as we move up through the value supply chain of agricultural production of commodities, to their transformation, marketing, distribution and consumption in different forms.

Complementing budget accounting with emergy accounting brings the possibility of evaluating the bio-geophysical system's work in farming systems and thereby bringing a comprehensive evaluation of resources to economic analysis. In doing so, it enlarges the total economic value of resources with a donor perspective that enriches economic analysis and encourages economic decisions that are better informed, fully accounted for and sustainable. Comparing the economic budgeting for resource costs using the monetary values society is willing to pay with the emergy value provides a measure of how far markets diverge from donor values based on estimates of resource contributions to systems (Campbell & Tilley, 2014b). In the case of the Holm Oaks farm, emergy estimates the bio-geophysical system's work as being 27% of the total emergy invested in the system, while economy estimates this work as being only 11%.

Unlike in economic methods, emergy evaluation enables the evaluation of natural resources and their contribution to producing goods and services, particularly non-tradable ones. Emergy evaluation is therefore a framework which, in addition to tradable factors of production, can evaluate the bio-geophysical system's work and its relative contribution, thus fully accounting for goods and services at universal values. The approach produces a donor-rather than a receiver-based evaluation that can also be described as ecocentric.

Further, comparing emergy and economic evaluations in terms of the use of renewable and non-renewable resources, the latter gives special attention to identifying the renewability of the resources used by the system in question (Brown & Buranakarn, 2003; Brown & Ulgiati, 1997, 1999; Ulgiati et al., 1995). Even for those resources that have already been transformed by human action (e.g. medicines, agricultural machinery, fuels), there is a concern for determining the amount of renewable and non-renewable resources used. This is

done by studying the production processes for each product where possible and estimating the renewability factors associated with it (Odum, 1996). The aim is to make an impact assessment of the processes in the surrounding system and propose alternative processes with fewer negative impacts (Wright & Østergård, 2015).

Effectively, emergy accounting provides an indication of the proportional value of resources that standard farm budgeting fails to account for in cases where markets either do not exist, do not function adequately, or where market prices are either available or fail to incorporate the full value of those resources. The emergy evaluation method is not intended to replace the economic evaluation, however, but rather to better inform it and, where necessary, provide the economy with credible and appropriate values for the allocation of natural goods and services that are usually not accounted for by markets (Campbell & Tilley, 2014a).

5. Conclusions

Emergy and economy differ in valuing the different inputs to the system. Emergy provides insights for the relative contributions of the bio-geophysical system, in addition to distinguish local renewable and non-renewable resource values within the total resources used in agricultural and farming systems. Determining non-renewable emergy fractions of inputs can serve as a guide to areas of investment that can be made in the system in order to avoid its deterioration. These investments can be made by managers, at farm level, or result from integrated policy measures.

Emergy evaluation helps in estimating the real price of products for local and wider system. Valuing the bio-geophysical system's work makes it possible to establish, for instance, the ecological contributions of farmers. This is potentially an effective way to introduce ecological values into public policy formulation and decision-making processes.

The emergy evaluation of complex systems does not require the evaluation of all similar systems to understand and measure the main factors intervening in output production. After the analysis of a single typical situation, it is possible to build scenarios and understand the implications for all components of the farming system.

At a time when the sustainability of farming systems is highly sought after and promoted in all its components (economic, environmental and social), only the emergy evaluation method can be used to properly evaluate the overall sustainability of complex farming systems.

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Fig. 1.
Location of the Alentejo region, the Montemor-o-Novo municipality and the *montado* farm.

Fig. 2.

Emergy diagram for the *montado* farm

k1: Solar radiation; k2: Wind, kinetic; k3: Rain, geo-potential absorbed; k4: Ground water, chemical potential; k5: Rain, chemical potential; k6: Evapotranspiration; k7: Trees biomass; k8: Acorns; k9: Natural pasture; k10: Hay for bales; k11: Seeds; k12: Erosion, topsoil; k13: Fuels; k14: Fertilisers; k15: Mechanical equipment; k16: Plastic; k17: Feeding trough; k18: Materials for fences; k19: Medication; k20: Labour; k21: Subsidies; k22: Taxes paid to the government; k23: Land use permit; k24: Hunting; k25: Firewood; k26: Cork; k27: Calves

Table 1

Lifetime periods attributed to the equipment in the first (Fonseca et al., 2016) and second evaluations.

Lifetime of the equipment	First evaluation (Fonseca et al. 2016)	Second evaluation
Tractors	12	6
Pendulum sower	10	8
Chainsaw	8	1
Water pump	12	8
Van	10	4
Atomiser	10	8
Other mechanical equipment	12	8
Feeding trough	10	10
Ponds	20	20
Fences	10	10

Table 2

Emergy accounting table of the *montado* farm

Notes	Raw data (Unit y ⁻¹)	Units (b)	UEV (sej unit ⁻¹) (c)	Emergy (sej y ⁻¹)	%	Prices (\$ y ⁻¹)	EMR (sej y ⁻¹)	Reference for UEV
Farm resources (with services included)								
1 Solar radiation (a)	9.02E+15	J	1	9.2E+15	1.98			By definition
2 Wind, kinetic (a)	5.11E+12	J	1240	6.33E+15	1.39			Campbell & Erban 2016
3 Rain, geo-potential absorbed (a)	5.82E+09	J	35435	2.06E+14	0.05			Odum, 1996, p. 309
4 Ground water, chemical potential	2.45E+09	J	283056	6.94E+14	0.15			Buenfil (2001)
5 Rain, chemical potential (a)	5.16E+12	J	23456	1.21E+17	26.55			Campbell, 2003
6 Evapotranspiration	2.94E+12	J	36415	1.07E+17	23.48			Campbell, 2003
Sum renewable (4+6)				1.08E+17	23.63			
Nutrients mobilised by native plants								
7 Trees biomass	3.69E+11	J	159707	5.89E+16	12.91			This study
8 Acorns (a)	1.39E+12	J	42381	5.89E+16	12.91			This study
9 Natural pasture	1.02E+13	J	1006	1.02E+16	2.25			This study
10 Hay for bales	1.98E+12	J	19282	3.81E+16	8.36			Emergy
Sum additional renewable (7+9+10)				1.07E+17	23.52			
Sum all renewable resources (R)				1.08E+17	23.63			
Non-renewable resources from within the system (N)								
11 Erosion, topsoil	1.37E+09	J	145555	1.99E+14	0.04			Cohen et al., 2006
Sum free inputs (R+N)		J		1.08E+17	23.67			
Purchased Inputs (M)							1.33E+17	
12 Seeds	7.19E+09	J	195546	1.41E+15	0.32	422.90	1.36E+15	Bastianoni 2001
13 Fuels	2.57E+11	J	85304	2.19E+16	4.81	9558.82	3.08E+16	Bastianoni et al. 2009
14 Fertilisers	1.08E+06	g	2.52E+09	2.72E+15	0.60	2020.92	6.51E+15	Brandt-Williams 2001
15 Mechanical equipment	9.96E+05	g	1.01E+10	1.00E+16	2.20	11658.75	3.75E+16	Ulgiati et al. 1994
16 Plastic	2.19E+05	g	6.87E+09	1.51E+15	0.33	571.50	1.84E+15	Buranakarn 1998
17 Feeding trough	3.75E+06	g	4.66E+08	1.75E+15	0.38	11004.30	3.54E+16	This study
18 Fences (material)	1.36E+07	g	3.39E+09	4.61E+16	10.11	5058.98	1.63E+16	Campbell et al. 2004
19 Medication	4620	g	3.56E+09	1.65E+13	0.00	1119.51	3.60E+15	Campbell & Ohrt 2009
Total purchased materials from economy (M)				8.54E+16	18.74			
Labour and services (S)								
20 Labour	3.64E+08	J	5.62E+08	2.05E+17	44.88	16808.63	5.41E+16	This study
21 Subsidies	27054	\$	3.22E+12	8.71E+16	19.11	44261.95	8.71E+16	This study
22 Taxes paid to the government	9054.08	\$	3.22E+12	2.92E+16	6.40	-9054.08	-2.92E+16	This study
Difference between subsidies and taxes (21-22)				5.80E+16	12.72			

Notes	Raw data (Unit y ⁻¹)	Units (b)	UEV (sej unit ⁻¹) (c)	Emergy (sej y ⁻¹)	%	Prices (\$ y ⁻¹)	EMR (sej y ⁻¹)	Reference for UEV	
Farm resources (with services included)									
23	Land use permit (rent to the owner)	7563.03	\$	3.22E+12	2.44E+16	5.34	-7563.03	-2.44E+16	This study
	Net flow of services				2.63E+17	57.59			
	Feedback from Economy (F)				3.48E+17	76.33			
	Y = R+N+M+S				4.56E+17	100.00			
	Output (Y)								
24	Hunting	6.97E+08	J	3.06E+06	2.13E+15	0.38	1680.21	5.41E+15	Brown & Arding 1991
25	Firewood	1.98E+11	J	386962	7.65E+16	13.70	1380.74	4.45E+15	This study
26	Cork	3.06E+08	J	1.13E+08	3.44E+16	6.17	13335.00	4.29E+16	This study
27	Calves	8.78E+10	J	4.39E+06	3.85E+17	68.99	52209.92	1.68E+17	This study
28	Calves (labour, taxes, subsidies and rent)	8.78E+10	J	5.07E+06	4.45E+17	79.75			
	Total of outputs	2.86E+11	J	1.95E+06	5.58E+17	100.00			

a) Values not considered to avoid double counting;

b) \$ refers to 2005 values;

c) Transformaties are relative to the 1.2E+25 sej y⁻¹ planetary baseline (Campbell 2016).

Table 3Emergy accounting table of the *montado* farm

Inputs		RNF	Renewable componente (sej y ⁻¹)	Non-renewable component (sej y ⁻¹)
1	Solar radiation	1.0000	9.02E+15	0.00E+00
2	Wind, kinetic	1.0000	6.33E+15	0.00E+00
3	Rain, geo-potential absorbed	1.0000	2.06E+14	0.00E+00
4	Ground water, chemical potential	1.0000	6.94E+14	0.00E+00
5	Rain, chemical potential	1.0000	1.21E+17	0.00E+00
6	Evapotranspiration	1.0000	1.07E+17	0.00E+00
7	Trees biomass	1.0000	5.89E+16	0.00E+00
8	Acorns	1.0000	5.89E+16	0.00E+00
9	Natural pasture	1.0000	1.02E+16	0.00E+00
10	Hay for bales	1.0000	3.81E+16	0.00E+00
11	Erosion, topsoil	1.0000	1.99E+14	0.00E+00
12	Seeds	0.1280	1.80E+14	1.23E+15
13	Fuels	0.0128	2.81E+14	2.17E+16
14	Fertilizers	0.0598	1.63E+14	2.56E+15
15	Mechanical equipment	0.0137	1.37E+14	9.88E+15
16	Plastic	0.0204	3.07E+13	1.48E+15
17	Feeding trough	0.0281	4.91E+13	1.70E+15
18	Fences (material)	0.0493	2.27E+15	4.38E+16
19	Medication	0.0598	9.85E+11	1.55E+13
20	Labor	0.1000	2.05E+16	1.84E+17
21	Subsidies to the farm	0.0353	1.96E+15	5.35E+16
21	Subsidies to cattle	0.0359	3.13E+15	8.40E+16
22	Taxes paid to the government	0.3761	1.10E+16	1.82E+16
23	Land use permit (rent to the owner)	0.3761	9.16E+15	1.52E+16
Total			1.95E+17	4.37E+17
Inputs' Renewability			31%	69%
Outputs				
24	Hunting	0.8386	1.79E+15	3.44E+14
25	Firewood	0.7845	6.00E+16	1.65E+16
26	Cork	0.1577	5.43E+15	2.90E+16
27	Calves	0.1850	7.12E+16	3.14E+17

Table 4

Determination of the Emery Exchange Ratio (EER) for the different outputs of the farm

Output (Y)	Emery (sej y ⁻¹)	Emery in the Money (sej y ⁻¹)	Money paid by the product (\$)	EER
Hunting	2.13E+15	5.41E+15	1680.21	2.54
Firewood	7.65E+16	4.45E+15	1380.74	0.06
Cork	3.44E+16	4.29E+16	13335.00	1.25
Calves	3.85E+17	1.68E+17	52209.92	0.44

Table 5

Determination of the Non-renewable Emergy Exchange Ratio (EER_N) for the different outputs of the farm

Output (Y)	Non-renewable emergy (sej y ⁻¹)	Emergy in the Money (sej y ⁻¹)	Money paid by the product (\$)	EER_N
Hunting	3.44E+14	5.41E+15	1680.21	22.17
Firewood	1.65E+16	4.45E+15	1380.74	0.27
Cork	2.90E+16	4.29E+16	13335.00	1.48
Calves	3.14E+17	1.68E+17	52209.92	0.53

Table 6

Proposal of the annual investment, and corresponding area, in order to compensate the impacts of calves' production

	Non-renewable energy	Investment in compensation (\$)	Area of investment
Emergy of fences (annual contribution)	4.38E+16	13 596	Forest and soils
Emergy for the labor in cattle	1.10E+17	34 123	More sustainable lifestyle
Emergy of the plastic used in the farm	1.48E+15	458	Plastic substitutes
Emergy of the seeds	3.81E+13	12	More sustainable lifestyle
Emergy of the feeding trough	1.72E+15	535	Soils and alternatives to iron and steel (eg.wood)
Emergy of medication	1.55E+13	5	Homeopathic medication
Emergy of labor for other activities	1.25E+16	3 880	More sustainable lifestyle
Emergy of fuels for other uses	4.53E+14	141	Renewable energies, carbon sequestration
Emergy of mechanical equipment for other uses	6.08E+14	189	Alternatives to mechanized work
Emergy of the subsidies received for the farm in general	3.99E+16	12 378	Sustainable lifestyle in Portugal and Europe
Emergy of mechanical equipment for cattle	7.74E+15	2 404	Alternatives to mechanized work
Emergy in fuels for cattle	1.67E+16	5 173	Renewable energies, carbon sequestration
Emergy of the fertilizers for bales	2.56E+15	794	Organic compost and fertilizers
Emergy of governmental support to cattle rearing	8.40E+16	26 092	Sustainable lifestyle in Portugal and Europe
Emergy of the taxes	2.78E+16	8 640	Investment from government in sustainable lifestyles in Portugal

Table 7Emergy versus budget accounting for the *montado* farm

Notes	Resources	Emergy (a)		Economy		
		Values (sej y ⁻¹)	%	Values \$ (c)	Values EMR (c)	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Farm renewable resources (R)						
1	Solar radiation (b)	9.02E+15	2.27	7563.03	23 Land-use permit 2.44E+16	(rent) 11.57
2	Wind, kinetic (b)	6.33E+15	1.59			
3	Rain, geo-potential absorbed (b)	2.06E+14	0.05			
4	Ground water, chemical potential	6.94E+14	0.17			
5	Rain, chemical potential (b)	1.21E+17	30.42			
6	Evapotranspiration	1.07E+17	26.90			
7	Trees biomass (b)	5.89E+16	14.79			
8	Acorns (b)	5.89E+16	14.79			
9	Natural pasture (b)	1.02E+16	2.57			
10	Hay for bales (b)	3.81E+16	9.58			
Farm non-renewable resources (N)		1.99E+14	0.05		0.00	
11	Erosion, topsoil	1.99E+14	0.05		0.00	
Local resources (I=R+N)		1.08E+17	27.12			
Purchased Inputs (M)		8.54E+16	21.46	40992.77	1.32E+17	62.71
12	Seeds	1.41E+15	0.35	422.90	1.36E+15	0.65
13	Fuels	2.19E+16	5.51	9558.82	3.08E+16	14.62
14	Fertilisers	2.72E+15	0.68	2020.92	6.51E+15	3.09
15	Mechanical equipment	1.00E+16	2.52	11658.75	3.75E+16	17.84
16	Plastic	1.51E+15	0.38	571.50	1.84E+15	0.87
17	Feeding trough	1.75E+15	0.44	11004.30	3.54E+16	16.84
18	Fences (material)	4.61E+16	11.58	5058.98	1.63E+16	7.74
19	Medication	1.65E+13	0.00	1119.51	3.60E+15	1.71
Services (S)		2.05E+17	51.41			
20	Labour	2.05E+17	51.41	16808.63	5.41E+16	25.72
Total Social Cost = R+N+M+S		3.98E+17	100.00	65364.43	2.10E+17	100.00
Transfers		-5.80E+16	-14.57	-	-1.13E+17	-53.86
21	Subsidies	-8.71E+16	-21.90	44261.95	-1.43E+17	-67.72
22	Taxes paid to the government	2.92E+16	7.33	9054.08	2.92E+16	13.85
Total Private Cost		3.40E+17	85.43	30156.55	9.71E+16	46.14
Output (Y)						
24	Hunting	2.13E+15	0.40	1680.21	5.41E+15	2.45
25	Firewood	7.65E+16	15.92	1380.74	4.45E+15	2.01
26	Cork	3.44E+16	7.17	13335.00	4.29E+16	19.44
27	Calves	3.67E+17	76.46	52209.92	1.68E+17	76.10
Total		4.80E+17	100.00	68605.87	2.21E+17	100.00
Returns						
Social Net Return		8.24E+17	20.70	3241.45	1.04E+16	4.96
Private Net Return		1.40E+17	35.27	98762.43	3.18E+17	151.10
a) Transformities are relative to the 1.2E+25 sej y ⁻¹ planetary baseline (Campbell, 2016); b) Values not considered to avoid double counting; c) \$ refers to 2005 values.						